DATA CHANGE NOTICE SHUTTLE CREW OPERATIONS MANUAL		
AMENDMENT: Rev. B, CPN-1	DATE: January 5, 2001	PAGE: 1 of 155
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	APPROVED BY	
Brett L. Jackman Project Manager, USA	the parlor	Date: 12 - 01

Space Flight Operations Contract

Shuttle Crew Operations Manual

OI-28

January 5, 2001

DRD-1.6.1.3-b

Contract NAS9-20000



Questions regarding the organization and content of the Shuttle Crew Operations Manual should be directed to one of the following SCOM representatives:

NASA	
TBA, CB	281-
Steve Hirshorn, DF	281-483-0652
Ed Gonzalez, DM	281-483-1927
USA	
Brett Jackman, DT	281-244-8106
Project Manager	
Dave Pitre, DT	281-244-7416
Hernandez Engineering Inc	

Hernandez Engineering Inc. Vicki Atkins

281-280-6787

REVISION LOG

REV	CHNG			
LETTER	NO.	DES	DATE	
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PREFACE

The Shuttle Crew Operations Manual (SCOM) is a unique document containing information about each shuttle system and every phase of a generic space shuttle mission.

The SCOM is a reference document for space shuttle crewmembers. The complexity of the shuttle systems and the unique operational environment, coupled with the numerous malfunction/emergency procedures, necessitated some departures from a Dash1/NATOPS approach. Nonetheless, the SCOM is the only single source document, written specifically for shuttle astronauts, with comprehensive data about shuttle systems and operations.

This document contains condensed information from a large number of space shuttle publications, including the Flight Data File (FDF), Crew Training workbooks, Flight Procedure Handbooks (FPH), Flight Rules, Shuttle Operational Data Book, and Shuttle Performance Assessment Data Book. The SCOM is not a replacement for any of these documents. It has been carefully reviewed by FCOD and MOD personnel to ensure accuracy of information. In all cases, should a conflict arise between the SCOM and FDF or Flight Rules, the FDF and Flight Rules will govern. If conflicts arise between the SCOM and workbooks or FPH, the conflicts should be resolved with the appropriate book manager or system representative.

Information contained in the SCOM is current as of October 2000 and OI-28. CRT displays documented in the text and in Appendix B are the CRT displays documented in the Level C Functional Subsystem Software Requirements Display and Controls Specification, STS 83-0020H dated February 10, 1992, effectivity OI-28 and subs. It should be noted that several CRT displays provided in the body of this document are for illustrative purposes only; certain CRT displays contain data combined in one illustration that do not appear simultaneously in operational use.

Additional information or clarification is presented in three formats: notes, cautions, and warnings. Notes provide amplifying information of a general nature. Cautions provide information and instructions necessary to prevent hardware damage or malfunction. Warnings provide information and instructions necessary to ensure crew safety. The formats in which this material appears are illustrated below.

NOTE

A barberpole APU/HYD READY TO START talkback will not inhibit a start.

CAUTION

After an APU auto shutdown, the APU FUEL TK VLV switch must be taken to CLOSE prior to inhibiting auto shutdown logic. Failure to do so can allow the fuel tank isolation valves to reopen and flow fuel to an APU gas generator bed that is above the temperature limits for safe restart.

WARNING

The FUEL CELL REAC switches on panel R1 are in a vertical column with FUEL CELL 1 REAC on top, FUEL CELL 3 REAC in the middle, and FUEL CELL 2 REAC on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to inadvertently close the wrong fuel cell reactant valve when shutting down a fuel cell.

The SCOM will be updated according to the process described in the Configuration Control Plan.

Configuration Control Plan

Your inputs are vital for the SCOM to remain a useful document. Changes may be submitted via the SCOM Change Request (CR) Form. Corrections, additions, deletions, or other constructive suggestions should be submitted to mail code CB-SCOM on the SCOM CR form. The form should be filled out in its entirety except for the Disposition blocks and the Control Number block. CB-SCOM will assign a control number. The initiator should clearly explain the correction or modification and list the applicable page number(s). Additional pages or annotated copies of the applicable SCOM pages may be submitted with the CR. Each CR should contain only corrections or modifications.

CRs containing recommended corrections will be verified by CB designated personnel and incorporated through pen and ink changes or page change notifications (PCNs). The CB representative will determine whether the number of verified corrections warrant a PCN prior to a semiannual review.

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Program Documentation

There are many hundreds of documents delineating the organization and operation of the space shuttle program. Over 100 of these documents have been utilized in the development of the Shuttle Crew Operations Manual. The following flow chart depicts the organization and hierarchy of the significant documents used in this effort. The level of a document in this "document tree" should not be equated with its relative importance to other shuttle publications. The level is strictly an indication of the management level that controls the development of the publication and subsequent changes.





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The section provides general background information about the orbiter, its configuration and coordinate systems, the nominal mission profile, and general procedures followed during a shuttle mission. It also briefly discusses components, such as the external tank and solid rocket, that are not included in the next section on orbiter systems. Space Shutlly Requirements

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Space Shuttle Statutics

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Space Shuttle Requirements

The space shuttle system consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRBs), an external tank (ET) to house fuel and oxidizer, and three space shuttle main engines (SSMEs). The shuttle can transport payloads into near Earth orbit 100 to 312 n. mi. above the Earth. Payloads are carried in a bay 15 feet in diameter and 60 feet long. Major system requirements are that the orbiter and the two SRBs be reusable.

The orbiter has carried a flight crew of up to eight persons. The nominal mission is 4 to 16 days in space. The crew compartment has a shirtsleeve environment, and the acceleration load is never greater than 3 g's. In its return to Earth, the orbiter has a crossrange maneuvering capability of about 1,100 n. mi..



1.1-1

Nominal Mission Profile

Launch

In the launch configuration, the orbiter and two SRBs are attached to the ET in a vertical (noseup) position on the launch pad. Each SRB is attached at its aft skirt to the mobile launcher platform by four bolts.

The three SSMEs, fed liquid hydrogen fuel and liquid oxygen oxidizer from the ET, are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the SRBs. At the proper thrustto-weight ratio, initiators (small explosives) at eight hold-down bolts on the SRBs are fired to release the space shuttle for lift-off. Elapsed time is a few seconds.

Maximum dynamic pressure is reached early in the ascent, nominally 30 to 60 seconds after liftoff. Approximately 1 minute later (2 minutes into the ascent phase), the two SRBs have consumed their propellant and are jettisoned from the ET. This is triggered by a separation signal from the orbiter.

The boosters briefly continue to ascend, while small thrusters fire to carry them away from the space shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate them for a safe splashdown in the ocean. Splashdown occurs approximately 141 n. mi. from the launch site. The boosters are recovered and reused.

The orbiter and ET continue to ascend, using the thrust of the three SSMEs. Approximately 8 minutes after launch and just short of orbital velocity, the three engines are shut down (main engine cutoff or MECO), and the ET is jettisoned on command from the orbiter.

The forward and aft reaction control system (RCS) jets provide attitude control, translate the orbiter away from the ET at separation, and maneuver the orbiter to burn attitude prior to

the orbital maneuvering system (OMS) burn. The ET continues on a ballistic trajectory and enters the atmosphere, where it disintegrates. Its nominal impact is in the Indian Ocean for a 28° inclination launch.

Orbit Insertion and Circularization

One type of mission profile, called a standard insertion because it was the standard early in the shuttle program, uses two OMS burns for orbital insertion. The first OMS burn (OMS 1) raises maximum altitude and occurs just a few minutes after MECO. The second OMS burn (OMS 2) occurs at the highest point of the trajectory after MECO/OMS 1. OMS 2 raises the lowest point of the orbit (perigee) and usually is targeted to achieve a circular orbit. Standard insertions were used on early flights when less information was available on SSME performance and targeting precision. At present, a standard insertion would only be used for flights to low orbital altitudes where the ET impact point is outside of limits using a direct insertion.

Normally, only one OMS burn is required to place the orbiter in a circular orbit. Missions planned with only one insertion OMS burn are called direct insertion missions. Direct insertions allow the highest orbital altitudes by maximizing the amount of OMS propellant available for altitude raising while ensuring that the external tank will reenter the atmosphere and impact in a safe area.

The direct insertion OMS burn is referred to as an OMS 2 burn since it performs the same function as a standard insertion OMS 2 burn. Orbital altitudes can vary from 100 to 312 n. mi., depending on mission requirements. Insertion OMS burns typically add 200 to 550 fps to the orbiter's velocity.

MAIN ENGINE CUTOFF, EXTERNAL TANKS SEPARATION

Altitude: 59 nautical miles Velocity: 25,581 feet per second about 8.5 minutes after launch (just before orbit insertion)





ORBITER INSERTION AND CIRCULARIZATION

For either one or two OMS burns to change trajectory from suborbital to orbital; typically 200 to 550 feet per second velocity increase. Altitude 100 to 312 nautical miles

> DEORBIT Velocity decreased nominal (200 to 550 feet per second) from Earth orbit operations



ORBITAL **OPERATIONS**

Mission: Nominal 4 to 16

second

days; 100 t0 316

25,000 feet per

nautical mile orbits;



LAUNCH pressure about 60 seconds after launch



LANDING Touchdown speed 195 or 250 knots





Maximum dynamic

SRB SEPARATION

Two minutes after

launch



Orbit

The forward and aft RCS jets provide attitude control of the orbiter as well as any minor translation maneuvers along a given axis on orbit. While on orbit, the crew fulfills mission objectives, such as payload deployment or retrieval, or scientific experiments.

Deorbit

At the completion of orbital operations, the RCS is used to orient the orbiter in a tail first attitude. The two OMS engines are burned to slow the orbiter for deorbit. The deorbit burn usually decreases the orbiter's velocity 200 to 550 feet per second depending on orbital altitude. When the deorbit burn is complete, the RCS is used to

rotate the orbiter's nose forward for entry. The RCS controls the orbiter until atmospheric density is sufficient for the pitch, roll, and yaw aerodynamic control surfaces become to effective.

Entry

Entry interface is considered to occur at 400,000 feet altitude approximately 4,200 n. mi. from the landing site and at approximately 25,000 feet per second velocity. The orbiter is maneuvered to 0° roll and yaw (wings level) and a 40° angle of attack for entry. The flight control system issues the commands to roll, pitch, and yaw RCS iets for rate damping.

Without forward RCS programmed test inputs, the forward RCS jets are inhibited prior to entry interface, and the aft RCS jets maneuver the spacecraft until a dynamic pressure of 10 pounds per square foot is sensed. This is when the orbiter's ailerons become effective. The aft RCS roll jets are then deactivated. At a dynamic pressure of 2 pounds per square foot, the orbiter's elevators become active, and the aft RCS pitch jets are deactivated at a q-bar of 40. The orbiter's speed brake is used below Mach 10 to induce a more positive downward elevator trim deflection. At approximately Mach 5, the rudder becomes activated, and the aft RCS jets are deactivated at Mach 1.

Entry guidance must dissipate the tremendous amount of energy the orbiter possesses when it enters the Earth's atmosphere to assure that the orbiter does not either burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow) and that the orbiter is properly positioned to reach the desired touchdown point.

During entry, energy is dissipated by the atmospheric drag on the orbiter's surface. The thermal protection system covering the entire orbiter provides the protection necessary for the orbiter to survive the extremely high temperatures encountered. Higher atmospheric drag levels enable faster energy dissipation with a steeper trajectory.

Normally, the angle of attack and bank angle enable the atmospheric drag of any flight vehicle to be controlled. However, for the orbiter, angle of attack was rejected because it creates surface temperatures above the design specification. The angle of attack scheduled during entry is loaded into the orbiter computers as a function of relative velocity, leaving bank angle for energy control. Increasing the bank angle decreases the vertical component of lift, causing a higher sink rate and energy dissipation rate. Increasing the bank angle does raise the surface temperature of the orbiter, but not nearly as drastically as an equal angle of attack increase.

If the orbiter is low on energy (current range-togo much greater than nominal at current velocity), entry guidance will command lower than nominal drag levels. If the orbiter has too much energy (current range-to-go much less than nominal at the current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Bank angle is used to control cross range. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cone tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds a computer-loaded number, the orbiter's bank angle is reversed.

Thus, descent rate and downranging are controlled by bank angle. The steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum drag attitude is wings level. Cross range is controlled by bank reversals. The entry thermal control phase is designed to keep the backface and surface temperatures within the design limits. A constant heating rate is established until below 19,000 feet per second.

The equilibrium glide phase transitions the orbiter from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. The equilibrium glide flight is defined as flight in which the flight path angle, which is the angle between the local horizontal and the local velocity vector, remains constant. Equilibrium glide flight provides the maximum downrange capability. It lasts until the drag acceleration reaches 33 feet per second squared.

The constant drag phase begins at that point. The angle of attack is initially 40°, but it begins to ramp down to approximately 36° by the end of this phase.

In the transition phase, the angle of attack continues to ramp down, reaching the approximately 14° angle of attack at the entry terminal area energy management (TAEM) interface, at approximately 83,000 feet altitude, 2,500 feet per second, and 60 n. mi. from the landing runway. Control is then transferred to TAEM guidance.

During the entry phases described, the orbiter's bank commands keep the orbiter on the drag profile and control cross range.

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TAEM guidance steers the orbiter to one of two 18,000-ft radius heading alignment cones (HAC), which are located tangent to and on either side of the runway centerline on the approach end. In TAEM guidance, excess energy is dissipated with an S-turn. This increases the ground track range as the orbiter turns away from the HAC until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet altitude. The orbiter also can be flown near the velocity for maximum lift over drag or wings level for the range stretch case. The spacecraft slows to subsonic velocity at approximately 49,000 feet altitude, about 26 n. mi. from the landing site.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the HAC and continues until it reaches way point (WP) 1. At WP-1, the TAEM heading alignment phase The HAC is followed until landing begins. runway alignment, ±20°, has been achieved. In the TAEM prefinal phase, the orbiter pitches down to acquire the steep glideslope, increases airspeed, banks to acquire the runway centerline, and continues until on the runway centerline, on the outer glideslope, and on airspeed. The approach and landing guidance phase begins with the completion of the TAEM prefinal phase and ends when the spacecraft comes to a complete stop on the runway.

Landing

The approach and landing trajectory capture phase begins at the approach and landing interface and continues to acquisition of the The approach and steep outer glideslope. landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 300 knots equivalent airspeed (KEAS) and 5.8 or 6.3 n. mi. (for -20° or -18° glideslope, respectively) from touchdown. Approach and landing guidance is initiated at this point to guide the orbiter to the -20° or -18° glideslope aimed at a target 7,500 feet short of the runway. The speed brake is modulated to hold the reference velocity. The descent rate in the later portion of TAEM and approach and landing is greater than 10,000 feet per minute.

At 2,000 feet above ground level (AGL), a preflare maneuver is started to position the spacecraft for a 1.5° inner glideslope in

preparation for landing with the speed brake positioned to control touchdown energy. The flight crew deploys the landing gear at 300 feet AGL. The final flare reduces the sink rate of the spacecraft to a target value of 3 feet per second. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 195 KEAS (lightweight orbiters) or 205 KEAS (heavyweight orbiters).

Launch and Landing Sites

The Kennedy Space Center (KSC) in Florida is used for all shuttle launches. Edwards Air Force Base in California and KSC are the primary landing sites. The incorporation of a drag chute and carbon/carbon brakes will now allow more missions to land at KSC. Contingency landing sites are also provided in the event the orbiter must return to Earth in an emergency.

A 035° azimuth launch places the spacecraft in an orbital inclination of 57°, which means the spacecraft in its orbital trajectories around Earth will never exceed an Earth latitude higher or lower than 57° north or south of the equator. A launch path from KSC at an azimuth of 090° (due east from KSC) will place the spacecraft in an orbital inclination of 28.5°.

These two azimuths, 035° and 090°, represent the current launch limits from KSC. Any azimuth angles further north or south would launch a spacecraft over a habitable land mass, adversely affect safety provisions for abort or vehicle separation conditions, or present the undesirable possibility that the SRB or external tank could land on inhabited territory.

The Earth rotates from west to east at a speed of approximately 900 nautical miles (n. mi.) per hour. For due east launches (090° azimuth), the Earth's rotational velocity adds to the velocity increase caused by the SRBs and main engines. Due east launches provide the maximum payload and altitude capability. Launches on azimuths other than due east benefit less and less from Earth's rotation as the launch azimuth approaches north or south. Westerly launches would decrease performance even further.

Orbiter Ground Turnaround

Spacecraft recovery operations at the nominal end-of-mission landing site are supported by approximately 160 space shuttle launch operations team members. Ground team members wearing self-contained atmospheric protective ensemble suits that protect them from toxic chemicals approach the spacecraft as soon as it stops rolling. The ground team members take sensor measurements to ensure the A second GSE ground cooling unit is connected to the left-hand orbiter T-0 umbilical spacecraft Freon coolant loops to provide cooling for the flight crew and avionics during the postlanding and system checks. The spacecraft fuel cells remain powered up at this time. The flight crew then exits the spacecraft, and a ground crew powers down the spacecraft.

At KSC, the orbiter and GSE convoy move from the runway to the Orbiter Processing Facility



Kennedy Space Center Ground Turnaround Sequence

atmosphere in the vicinity of the spacecraft is not hazardous. In the event of propellant leaks, a wind machine truck carrying a large fan is moved into the area to create a turbulent airflow that will break up gas concentrations and reduce the potential for an explosion.

A ground support equipment (GSE) airconditioning purge unit is attached to the righthand orbiter T-0 umbilical so cool air can be directed through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and OMS/RCS pods to dissipate the heat of entry. (OPF). If the spacecraft lands at Edwards Air Force Base in California, the same procedures and GSE are used after the orbiter has stopped on the runway. The orbiter and GSE convoy move from the runway to the orbiter mate and demate facility. After detailed inspection, the spacecraft is prepared to be ferried atop the Shuttle Carrier Aircraft from Edwards Air Force Base to KSC. For ferrying, a tail cone is installed over the aft section of the orbiter.

In the event of a landing at an alternate site, a crew of about eight will move to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the Shuttle Carrier Aircraft for transport back to KSC. For landings outside the U.S., personnel at the contingency landing sites will be provided minimum training on safe handling of the orbiter with emphasis on crash rescue training, towing the orbiter to a safe area, and prevention of propellant conflagration.

Upon its return to the OPF at KSC, the orbiter is safed (ordnance devices safed), the payload (if any) is removed, and the orbiter payload bay is reconfigured for the next mission. Any required maintenance and inspections are also performed while the orbiter is in the OPF. A payload for the orbiter's next mission may be installed in the orbiter's payload bay in the OPF or when the orbiter is at the launch pad.

The spacecraft is then towed to the Vertical Assembly Building and mated to the external tank. The external tank and SRBs are stacked and mated on the mobile launcher platform while the orbiter is being refurbished. Space shuttle orbiter connections are made, the integrated vehicle is checked, and ordnance is installed.

The mobile launcher platform moves the entire space shuttle system on a crawler transporter to the launch pad, where connections are made, and servicing and checkout activities begin. If the payload was not installed in the OPF, it is installed at the launch pad followed by prelaunch activities. KSC Launch Operations has responsibility for all mating, prelaunch testing, and launch control ground activities until the space shuttle vehicle clears the launch pad tower. Responsibility is then turned over to NASA's Johnson Space Center Mission Control Center. Mission Control's responsibility includes ascent, on-orbit operations, entry, approach, and landing until crew egress, at which time the orbiter is handed over to the postlanding operations at the landing site for turnaround and relaunch. At the launch site, the SRBs and ET are processed for launch, and the SRBs are recycled for reuse.

Space Shuttle Coordinate Reference System

The space shuttle coordinate reference system is a means of locating specific points on the orbiter. The system is measured in inches and decimal places; X_o designates the longitudinal axis, Y_o the lateral axis, and Z_o the vertical axis. The subscript "o" indicates orbiter; similar reference systems are used for the ET (T), SRB (B), and overall space shuttle system (S).

In each coordinate system, the X-axis zero point is located forward of the nose tip; that is, the orbiter nose tip location is 236 inches aft of the zero point (at $X_o = 236$), the ET nose cap tip location is at $X_T = 322.5$, and the SRB nose tip location is at $X_B = 200$. In the orbiter, the horizontal X_o , Y_o reference plane is located at Z_o = 400, which is 336.5 inches above the external tank horizontal X_T , Y_T reference plane located at





Crew Cabin (Cutaway View)

 $Z_{T} = 400$. The solid rocket booster horizontal $X_{\mu\nu}$ $Y_{\rm B}$ reference plane is located at $Z_{\rm B} = 0$ and coincident with the external tank horizontal plane at $Z_r = 400$. The solid rocket booster vertical $X_{BV} Z_T$ planes are located at + $Y_s = 250.5$ and $-Y_s = 250.5$. Also, the orbiter, external tank, and shuttle system center X, Z planes coincide.

From the X = 0 point, aft is positive, and forward is negative for all coordinate systems. Looking forward, each shuttle element Y-axis point right of the center plane (starboard) is positive and each Y-axis point left of center (port) is negative. The Z axis of each point within all elements of the shuttle except the SRBs is positive, with Z = 0 located below the element. In the SRBs, each Z-coordinate point below the X_{μ} , Y_{μ} reference plane is negative, and each point above that plane is positive.

The shuttle system and shuttle element coordinate systems are related as follows: the external tank $X_{T} = 0$ point coincides with $X_{s} = 0$, the SRB X_B 0 point is located 543 inches aft, and the Y_{o} , Z_{o} reference plane is 741 inches aft of $X_{s} = 0$.

Location Codes

Orbiter location codes enable crewmembers to locate displays and controls, stowage compartments and lockers, access panels, and wall-mounted equipment in the orbiter crew compartments. The orbiter crew compartments are the flight deck, middeck, and airlock. A fourth compartment becomes part of the configuration when the Spacelab is flown. Because of compartment functions and geometry, each has a unique location coding format.

Flight Deck Location Codes

A flight deck location code consists of two or three alphanumeric characters. The first character is the first letter of a flight deck surface as addressed while sitting in the commander/pilot seats. The characters are:

nsole

L	_	Left
R	-	Right
F	-	Forward
A	-	Aft
С	-	Center Co
0	-	Overhead
S	-	Seats
TAT		TAT: I

- Windows

SURFACES	GENERAL NUMBERING PHILOSOPHY
L - Left R - Right C - Center console	Numbered from the top to bottom, forward to aft
O - Overhead	Numbered from left to right, forward to aft
F - Forward A - Aft	Numbered left to right, top to bottom(facing the surface)
W - Windows	 The forward windows are numbered left to right (W1 through W6) facing forward The overhead windows are numbered left to right (W7 and W8) facing aft The aft windows are numbered left to right
	(W9 and W10) facing aft
S - Seats	The CDR's seat is <u>S1</u> and the PLT's seat is <u>S2</u>

General Numbering Scheme for Flight Deck Surfaces

The second and third characters are numerics identifying the relative location of components on each flight deck surface. The numbering system philosophy is summarized in the table above.



Flight Deck Location Codes (1 of 2)



Flight Deck Location Codes (2 of 2)

Middeck Location Codes

The middeck location codes have five characters specifying the following:

First character - M for middeck

<u>Second character</u> – The first letter of a middeck surface; the characters and surfaces are:

L – Left	A – Aft
----------	---------

R – Right D – Deck

F – Forward O – Overhead

SURFACES	REFERENCE POSITION
L, R, F, A	Standing on deck facing the surface
D	Standing on deck facing forward (+X) looking down
0	The overhead location grid matches the grid on the deck; i.e., a point on the overhead has the same third, fourth, fifth characters as a point directly below it on the deck

Middeck Location Codes (2 of 2)

The reference position for identifying the surface is standing on the middeck floor (deck) facing forward $(\pm X)$.

<u>Third/fourth/fifth characters</u> – These characters form a location grid on each middeck surface. The <u>third</u> and <u>fourth</u> characters are numerics indicating the

distance from the <u>left</u> side of a surface expressed as a <u>percentage</u> of the total width of the surface (follows the contour of the wall).

The <u>fifth</u> character is an alpha character indicating the distance from the <u>top</u> of a surface expressed <u>alphabetically</u> in increments of 6 inches.

NOTE

The middeck panel numbers are not consistent with the location coding system defined by this document. However, in each case, the location coding, as indicated, is in close proximity to the actual location. Panel numbers were assigned prior to the middeck closeout panel design definition. The starting points for location coding were behind the closeout panels, whereas the starting points used in this document are in front of the closeout panels.

Airlock Location Codes

An airlock code consists of four or five alphanumeric characters, which specify the following:

First character - A for airlock

<u>Second character</u> – The first letter of an airlock surface; the characters and surfaces are:

W – Wall

O – Overhead

D - Deck

The "wall" is the inner wall of the cylindrical airlock. The "overhead" and "deck" are flat surfaces at each end of the cylinder. The airlock is oriented upside down with respect to the middeck, so that the airlock <u>overhead</u> corresponds to the middeck floor. The wall location codes have five characters, and the overhead/deck codes have four characters.

Third/fourth/fifth characters (wall only) – These characters form a location grid on the airlock wall. The <u>third</u> and <u>fourth</u> characters are numerics indicating the distance (clockwise) from the vertical centerline of the forward hatch (airlock in) expressed as a <u>percentage</u> of the total airlock circumference. The <u>fifth</u> character is an alpha character indicating the distance from the overhead surface expressed alphabetically in increments of 6 inches.

Third/fourth characters (overhead/deck only)– These characters form location grids on the deck and overhead surfaces. Since these surfaces are small, items can be easily located without the aid of the location grids.



Middeck Location Codes (1 of 7)


Middeck Location Codes (2 of 7)









FOUR-TIER SLEEP STATION ON MIDDECK RIGHT WALL

Middeck Location Codes (6 of 7)

1.1 Overview



FIRE

EXT

- 2.7 IN. MIDDECK AFT

25

HITTLU

15

30

40

erriture rentres

35

50

45

AIRLOCK

60

65

55

1

80

75

MA73C PANEL

MA73J

VOLUME 3B)

85

THEFT

90 95

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Middeck Location Codes (7 of 7)





Airlock Location Codes



Airlock Equipment and Associated Location Codes

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1.1-19

1. GENERAL DESCRIPTION 1.1 Overview

1.2 ORBITER STRUCTURE

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The orbiter structure is divided into nine major sections: (1) forward fuselage, which consists of upper and lower sections that fit clamlike around a pressurized crew compartment, (2) wings, (3) midfuselage, (4) payload bay doors, (5) aft fuselage, (6) forward RCS, (7) vertical tail, (8) OMS/RCS pods, and (9) body flap. The majority of the sections are constructed of conventional aluminum and protected by reusable surface insulation.

Forward Fuselage

The forward fuselage consists of the upper and lower fuselages. It houses the crew compartment and supports the forward RCS module, nose cap, nose gear wheel well, nose gear, and nose gear doors.

The forward fuselage is constructed of conventional 2024 aluminum alloy skin-stringer panels, frames, and bulkheads. The panels are single curvature, stretch-formed skins with riveted stringers spaced 3 to 5 inches apart. The frames are riveted to the skin-stringer panels. The major frames are spaced 30 to 36 inches apart. The $Y_o = 378$ upper forward bulkhead is constructed of flat aluminum and formed sections riveted and bolted together; the lower is a machined section. The bulkhead provides the interface fitting for the nose section.

The nose section contains large machined beams and struts. The structure for the nose landing gear wheel well consists of two support beams, two upper closeout webs, drag-link support struts, nose landing gear strut and actuator attachment fittings, and the nose landing gear door fittings. The left and right landing gear doors are attached by hinge fittings in the nose section. The doors are constructed of aluminum alloy honeycomb, and although the doors are the same length, the left door is wider than the





Orbiter Dimensions

right. Each door has an up-latch fitting at the forward and aft ends to lock the door closed when the gear is retracted, and each has a pressure seal in addition to a thermal barrier. Lead ballast in the nose wheel well and on the $X_o = 293$ bulkhead provides weight and center-of-gravity control. The nose wheel well will accommodate 1,350 pounds of ballast, and the $X_o = 293$ bulkhead will accommodate a maximum of 1,971 pounds.

The forward fuselage carries the basic bodybending loads (loads that have a tendency to change the radius of a curvature of the body) and reacts to nose landing gear loads.

The forward fuselage is covered with reusable insulation, except for the six windshields, two overhead windows, and side hatch window areas around the forward RCS jets. The nose cap is also a reusable thermal protection system constructed of reinforced carbon-carbon with thermal barriers at the nose cap-structure interface.

The forward fuselage skin has structural provisions for installing antennas, deployable air data probes, and the door eyelet openings for the two star trackers. Two openings are required in the upper forward fuselage for star tracker viewing. Each opening has a door for environmental control.

The forward orbiter/ET attach fitting is at the X_o = 378 bulkhead and the skin panel structure aft of the nose gear wheel well. Purge and vent control is provided by flexible boots between the forward fuselage and crew compartment around the windshield windows, overhead observation window, crew hatch window, and star tracker openings. The forward fuselage is isolated from the payload bay by a flexible membrane between the forward fuselage and crew compartment at X_o = 582.

The forward RCS module is constructed of conventional 2024 aluminum alloy skin-stringer panels and frames. The panels are composed of single-curvature, stretch-formed skins with riveted stringers. The frames are riveted to the skin-stringer panels. The forward RCS module is secured to the forward fuselage nose section and forward bulkhead of the forward fuselage with 16 fasteners, which permit the installation and removal of the module. The components of the forward RCS are mounted and attached to the module, which has a reusable thermal protection cover, in addition to thermal barriers installed around it and the RCS jet interfaces and the interface-attachment area to the forward fuselage.



Forward Fuselage Structure

Crew Compartment

The three-level crew compartment is constructed of 2219 aluminum alloy plate with integral stiffening stringers and internal framing welded together to create a pressure-tight vessel. The compartment has a side hatch for normal ingress and egress, a hatch into the airlock from the middeck, and a hatch from the airlock through the aft bulkhead into the payload bay for extravehicular activity and payload bay access. The side hatch can be jettisoned.

Redundant pressure window panes are provided in the six forward windshields, the two overhead viewing windows, the two aft viewing windows, and the side hatch windows. Approximately 300 penetrations in the pressure shell are sealed with plates and fittings. A large removable panel in the aft bulkhead provides access to the interior of the crew compartment during initial fabrication and assembly and provides for airlock installation and removal. The compartment supports the ECLSS, avionics, GNC equipment, inertial measurement units, displays and controls, star trackers, and crew accommodations for sleeping, waste management, seats, and an optional galley. The crew compartment is supported within the forward fuselage at only four attach points to minimize the thermal conductivity between them. The two major attach points are located at the aft end of the crew compartment at the flight deck floor level. The vertical load reaction link is on the centerline of the forward bulkhead. The lateral load reaction is on the lower segment of the aft bulkhead.

The compartment is configured to accommodate a crew of four on the flight deck and three in the middeck. In OV-102, four can be accommodated in the middeck. The crew cabin arrangement consists of a flight deck, middeck, and lower level equipment bay.

The crew compartment is pressurized to 14.7 ± 0.2 psia and is maintained at an 80-percent nitrogen and 20-percent oxygen composition by the ECLSS, which provides a shirt-sleeve environment for the flight crew. The crew compartment is designed for 16 psia.

The crew compartment's volume with the airlock in the middeck is 2,325 cubic feet. If the airlock is in the payload bay, the crew compartment's cabin volume is 2,625 cubic feet.



Flight Deck

The flight deck is the uppermost compartment of the cabin. The commander's and pilot's work stations are positioned side by side in the forward portion of the flight deck. These stations have controls and displays for controlling the vehicle throughout all mission phases. Directly behind and to the sides of the commander and pilot centerline are the mission specialist seats.



Aft Flight Station

The aft flight deck has two overhead and aft viewing windows for viewing orbital operations. The aft flight deck station also contains displays and controls for executing attitude or translational maneuvers for rendezvous, stationkeeping, docking, payload deployment and retrieval, payload monitoring, remote manipulator system controls and displays, payload bay door operations, and closed-circuit television operations. The aft flight deck is approximately 40 square feet.

The forward flight deck, which includes the center console and seats, is approximately 24 square feet. However, the side console controls and displays add approximately 3.5 more square feet. If the center console is subtracted from the 24 square feet, this would amount to approximately 5.2 square feet.

Middeck

Directly beneath the flight deck is the middeck. Access to the middeck is through two interdeck openings, which measure 26 by 28 inches. Normally, the right interdeck opening is closed, and the left is open. A ladder attached to the left interdeck access allows easy passage in 1-g conditions. The middeck provides crew accommodations and contains three avionics equipment bays. The two forward avionics bays utilize the complete width of the cabin and extend into the middeck 39 inches from the forward bulkhead. The aft bay extends into the middeck 39 inches from the aft bulkhead on the right side of the airlock. Just forward of the waste management system is the side hatch. The completely stripped middeck is approximately 160 square feet; the gross mobility area is approximately 100 square feet.

The side hatch in the middeck is used for normal crew ingress/egress and may be operated from within the crew cabin middeck or externally. It is attached to the crew cabin tunnel by hinges, a torque tube, and support fittings. The hatch opens outwardly 90° down with the orbiter horizontal or 90° sideways with the orbiter vertical. It is 40 inches in diameter and has a 10-inch clear-view window in the center of the hatch. The window consists of three panes of glass. The side hatch has a pressure seal that is compressed by the side hatch latch mechanisms when the hatch is locked closed. A thermal barrier of Inconel wire mesh spring with a ceramic fiber braided sleeve is installed between the reusable surface insulation tiles on the forward fuselage and the side hatch. The total weight of the side hatch is 294 pounds.



Crew Compartment Middeck

Depending on the mission requirements, bunk sleep stations and a galley can be installed in the middeck. In addition, three or four seats of the same type as the mission specialists' seats on the flight deck can be installed in the middeck. Three seats over the normal three could be installed in the middeck for rescue missions if the bunk sleep stations were removed.

The middeck also provides a stowage volume of 140 cubic feet. Accommodations are included for dining, sleeping, maintenance, exercising, and data management. On the orbiter centerline, just aft of the forward avionics equipment bay, an opening in the ceiling provides access to the inertial measurement units.

The middeck floor contains removable panels that provide access to the ECLSS equipment. The middeck equipment bay below the middeck floor houses the major components of the waste management and air revitalization systems, such as pumps, fans, lithium hydroxide carbon dioxide absorbers, heat exchangers, and ducting. This compartment has space for stowing lithium hydroxide canisters and five separate spaces for crew equipment stowage with a volume of 29.92 cubic feet.

Modular stowage lockers are used to store the flight crew's personal gear, mission-necessary equipment, personal hygiene equipment, and experiments. There are 42 identical boxes, which are 11 by 18 by 21 inches.

An airlock located in the middeck is composed of machined aluminum sections welded together to form a cylinder with hatch mounting flanges. The upper cylindrical section and bulkheads are constructed of aluminum honeycomb. Two semicylindrical aluminum sections are welded to the airlock's primary structure to house the ECLSS and electrical support equipment. Each semicylindrical section has three feedthrough plates for plumbing and cable routings from the orbiter to the airlock.

Normally, two extravehicular mobility units are stowed in the airlock.



Forward Fuselage and Crew Compartment Windows

The orbiter windows provide visibility for entry, landing, and on-orbit operations. For atmospheric flight, the flight crew needs forward, left, and right viewing areas. On-orbit mission phases require visibility for rendezvous, docking, and payload-handling operations.

The six windows located at the forward flight deck commander and pilot stations provide forward, left, and right viewing. The two overhead windows and two payload-viewing windows at the aft station location on the flight deck provide rendezvous, docking, and payload viewing. There is also a window in the middeck side hatch.

The six platform-shaped forward windows are the thickest pieces of glass ever produced in the optical quality for see-through viewing. Each consists of three individual panes. The innermost pane, which is 0.625 of an inch thick, is constructed of tempered aluminosilicate glass to withstand the crew compartment pressure. Aluminosilicate glass is a low-expansion glass that can be tempered to provide maximum mechanical strength. The exterior of this pane, called a pressure pane, is coated with a red reflector coating to reflect the infrared (heat portion) rays while transmitting the visible spectrum.

The center pane is constructed of lowexpansion, fused silica glass because of its high optical quality and excellent thermal shock resistance. This pane is 1.3 inches thick.

The inner and outer panes are coated with a high-efficiency, anti-reflection coating to improve visible light transmission. These windows withstand a proof pressure of 8,600 psi at 240° F and 0.017 relative humidity.

The outer pane is made of the same material as the center pane and is 0.625 of an inch thick. The exterior is uncoated, but the interior is coated with high-efficiency, anti-reflection coating. The outer surface withstands approximately 800° F.

Each of the six forward windows' outer panes measures 42 inches diagonally, and the center and inner panes each measure 35 inches



Flight Deck Windows





diagonally. The outer panes of the six forward windows are mounted and attached to the forward fuselage. The center and inner panes are mounted and attached to the crew compartment. Redundant seals are employed on each window. No sealing/bonding compounds are used.

The two overhead windows at the flight deck aft station are identical in construction to the six forward windows except for thickness. The inner and center panes are 0.45 of an inch thick, and the outer pane is 0.68 of an inch thick. The outer pane is attached to the forward fuselage, and the center and inner panes are attached to the crew compartment. The two overhead windows' clear view area is 20 by 20 inches. The left-hand overhead window provides the crew members with a secondary emergency egress. The inner and center panes open into the crew cabin, and the outer pane is jettisoned up and over the top of the orbiter. This provides a secondary emergency exit area of 20 by 20 inches.

On the aft flight deck, each of the two windows for viewing the payload bay consists of only two panes of glass, which are identical to the forward windows' inner and center panes. The outer thermal panes are not installed. Each pane is 0.3 of an inch thick. The windows are 14.5 by 11 inches. Both panes are attached to the crew compartment.

The side hatch viewing window consists of three panes of glass identical to the six forward windows. The inner pane is 11.4 inches in diameter and 0.25 of an inch thick. The center pane is 11.4 inches in diameter and 0.5 of an inch thick. The outer pane is 15 inches in diameter and 0.3 of an inch thick.

During orbital operations, the large window areas of transparency expose the flight crew to sun glare; therefore, window shades and filters are provided to preclude or minimize exposure. Shades are provided for all windows, and filters are supplied for the aft and overhead viewing windows. The window shades and filters are stored in the middeck of the orbiter crew compartment. Attachment mechanisms and devices are provided for their installation at each window on the flight deck.

The forward station window shades (W-1 through W-6) are rolled up and stowed at the base of the windows. Solid metal shades are used on overhead windows (W-7 and W-8). The overhead window filters are fabricated from Lexan and are used interchangeably with the shades.

The aft window shades (W-9 and W-10) are the same as the overhead window shades except that a 0.63-inch-wide strip of Nomex Velcro has been added around the perimeter of the shade. The shade is attached to the window by pressing the Velcro strip to the pile strip around the window opening. The aft window filters are the same as the overhead window filters except for the addition of the Velcro hook strip. The filters and shades are used interchangeably.

The side hatch window cover is permanently attached to the window frame and is hinged to allow opening and closing.

Wing

The wing is an aerodynamic lifting surface that provides conventional lift and control for the orbiter. The left and right wings consist of the wing glove, the intermediate section (which includes the main landing gear well), the torque box, the forward spar for mounting the reusable reinforced carbon-carbon leading edge structure thermal protection system, the wing/elevon interface, the elevon seal panels, and the elevons.

The wing is constructed of conventional aluminum alloy with a multirib and spar arrangement with skin-stringer-stiffened covers or honeycomb skin covers. Each wing is approximately 60 feet long at the fuselage intersection and has a maximum thickness of 5 feet.

The forward wing box is an extension of the basic wing that aerodynamically blends the wing leading edge into the midfuselage wing glove. The forward wing box is a conventional design of aluminum ribs, aluminum tubes, and tubular struts. The upper and lower wing skin panels are stiffened aluminum. The leading edge spar is constructed of corrugated aluminum.

The intermediate wing section consists of the aluminum multiribs conventional and aluminum tubes. The upper and lower skin constructed covers are of aluminum honeycomb. A portion of the lower wing surface skin panel includes the main landing gear door. The intermediate section houses the main landing gear compartment and reacts to a portion of the main landing gear loads. A structural rib supports the outboard main landing gear door hinges and the main landing gear trunnion and drag link. The support for the inboard main landing gear trunnion and drag link attachment is provided by the midfuselage. The main landing gear door is conventional aluminum honeycomb.

The four major spars are constructed of corrugated aluminum to minimize thermal loads. The forward spar provides the attachment for the thermal protection system reusable reinforced carbon-carbon leading edge structure. The rear spar provides the attachment interfaces for the elevons, hinged upper seal panels, and associated hydraulic and electrical system components. The upper and lower wing skin panels are stiffened aluminum.



Wing Structure

The elevons provide orbiter flight control during atmospheric flight. The two-piece elevons are conventional aluminum multirib and beam construction with aluminum honeycomb skins for compatibility with the acoustic environment and thermal interaction. The elevons are divided into two segments for each wing, and each segment is supported by three hinges. The elevons are attached to the flight control system hydraulic actuators at points along their forward extremities, and all hinge moments are reacted to at these points. Each elevon travels 33° up and 18° down (software limits).

The transition area on the upper surface between the torque box and the movable elevon consists of a series of hinged panels that provide a closeout of the wing-to-elevon cavity. These panels are of Inconel honeycomb sandwich construction outboard of wing station $Y_w = 312.5$ and titanium honeycomb sandwich of construction inboard of wing station $Y_w = 312.5$. The upper leading edge of each elevon incorporates titanium rub strips. The rub strips are of titanium honeycomb construction and are not covered with the thermal protection system reusable surface insulation. They provide the sealing surface area for the elevon seal panels.

Except the elevon seal panels, the exposed areas of the wings, main landing gear doors, and elevons are covered with reusable surface insulation thermal protection system materials. Thermal seals are provided on the elevon lower cove area along with thermal spring seals on the upper rub panels. Pressure seals and thermal barriers are provided on the main landing gear doors.

The wing is attached to the fuselage with a tension bolt splice along the upper surface. A shear splice along the lower surface in the area of the fuselage carry-through completes the attachment interface.

Prior to the manufacturing of the wings for Discovery (OV-103) and Atlantis (OV-104), a weight reduction program resulted in a redesign of certain areas of the wing structure. An assessment of wing air loads was made from actual flight data that indicated greater loads on the wing structure. As a result, to maintain positive margins of safety during ascent, structural modifications were incorporated into certain areas of the wings. The modifications consisted of the addition of doublers and stiffeners.

Midfuselage

The midfuselage structure interfaces with the forward fuselage, aft fuselage, and wings. It supports the payload bay doors, hinges, tiedown fittings, forward wing glove, and various orbiter system components, and it forms the payload bay area.

The forward and aft ends of the midfuselage are open, with reinforced skin and longerons interfacing with the bulkheads of the forward and aft fuselages. The midfuselage is primarily an aluminum structure 60 feet long, 17 feet wide, and 13 feet high. It weighs approximately 13,502 pounds.

The midfuselage skins are integrally machined by numerical control. The panels above the wing glove and the wings for the forward eight bays have longitudinal T-stringers. The five aft bays have aluminum honeycomb panels. The side skins in the shadow of the wing are also numerically control machined but have vertical stiffeners.

Twelve main-frame assemblies stabilize the midfuselage structure. The assemblies consist of vertical side elements and horizontal elements. The side elements are machined; the horizontal elements are boron/aluminum tubes with bonded titanium end fittings. In the upper portion of the midfuselage are the sill and door longerons. The machined sill longerons not only make up the primary bodybending elements, but also take the longitudinal loads from payloads in the payload bay. The payload bay door longerons and associated structure are attached to the 13 payload bay door hinges. These hinges provide the vertical reaction from the payload bay doors. Five of the hinges react to the payload bay door shears. The sill longeron also provides the base support for the payload bay manipulator arm (if installed) and its stowage provisions, the Kuband rendezvous antenna, the antenna base support and its stowage provisions, and the payload bay door actuation system.

The side wall forward of the wing carry-through structure provides the inboard support for the main landing gear. The total lateral landing gear loads are reacted to by the midfuselage structure.

The midfuselage also supports the two electrical wire trays that contain the wiring between the crew compartment and aft fuselage.

Plumbing and wiring in the lower portion of the midfuselage are supported by fiberglass milk stools. The other exposed areas of the midfuselage are covered with the reusable surface insulation thermal protection system.



Because of additional detailed analysis of actual flight data concerning descent stress thermal gradient loads, torsional straps were added to the lower midfuselage stringers in bays 1 through 11. The torsional straps tie all stringers together similarly to a box section, which eliminates rotational (torsional) capabilities to provide positive margins of safety.

Also, because of additional detailed analysis of actual flight data during descent, roomtemperature vulcanizing silicone rubber material was bonded to the lower midfuselage from bay 4 through 12 to act as a heat sink and distribute temperatures evenly across the bottom of the midfuselage, which reduces thermal gradients and ensures positive margins of safety.

Aft Fuselage

The aft fuselage consists of an outer shell, thrust structure, and internal secondary structure. It is approximately 18 feet long, 22 feet wide, and 20 feet high.

The aft fuselage supports and interfaces with the left-hand and right-hand aft OMS/RCS pods, the wing aft spar, midfuselage, orbiter/external tank rear attachments, main engines, aft heat shield, body flap, vertical tail, and two T-0 launch umbilical panels. The aft fuselage provides the load path to the midfuselage main longerons, main wing spar continuity across the forward bulkhead of the aft fuselage, structural support for the body flap, and structural housing around all internal systems for protection from operational environments (pressure, thermal, and acoustic) and controlled internal pressures during flight.

The forward bulkhead closes off the aft fuselage from the midfuselage and is composed of machined and beaded sheet metal aluminum segments. The upper portion of the bulkhead attaches to the front spar of the vertical tail.

The internal thrust structure supports the three SSMEs. The upper section of the thrust structure supports the upper SSME, and the lower section of the thrust structure supports the two lower SSMEs. The internal thrust structure includes the SSMEs, load reaction truss structures, engine interface fittings, and the actuator support structure. It supports the SSMEs and the SSME low-pressure turbopumps and propellant lines. The two orbiter/external tank aft attach points interface at the longeron fittings.

The internal thrust structure is composed mainly of 28 machined, diffusion-bonded truss members. In diffusion bonding, titanium strips are bonded together under heat, pressure, and



time. This fuses the titanium strips into a single hollow, homogeneous mass that is lighter and stronger than a forged part. In looking at the cross section of a diffusion bond, no weld line is visible. It is a homogeneous parent metal, yet composed of pieces joined by diffusion bonding. (In OV-105, the internal thrust structure is a forging.) In selected areas, the titanium construction is reinforced with boron/epoxy tubular struts to minimize weight and add stiffness.

The upper thrust structure of the aft fuselage is of integral-machined aluminum construction with aluminum frames except for the vertical fin support frame, which is titanium. The skin panels are integrally machined aluminum and attach to each side of the vertical fin to react to drag and torsion loading.

The outer shell of the aft fuselage is constructed of integral-machined aluminum. Various penetrations are provided in the shell for access to installed systems. The exposed outer areas of the aft fuselage are covered with reusable thermal protection system.

The secondary structure of the aft fuselage is of conventional aluminum construction except that titanium and fiberglass are used for thermal isolation of equipment. The aft fuselage secondary structures consist of brackets, buildup webs, truss members, and machined fittings, as required by system loading and support constraints. Certain system components, such as the avionics shelves, are shock-mounted to the secondary structure. The secondary structure includes support provisions for the auxiliary power units, hydraulics, ammonia boiler, flash evaporator, and electrical wire runs.

The two ET umbilical areas interface with the orbiter's two aft ET attach points and the ET's liquid oxygen and hydrogen feed lines and electrical wire runs. The umbilicals are retracted, and the umbilical areas are closed off after ET separation by an electromechanically operated beryllium door at each umbilical. Thermal barriers are employed at each umbilical door. The exposed area of each closed door is covered with reusable surface insulation.

The aft fuselage heat shield and seal provide a closeout of the orbiter aft base area. The aft heat

shield consists of a base heat shield of machined aluminum. Attached to the base heat shield are domes of honeycomb construction that support flexible and sliding seal assemblies. The enginemounted heat shield is of Inconel honeycomb construction and is removable for access to the main engine power heads. The heat shield is covered with a reusable thermal protection system except for the Inconel segments.

Orbital Maneuvering System/Reaction Control System (OMS/RCS) Pods

The OMS/RCS left- and right-hand pods are attached to the upper aft fuselage left and right sides. Each pod is fabricated primarily of graphite epoxy composite and aluminum. Each pod is 21.8 feet long and 11.37 feet wide at its aft end and 8.41 feet wide at its forward end, with a surface area of approximately 435 square feet. Each pod is divided into two compartments: the OMS and the RCS housings. Each pod houses all the OMS and RCS propulsion components and is attached to the aft fuselage with 11 bolts. The pod skin panels are graphite epoxy honeycomb sandwich. The forward and aft bulkhead aft tank support bulkhead and floor truss beam are machined aluminum 2124. The centerline beam is 2024 aluminum sheet with titanium stiffeners and graphite epoxy frames. The OMS thrust structure is conventional 2124 aluminum construction. The cross braces are aluminum tubing, and the attach fittings at the forward and aft fittings are 2124 aluminum. The intermediate fittings are corrosion-resistant steel. The RCS housing, which attaches to the OMS pod structure, contains the RCS jets and associated propellant feed lines. The RCS housing is constructed of aluminum sheet metal, including flat outer skins. The curved outer skin panels are graphite epoxy honeycomb sandwich. Twenty-four doors in the skins provide access to the OMS and RCS and attach points.

The exposed areas of the OMS/RCS pods are covered with a reusable thermal protection system, and a pressure and thermal seal is installed at the OMS/RCS pod aft fuselage interface. Thermal barriers are installed, and they interface with the RCS jets and reusable thermal protection system. The pods will withstand 162-decibel acoustic noise and a temperature range from minus 170° to plus 135° F.



Aft Orbital Maneuvering System/Reaction Control System Pod

Body Flap

The body flap thermally shields the three SSMEs during entry and provides the orbiter with pitch control trim during its atmospheric flight after entry.

The body flap is an aluminum structure consisting of ribs, spars, skin panels, and a trailing edge assembly. The main upper and lower forward honeycomb skin panels are joined to the ribs, spars, and honeycomb trailing edge with structural fasteners. The removable upper forward honeycomb skin panels complete the body flap structure.

The upper skin panels aft of the forward spar and the entire lower skin panels are mechanically attached to the ribs. The forward upper skin consists of five removable access panels attached to the ribs with quick-release fasteners. The four integral-machined aluminum actuator ribs provide the aft fuselage interface through self-aligning bearings. Two bearings are located in each rib for attachment to the four rotary actuators located in the aft fuselage, which are controlled by the flight control system and the hydraulically actuated rotary actuators. The remaining ribs consist of eight stability ribs and two closeout ribs constructed of chemically milled aluminum webs bonded to aluminum honeycomb core. The forward spar web is of chemically milled sheets with flanged holes and stiffened beads. The spar web is riveted to the ribs. The trailing edge includes the rear spar, which is composed of piano-hinge half-cap angles, chemically milled skins, honeycomb aluminum core, closeouts, and plates. The trailing edge attaches to the upper and lower forward panels by the piano-hinge halves and hinge pins. Two moisture drain lines and one hydraulic fluid drain line penetrate the trailing edge honeycomb core for horizontal and vertical drainage.

The body flap is covered with a reusable thermal protection system and an articulating pressure and thermal seal to its forward cover area on the lower surface of the body flap to block heat and air flow from the structures.



Body Flap

Vertical Tail

The vertical tail consists of a structural fin surface, the rudder/speed brake surface, a tip, and a lower trailing edge. The rudder splits into two halves to serve as a speed brake.

The vertical tail structure fin is made of aluminum. The main torque box is constructed of integral-machined skins and strings, ribs, and two machined spars. The fin is attached by two tension tie bolts at the root of the front spar of the vertical tail to the forward bulkhead of the aft fuselage and by eight shear bolts at the root of the vertical tail rear spar to the upper structural surface of the aft fuselage.

The rudder/speed brake control surface is made of conventional aluminum ribs and spars with aluminum honeycomb skin panels and is attached through rotating hinge parts to the vertical tail fin.

The lower trailing edge area of the fin, which houses the rudder/speed brake power drive unit, is made of aluminum honeycomb skin. The hydraulic power drive unit/mechanical rotary actuation system drives left- and righthand drive shafts in the same direction for rudder control of plus or minus 27°. For speed brake control, the drive shafts turn in opposite directions for a maximum of 49.3° each. The rotary drive actions are also combined for joint rudder/speed brake control. The hydraulic power drive unit is controlled by the orbiter flight control system.

The vertical tail structure is designed for a 163decibel acoustic environment with a maximum temperature of 350° F.

All-Inconel honeycomb conical seals house the rotary actuators and provide a pressure and thermal seal that withstands a maximum of 1,200° F.

The split halves of the rudder panels and trailing edge contain a thermal barrier seal.

The vertical tail and rudder/speed brake are covered with a reusable thermal protection system. A thermal barrier is also employed at the interface of the vertical stabilizer and aft fuselage.



Vertical Tail

Orbiter Passive Thermal Control

A passive thermal control system helps maintain the temperature of the orbiter spacecraft, systems, and components within their temperature limits. This system uses available orbiter heat sources and sinks supplemented by insulation blankets, thermal coatings, and thermal isolation methods. Heaters are provided on components and systems in areas where passive thermal control techniques are not adequate. (The heaters are described under the various systems.)

The insulation blankets are of two basic types: fibrous bulk and multilayer. The bulk blankets are fibrous materials with a density of 2 pounds per cubic foot and a sewn cover of reinforced acrylic film Kapton. The cover material has 13,500 holes per square foot for venting. Acrylic film tape is used for cutouts, patching, and reinforcements. Tufts throughout the blankets minimize billowing during venting.

The multilayer blankets are constructed of alternate layers of perforated acrylic film Kapton reflectors and Dacron net separators. There are 16 reflector layers in all, the two cover halves counting as two layers. Covers, tufting, and acrylic film tape are similar to that used for the bulk blankets.

Thermal Protection System

The thermal protection system (TPS) consists of various materials applied externally to the outer structural skin of the orbiter to maintain the skin within acceptable temperatures, primarily during the entry phase of the mission. The orbiter's outer structural skin is constructed primarily of aluminum and graphite epoxy.

During entry, the TPS materials protect the orbiter outer skin from temperatures above 350° F. In addition, they are reusable for 100 missions with refurbishment and maintenance. These materials perform in temperature ranges from minus 250° F in the cold soak of space to entry temperatures that reach nearly 3,000° F. The TPS also sustains the forces induced by deflections of the orbiter airframe as it responds to the various external environments. Because the TPS is installed on the outside of the orbiter skin, it establishes the aerodynamics over the vehicle in addition to acting as the heat sink.

Orbiter interior temperatures also are controlled by internal insulation, heaters, and purging techniques in the various phases of the mission.

The TPS is a passive system consisting of materials selected for stability at high temperatures and weight efficiency. These materials are as follows:

- Reinforced carbon-carbon (RCC) is 1. used on the wing leading edges, the nose cap, including an area immediately aft of the nose cap on the lower surface (chine panel), and the immediate area around the forward orbiter/ET structural attachment. protects RCC areas where temperatures exceed 2,300° F during entry.
- 2. Black high-temperature reusable surface insulation (HRSI) tiles are used in areas on the upper forward fuselage, including around the forward fuselage windows, the entire underside of the vehicle where RCC is not used, portions of the OMS/RCS pods, the leading and trailing edges of the vertical stabilizer, wing glove areas, elevon trailing edges adjacent to the RCC on the upper wing surface, the base heat shield, the interface with wing leading edge RCC, and the upper body flap surface. The HRSI tiles protect areas where temperatures are below 2,300° F. These tiles have a black surface coating necessary for entry emittance.
- 3. Black tiles called fibrous refractory composite insulation (FRCI) were developed later in the TPS program. FRCI tiles replace some of the HRSI tiles in selected areas of the orbiter.
- 4. Low-temperature reusable surface insulation (LRSI) white tiles are used in selected areas of the forward, mid-, and aft fuselages, vertical tail, upper wing, and OMS/RCS pods. These tiles protect areas where temperatures are below 1,200° F. These tiles have a white surface coating to provide better thermal characteristics on orbit.

- 5. After the initial delivery of Columbia, an advanced flexible reusable surface insulation (AFRSI) was developed. This material consists of sewn composite quilted fabric insulation batting between two layers of white fabric that are sewn together to form a quilted blanket. AFRSI was used on Discovery and Atlantis to replace the vast majority of the LRSI tiles. Following its seventh flight, Columbia also was modified to replace most of the LRSI tiles with AFRSI. The AFRSI blankets provide improved producibility and durability, reduced fabrication and installation time and costs, and a weight reduction over that of the LRSI tiles. The AFRSI blankets protect areas where temperatures are below 1,200° F.
- 6. White blankets made of coated Nomex felt reusable surface insulation (FRSI) are used on the upper payload bay doors, portions of the midfuselage and aft fuselage sides, portions of the upper wing surface, and a portion of the OMS/RCS pods. The FRSI blankets protect areas where temperatures are below 700° F.
- 7. Additional materials are used in other special areas. These materials are thermal panes for the windows, metal for the forward RCS fairings and elevon seal panels on the upper wing to elevon interface, a combination of white- and black-pigmented silica cloth for thermal barriers and gap fillers around operable penetrations, such as main and nose landing gear doors, egress and ingress flight crew side hatch, umbilical doors, elevon cove, forward RCS, RCS jets, midfuselage vent doors, payload bay doors, rudder/speed brake, OMS/RCS pods, and gaps between TPS tiles in high differential pressure areas, and room-temperature vulcanizing material for the thick aluminum T-0 umbilicals on the sides of the orbiter aft fuselage.

4. OPERATING LIMITATIONS

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This section delineates limitations for selected orbiter systems, equipment, and operations. It is not all inclusive. Limitations that the flight crew should be aware of have been emphasized. It must be noted that operations up to and including the given limits for one system may cause a violation of the limits for another. An example would be flying at the flight control system maximum allowable knots equivalent airspeed (KEAS). This KEAS would overspeed the landing gear with a lower maximum allowable KEAS.

"Limitations are those measurable or detectable operational limits, which if exceeded, will affect crew safety or result in performance degradation."

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OMS PRESS Fr Maler

The left and right PC (thrust obsistion prossure) is measured by a senser that is reacted through a dedicated signal conditioner (DSC) to some being displayed on the PC Meter and contras the GPCs.

OMS PRESS N2/He Tank Meter

Separate NO and He presenter sensors (left and right) are wired through a DSC to the meter and GPCs. Rodundard pressure conton provide the pressness readings for N2 and He on the GNC SYS SUMMER display.

4.1 INSTRUMENT MARKINGS

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Description

Instrument markings reflect the normal range (green) and upper/lower limits (red). Caution and warning alarms/tones will normally sound at the points marked in red. In some cases an SM alert will sound prior to the limits on the meters being reached. The meter indications in this section are arbitrary and are not intended to reflect actual flight conditions. For MEDS vehicles, see section 2.18, MEDS for OMS/MPS, HYD/APU, SPI, and Flight Instruments.

Alpha/Mach Indicator

The MEDS alpha tape displays a maximum liftto-drag (L/D) black diamond. The maximum L/D is displayed when Mach \leq 3.0. The diamond position is a linear interpolation of table values from Mach 3.0 to 0.95. For Mach \leq 0.95, the diamond is fixed at 10.5°.

The MEDS alpha tape also displays a green bar indicating maximum and minimum alpha limits when Mach \leq 2.5. The maximum and minimum positions are a linear interpolation of a table of values based on the current flight rule limits.



HSI/AMI MEDS Display with Alpha Tape Markings

Subsystem Status MEDS Display

The meters on panels F7 and F8 have been removed and replaced with a MEDS display. The following parameters can be viewed by depressing the SUBSYSTEM STATUS key on the MEDS toolbar and then selecting the appropriate subsystem (OMS/RCS, HYD/APU, SPI).

Normal operating ranges are indicated by:



High/low limits are indicated by:





OMS/MPS MEDS Display

OMS PRESS Pc Meter

The left and right Pc (thrust chamber pressure) is measured by a sensor that is routed through a dedicated signal conditioner (DSC) before being displayed on the Pc Meter and sent to the GPCs.

OMS PRESS N2/He Tank Meter

Separate N2 and He pressure sensors (left and right) are wired through a DSC to the meter and GPCs. Redundant pressure sensors provide the pressure readings for N2 and He on the GNC SYS SUMM 2 display.

Meter	Meter Marking(s)	Marking Explanation(s)
OMS He TK P (L, R)	<1500 psia (red)	Low limit (Class 3 C/W)
OMS N2 TK P (L, R)	<1200 psia (red)	Low limit (Class 3 C/W)
OMS Pc %	95 - 110% Pc (white)	Normal operating range
(L, R)	<80% Pc (red)	Low limit (Class 2 C/W) 72% Pc allowed during ullage blowdown
MPS HE TANK P (C, L, R)	<1150 psia (red)	Low limit (Class 2 C/W)
MPS HE REG A P	>810 psia (red)	High limit (Class 2 C/W)
(C, L, R)	<680 psia (red)	Low limit (Class 2 C/W)
MPS Pc % (C, L, R)	65 - 109% Pc (white)	Normal operating range (104% Pc is the nominal maximum with power available up to 109% Pc)
MPS PNEU TANK P	<3800 psia (red)	High limit (Class 3 C/W)
MPS PNEU REG P	>810 psia (red)	High limit (Class 3 C/W)
	<700 psia (red)	Low limit (Class 3 C/W)
MPS ENG MANF LO2	>249 psia (red)	High limit (Class 2 C/W)
	45-175 psia (green)	Normal operating range for LO2
MPS ENG MANF LH2	>60 psia (red)	High limit (Class 2 C/W)
	30-45 psia (green)	Normal operating range for LH2

MPS PRESS Pc Meter

The left, center, and right Pc (thrust chamber pressure) are measured by a sensor that is wired via the GPCs through flight forward multiplexer/demultiplexer (MDM) 2, 1, or 3 respectively, to the Pc meter. Power failure of an MDM or a data path failure will cause the affected Pc meter to drop to zero. GPC failure and some flight forward MDM failures can cause the affected Pc reading to freeze.

WARNING

MPS performance has not been verified in flight beyond a power level of 104 percent.

WARNING

MDM power failure can cause MPS Pc indication to drop to zero. Confirm engine failure with acceleration cues, MPS He consumption, or MCC call.

MPS PRESS ENG MANF Meter

The LO_2 and LH_2 manifold pressures are measured by a single transducer in each LO_2 and LH_2 line between the ET and SSMEs. The data are sent directly to the meter and through an MDM to the BFS GNC SYS SUMM 1 display.

MPS PRESS HELIUM and PNEU Meters

The pneumatic, left, center, and right He tank pressures are measured by a single sensor in each system manifold. Data are sent directly to the meter and through an MDM to the GPCs. The data are available on this meter (TANK selected) by reading the upper (non-boxed) numbers x 100 and on the BFS GNC SYS SUMM 1 display. The Pneumatic regulator, Left, Center, and Right He Regulator A pressures are measured by a single sensor downstream of each regulator. Data are sent directly to the meter and through an MDM to the GPCs. The data are available on this meter (REG selected) by reading the boxed numbers x 100 and on the BPS GNC SYS SUMM 1 display.



HYD/APU MEDS Display

hate are two attenties the on the X and and me on the indeside, Bolts go to are 9000 86 OUTHYD display but pnly the N, side sensor as to the mean with a DSC.

WSB H2Q Quantity

The HO quantity is determined by a PVT calciumiter conserver H Dranscrpressure and temperature transformer fieldings as well as GN, and pressure and temperature transducer readings. The Calculated quantity is oilibut to the HYDARPLandispiner and to these M BYS SUMM 2 and SPEC 80 APU/HYD dispurys.

Meter	Meter Marking(s)	Marking Explanation(s)
Hydraulic Pressure	2900 - 3200 psia (green) 2400 psia (red) 500 - 1000 psia (green)	Normal operating range Low limit (Class 2 C/W) Normal "low pressure" operating range
Hydraulic Ouantity	40 - 80% (green)	Normal operating range
	>95 or <40% (red)	SM alert sounds
Fuel Quantity	>20% (green)	Normal operating range
	<20% (red)	SM alert sounds at 20%
Fuel Pressure	50 - 370 (green) 110 psia (red)	Normal operating range; however, it would require multiple failures before the pressure could reach 50. SM alert sounds at 100 and 350 psia Low limit for hot restart
Water Quantity	>40% (green)	Normal operating range
	<40% (red)	SM alert sounds at 40%

Hydraulic Pressure Meter

Three sensors in each hydraulic system measure the fluid pressure. The "A" sensor is wired through a DSC to the HYDRAULIC PRESSURE meter (HYD/APU MEDS display), while the "B" sensor provides inputs for the SM SYS SUMM 2, SPEC 87 APU/HYD, and SPEC 87 HYD THERMAL displays. Mission Control has access to the data from the "C" sensor via downlist data. All three sensors are used for priority rate limiting (PRL). PRL status is available on the OVERRIDE (SPEC 51) display.

Hydraulic Quantity Meter

A sensor located in each of the three hydraulic reservoirs provides the information displayed on the HYDRAULIC QUANTITY meter and on the SM SYS SUMM 2 and SPEC 86 APU/HYD displays. Data is sent to the meter and GPCs via a DSC. It is also sent to the GPCs via an orbiter instrumentation MDM.

Fuel Quantity

Fuel quantity is determined by a pressure/ volume/temperature (PVT) calculation performed by the onboard computers. The calculated quantity is output to the HYD/APU display and to CRT displays SM SYS SUMM 2 and SPEC 86 APU/HYD.

Fuel Pressure

There are two sensors: one on the N_2 side and one on the fuel side. Both go to the SPEC 86 APU/HYD display, but only the N_2 side sensor goes to the meter via a DSC.

WSB H2O Quantity

The H₂O quantity is determined by a PVT calculation based on H₂O tank pressure and temperature transducer readings as well as GN₂ tank pressure and temperature transducer readings. The calculated quantity is output to the HYD/APU display and to the SM SYS SUMM 2 and SPEC 86 APU/HYD displays.

Oil Temperature

Oil temperature in the three APUs is measured by sensors located upstream and downstream of the water spray boilers. Data from the downstream sensor (OIL IN T) is routed to the OIL IN TEMP meter (HYD/APU MEDS display) via a DSC. The SM SYS SUMM 2 and SPEC 86 APU/HYD displays show data from both sensors (OIL IN T and OIL OUT T).

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° - 70° F (green)	Normal operating range when APUs are off
200° - 270° F (green)	Normal operating range when APUs are off
290° F (red)	High limit (Class 2 C/W)

Panel F9 Meters

AC VOLTS Meter

AC phase voltage (A, B, and C) is read directly at each of the three buses. There is no AC AMPS meter for the AC system that monitors AC current. The data is sent to this meter and to the SM SYS SUMM 1 and SM SPEC 67 ELECTRIC displays.



AC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
115 — 119 (green)	Normal operating range
123 (red)	High limit (Class 2 C/W)
108 (red)	Low limit (Class 2 C/W)

DC VOLTS Meter

DC voltage is read directly at each fuel cell, main bus, and essential bus. The data is routed to the meter and to the SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS displays.



DC VOLTS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
28 — 32 (green)	Normal operating range (SM alert at 32.5)
26.4 (red)	Low limit (Class 2 C/W)

DC AMPS/SIG STR Meter

A current sensor for each of the three fuel cells provides an input to the DC AMPS/SIG STR Meter. ("SIG STR" refers to S-band signal strength that is also monitored on this meter.) Essential and main bus current are not monitored. The data also appear on the SM SYS SUMM 1, SPEC 67 ELECTRIC, and SPEC 69 FUEL CELLS displays.



DC AMPS/SIG STR Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
90 — 350 A (green)	Normal operating range

Panel O1 Meters

AIR TEMP, H₂O PUMP OUT PRESS Meter

Cabin Heat Exchanger Air Temperature

Temperature data from a sensor downstream from the cabin heat exchanger are sent directly to the dual function AIR TEMP Meter and are also available on the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

Avionics Bay Air Temperature

Temperature data from a sensor located downstream of the avionics bay fans are sent directly to the AIR TEMP Meter. These data are also available on the SM SYS SUMM 2 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
75° — 110° F (green) 130° F (red)	Normal operating range High limit for avionics bay air temp (Class 2 C/W)



AIR TEMP, H,O PUMP OUT PRESS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
50° — 60° F (green)	Normal operating range

H,O Pump Out Pressure

Sensors in water loops 1 and 2 send data to this meter via a DSC and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays via an MDM. Certain preconditions must exist for the C/W system to activate at the values listed below. Those preconditions are found in the FDF Reference Data book.

METER MARKINGS(S)	MARKING EXPLANATION(S)	
Loop 1	The second second	
55 — 65 psia (green)	Normal operating range	
79.5 (unmarked)	High limit (Class 2 C/W)	
19.5 Psia (red)	Low limit (Class 2 C/W)	
Loop 2	Constant in the second second second second	
55 — 65 psia (green)	Normal operating range	
81 psia (red)	High limit (Class 2 C/W)	
45 psia (red)	Low limit (Class 2 C/W)	

NOTE

SM alerts will occur at 75 psia (high) and 50 or 20 psia (low), depending on preconditions for both loops.

FREON FLOW, EVAP OUT TEMP Meter

Flow

A sensor located upstream from the H2O/ Freon Interchanger in Freon Loops 1 and 2 provides a readout of Freon interchanger flow directly to the meter and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays.



FREON FLOW, EVAP OUT TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
2300 — 2500 psia (green)	Normal operating range (Flow Proportioning Valve in Payload (PL), SM alert at 1300 psia)
1400 — 2200 psia (green)	Normal operating range (Flow Proportioning Valve in Interchanger (ICH), SM alert at 1950 psia) [Change pending to meter markings to reflect C/W limits]
1200 psia (red)	Low limit (Class 2 C/W)
В	Bypass
R	Radiator

Evaporator Out Temperature

A sensor located downstream from the flash evaporator in each Freon Loop 1 and 2 provides data directly to the meter and to the SM SYS SUMM 2 and SPEC 88 APU/ENVIRON THERM displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)	
38° — 40° F (green)	Normal operating range	
65° F (red)	High limit (Class 2 C/W)	
32° F (red)	Low limit (Class 2 C/W)	

CABIN dP/dT PSIA/MIN, O2/N2 FLOW Meter

Cabin dP/dT

The indication on this meter is a direct readout of the dP/dT sensor. The data are also transmitted to the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays. The CRT displays also contain an additional backup dP/dT supplied by computations.

O2/N2 Flow

An O2 and N2 flow sensor in the two pressure control systems (four total) send data directly to the O2/N2 FLOW Meter. The readings are also available on the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)	
0.0 — 0.75 pph (green)	Normal operating range	
4.9 pph (red)	High limit (Class 2 C/W)	



T	D	0	
r	P	U	2

Dual selectable sensors (A or B) send data directly to this meter and for the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays.

METER MARKINGS(S)	MARKING EXPLANATION(S)
2.95 — 3.45 psia (green)	Normal operating range
3.6 psia (red)	High limit (Class 2 C/W)
2.7 psia (red)	Low limit (Class 2 C/W)

CABIN PRESS, PPO Meter

MARKING EXPLANATION(S)

Normal operating range

Low limit (Class 2 C/W)

Cabin Pressure

A cabin pressure sensor provides a direct indication for this meter and for the SM SYS SUMM 1 and SPEC 66 ENVIRONMENT displays. (The airlock pressure on the CRT ENVIRONMENT display can be used as a backup.)

METER MARKINGS(S)

0.0 psia (green)

-0.08 psia (red)

Panel O2 Meters

CRYO O2 HTR ASSY TEMP Meter

A temperature sensor in each of the eight O_2 tank heater assemblies monitors the temperature of warmed O_2 and sends the data via a DSC to this meter and the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.



CRYO O, HTR ASSY TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
-300° — +200° F (green)	Normal operating range
+349° F (red)	High limit (Class 2 C/W)

NOTE

For OV-105, the *METER TANK SELECT* switch will show HTRS 1 and 2 for tank 5 as well.

CRYO O₂ PRESS Meter

One sensor for each of the O_2 tanks provides pressure data via a DSC to the meter and SM program while another sensor (heater controller) sends data to the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.



CRYO O, PRESS Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)
802 — 930 psia (green)	Normal operating range
985 psia (red)	High limit (Class 2 C/W)
540 psia (red)	Low limit (Class 2 C/W)

NOTE

SM alerts occur at 960 psia (high) and 575 psia (low), with heaters not in AUTO or 740 psia (low) with A or B heater in AUTO.

CRYO H₂ PRESS Meter

One sensor for each H₂ tank provides pressure data to the meter via a DSC and SM software, while another sensor (heater controller) sends data to the SM SYS SUMM 2 and SPEC 68 CRYO SYSTEM displays.

4.1 Instrument Markings



CRYO H₂ PRESS Meter

NOTE

Tank 5 *SELECT* position is included on OV-105.

METER MARKINGS(S)	MARKING EXPLANATION(S)	
200 — 250 psia (green)	Normal operating range	
293.8 psia (red)	High limit (Class 2 C/W)	
153 psia (red)	Low limit (Class 2 C/W)	

NOTE

SM alerts occur at 283 psia (high) and 165 psia (low) with heaters not in AUTO, or 189.8 psia (low) with A or B heater in AUTO.

CRYO FUEL CELL STACK TEMP Meter

A sensor in each of the three fuel cell systems measures the temperature of the coolant leaving the fuel cell stack and sends the data via a DSC to this meter and the SM SYS SUMM 1 and SPEC 69 FUEL CELLS displays.



CRYO FUEL CELL STACK TEMP Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)	
190° — 225° F (green)	Normal operating range	
243.7° F (red)	High limit (Class 2 C/W)	
172.5° F (red)	Low limit (Class 2 C/W)	

NOTE

SM alerts occur at:

High	Low	If FC Output i
(1) 212° F	180° F	Less than 3.5 kW
(2) 222° F	190° F	3.5 - 7.5 kW
(3) 238° F	198° F	More than 7.5 kW

Panel O3 Meters

RCS/OMS PRESS LEFT/FWD/ RIGHT OXID, FUEL Meter



RCS/OMS PRESS LEFT/FWD/RIGHT OXID, FUEL Meter

METER MARKINGS(S)	MARKING EXPLANATION(S)	
235 — 255 psia (green)	Normal operating range	
312 psia (red)	High limit (Class 2 C/W)	
200 psia (red)	Low limit (Class 2 C/W)	

Pe Chart

RCS Pressure

RCS oxidizer, fuel, and helium (X10) pressures are displayed for the left, forward, and right systems by way of dual sensors. One sensor sends data via a DSC to the meter and the SPEC 23 RCS display, while the other routes data via a DSC to the GNC SYS SUMM 2 display. RCS pressure limits/normal ranges are marked on the left side of the meters and are identical for oxidizer and fuel.

NOTE

There are no He limits marked on the meters. An SM alert is generated if He pressure reaches 500 psia (low).

OMS Pressure

OMS oxidizer and fuel pressures are displayed for the left and right systems by way of a single sensor in each tank. The sensors send data via a DSC to the meters and the GNC SYS SUMM 2 display. OMS limits/normal ranges are marked on the right side of the meters and are identical for oxidizer and fuel.

METER MARKINGS(S)	MARKING EXPLANATION(S)
245 — 255 psia (green)	Normal operating range
284 psia (red)	High limit (Class 3 C/W; Class 2 and BFS C/W at 288 psia))
232 psia (red)	Low limit (Class 2 hardware C/W; software 234 psia)

expending any of their dunits will report to a main magine abuildoorn unless the score has manually schelened the sindulous limits the red Mit STATIPS light will ultrainede neordines of me position of the system. The crew has used in the GM2 OUT P tractice procession, which can be found on Rich GMC SYS SUMM 1. This pressure varies directly with the engine process level and can be used in the trees to determine if the engine is out. An SM silen is annexested when this value drops below 2050 psi

Engine Nozale Position

the MPS possiles have sufficient dynaminvelope such that they can collide with up

4.2 ENGINE LIMITATIONS

CONTENTS	
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Space Shuttle Main Engines	
(SSMEs)	4.2-1
Orbital Maneuvering System	
(OMS) Engines	4.2-2
Reaction Control System (RCS) Jets	4.2-3

Space Shuttle Main Engines (SSMEs)

Power

The SSMEs are designed to operate from 65 percent Pc to 109 percent Pc above 8,700 MSL. The GPCs can command the engines only within this Pc range. The following chart shows minimum Pc's for altitudes below 20,000 ft. MSL. The engines are limited to 736 seconds of operation in the range of 65 percent to 104 percent Pc.



WARNING

Shuttle MPS in flight performance has not been verified beyond a power level of 104 percent Pc.



SSME Temperature

Mission Control Center (MCC) personnel monitor three critical engine temperatures: high turbopump pressure fuel (HPFT) high temperature, high pressure oxidizer turbopump (HPOT) high temperature, and HPOT low temperature. Temperatures exceeding any of their limits will result in a main engine shutdown unless the crew has manually inhibited the shutdown limits via the MAIN ENGINE LIMIT SHUTDN switch. The red Main Engine STATUS light will illuminate, regardless of the position of the switch, if any one of these limits is exceeded. The crew has insight into the GO2 OUT T (outlet temperature), which can be found on BFS GNC SYS SUMM 1. This temperature varies directly with engine power levels and can be used by the crew to determine if the engine is out. An SM alert is annunciated when this value drops below 125°.

Propellant Pressure

In addition to the main propulsion system (MPS) manifold LH2 and LO2 pressure limits indicated on the ENG MANF meter (MEDS OMS/MPS display), an SM alert will sound if MPS ULL P (ullage pressure), on BFS GNC SYS SUMM 1, for LH2 or LO2 reaches the indicated maximums/minimums: LH2 34.0 psi/28.0 psi, LO2 29 psi/0 psi. MCC personnel monitor additional data not available on crew CRTs such as HPFT coolant liner pressure-high, HPOT intermediate seal purge pressure-low, HPOT secondary seal pressure-high, and main combustion chamber pressure-low. Pressures exceeding any of their limits will result in a main engine shutdown unless the crew has manually inhibited the shutdown limits; the red ME STATUS light will illuminate regardless of the position of the switch. The crew has insight into the GH2 OUT P (outlet pressure), which can be found on BFS GNC SYS SUMM 1. This pressure varies directly with the engine power level and can be used by the crew to determine if the engine is out. An SM alert is annunciated when this value drops below 1050 psi.

Engine Nozzle Position

The MPS nozzles have sufficient dynamic envelope such that they can collide with one
another, OMS engine nozzles or pods (upper SSME), or the body flap (lower SSMEs). The crew cannot monitor this envelope. Post MECO, the GPCs will position the nozzles to prevent interference and control entry heating on the lower engine nozzles. SODB Vol 1, section 3, and The Shuttle Performance Analysis Databook (SPAD), Chapter 6, graphically depict the nozzle envelopes.

MPS He Pressure

The first indication of a He leak will be an SM alert annunciated when the He dp/dt exceeds 20 psi for three BFS cycles. The He dp/dt, along with other MPS He pressures, is available on BFS SYS SUMM 1 (He dp/dt is only available in OPS 1 and 3). In addition, MPS He TK P (tank pressures) and REG P. A (regulator A pressures) are also available on the MEDS OMS/MPS display.

C&W for Main Engine He Pressure			
ME He Tanks low	-	1150	
Regs low	-	679	
Regs high	-	810	
Pneu He tank low	-	3800	
Accum low	-	700	

SSME AC Power

SSME controller operation requires that all three ac phases and voltages must not fall below 100 volts (root mean square) for longer than 500 msec. Should this happen, channel switchover (A to B) or engine shutdown will occur. An electric lockup can occur if the main engine controller loses both channels of Pc or fuel flow meter data. This will cause the controller to maintain the last commanded throttle position. The crew will see the corresponding amber MAIN ENGINE STATUS light illuminate and an MPS ELEC (L,R,C) message.

Engine Hydraulics

The engine design specifications state that the engine must operate if hydraulic pressure is greater than 1500 psia and that it must go into hydraulic lockup below 1100 psia. The loss of hydraulic pressure (any pressure below 1500 psia) will initially send the engine valves into

"soft lockup." Soft lockup implies that none of the five engine valves has failed their channel A and B actuator position checks. If no new throttle commands are being executed, it may take up to 1 minute for the valves to fail their If hydraulic pressure is actuator checks. recovered prior to failure of the position checks, the engine can come out of soft lockup and normal engine operation can resume. A "hard hydraulic lockup" will occur when any of the five engine valves fail their channel A and B actuator position checks. The controller software will then command all the valves to their last commanded position before the lockup occurred. The crew will see the corresponding amber MAIN ENGINE STATUS light illuminate and an MPS HYD (L,C,R) message.

Orbital Maneuvering System (OMS) Engines

Engine Chamber Pressure

There is no maximum Pc for the OMS engines due to the stoichiometry of the fuel/oxidizer mixture. Except during ullage blowdown, the OMS Pc should never fall below 80 percent. Operation with low Pc may cause engine damage or combustion instability.

Engine Operations

The engines are not rated for use below 70K feet due to exhaust flow separation and damage to the nozzles. With normal engine shutdown purge the following limitations apply: (1) engine firings of less than 2 seconds are prohibited due to possible propellant freezing or hard starts; (2) the minimum engine off-time between firings is 240 seconds for normal operations and 30 seconds for launch abort operations (15-second minimum burn) due to possible propellant freezing or hard starts. Without normal engine shutdown purge, the off-time increases to 10 minutes (for burns more than 10 seconds).

CAUTION

OMS engines must never be interconnected to use RCS propellant during OMS burns due to the smaller volume of the RCS tanks and the large propellant flow required by the OMS engines. RCS propellant tank damage will result.

Engine Temperature

The only OMS temperature monitored is the fuel injector temperature. This temperature is used to assess engine burn stability.

A fault message will be generated if the fuel injector temperature in either OMS pod exceeds 260° F (indicative of low or high fuel inlet pressure).

Engine Propellant

If the OMS propellant quantity is less than 11 percent, an RCS settling burn should be accomplished prior to OMS ignition. OMS propellant quantity should be less than 22 percent to remain within the structural limit for landing.

Engine Nozzle Position

If a nozzle moves more than 0.7° from its stowed position, a fault message will be generated to the ground and crew. If MCC is satisfied that it has moved more than 1.5° inboard or up during the maximum q-bar regime of ascent, the OMS engine will not be fired.

Engine N2 Pressure

The minimum nitrogen pressure for starting an OMS engine is 299 psi (254 psi for contingencies though abnormal start could occur). The maximum number of starts that can be supported with the N2 system is 17.

Reaction Control System (RCS) Jets

Jet Operations

The maximum nominal firing duration for forward and aft primary jets is 150 seconds, or 300 (-X forward RCS) and 800 (+X aft RCS) seconds for contingencies. Verniers are limited to 275 seconds in any 24-hour period. The GPC's will limit the number of simultaneous jet firings. The limit varies from 4 to 7 jets per pod, depending on propellant quantity, flight phase (mated coast, ET Sep, dump, etc.), and abort mode (norm, RTLS, TAL, etc.). A nominal ET separation requires the use of RCS from all three pods. On entry, the aft RCS roll jets are deactivated at a q-bar of 10 psf, the pitch jets at q-bar of 40 psf, and the yaw jets at Mach 1.

ET SEPARATION RCS REQUIREMENTS				
Jet	Minimum Requirements			
Group	Nominal	RTLS		
FWD down	1	3		
AFT left	1	3		
AFT right	1	3		
AFT up	1/side	2/side		
AFT down	1/side	2/side		
FWD yaw	-	1/side		

ET Separation Chart

Jet Propellant

The propellant tanks are not usable if pressure is less than 185 psi. During ascent and orbit (also entry when g-load is low) the maximum allowable pressure differential between tanks prior to initiating a crossfeed is 80 psi. When acceleration is between 0 and 1.5 g's, the maximum differential is 55 psi. The maximum acceleration for initiating a crossfeed is 1.5 g. A minimum of 1175 lb , or 53 percent total aft RCS, is required for entry with a c.g. ≤1095 in. For c.g. >1095, 1375 lb, or 62 percent total ARCS, is redlined.

RCS He Tank Pressure

The He tanks are considered lost if pressure is less than 456 psi.

4.3 AIRSPEED LIMITATIONS

CONTENTS

Ascent	4.3-1
Entry	4.3-1
Landing	4.3-2

Ascent

The maximum airspeed (based on the q-bar limit of 819 psf) for OV-103, -104, and -105 is 492 knots equivalent airspeed (KEAS) where KEAS = $\sqrt{q - bar} \times 17.18$. The OV-102 limit is 483 KEAS. These limits are based on thermal protection system (TPS) constraints. Flight design planning for each mission keeps the vehicle's airspeed (via q-bar) below about 475 KEAS.

There is no official minimum airspeed for ascent. There is, however, a minimum orbit (dictated by flight rule) that designates 80 n. mi. as the minimum acceptable perigee altitude. This altitude (given a minimum apogee of 155 n. mi.) ensures at least 48 hours before orbital decay to 400,000 ft. (A 105 n. mi. x 85 n. mi. orbit can be tolerated for a few hours before the orbiter must deorbit or raise the perigee.) The minimum circular orbit allowed by flight rule is 105 n. mi.



Source: NSTS 08934, SODB, Vol. VII

Mach Number V₁ Dynamic Pressure

Entry

The maximum certified speed during entry is also a function of q-bar, which varies during the descent profile. It reaches a maximum value at 350 psf or 321 KEAS. This protects for the actual limit of 333 KEAS by accounting for air data system and gauge tolerances. If the maximum flight control limit is exceeded, it is possible for the orbiter to go unstable in roll/yaw. For contingency aborts, the maximum airspeed limit is 486 KEAS. This is the ultimate limit for both flight control and the orbiter structure.

The minimum guidance and control airspeed for Mach less than 5.0 is 163 KEAS. The minimum practical airspeed below Mach 2.5 is based on not flying on the back side of the L/D curve. Although control is acceptable on the back side of the L/D curve, there is no reason to fly in this region. The only reason to fly slow is to stretch to the runway if low energy, and flying on the back side is not optimum for stretching. Minimum airspeed (max L/D) is a function of weight and Mach is about 190 to 220 KEAS. The minimum airspeed is available on the bottom line of the VERT SIT display; however, a better technique is to monitor maximum L/D alpha.

CAUTION

On a TAL, the VERT SIT may give the lightweight minimum airspeed when the TAL weight is heavy. This is because there is only one set of OPS 3 VERT SITs and flight software is always set to the EOM weight.

TAEM guidance will limit minimum airspeed. Unlike maximum airspeed, the gains for minimum airspeed are not set so low that the minimum airspeed will never be reached. TAEM guidance will very effectively fly maximum L/D if it needs to stretch to reach a runway.

WARNING

TAEM guidance must have air data to perform airspeed limiting. If air data is not incorporated to TAEM (G&C on SPEC 50), the crew must fly pitch attitude limits (theta limits) to avoid violating airspeed limits. See section 7.4 for more details.

Minimum airspeed is further limited by an uncontrollable pitch-up divergence. This pitchup divergence always occurs at a slower speed than maximum L/D; however, at Mach 1.5 the limit is close to maximum L/D. The airspeed pitch-up divergence is not available onboard. Alpha must be monitored to avoid a pitch-up divergence. See section 4.4.

Landing

Maximum airspeed for lowering the gear is 312 KEAS, based on landing gear structural limits.

Maximum speed at landing is based on the 225 knots ground speed (KGS) certified tire speed limit. To protect against this tire limit, the maximum predicted ground speed at the T/D evaluation velocity should not exceed 214 kt. The short field speed brake may be used to achieve the 11 kt pad. This pad was based on errors in the air data system, changing winds, and landing dispersions. Full 3 sigma protection does not always exist for this limit, nor does it exist for the minimum airspeed associated with the tailscrape.





Minimum airspeed at touchdown is limited by body flap scrape. This limit is protected by not landing slower than the targeted landing speed. For minimum airspeed, flight design protects for the crew landing 10 knots slow. The term "energy reserve" is often used to indicate the amount of time that the crew can delay touchdown and not scrape the body flap. See orbit landing speed restrictions chart.

Derotation speed is limited by main gear loading for maximum speed and nose gear loading for minimum airspeed. The current technique is to derotate at 185 KGS using the beep trim on the RHC. Beep trim derotation may be delayed to no slower than 165 KEAS. Maximum airspeed for drag chute deploy is 230 KEAS. Above this velocity, the drag chute shear pin will fail. This protects the orbiter from an inadvertent deploy on final. Minimum deploy speed is 80 KEAS.

Nominal drag chute jettison speed is 60 KGS; however, the drag chute must be jettisoned by 40 KGS to protect the main engine nozzle. If ground speed goes below 40 knots, the drag chute should not be jettisoned

> 4. OPERATING LIMITATIONS 4.3 Airspeed Limitations





Attention and even at food down is antibad or body they states. This lifting is protected by not likeding slewer than the targeted landing mean for the crew banding 10 knots slow. The tellar energy reserve is often used to indicate the annount of time that the crew can delay which invelops and for strapp the body flop. Se-

Derotation speed is limited by main goar leading the marginum speed and more pear loading for an hnum alcopect. The current technique is to derotate at 185 KGS using the beep train on the RHC. Beep true derotation may be defayed to no slower from NG SE at

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nonverses the data data must be a deviced by a ALD to protect the main engles, words. If gates great presidence to tages the magnitude dataid as to remission

4.4 ANGLE OF ATTACK LIMITATIONS



Entry

The maximum alpha for the orbiter during entry is designed to protect the TPS, maintain control in the three axes, meet structural requirements during venting, ensure aerosurface hinge moments remain within limits, and keep the orbiter within guidance limits. Consequently, the alpha limits may be well below the maximum/minimum usable alphas.

The maximum L/D alphas for various Mach numbers are:

Mach	Max L/D α
3	17
2	15
1	12
Subsonic	10.5

The MEDS alpha tape displays the maximum L/D alpha as a magenta and black diamond for Mach \leq 3.0. The tape also displays a green band denoting the maximum/minimum alpha range for Mach 2.5.

The Mach 1, 2, and 3 values are listed on the Entry Alpha cue card. The subsonic value is not listed in the FDF.

The following tables from Flight Rule A4.1.5-7, Entry Limits, list the normal angle of attack limits for the orbiter during entry.



Orbiter Design Angle of Attack Limits



Orbiter Nominal Angle of Attack Profile

SFOC-FL0884 Rev. B







Mach	Max Alpha	Min Alpha	Mach	Max Alpha	Min Aloha
2.5	18.0	60	0.0		Mill Alpha
3.2	20.8	82	0.0	20.0	-4.0
3.5	22.0	12.0	0.2		-4.0
5.0	28.0	16.0	0.		0.0
8.0	40.0	28.9	0.6	20.0	Contraction of the second
9.6	44.0	33.0	0.8	15.0	Marine Street Street
11.4	44.0	36.0	1.1		4.0
25.0	44.0	36.0	2.0	15.0	4.0

 Obtainer fores back alide of actives curve (increasing sights implies actives aligned by a death - 2.3.
Obtainer take include of pairware calmon at Machine - 3.6.
Obtainer take obser optimizing previate righting many sUD adjobane and Machine

Cability Norminal Angle of Allack Pro-

4.5 SIDESLIP LIMITATIONS

Numerous sideslip, β , limitations for the various ascent flight phases (SRB separation, ET separation, aborts, etc.) are available in the Shuttle Performance Assessment Databook (SPAD). During the high dynamic pressure phase of the ascent, the maximum sideslip angle is also a function of angle of attack. Typically, the maximum β allowable ranges from $\pm 3^{\circ}$ to $\pm 6^{\circ}$.

During entry, the maximum sideslip angle is $\pm 5^{\circ}$. Also during entry (2< Mach <12), the crew, by using the Roll Trim switch, will manually trim to reduce RCS jet firings if steady state sideslip exceeds 2° , one or more yaw jets fire continuously, or if scaled Ay (sensed lateral acceleration) exceeds the two-jet capability.

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4.6 LANDING WEIGHT LIMITATIONS

CONTENTS

Maximum Landing Weight..... 4.6-1

Maximum Landing Weight

Landing weight limits are reduced for higher inclination flights because of orbiter thermal restrictions. Any flight with a manifest that results in an intact abort or end of mission (EOM) landing weight greater than the certified limits must have a waiver specifying the limit for that flight. Approval of the waiver will be based on a case-by-case thermal analysis of the entry trajectory.

The following table lists orbiter maximum landing weights for ascent aborts and EOM.

Orther grass Int	Inclination			
Flight Phase	28.5°	39.0°	51.6°	57.0°
RTLS	248k lb	248k lb	245k lb	242k lb
TAL	248k lb	248k lb	244k lb	241k lb
AOA/ATO	248k lb	248k lb	242k lb	239k lb
EOM	233k lb	233k lb	233k lb	233k lb

Source: NSTS 07700, Vol. X, Book 1



Main Gear Sink Rate



4.7 DESCENT RATE LIMITATIONS

CONTENTS

Main Gear Touchdown	4.7-1
Nose Gear Touchdown	4.7-1

Main Gear Touchdown

The orbiter was designed to withstand the loads developed from landing at the maximum sink rates shown in the following figure. The maximum allowable sink rate is a function of orbiter gross landing weight and crosswind. Crosswinds reduce the allowable sink rate.

The type of payload returned in the payload bay also establishes the maximum allowable sink rate at main gear touchdown. The second graph shows the limit for crosswind and sink speed for the main gear for returnable and nonreturnable payloads.



Source: NSTS 08934, SODB, Vol. V

Main Gear Sink Rate





Nose Gear Touchdown

The maximum rate of descent at nose gear touchdown must not exceed 11.5 fps (9.9° per second) or the rate needed to prevent nose gear vertical loads in excess of 90,000 lb. (Operational rates of descent average 5 fps.)



Nose Gear Slapdown Pitch Rate Limit

4.8 CENTER OF GRAVITY LIMITATIONS

The orbiter X and Y c.g. limits are shown in the following figure. Mission planning for abort propellant dumps will ensure an adequate c.g. margin for intact aborts. Real-time mission management of orbiter consumables; i.e., cryo, propellant, water, will ensure the EOM c.g. is

within limits. This is most easily accomplished via the forward RCS propellant dump and OMS propellant wasting during the deorbit burn.

The Z axis c.g. must be within the limits of 360.0 to 384.0 inches at entry interface (approximately 400,000 ft).







4.9 ACCELERATION LIMITATIONS

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Ascent	4.9-1
Entry	4.9-1
Vn Diagrams	4.9-1

Ascent

The orbiter is constrained to the following translational accelerations during ascent.

Nx =	+3.11 g/-0.00 g
Ny =	+0.18 g/-0.18 g
Nz =	+0.73 g/-0.06 g

Entry

For orbiter Mach numbers less than 5.0 and weights less than, or equal to 211,000 lb, the maximum symmetrical Nz is 2.5 g. The following graph shows the allowable Nz for various gross weights. The negative acceleration limit is -1.0 g for Mach numbers less than 3.0 and is 0.0 g for Mach numbers greater than 3.0.

For rolling maneuvers, the maximum normal load factor is reduced by approximately 1 percent for every degree per second of roll rate, down to a maximum of Nz of 80 percent of the symmetrical load limit at 20 deg/sec roll rate. For example, at 5 deg/sec roll rate, the Nz maximum is 95 percent of the symmetrical load limit.

Vn Diagrams

The following Vn diagram demonstrates the acceleration limits in the TAEM region of entry.







4.10 WEATHER LIMITATIONS

Weather limitations for launch, abort landing, and end of mission landing are presented below.

Ceiling/Visibility (k ft)/(SM)		Redundant MLS	Single-String MLS	No MLS	
KSC, EDW,	Concrete	Day	≥10/7		0/7
NOR, AOA	X	Night	≥8/5	NO	-GO
Daily PLS	Lakebed	Day	(WX recon required)	n 02 of tug	≥10/7
(all sites)	300°	Night		≥15/7	NO-GO
RTLS, TAL	Concrete	Day	≥5/4 RTLS	≥1	0/7
-2014-200	-	Night	>5/5 TAL (WX recon required)	NC	-GO
ACLS/ECAL/E	ELS	>10	0,	/0silerai.e0/	≥8/5
Predeorbit: One APU failed or attempt two APUs procedure		ath mi	≥10/7		

Ceiling and Visibility Limits

						ndans in the second	F. T. M. C. C. C.		
Su	rrface Wind (Knots) and Turbulence	Cross Peak	Head Peak	Tail AVG	Tail Peak	Gust	Turb		
RTLS		≤15*	≤25	≤10	≤15	≤10	≤MOD		
Day	EOM, TAL, AOA, daily PLS selection	≤15	1807 17	don wood	-toppiov -toppiov				
Night	EOM, TAL, AOA, daily PLS selection	Lateral a approact	amulus clouds oduced by						
Crosswir	id DTO	≥10 ≤15	raim téo-fi	winds at	ne pad)	the op to Sec			
Nominal	drag chute deploy	≤15	intelation of	alashaa	T				
Landing	≥ CDR FD19	≤12	unudra in	LOVE COMPANY					
Predeorb attempt t	it: One APU failed or wo APUs procedure	≤10					≤LGT		
ECAL/E	LS	≤15	N/A						

*Requires an STA evaluation to 17 knots and a GO from the STA pilot.

Surface Winds and Turbulence Limits

Thunderstorm Precipitation F (n.	, Lightning, and Proximity Limits mi.)	Prelaunch (RTLS, TAL)	Predeorbit (EOM Daily PLS) Prelaunch (AOA)	Redesig Criteria	ELS, ECAL, ACLS				
Tstorm (inclu-	Radial from center of prime runway	>20	>30	>15	None at site				
nontransparent anvils) and lightning	Lateral along approach path out to 30 n. mi.	>10	>20	>5	KSC, EDW. NOR, AGA Daily FLS				
10-00	Vertical from top of cloud		>2						
Detached	Radial from center of prime runway	>15	>20	>15	N/A				
anvil <3 hours old	Lateral along approach path out to 30 n. mi.	>5	>10	>5	ACLS/ECAL				
	Vertical from top of cloud	ytilidiaiV bee	>2		in the representation				
Precipitation	Radial from center of prime runway	>20	>30	>15	N/A				
	Lateral along approach path out to 30 n. mi.	>10	>20	>5	Surface				
	Vertical from top of cloud		>2	AOA JAT N	Day EOI				
Cumulus clouds produced by smoke/fire up to 1 hour after	Lateral along approach path		>0	A, TAL, AOA, v PLS ectedent	N/A				
detaching	Thunderstor	m, Lightning, a	and Precipitati	on	Summal days				
			12 3						

quines an STA evaluation to 17 knots and a (A) upon ave 514

Surface Winds and Turbulence Lim



Launch Commit Constraint (60-ft winds at the pad)

5. NORMAL PROCEDURES SUMMARY

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5.1	PRELAUNCH
5.2	ASCENT
5.3	ORBIT5.3-1
5.4	ENTRY
5.5	POSTLANDING

This section summarizes nominal procedures for a generic space shuttle mission. More detailed procedures may be found in the Astronaut Support Personnel Book, the various Flight Procedures Handbooks (FPH), and Flight Data File (FDF) documents. The FPH documents also contain rationales for the various procedures listed herein. For flight-specific training, refer to the applicable FDF checklists/ cue cards.

> Crew arrives of the Wilds Room, ASP sectors CDS and PLT boundalentry and CLES//Bicht oppipment is properly configured betwee and menulation of access fOR measures CDR/PLT consection of a sector ground checks, assists with post-agress and the reconfiguration, and chordinates the C/W and intercom colume adjustment as the Alexangress. We ASP verifies their LLS/flight explores the for examples and assists largest and research and and assists largest and disclos

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After the hotels is closed, a cabin leak check is performed.

- 5 CDR initiates the cabus your redundancy checks at LCC direction.
- 1:00 COE opens the orbit sent bolation value

Min:Sec (approx.

52:00 CDR properties for the primiting and onice antowner system (PASS) backap fileful evolution (BPS) transfer. The LCC sell portcarn Bie transfer via uplicik

5.1 PRELAUNCH

Prelaunch Procedures

Hr:Min (approx)

L-33:00 Astronaut support personnel (ASP) conduct communications checks with the launch team. Caution and warning (C/W) volumes are adjusted so the air-toground communication can be heard over the C/W tone. UHF Guard is checked, and headset interface units (HIUs) are checked for proper operation, along with intercom (ICOM) loops A and B. If the ICOM recorder has been manifested, it is installed and tested.

- L-18:30 ASP ensures crew module has been vacuumed and performs ascent switch list configuration.
- L-16:30 The backup ASP conducts a check of the middeck and flight deck and installs certain cue cards, flipbooks, and checklists.
- L-12:45 The backup ASP adjusts CDR and PLT seats to the full down and aft position and then configures all seats for launch. Rotational hand controllers (RHCs) are adjusted, and SBTCs are set full forward.
- L- 8:15 Pad is cleared for tanking.
- L-5:35 ASP reports panel *ABORT* light status when initiated by the Flight Director.
- L-5:30 ASP Checklist is initiated. Checklist includes communications check, potable/supply water quantity adjustment, LiOH canister installation, air sample, preingress switch reconfiguration, ECLSS Freon coolant loop "payload" heat exchanger flow verification, navigation aids activation, and C/W memory clearing.

- L-4:55 Crew wakeup.
- L-4:25 Crew breakfast and photo opportunity.
- L-3:55 CDR, PLT, MS2 get weather briefing. MS1/3 (PSs) don flight clothing and equipment.
- L-3:45 CDR, PLT, MS2 don flight clothing and equipment.

L-3:15 Crew departs for the Pad.

- L-2:45 Crew arrives at the White Room: ASP verifies CDR and PLT launch/entry suit (LES)/flight equipment is properly configured before seat ingress, assists with ingress and installation of ascent FDF, monitors CDR/PLT communication air-to-ground checks, assists with post-ingress switch reconfiguration, and coordinates the C/W and intercom volume adjustment; as the MSs ingress, the ASP verifies their LES/flight equipment configuration and assists ingress and communication hook up and checks.
- L-1:45 ASP verifies all non-flight equipment is removed from the crew compartment, terminates communication with the Launch Control Center (LCC), and egresses.
- L-1:30 After the hatch is closed, a cabin leak check is performed.
- L-1:05 CDR initiates the cabin vent redundancy checks at LCC direction.
- L-1:00 CDR opens the cabin vent isolation valve.

Min:Sec (approx)

L-52:00 CDR prepares for the primary avionics software system (PASS)/ backup flight system (BFS) transfer. The LCC will perform the transfer via uplink.

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L-50:00	CDR places the OMS ENG switches to ARM/PRESS for GN2 pressurization and opens the cabin vent isolation valve	T-7:30	Access arm retracts, and the crew makes final checks on seat positions, suit closures, and restraints.					
L-45:00	All crewmembers conduct an A/G voice check with MCC and receive updates to ascent/abort data.	T-6:15	PLT performs APU prestart and verifies three gray " <i>READY TO START</i> " talkbacks.					
L-42:00	CDR closes the cabin vent isolation valve (if not already directed to do so by LCC).	T-5:00	Pilot starts APUs and verifies normal pressure. CDR turns off flash evaporator feedline heaters.					
L-30:00	Planned 10 min hold; OPS 1 Load is initiated. A ground-controlled fuel cell purge takes place about	T-3:25	Main engine nozzles are gimbaled during the next 30 sec. The crew may feel the motion/vibration.					
	this time.	T-2:30	PLT clears the C/W.					
L-29:00 L-27:00	CDR transitions BFS to OPS 1. PLT conducts horizontal situation	T-2:00	All crewmembers start O2 flow and close their visors.					
	configuration for TAL sites and RTLS to KSC. When this activity is complete, the PLT configures for OMS interconnect with PASS and BFS	T-0:07	Ignition sequence for main engines begins. Crew monitors Pc's increase.					
L-26:00	PLT performs the MPS He reconfiguration by opening He and pneumatic isolation valves.	T-0:03	Crew monitors main engines, which should have Pc's above 90 percent.					
L-25:00	The OMS/RCS crossfeed valves are configured for launch by the Launch Processing System.							
L-19:00	Planned 10 min hold, which synchronizes L and T time.							
T-9:00	GO for launch given, and event timers started.							
T-8:00	PLT connects essential buses to the fuel cells.							

I

5.2 ASCENT

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Powered Flight

Min:Sec (approx)

T-0:00

SRB ignition, software transitions to MM 102, main engines at ~100 percent Pc, and event timer counts up from zero. Throughout ascent phase, the crew monitors vehicle performance using CRT and dedicated displays intervening as required/directed by MCC. The also uses the Flight crew Instruments, ADI, No-Comm Ascent Abort Mode Boundaries, and Contingency Abort cue cards, to monitor the ascent trajectory and maintain awareness of abort options. Cue cards are used for malfunctions procedures.

Typical displays for ascent are ASCENT TRAJ, GNC SYS SUMM 1, and BFS ASCENT TRAJ. BFS GNC and SM SYS SUMM 1/2 are used as required.

Mission Elapsed Time (MET)

Min:Sec (approx)

0:01

Ensure that FCS (pitch and roll/yaw) are still in Auto. If not, select Auto. Otherwise BFS Engage may be required for roll program at 0:07.

0:04

If 104 percent is programmed for launch, at a velocity of 60 fps, the main engines are commanded to that level.

0:07

At a velocity ≥127 fps, the vehicle rolls, yaws, and pitches to the heads-down ascent attitude. Crew monitors and engages the BFS if maneuver not begun when required or not properly completed. CDR/PLT select LVLH on ADI ATTITUDE switch.

0:20 or 0:30

(flight specific)

1:00

1:30

2:00

Crew monitors main engines' throttling down to limit maximum flight dynamic pressure and to adjust for off-nominal performance. Throttle level can vary, depending on flight design and SRB performance.

Crew monitors main engines throttling back up to ~104 percent. Manual throttle may be selected if required.

Maximum q-bar phase is passed. Control stick steering (CSS) may now be selected in lieu of BFS Engage if PASS guidance is not nominal

ASCENT TRAJ display will indicate Pc <50 when both SRB Pc's drop below 50 psi. SRB separation should occur shortly thereafter (no later than MET 2:20). When the SRBs are separated, GNC changes to MM 103. BFS commands flash evaporator system (FES) on via payload buses.

Post-SRB separation, the crew checks that PASS and BFS TMECOs converge to expected values to verify performance of Ascent Guidance.

OMS Assist

MM 103 transition + 10 seconds

An OMS assist burn during nominal ascent may be manifested on some performance-critical missions. A 4000-lb OMS assist burn takes about 1:42 to complete

and provides a 250-lb performance gain. For OMS assist flights, SPEC 51 will display the manual dump quantity and timer until the OMS assist initiates. Then, the OMS assist information will be displayed. For a 4000-lb OMS assist, SPEC 51 will display 15% for the Item 9 quantity and 1:42 for the initial dump time to go (DTG). The crew should verify the OMS assist by monitoring the OMS PRESS Pc gauges and OMS quantity. When the OMS assist completes, DTG should display 0. For OMS assist missions, if an ATO abort is selected pre-MECO, the Item 9 quantity will reflect the calculated ATO abort dump quantity plus the OMS assist quantity. However, DTG will reflect any amount of OMS assist completed. In other words, if the OMS assist completed, DTG would only reflect the ATO dump because the dump time during the OMS assist has already been decremented.

8:30

MET

Min:Sec (approx)

3:00 Crew verifies the flash evaporator is working properly (T < 60° F and decreasing on EVAP OUT T overhead meter).

Roll to Heads Up (RTHU)

28.5° inclination RTHU at VI = 13.6 K (Vrel 12,200 fps)

 39.0° inclination RTHU at VI = 13.4 K (Vrel 12,200 fps)

51.6° inclination RTHU at VI = 13.2 K (Vrel 12,200 fps)

57.0° inclination RTHU at VI = 13.0 K (Vrel 12,200 fps)

Beginning with STS-87, an RTHU is performed during nominal ascent to allow an early handup from MILA to TDRS east in anticipation that the Bermuda Main engine cutoff (MECO) occurs. Crew cues are that the main engine MPS PRESS Pc meters drop to zero, the MAIN ENGINE STATUS lights illuminate red, and the cutoff bug on the BFS ASCENT TRAJ 2 indicates MECO velocity. MECO time may vary, depending on flight profile, but should match simulation time.

Post MECO MECO velocity should be approximately 25,650 fps (standard insertion (SI) due east) or 25,850 fps (DI due east). Crew verifies ORBITAL DAP lights illuminated, indicating MECO confirmed for ET separation. Crew verifies external tank (ET) separation (MAIN ENGINE STATUS lights extinguish). If ET separation is inhibited, the crew must null rate(s) (if >0.7°/sec) or react to feedline disconnect failure. -Z translation occurs and GNC transitions to MM 104 at completion of -Z translation. Once in MM 104, the crew refers to the Ascent Pocket Checklist for malfunction procedures. Crew verifies OMS 1/2 targeting, using current orbit HA and HP displayed on GNC OMS 1 MNVR EXEC, to determine if an OMS 1 burn is required. For nominal MECO, no OMS 1 is required.

OMS Burns

SI

OMS 1 targets appear on GNC OMS 1 MNVR EXEC displays. The burn is executed for SI OMS 1 and available for DI OMS 1 if required due to a large underspeed. The OMS 1 Burn cue card and the OMS 1 Burn Monitor cue card are referenced for normal OMS 1 burn procedures and malfunctions that occur during the burn.

Crew selects *INRTL* on *ADI ATTITUDE* switch and begins the automatic maneuver to burn attitude if OMS 1 burn is required. When in the proper attitude, the error needles should be centered and ADI inertial attitude should match burn attitude on the MNVR display. VGOs should be crosschecked for proper burn attitude and guidance.

MECO

Min:Sec (approx)

+1:45

EXEC key must be pressed on CDR/PLT keyboard within 15 sec of OMS TIG to enable burn.

+2:00

OMS 1 ignition. Crew monitors burn (OMS Pc ~100 percent, engine control valves ~100 percent, He pressure decreasing slowly, engine inlet pressure drops to ~200 psi, OMS quantity decreases ~15 sec after ignition, delta VTOT decrementing nominally) and prepares to respond in case of an off-nominal burn; burn duration ~2:30. Two seconds after the end of the burn, the CDR places the OMS ENG switches to OFF and trims out any delta V residuals in the X and Z directions using the THC.

If DI (or if OMS 1 is MECO +6 min or more), the MPS propellant dump is automatically initiated at MECO +2 min.

DI or SI The crew performs the tasks listed Post OMS 1 in the Post OMS 1 procedures section of the Ascent Checklist.

CDR and PLT turn *FLT CNTLR POWER* switches (2) *OFF* to prevent inadvertent inputs to the RHCs (which can initiate manual DAP).

NOTE

Taking *FLT CNTLR POWER* switches to *ON* or *OFF* may cause the DAP to downmode from Auto to Manual. Power surges in the system can be confused with an RHC input, causing the DAP to downmode.

MET

12:55

Min:Sec (approx)

PLT verifies the *BODY FLAP* pushbutton light is out (light will extinguish at the end of a timer). During that time, the MPS dump should have completed (~2:00 duration). APU shutdown is then performed after checking with MCC.

CDR takes the FES Primary Controller to ON from the GPC position and reenables the FES feedline heaters prior to the OPS 2 transition and securing BFS. PLT takes the cryo O2 tank 1 and 2 B heaters to AUTO.

MS1 takes the APU tank, fuel line, and H2O line heaters to "A" auto for freeze protection.

PLT sets the *AC BUS SNSR* switches to the *AUTO TRIP* position (MONITOR during ascent to prevent SSME loss due to bus trip).

CDR/PLT modes GPCs to MM 105 for the OMS 2 burn.

CDR/PLT load OMS 2 targets as required and OMS gimbal trim data (OMS 1 trim remains until changed. Gimbals do not move until 15 sec before burn); OMS targets are verified (PASS and BFS).

PLT secures MPS engine power and performs GH2 inerting.

PLT closes the ET umbilical doors.

WARNING

ET centerline latches must be stowed prior to door closure to prevent door drive mechanism damage.

> PLT prepares OMS for the burn by verifying proper valve configurations.

CDR, PLT set *ADI ATTITUDE* to *INRTL* position and maneuver to the burn attitude.

OMS 2 Burn TIG

Min:Sec (approx)

-5:00 Crew transitions to OMS 2 Burn and Burn Monitor cue cards for procedural reference.

> CDR, PLT make final verification of burn attitude, engine selection, DAP selection, OMS gimbal trim, He PRESS/VAP ISOL valve positions, and activate their FLT CNTLR POWER.

TIG

Min:Sec (approx)

-2:00 CDR/PLT set OMS ENG switches to ARM/PRESS and verify the engine press valves are open.

-0:15 CDR/PLT initiates EXEC command to perform burn. There is no need for the crew to correct

attitude errors prior to OMS 2 ignition because OMS engine thrust vector control (TVC) will fly the vehicle to the proper attitude. OMS TVC can be used to take out attitude errors up to the maximum error limit for OMS ignition to occur. (Limit is variable as a function of remaining ΔV and attitude error; however, an attitude error $\geq 90^{\circ}$ guarantees ignition cutoff.)

MET

TIG

Hr:Min (approx)

00:30-00:60 (00:42 nominal for DI) CDR, PLT monitor OMS 2 burn, Pc's (~100 percent), delta VTOT and time to go (TGO) decreasing, bipropellant valves (100 percent), and perigee increasing. Crew prepares to complete burn with single engine or RCS if failures occur. Burn duration is ~2 min for 160 n. mi. circular orbit (based on nominal ascent).

OMS 2 Cutoff

+2 sec

CDR/PLT secure OMS engines (2 sec delay for purge) and trim all axes residuals <2 fps (<0.2 fps for orbit critical burns).

Post OMS 2 The crew returns to the Ascent Post OMS 2 section of the Ascent Checklist for nominal procedures and the Ascent Pocket Checklist for malfunctions. CDR/PLT secure *FLT CNTLR POWER* and verify the *DAP* is in *AUTO*.

> CDR performs an OMS TVC gimbal check (secondary then primary checks are conducted to verify operations prior to on-orbit use).

> PLT reconfigures OMS and RCS valves for on-orbit operations.

CDR/PLT change to MM 106. Crew stows ascent-related FDF and unstows the Post Insertion Checklist, Orbit Operations Checklist and Pocket Checklist, cue cards, and the orbiter Malfunction Book.

Post Insertion

The Post Insertion Checklist is used for nominal procedures. The Orbit Pocket Checklist and Malfunction Book are references for malfunctions. During post insertion, the following five activities must be accomplished to prepare for on-orbit operations:

- (1) Reconfigure to on-orbit software and GPC configuration.
- (2) Activate radiators.
- (3) Open payload bay doors.
- (4) Purge the fuel cells.
- (5) Doff and stow LES, reconfigure cockpit for orbit operations.

MET

Day/Hr:Min (approx)

0/0:53

CDR/PLT reconfigure the GPCs. On-orbit software (OPS 2) is loaded into GPCs 1 and 2. management (SM)Systems software is loaded into GPC 4. GNC OPS 2 data are loaded into GPC 3 and "freeze dried" (taken off line to preserve an independent source of data) while GPC 5 retains BFS software but is placed in HALT. With SM software loaded, uplink control for S-band and TDRSS is given to the SM computer. Because only 3 CRTs can be assigned to the PASS, CRT 3 is de-assigned, and CRT 4 (powered up during MS aft flight deck configuration) is assigned to GPCs 2 and 4 (GNC and SM OPS). Pulse-code modulation master unit (PCMMU) formats are loaded for on-orbit high and low data rate telemetry. Displays are called up as required, but the

Mission/payload specialists egress seats during this period. MSs perform the following functions on the middeck:

- Install UV filter on hatch window (except OV 102).
- Repressurize water supply tank A.
- Unstow and configure headsets and microphones.
- Configure middeck audio distribution unit (ADU) and speaker box.
- Stow ascent FDF in "return to Houston" bags and unstow on-orbit FDF.
- Close appropriate circuit breakers.

These activities may be accomplished piecemeal during the next hour.

0/0:59

An MS begins flight deck configuration to include: open cabin vent and cabin vent isolation cb's (to preclude accidental venting), activate the OMS and RCS heaters, which will keep them at 55° to 90° F (A-heater in AUTO-MATIC, B-heater OFF), and activate APU lube oil heaters. Although the gas generator bed temperatures will remain warm until about MET 6:00, a caution is included at this point to monitor the APU fuel pump outlet and bypass line temperatures and activate the gas gen/fuel pump heaters if required. Aft flight configcommunication deck uration is accomplished (OV-102 aft ATU is set up), S-band communication is configured for

TDRSS at the high rate, R15 cb's are closed as required, CRT 4 is powered up, ascent thrust vector control, engine interface units, and master event controllers for the main engines are secured, and the display driver units (DDUs) cb's for the aft flight controllers and displays are closed.

0/1:28

MET

Day/Hr:Min (approx)

- 0/1:00 MSs unstow and activate the payload general support computers (PGSCs).
- 0/1:08 PLT verifies the payload electrical bus configuration (payload dependent).

0/1:10 CDR, PLT don their headsets and configure their personal communications equipment, normally selecting push to talk (PTT) for air-to-ground and voice activation (VOX) for intercom.

- 0/1:12 PLT executes an automatic maneuver to the PLBD opening attitude -ZLV with a flight specific bias. This is a time critical action; DAP A/AUTO/PRI are selected.
- 0/1:18 CDR activates the radiators by placing both the *RADIATOR BYPASS VALVE MODE* and *RADIATOR CONTROLLER LOOP 1* and 2 switches (two each) to *AUTO*, *AUTO A*. *CDR* then takes the Freon *RADIATOR ISOLATION MODE* switch to *AUTO*.

0/1:20 An MS sets up the aft panel PAYLOAD BAY FLOOD switches as required (given possible payload limitations) for PLBD opening. Lights require ~3 min for full bright). If the CCTV is to be used for PLBD opening, it will be activated at this time. PLT or MS2 initiates automatic PLBD opening with the SM PL BAY DOORS display and switch throws on panel R13L. Centerline latches take ~20 sec, forward and aft bulkhead latches take ~30 sec, and each door (starboard then port) opens in ~63 sec. After the doors are open and power removed from them, display SM ANTENNA is usually selected when other displays are not required. The MCC will uplink table maintenance block updates (TMBU) as required.

0/1:36 If there are no indications of problems with the major orbiter systems at this point, the MCC will issue a GO for orbit operations.

0/1:37 CDR, PLT egress seats, and all crew doff and stow launch/entry suits. During this time, the MCC will uplink the orbiter state vector and RCS quantity compensations.

0/1:50 PLT initiates the fuel cell automatic purge and verifies H2 and O2 flow increase the SM 69 FUEL CELLS display.

0/1:52CDR selects the SM 88 APU/ENVIRON THERM display, and if Freon loops are operating nominally (Freon loop radiator out temp <60° F), secures the flash evaporator and turns the high load evaporator off. Radiators are deployed at this point if required.

> The CDR powers on the star trackers and both star tracker doors are opened (6 to 12 sec.). CDR selects GNC 22 S TRK/COAS CNTL display and activates the star trackers. SPEC 21 is then called up to initiate the calculations for the IMU delta angles, and then CRT 1 is returned to GNC UNIV PTG display.

0/1:56

are

others

0/1:57	PLT verifies the Main B Supply H2O Dump Isolation cb is closed,
	then opens the supply H2O dump isolation valve to ensure redundant dump.
0/2:00	PLT activates the APU steam vent heaters to remove any possible

ice formation on the water spray boiler (WSB) vent openings.

0/2:29

0/2:27

for system verification. Fuel cell performance is plotted using the FUEL CELL PURGE

Limits for some systems are

PLT switches the APU fuel pump and gas generator cooling from system A (activates during APU shutdown procedure) to system B

while

changed

inhibited.

cue card.

Day/Hr:Min (approx)

MET

- 0/0:2:05 MS/PS seats are removed and stowed.
- 0/2:10 After go for vernier operations from MCC, CDR verifies use of vernier jets is safe (radiators operating and FES hi-load off) and activates verniers on MCC call. DAP selection is typically *A/AUTO/VERN*.
- 0/2:12 Crew configures controls for onorbit operations by using panel diagrams in the Post Insertion Checklist that depict switch positions.
- 0/2:20 If the remote manipulator system (RMS) is flown, initial activation procedures begin at about this time. RMS AC cb's are closed, power is applied to the manipulator controller interface unit, RMS shoulder brace is released, heaters are activated, and, if required by payload operations or constraints, the arm is deployed.

0/2:21 PLT performs the hydraulic thermal conditioning enable steps in the Orbit Operations Checklist, which allows the GPCs to operate hydraulic circulation pumps when pressures or temperatures are below set limits.

> Note: Payload electrical constraints may alter this activity.

0/2:24 MS resets C/W system from ascent to on-orbit operations.

5.2-7 5. NORMAL PROCEDURES SUMMARY

5.3 ORBIT

CONTENTS

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Orbit Operations

This section summarizes typical orbit operations for METs 0/2:30 through 0/22:00. Activities occurring after 0/6:30 are representative of subsequent flight days until the last full on-orbit day.

Note: Actual activities and times will vary from mission to mission.

D/H:M (approx)

0/2:30

Crew completes post insertion activity. Post Insertion Checklist is stowed, and crew refers to the Flight Plan for nominal activities. FD1 EZ activities are begun; i.e., lamp test, smoke detection circuit test, combustion products analyzer (CPA) ops, and orbiter cabin air cleaner (OCAC) filter cleaning. The Photo/TV Checklist is unstowed, and camera assembly is begun. Other equipment required for flight day (FD) 1 activities is unstowed and set up.

0/2:45

IMU alignment (S TRK) using Star Data is accomplished. GNC UNIVERSAL POINTING, GNC 21 IMU ALIGN, and GNC 22 S TRK/COAS CNTL displays are used for this activity.

0/3:10 Aft controller checkout initiated in each axis with the output verified on the GNC 25 RM ORBIT display.

0/3:20

times)

- Ku-band antenna is deployed (~23 sec). Antenna data is monitored on display SM ANTENNA.
- 0/3:30 Ku-band antenna activation (comm mode only normally). Signal strength is available on panel F9 DC AMPS/SIG STR meter (Ku selected) as well as SM ANTENNA display.
- APU steam vent heaters are 0/3:45 secured (initiated at MET 2 hr). APU gas generator and fuel pump heaters (A) are placed in AUTO at panel A12 to keep the generator bed 360° to 425° F and the fuel pump 80° to 95° F (the B heaters are used mid-mission to exercise the redundant system).
- 0/3:50 CRYO O2 tank heater sensor check is accomplished to verify short circuit protection for the O2 tank heaters (SM 68 CRYO SYSTEM display).
- 0/4:00 Unless there is an FD1 deploy or other mission-specific requirement, the first on-orbit meal is prepared and eaten at this time.
- (various Crew begins payload activities. These activities may include Spacelab payload deploy, activation, or secondary experiment activation, depending on the type of mission.
- 0/8:00 Presleep activities begin 3 hr (2:15 for dual-shift operations) prior to the sleep period (this can be shortened to 2 hours for single shift and 1:30 for dual-shift operations if required). Presleep activities on the flight deck include:
 - Manually purge fuel cells (FD) 1 only to save ground turn-Use SM 69 around time). display FUEL CELLS to All other monitor purge.

purges will be uplinked from MCC. Note: This could be accomplished postsleep on FD1. May vary, depending on mission.

- Conduct supply/wastewater dump, monitored using SM 66 ENVIRONMENT display (purges and dumps are not accomplished during star tracker use due to possible contamination). Check with MCC if required presleep.
- Configure cryo heaters and manifold valves as directed by MCC.
- Install O2 bleed orifice. Note: This may be accomplished postsleep, depending on PPO2 levels.
- Update SM checkpoints.
- Set CRT timer for crew wake up and C/W alert tone duration.
- Adjust the cabin temperature control as required.
- Configure active PCS O2/N2 controller to OPEN to avoid nuisance "FLOW" alarms while sleeping (14.7 config only).
- Power down unnecessary electrical equipment (IDPs (CRTs), TV power, TV cameras, VTR, cabin and PLB lights, DDUs).
- Reposition the Ku-band antenna cable to prevent chafing.
- Install window shades/filters.
- Remove power from primary reaction jet drivers (8) to preclude primary jet ON failures.

Minor payload or experiment related activity can also be scheduled during the presleep if required.

Presleep activities on the middeck include:

- Food preparation and cleanup for the evening meal.
- CO2 absorber (LiOH) replacement (one of two canisters is replaced).
- General housekeeping and WCS cleaning.
- Set up of next day's equipment (if practical).
- Write/record mission notes.
- Configure communications panels and lighting.
- 0/9:50 APU gas generator and fuel pump heaters (A) are activated at panel A12 along with the APU tank/fuel line/H2O system (A) heaters (3) (B heaters off).
- 0/11:00 Sleep period is scheduled to begin no later than 16 hr after the crew's launch day wakeup (4:55 prior to launch) but can be extended up to 2 hr if unexpected launch holds occur. The sleep period will be scheduled for 8 hr but can be shortened to 6 hr if required.
- 0/19:00 The postsleep period begins about 8 hr after the start of the sleep period and extends for 3 hr for single-shift operations (1:30 for dual shift) but may be shortened to 2 hr (1:15 dual shift) if required.

Middeck postsleep activities include:

 Reconfigure lighting and communications panels.

- Replace CO2 absorber (one of two canisters is replaced).
- Review TIPS messages.
- Install O2 bleed orifice (first postsleep) to increase O2 to the middeck, if not installed presleep.
- Meal preparation and cleanup.
- General housekeeping.

Postsleep flight deck activities include:

- Reconfigure lighting, window shades, communications panels and instruments.
- Reposition Ku-band antenna cable.
- Power on IDPs (CRTs) (3).
- Adjust cabin temperature (if required).
- Configure active PCS O2/N2 controller to AUTO.
- Configure OMS/RCS interconnect as required to preserve aft RCS propellant.
- Power primary RJD drivers (8) ON.
- Initiate supply/wastewater dump. Check with MCC.
- Configure cryo heater/manifold valves per MCC instructions.
- Fuel cell monitoring system operations record individual fuel cell voltage as an operational baseline. Data recorded and downlinked to MCC.
- 0/22:00 The crew begins a full workday on orbit with their flight-specific activities. Each day, photo/TV

scenes are activated per the P/TV Checklist. Normally, the crew downlinks live TV of flight deck or middeck activities once each day. At a minimum, a VTR dump of crew activities is downlinked. When the PLB cameras are not required for flight requirements, MCC occasionally asks to control the cameras and conduct Earth viewing. MCC will not activate cabin cameras without prior crew coordination. Once during a 4-day mission (twice for longer flights) the avionics filters are cleaned. Also, the operating humidity separator is checked for water accumulation about every 12 hours during the first few onorbit days. Once each flight day (the morning of likely/scheduled EVAs and entry day), each crewmember has an opportunity to communicate privately with a flight surgeon during a private medical conference (PMC).

OMS (RCS) Burns

OMS/RCS burns are used on orbit to raise or lower the orbital altitude, for rendezvous phasing, and deorbit. The burn may be done with one or both OMS engines or the RCS, depending on the delta V required. Propellant for the burn can come from either OMS pod or the RCS system. OMS BURN cue cards (OMS-2/ORBIT OMS BURNS (2) and OMS BURN MONITOR (2)) are installed on the forward panels for the burn. On-orbit burns require OPS 202 (302 for entry) with GNC ORBIT MNVR EXEC and GNC SYS SUMM 2 displays. Procedures for on-orbit OMS/RCS burns are similar to those discussed in the OMS 2 section. Burn target data is normally uplinked by MCC and loaded automatically. If delta V total >6 fps, an OMS burn will be required. If delta V total is \geq 4 and \leq 6 fps, a +X RCS burn is used (thereby limiting the amount of forward RCS burned). If the delta V total <4 fps, the burn is multi-axis (RCS) with no maneuver to burn attitude.

Rendezvous

This section summarizes the major events that occur during the final phases of a rendezvous. Flight-specific rendezvous procedures are located in the Rendezvous Checklist. The phase elapsed time (PET) below is referenced to target intercept (Ti) TIG. PET is used to track rendezvous events and normally is displayed on the CRT. Actual times will vary, depending on flight profile. **NH Burn** (not shown) – NH is a groundtargeted height adjust burn. This burn is actually not done, but is accommodated in the checklist, if necessary.

NC Burns – The NC burns are phasing maneuvers used to initiate or modify the rendezvous approach (closing rate). They are ground-targeted burns, the last of which are designed to place the orbiter 8 n. mi. behind the target (Ti point) in one or two revs.



Orbit Rendezvous Profile

5. NORMAL PROCEDURES SUMMARY 5.3. Orbit



Orbit Post Ti Profile

Star Tracker NAV – After the final NC burn, the crew maneuvers the orbiter to a -Z (-Y) target track attitude, which will point the desired Star Tracker (ST) at the target to provide relative navigation data. The ST angle will be used to improve the onboard filter (FLTR) state vector.

NCC Burn – This is the first onboard targeted burn. It uses the filter state vector updated by the two star tracker passes. This is a corrective combination burn that will try to create a node at and correct the transfer to the Ti point, 1200 feet below and 48,600 feet (8 n. mi.) behind the target.

Radar NAV – The rendezvous radar is expected to lock on at a range of approximately 150 kft. The radar provides range and range rate data, in addition to the angle data. The FLTR vector with the ST pass data is saved to the propagated vector (FLTR to PROP transfer) to protect for a radar bias or failure.

Ti Burn – The Ti burn initiates the final (transition) phase of rendezvous. It is targeted onboard using the updated FLTR vector. Ti is primarily a posigrade phasing burn designed to place the orbiter at the MC4 position (900 feet behind and 1800 feet below the target). Targeting to MC4 has been shown to reduce the dispersions at MC4 and, therefore, reduce the dispersions at manual takeover.

RADAR/S TRK NAV – During this portion of the profile, the orbiter will be in a -Z (-Y) target track attitude. NAV will be updated with radar or ST data. This data will be used to target the four midcourse correction burns and perform the out-of-plane null.



1095a.tif

	ISS-Centered LVLH Frame										
1111	APPROX. PET (h:mm)	EVENT									
1	0:00	MANUAL PHASE TAKEOVER (POST MC4 2000 FT BRAKING GATE (Rdot = -3.0 fps)									
2	0:03	1500 FT BRAKING GATE (Rdot = -2.3 fps)									
3	0:08	1000 FT BRAKING GATE (Rdot = -1.5 tps) SWITCH TO LOWZ									
4	0:13	600 FT BRAKING GATE (Rdot = -0.8 fps) RBAR ARRIVAL									
5	0:35	ARRIVE AT 170 FT STATIONKEEPING									
	0:50	RE-ESTABLISH APPROACH									
6	1:11	STATIONKEEPING AT 30 FT									
	1:16	RE-ESTABLISH APPROACH									
7	1:22	DOCKING									

EARTH

Orbit Terminal Phase and R-bar Approach

MC1 Burn – The MC1 burn will trim any dispersions left over from the Ti burn, taking advantage of more sensor data. MC1 targets to the MC4 position.

Planar Null – The next task is to monitor the GNC 33 REL NAV display closely to watch for the point when the out-of-plane distance between the two orbits (Y) becomes zero (nodal crossing). At this point, the crew will null the rate (Y-DOT), which will put the orbiter in the same orbital plane as the target.

MC2 Burn – This is a special burn because it is based upon the elevation angle to the target, not on a time. The burn TIG can slip so the burn will occur at the desired elevation angle. The MC2 burn sets up the standard trajectory and reduces the dispersions at MC3. This burn will maintain latest sunrise at MC3 + 2 minutes to ensure a lighted manual phase.

MC3 and MC4 Burns – The MC3 burn also targets to MC4 and, typically, is just a "trim burn" similar to MC1.

The MC4 burn targets to 600 feet on the +R-bar. This burn should "coast" the orbiter to the desired range on the +R-bar. In the nominal case, MC4 will be mostly a non-zero +X burn.

Manual Phase – Post-MC4, the orbiter is on a coasting trajectory to the 600-foot point on the +R-bar. An attitude maneuver will be performed to put the orbiter in the +R-bar attitude by the time it reaches the R-bar. R-dot corrections (braking gates) will be performed.

Flight-Specific Final Approaches – (Covered in detail during Prox Ops lessons)

R-bar: Fly up the +R-bar from the 600-foot point.

TORRA: Fly to the +R-bar until 600 feet, then transition to the –R-bar at twice orbit rate.

TORVA: Fly to the +R-bar until 600 feet, then transition to the +V-bar at twice orbit rate.

INERTIAL: Orbiter maintains inertial attitude hold during final approach to target.

Last Full On-Orbit Day

The last full on orbit day includes the nominal flight day activities plus general cabin stowage, FCS checkout, RCS hot fire, and those unique procedures that must be accomplished prior to transition to the Deorbit Prep Checklist (-04:00 TIG). Prior to the presleep activities the crew conducts entry planning, secures IDP (CRT) 4 (if not required), and stows the Ku-band antenna.

Presleep and postsleep activities are nominal with the exception of the continuation of general cabin stowage. Additionally, fluid loading preparation (four 8 oz containers per person) and cabin air samples may be accomplished in the postsleep period or deorbit preparation. The flight control system is checked for proper entry operation (also saves ground test time). The test (conducted in two parts) will be accomplished with an APU (MCC designated), but may be done with a circulation pump if required.

FCS Checkout, Part 1

FCS checkout Part 1 consists of the following activities:

- Power on FCS sensors and controls prior to the transition to OPS 8. Aerosurface amplifiers (ASAs) must be ON prior to OPS 8 if an APU is used and OFF if a circulation pump is used.
- Event timer is set to count up (to track APU ON time).
- Hydraulic thermal conditioning is terminated and the APU is prepared for operation.
- ON MCC GO, the selected APU is brought on line in low pressure and event timer is started.
- If APU operation is nominal, normal pressure is selected for actuator checkout (SM 87 HYD THERMAL display).
- Proper elevon switching valve operation should be noted.

- Surface drive is initiated (some surfaces may not drive properly right away due to cold hydraulic fluid). Test should be complete in about 30 sec.
- A secondary actuator check is initiated to test the bypass feature of the actuators. When the test is complete, the APU is shut down and hydraulic thermal conditioning is re-enabled (if required). Expect a marked structural vibration when ports pop during the secondary actuator check.

FCS Checkout, Part 2

Part 2 of the FCS checkout begins with a sensor test (GNC 40 SENSOR TEST). The orbiter is placed in free drift. The crew then initiates the sensor tests (accelerometer assemblies (AAs), microwave landing system (MLS), TACAN, radar altimeter, rate gyro assemblies (RGA), and air data transducer assemblies (ADTA)). Sensors failing the test will be deselected for entry. Following the sensor test, the FCS mode/ channel switch test is conducted. These procedures verify FCS switch contacts and all entrycritical switches (flight controller power required). Next a test of the nose wheel steering system is performed. The next series of procedures verify proper operation of controllers and

their associated switches (left and right). Finally the DDUs and head-up displays (HUDs) are tested and adjusted for entry. When the FCS checkout is complete, the DPS is returned to OPS 2 GNC (G8 to G2 transition), and all entry equipment is secured.

RCS Hot Fire

This test is conducted to verify the operation of seldom used RCS jets (thereby decreasing ground turnaround time). Manual DAP is selected and the orbiter is verified/placed in free drift. Each RCS jet is tested (GNC 23 RCS display) and the results noted (3 sec delay between pulses to allow time for a fault message and 30 sec delay if a failure is annunciated). When the Hot Fire test is complete, the vehicle is placed in inertial hold to allow damping of rates before returning to the required attitude. RJDs, DDUs, and MDMs are then secured as required.

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5. NORMAL PROCEDURES SUMMARY 5.3. Orbit

5.3-8

5.4 ENTRY

CONTENTS

Deorbit Preparation	
Deorbit Burn	
Entry Interface	
Terminal Area Energy	
Management (TAEM)	
Approach and Landing	
TRACT OF DAUNA THE CTO OWED AND	

Deorbit Preparation

TIG

Hr:Min (approx)

-4:00

The crew transitions to the Deorbit Prep Checklist for nominal procedures. PLT sets CRT timer for deorbit TIG using the GNC 2 TIME display and SM timer.

-3:56

CDR initiates radiator coldsoak by placing RAD *CNTLR OUT TEMP* switch to the *HI* position and activating topping FES to minimize propulsive venting. Vehicle is maneuvered to "tail sun" attitude (-X SI) for the coldsoak. The H2O Loop Bypass controllers are checked out and the H2O loops are configured for entry.

- -3:50 MSs continue entry stowage along with entry airlock configuration.
- -3:48 Ku-band antenna is stowed (if not already accomplished in last presleep period).
- -3:45 Radiators are stowed (if deployed).
- -3:42 Compute N. quantity and identify depleted H. tanks.
- -3:35 Specialists install seats and FDF containers.

-3:30 to -2:30

-3:27

-3:25

-3:10

-2:55

-2:51

- MS performs payload deactivation/entry preparation in this timeframe, as required.
- DPS is configured for deorbit preparation. The BFS is woken up to ensure it has interface to the forward CRTs (IDPs).

PLT activates APU water boiler steam vent heaters (at least 2 hr before APU start) and terminates hyd thermal conditioning. PLT prepares for hydraulic repressurization of the main engine thrust vector controls (engine bells must be properly stowed to prevent thermal damage).

-3:15 CDR, PLT power up FCS, DDUs, and navigation aids for entry (RGAs and ASAs must be on prior to OPS 3 transition).

> Crew begins Entry Switch List verification by comparing crew compartment switch positions with diagrams in the Deorbit Prep book.

CDR initiates radiator bypass to retain Freon coldsoak. Alternate FES is checked out to save ground test time. PLBDs will not be closed until this check out and until Freon temperatures are down to 39° F. Primary RCS jets are used because FES Hi Load vent forces are too strong for vernier jets. H20 crossover valve is opened to allow all water tanks to feed the FES equally.

MS prepares for PLBD closing (PLB lights activated (as required), cameras/VTR readied, RMS TV camera positioned and RMS heaters secured (if RMS flown)).

TIG

-2

Hr:Min (approx)

:40	PLT, MS close PLBDs usin
	SM PL BAY DOORS displa
	or BFS SM 63 PL BA
	DOORS. After door closure
	IDP (CRT) 4 is powered OFF.

Ý

-2:25 MS performs post-PLBD closing procedures, which include securing PLB lights, deactivating/stowing cameras, and taping down foot restraints (to prevent tripping during egress).

- -2:23 CDR monitors auto maneuver to attitude suitable for S-band communications if required. Crew may go to deorbit attitude, depending on flight profile and TDRS position.
- -2:16 CDR, PLT configure DPS (three phases) to place GPCs 1, 2, 3, and 4 in PASS OPS 3 and GPC 5 in BFS OPS 3. Prior to OPS 3 transition, entry TFLs are loaded and SM Checkpoint Initiate is performed to update the FDA in case a wave-off is required. Once in OPS 3, the crew refers to the Entry Pocket Checklist for malfunction procedures.

-1:58

-1:55

MS deactivates star tracker and closes doors.

CDR, PLT, MSs perform entry switch list configuration and verification at this time. The following items will be performed or verified:

Forward Flight Deck

• Electrical power to brakes, brake heaters, anti-skid, and nose wheel steering (NWS) is applied.

- Verniers are secured.
- FES control is given to GPCs. Freon loop RADIATOR ISOLATION MODE switch is taken to OFF. Cb's for HUM SEP and IMU FAN signal conditioners are opened.
- One O2/N2 valve is opened in case of a cabin leak.
- Communications panels are configured to provide maximum redundancy.

Aft Flight Deck

- Activate entry monitoring equipment unique to particular vehicles (Aerodynamic Instrumentation Package and Shuttle Infrared Leeside equipment-OV102, Modular Auxiliary Data System-OVs 103 - 105.
- Secure hydraulic heaters.
- Secure the teleprinter (via dc utility power MN C) and remove the power cable.
- Connect an LES communications cable (dC Utility Power MN C).
- Open Ku-band circuit breakers.

Middeck

- Configure communications panel for entry.
- Pressure control system (PCS) is configured for N2 water tank ullage pressure.
- Close 14.7 cabin regulators (protects N2 if leak occurs).

5.4-2
ARMIPRES

- Close O2 regulators (so O2 flow goes only to LES).
- Remove and stow bleed orifice.

TIG

-1:40

-1:06

Hr:Min (approx) -1:42

CDR receives MCC readup of PADs (OMS propellant PAD, deorbit/entry/land PAD, and deorbit maneuver PAD). The current state vector, and deorbit targets are also uplinked. Crew can use PGSC (SPOC) to determine targets and c.g. if required.

MS enables MPS helium system pressure C/W (assists crew in isolating failed open regulator). Hydraulic system C/W parameters for low pressure are activated (alarm will sound immediately since APU's are OFF).

-1:39 Crew conducts entry review as required (15 min alloted).

-1:24 CDR, PLT don LESs.

-1:10 Specialists don LESs.

Final IMU alignment is performed by CDR to reset RM threshold prior to deorbit burn. This maximizes IMU RM, two-level attitude failure detection.

- -1:04 Crew begins fluid loading (containers filled in post-sleep).
- -0:59 CDR, PLT ingress seats.

-0:57 CDR, PLT remove HUD covers.

-0:53 Crew performs LES pressure integrity check.

0:50	Crew doffs and stows on- orbit communications head- sets.	
Veni la v	-0.25 PLA partorms	

-0:33 MS deactivates WCS.

Deorbit Burn

-1:03 All begin fluid loading per individual prescription.

CDR, PLT perform LES pressure integrity check.

-0:47

-0:55

CDR, PLT stow all unnecessary FDF items and transition to the Entry Checklist for the nominal procedures.

-0:46 CDR, PLT receive final deorbit update/uplink. Deorbit flight rules are verified with MCC. Exact time may vary.

-0:40 CDR performs OMS TVC gimbal check (during AOS), using OMS MNVR EXEC display.

PLT initiates APU pre-start procedures (during AOS). BFS, SM SYS SUMM 2 is used to check APU status.

CDR, PLT conduct horizontal situation configuration using GNC 50 HORIZ SIT; BFS GNC 50 HORIZ SIT; and GNC 51 OVERRIDE for both PASS and BFS.

PLT initiates OMS burn preparation, which includes checking engine trims and placing OMS and RCS valve switches in the pre-burn configuration.

MS3 removes and stows side hatch UV filter, locking device, and Pyro Box Safing pin. -0:35 MS deactivates the galley and the WCS.

-0:25 PLT performs vent door closure with the GNC 51 OVERRIDE display.

CDR, PLT receive final deorbit update/uplink if required. MS1 and MS2 ingress their seats.

CDR proceeds to OPS 302 and GO/NO-GO is given for deorbit burn.

TIG Hr:Min (approx)

CDR initiates maneuver to deorbit burn attitude on OMS MNVR EXEC display. CDR, PLT verify *ADI* switches in proper positions. MS places OMS/RCS heater switches in proper configuration for entry.

-0:05

-0:15

PLT performs single APU start, one APU must be operating in low pressure prior to the burn. First APU start procedures vary, depending on weather. CDR verifies orbiter is in the deorbit burn attitude $\pm 5^{\circ}$. The crew transitions to the Deorbit Burn cue card for nominal procedures, and the Burn Monitor cue card for malfunction procedures. The Deorbit Burn Flight Rules cue card should be consulted prior to executing the burn.

Deorbit Burn TIG Hr:Min (approx)

-5:00

Once on the Deorbit Burn cue cards, CDR and PLT ensure OMS He switches, ADI switches, and FLT CNTRL PWR are in the proper burn configuration. -2:00

-0:15

0:00

Deorbit burn TIG. CDR, PLT monitor the burn using delta VTOT, VGO, TGO, and Hp from GNC OMS MNVR EXEC. BFS GNC SYS SUMM 2 display is used for OMS systems data. Section 7 discusses deorbit burn monitoring and downmoding.

CDR takes OMS

OMS ignition.

preparation for the burn.

switches to ARM/PRESS in

CDR hits EXEC key to trigger

ENG

As burn termination nears (TGO going to 0), crew monitors current perigee (HP) approaching targeted HP and delta VTOT approaching 0. Deorbit OMS burn time varies with orbital altitude. Typical burn times are 2-3 minutes. During the burn, the Deorbit Burn Monitor cue card is used for malfunction procedures.

OMS Cutoff

+2 sec

If nominal burn, CDR secures OMS engines following the automatic purge and trims residual X and Z velocities (< 2 fps for steep targets and - 0.5 fps for shallow ones). The crew returns to the Entry Checklist Post Deorbit Burn section for nominal procedures and to the Entry Pocket Checklist for malfunction procedures.

PLT performs OMS/RCS reconfiguration by verifying the proper position of RCS switches and closing OMS HE and crossfeed valves; MS stows PGSC (SPOC).

CDR proceeds to OPS 303. CDR verifies the proper attitude, and initiates maneuver to the EI -5 min attitude. CDR also conducts OMS gimbal powerdown verifying after gimbals have driven to the proper entry position.

EI

Min:Sec (approx)

-20:00

CDR initiates a secondary actuator check, if not previously performed during FCS checkout and time allows, using GNC 53 CONTROLS, BFS SM SYS SUMM 2, and GNC DEORB MNVR COAST displays.

-18:00

PLT performs forward RCS dump with GNC 23 RCS, GNC DEORB MNVR COAST, and GNC SYS SUMM 2 displays. Dump times for various forward RCS quantities are listed in the Entry Checklist. It takes 90 seconds to dump 50 percent forward RCS with 4 jets (twice as long using a 2 jet dump).

The forward RCS is always dumped unless needed for c.g. control. This reduces the hazard to the crew if a hard landing is made.

CDR, PLT perform entry switch checks (using GNC 51 OVERRIDE) and exercise brake pedals.

PLT starts remaining (2) APUs, verifies nominal performance, then switches all 3 APUs to normal pressure in preparation for the SSME hydraulic repress.

PLT performs main engine hydraulic system repressurization to ensure the nozzles are properly stowed.

If required, PLT initiates hydraulic fluid conditioning

Crew makes burn report to MCC and updates new state vector if required. All crew members inflate anti-g suits if desired.

PLT transitions AC BUS sensors to MONITOR.

The crew transitions to the Entry Maneuver cue card for nominal entry procedures.

CDR transitions GPCs to OPS 304 when verified at EI-5 attitude. Crew switches to AESP for malfunction procedures.

Program test inputs (PTIs) are enabled on SPEC 50 when applicable.

-3:00

-6:00

-5:00

PLT verifies FWD RCS MANI-FOLD ISOLATION valve switches (4) are closed (unless forward RCS PTIs are scheduled).

Entry Interface

+ = Time from EI
- = Time to touchdown Min:Sec (approx)

+0:00 -32:14

Orbiter reaches EI (400,000 ft) at an Earth relative velocity (V) of ~24,600 fps and descent rate (H-dot) of ~500 fps. The crew compares ADI, AMI, and AVVI data to Entry cue card data. ENTRY TRAJ (1 -5), HORIZ SIT, and GNC SYS SUMM 1 displays are monitored. The BFS ENTRY TRAJ display is available to compare PASS and BFS guidance. The PLT can call up BFS SYS SUMM displays as desired to check system operation.



-13:00

+2:39 -29:35 +3:32	Automatic elevon trim begins at a q-bar = 0.5 psf. Aerosurface control begins at	(Mach = 19) Alt = 215 k ft	RCS activity lights are reconfigured when q-bar = 50 psf to indicate RCS saturation.
-28:42 + = Time from I	q-bar = 2.0 psf. CDR, PLT monitor elevon and aileron deflection angles on surface position indicator. EI	+15:51 -16:23 V _m =17 k fps (Mach = 17) Alt = 200 k ft	PASS and BFSTRAJ displays mode to ENTRY TRAJ 2.
 – = Time to toue Min:Sec (approx) 	chdown	+17:00 -15:14	NAVAID power on is verified and I/O RESET
+4:45 -27:29	Closed loop guidance initiated (CLG Init) at q-bar = \sim 8 psf or drag = \sim 3 fps ² . Guidance box appears on ENTRY TRAJ to indicate closed loop guidance.	$V_{REL} = 15 \text{ k fps}$ (Mach = 15) Alt = 185 k ft	performed. This insures NAVAIDs will warm up before they are required (in case they were off due to a powerdown).
+5:00 27:14	Roll RCS jets deactivated at q-bar = 10 psf.	+17:57 -14:17 V_==14 k fps (Mach = 14)	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 3. Drag is up to 33 fps ² and Gs up to 15
+5:18 -26:56	First non-zero bank com- mand issued by guidance at	Alt = 182 k ft	land data patricular transation bad Diverta Range transation
	H-dot -240 ft/sec (CLG Init plus 15 to 30 sec).	+18:57 -13:17	Radiator bypass valves (2) are placed in automatic and
+6:10 -26:04	Maximum surface tempera- ture region begins (Mach 24 to 19). Actual drag should be within .5 fps ² of orbiter	$V_{REL} = 12 \text{ k fps}$ (Mach = 12) Alt = 176 k ft	are put in AUTO B(A). CDR and PLT begin monitoring for aileron saturation.
+8:04	bug drag. Pitch RCS jets deactivated at	+19:20 -12:54	PASS and BFS ENTRY TRAJ mode to ENTRY TRAJ 4.
-24:10	q-bar = 40.	$V_{REL} = 10.5 \text{ k fps}$ (Mach = 10.5)	Alpha and drag start to ramp down, but Gs stay up
+11:49 -20:25	At drag = 11 fps, drag H updates begin in NAV filter. Crew monitors data on GNC 50 HORIZ SIT display.	+20:03 -12:11 V _{REI} =10 k fps	Speedbrake opens to 81 percent.
+13:40 -18:34	First roll reversal is issued by guidance when azimuth	(Mach = 10) Alt = 150 k ft	
The and the grad	error (delta AZ) = $\pm 10.5^{\circ}$. Occurs at a flight-specific velocity between 23,000 and 6,200 fps, depending on crossrange.	+21:00 -11:14 V_{Rc} = 8.0 k fps (Mach = 8)	SSME repositioning for drag chute deploy. If GPC annunciates SSME REPOS FAIL, drag chute is emer- gency deploy only.
Note:	1 k fps = Mach 1.0		n Minabyli a shi ipidakan a shekara
+14:42 -17:32 V _m = 19 k fps	The PLT checks that the MPS TVC isolation valves are closed. Pitch and roll		

+ = Time from EI- = Time to touchdownMin:Sec (approx)+21:34MCC has sufficient tracking-10:40for state vector update. This V_m =7.5 k fpstime can vary depending on(Mach = 7.5)ground track and trackingAlt = 144 k ftstation performance.

+21:41 First TACAN acquisition.

MCC and the crew compare

TACAN data to NAV. If

acceptable, MCC tells the

crew to take TACAN. GNC

50 HORIZ SIT display is

used to check TACAN errors

and accept TACAN data for

PASS and BFS ENTRY TRAJ

displays mode to GNC

use by the NAV filter.

ENTRY TRAI 5.

 $V_{sc} = 7.3 \text{ k fps}$ (Mach = 7.3) Alt = 142 k ft

-10.33

+22:00 -10:14 V_{ac}=7 k fps (Mach = 7) Alt = 138 k ft

+22:41 -09:33 V_m=6 k fps (Mach = 6) Alt = 131 k ft

+23:30 -08:44 $V_{act} = 5 \text{ k fps}$ (Mach = 5) Alt = 120 k ft Air data probes are deployed. CDR, PLT begin aileron and rudder trim monitoring. The crew can check for good probe deploy discretes by noting the absence of OFF flags on the AMI and AVVI tapes when the AIR DATA select switch is taken from NAV to LEFT then RIGHT. This does not apply if the BFS is engaged. The BFS does not support OFF flags. Air data information will not be valid until Mach is <3.5.

+25:00 -07:14 (Mach = 3.4) Alt = 95 k ft Using GNC 51 OVRD, GNC 50 HORIZ SIT, and instrument tapes the crew checks air data is close to NAV. MCC will give a GO to take air data to NAV and/or G&C using Items 25 and 28 on GNC 50 HORIZ SIT.

+25:30	PLT verifies A	PUs oper	rating
-06:44	nominally.	CDR,	PLT
(Mach = 2.6)	activate HUD	s.	
Alt = 83 k ft			

Terminal Area Energy Management (TAEM)

+25:40 PLT verifies air data incorpo--06:34 rated into guidance. If not, (Mach = 2.5)the CDR must take CSS control to avoid a transient when Alt = 81 k ftair data is incorporated. Software transitions automatically to OPS 305. Guidance enters TAEM phase. VERT SIT 1 displays replace PASS and BFS ENTRY TRAJ displays. +25:55 Fuselage vents open. -06:19 (Mach = 2.4)Alt = 80 k ft+ = Time from EI

- = Time from EI
 - = Time to touchdown
 Min:Sec (approx)

-26:50	Air dat
05:24	to Gui
Mach = 2.0)	the cre
Alt = 75 k ft	theta li
	VERTS

Air data must be incorporated to Guidance and Control or the crew must stay within theta limits as shown on the VERT SIT display.

WARNING

If low energy, or flying a big heading alignment cone (HAC) (>320°), TAEM guidance will command an uncontrollable pitch up between Mach 1.0 and 1.5 if air data is not incorporated.

+27:53 -04:21 (Mach = 1.0) Alt = 54 k ft RCS vaw jets are deactivated.

5.4-7 5. NORMAL PROCEDURES SUMMARY 5.4. Entry

+28:17 -03:57 (Mach = 0.9) Alt = 46 k ft	CDR selects pitch, roll, and yaw (R/Y) CSS. Speedbrake "commanded" versus "actual" position is verified. Speed brake is now controlling energy. PLT flight controller is verified ON. This switch must be on for NWS to work. NWS is verified in system 1.	+31:35 -0:39 300 KEAS Alt = 3 k ft 31:41 -0:33 300 KEAS Alt = 2 k ft	MS2 checks speed brake command percent (actual will lag). CDR initiates preflare and begins transition onto ball bar. PLT arms landing gear on call from CDR.
+29:00 -03:14 (Mach = 0.7) Alt = 32 k ft	PLT verifies landing gear extend isolation valve is open. PASS and BFS VERT SIT displays transition to VERT SIT 2. PLT and CDR monitor PASS and BFS GNC 50 HORIZ SIT for HAC acquisition. The glide slope indicator (GSI) is now accurate enough to use.	+31:51 -00:23 297 KEAS Alt = 500 ft +31:54 -0:20 288 KEAS Alt = 300 ft	Shuttle will be lined up on ball bar. MS2 checks speed brake command percent (second smart speed brake reset). Pilot deploys the landing gear on call from CDR. PLT/MS2 check gear indicates down.
+30:00 -02:14 280 KEAS Alt = 15 k ft	MS2 monitors MLS acquisi- tion. All residuals and ratios disappear from PASS GNC 50 HORIZ SIT upon MLS acquisi- tion and an overbright MLS will appear in the middle right of the display. CDR and PLT check PAPIs and HUD overlays on runway to evalu- ate NAV state. De-clutter HUDs as required. Crew starts landing comm protocol.	+32:04 -0:10 261 KEAS Alt = 30-80 ft +32:14 -00:00 195 or 205 KEAS	Final flare begins. Main gear touchdown (195 KEAS GW <220,000 lb). CDR controls drift with rudder, maintains wings level with RHC. PLT and MS check speed brake opening. PLT
Approach and +31:00 -1:14 300 KEAS (18° at Alt = 12 k ft	Landing nd 20° OGS) CDR and PLT monitor outer glide slope (OGS) and verify with the PAPIs. At 10,000 ft crew verifies Approach and Landing guidance (flashing A/L on VERT SIT display), body flap to TRAIL, and LES visors down (KSC).	+32:15 +00:01 195 KEAS +32:16 +00:02 185 KEAS	WOW lock on (WOWLON) (HUD reconfigures and air- speed moves to upper left corner of the display). Also, the velocity vector disap- pears. PLT deploys drag chute on call from CDR. 195 KEAS. CDR initiates beep trim derotation, which targets 1.5 dag (cos
+31:24 -0:50 300 KEAS Alt = 5 k ft	PLT compares radar ALT 1 vs. 2.	+32:24 +00:10 145 to 155 KEAS	Nose gear touchdown (HUD reconfigures with a "G" show- ing up by the groundspeed). MS2 selects <i>SRB SEP</i> to <i>AUTO/MAN</i> or <i>ET SEP</i> to <i>MAN</i> and depresses the cor- responding pushbutton to

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backup automatic discretes for elevon load relief, NWS, and anti- skid circuitry. CDR maintains or slowly and judiciously corrects to centerline with NWS. MS checks elevons down (makes sure they have load relief) and NWS FAIL and anti-skid fail lights off. MS calls "NWS FAIL" as necessary. (If no load relief, RHC full forward. If NWS FAIL light comes on, steer with rudder, RHC, and brakes. NWS2 may be available.)

+3

+0

60

(±

+3

00 40

+3

+0

2:46 0:32 KGS 20 kts)	PLT jettisons drag chute on CDR call.
2:50 :36 KGS	CDR reduces braking to less than 6 ft/sec^2 until wheelstop.
92:56 90:42	Orbiter stops; CDR reports "wheels stop" to MCC. Crew transitions to Post Landing Procedures in the Entry Checklist. At wheel stop, speed brake is closed.

CDR checks ground speed and decel on HUD. Post midfield, CDR applies brakes at 140 knots ground speed (KGS) or 5000 feet runway remaining, whichever occurs first. If 140 KGS is reached first, nominal braking profile This deceleration is used profile is typically 8 to 10 ft/sec². At 5000 feet of runway remaining, if groundspeed is greater than 140 knots, CDR applies maximum braking.

+32:34 +00:20

•

5.4-9 5. NORMAL PROCEDURES SUMMARY 5.4. Entry

5.5 POSTLANDING

- CDR takes NWS, flight controller power, and HUD power off. PLT checks that APU auto shutdown is enabled and speed select is in norm. PLT takes HUD power off.
- CDR and PLT safe RCS/OMS, and deactivate air data probe heaters.
- CDR, PLT, and MS safe the landing gear.
- PLT, after notifying MCC, opens the ET umbilical doors. PLT initiates hydraulic load test on MCC call.
- CDR performs DPS transition to OPS 901 on MCC call.
- CDR performs the radiator reconfig and activates the NH3 boiler, as required (MCC call or C/W).
- PLT sets body flap to trail and performs main engine reposition with PASS OPS 9 display GNC 105 TCS CONTROL. PLT also performs APU/HYD shutdown after main engine repositioning is complete.
- CDR performs PCS deactivation. With a GO for extended powerup from MCC, CDR/PLT begin system deactivation. CDR secures GPCs 2-4 reassigning strings to

Fight Data File (FDF) checklists. It is very important that creatmentions learn to recognize tailants and east property. Pathere identifiestion is the key. Only through study, training, and practice will a creatmention schurve the destroit degree of profileseavy prior to flight

In some areas, actual crew operations are described, along with menitoring and control devices. This is particularly important for aborts where stynamic flight cars, instruments, and car cards must be applied interpreted. Some abort tationale is also, architect to ensure the measurements understands various story modes

The key to most emergencies is to which all miormation eveniable, excluding instats inves the Launch Control Center (LCC) while on the padGPC 1 and informs MS to proceed with MS System Deactivation Procedures (LRU and APU heater deactivation, RCS/OMS heaters turned OFF).

- PLT performs vent door purge positioning and RCS/OMS valve test.
- Convoy personnel open hatch.
- Flight Surgeon enters cabin for health check. ASP, suit tech, and Shuttle Processing Contract Spacecraft Operator (SPC SCO) enter the cabin to assist with egress and removal of experiments and early return items.
- CDR, MS, (PS) egress seats. MS, PS retrieve "return to Houston bags."
- CDR, PLT, MS, (PS) egress orbiter to begin postlanding activities. After medical evaluations, showers, visits with family and postlanding medical data collection, the crew returns to Houston. Normal return to Houston occurs 6 to 9 hours after landing.
- ASP removes special FDF but retains some entry related FDF until handover to KSC.
- ASP hands vehicle over to SPC SCO when MCC (Houston flight) hands off to Orbiter Test Conductor (OTC).

Failures level to fail into two general stagle overponent and multiple.

For single-component failures, pairway is important. Similar decays should allow that is properly analyze what has happened and what steps are becausery to regain the lost component or to optimize remaining systems to product against additional tailors. A common secuanong meriperienced personnel is to an hito quickly, do the wrong thing, and make the situation worse.

6. EMERGENCY PROCEDURES

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This section covers critical failures to which the crew must react expeditiously. Both performance-related and system failures are presented. Critical system failures are those requiring a response within 5 minutes to safe the system or restore its function. Performance-related failures may result in an abort, depending upon the severity. Launch and ascent aborts are discussed in detail.

The emergency procedures in this section are designed to be general in nature and not flight specific. Detailed procedures are available in Flight Data File (FDF) checklists. It is very important that crewmembers learn to recognize failures and react properly. Failure identification is the key. Only through study, training, and practice will a crewmember achieve the desired degree of proficiency prior to flight.

In some areas, actual crew operations are described, along with monitoring and control devices. This is particularly important for aborts, where dynamic flight cues, instruments, and cue cards must be rapidly interpreted. Some abort rationale is also included to ensure the crewmember understands various abort modes.

The key to most emergencies is to utilize all information available, including inputs from the Launch Control Center (LCC) while on the pad and postlanding, and from the Mission Control Center (MCC) during all flight phases. Both the LCC and MCC have an enormous amount of data at their disposal. With the highly trained Launch Team and Flight Team working together with the crew, most emergencies can be quickly identified and proper actions started.

There are three levels of protection to prevent loss of a shuttle because of failures: component failure prevention, vehicle design, and training.

Component failure prevention is accomplished through a stringent process of equipment design, qualification tests, maintenance, checkout, quality control, and proper operation.

The shuttle is designed to a "fail-ops/fail-safe" philosophy. This means that loss of any one component can be tolerated without compromising the mission, and loss of a second component will not result in loss of vehicle or crew. Obviously, this requires redundant systems and system components. Managing this redundancy adds to shuttle complexity.

The third level of protection is the human element: crew, MCC, and LCC training. In order to quickly and correctly respond to performance or systems problems, as well as complex multiple failures, the flight crew and ground crews must be experts on shuttle systems and how to control them. Prior to flight, both the ground teams and the crew participate in many hours of intense simulations to improve their teamwork and knowledge of shuttle systems. A stringent certification process is also in place to ensure qualified and current personnel in all disciplines.

Failures tend to fall into two general categories, single component and multiple.

For single-component failures, patience is important. Shuttle design should allow time to properly analyze what has happened and what steps are necessary to regain the lost component or to optimize remaining systems to protect against additional failures. A common error among inexperienced personnel is to act too quickly, do the wrong thing, and make the situation worse. Multiple failures are more difficult to deal with, because reaction time must be short, and procedures may not be explicit. Most FDF procedures are written considering a maximum of two failures. To avoid burdensome complexity and to maintain credibility, this is the only way to realistically tailor procedures to a vehicle as complex as the shuttle. The result is that a specific procedure may not be available to guide the crew, or several procedures must be combined or executed in rapid succession. For these cases, the crew and ground teams must rely on their knowledge and training. Once

design, qualification tesis, municipance, (heck out, quality control, and proper operation

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To cope with potential failures in a dynamic environment, such as ascent or entry, the flight crew must constantly keep in mind their current status and mentally prepare for potential additional failures before they occur. This "staying ahead of the airplane" philosophy, along with system reconfiguration for optimization and built-in graceful degradation of systems, enhances the chances of a successful outcome when multiple failures are encountered.

6.7 CONTINUENCY APORT 6.73 6.8 SYSTEME PARLURES 6.84 6.9 MULTHAE PARLURES 6.84 92 MULTHAE PARLURES 6.84 6.10 SWITCH AND PANEL CALFICRS. AND PANEL 6.11 SYSTEME FAILURE 8.11 SYSTEME FAILURE 6.10-1 SUMMARY 6.11

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6.1 LAUNCH ABORT MODES AND RATIONALE

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Mode 1 – Unaided Egress/Escape	6.1-1
Mode 2 – Aided Escape	6.1-1
Mode 3 – Aided Escape	6.1-2
Mode 4 – Aided Escape	6.1-2

A shuttle launch may be scrubbed or aborted up to solid rocket booster (SRB) ignition. Normally, launch scrubs prior to space shuttle main engine (SSME) start are followed by an orderly safing procedure and crew egress, assisted by the closeout crew. A fully fueled shuttle on the launch pad may present an extremely hazardous situation if toxic vapors, fire, or structural damage are present. A launch abort after SSME start is automatically controlled by the ground launch sequencer (GLS). The most serious hazard here is the presence of excess hydrogen, resulting in a hydrogen fire, which is invisible to the eye and very dangerous. This situation occurred during a launch attempt for STS-41D.

In the event of an emergency at the launch pad, the NASA Test Director (NTD), who mans a console in the Launch Control Center (LCC) firing room, is in command. Priority is flight and ground crew egress and escape, followed by preventing destruction of the shuttle, facilities, complex, and support equipment.

Should an abnormal event occur that terminates a flight or prelaunch operation and results in substantial damage to the shuttle and/or injury to personnel, the NTD will declare a contingency situation. This alerts fire and rescue personnel and puts in motion pre-planned procedures to minimize further damage and injuries.

The NTD may also initiate action if an emergency condition exists that requires immediate action to prevent loss of life or destruction of equipment. In preparation for a potential emergency condition, a hazardous condition may be declared if there is a threat to personnel health or safety. A hazardous condition may develop into an emergency condition. Depending upon the severity of the situation on the launch pad, an emergency egress/escape may be required to evacuate personnel. The shuttle program has classified four launch pad escape modes that are preplanned and rehearsed by the flight crew, closeout crew, and all launch pad personnel. Defining these modes prior to the development of an emergency condition or contingency situation ensures standard procedures can be followed and minimizes risk of additional injury and damage.

Mode 1 – Unaided Egress/Escape

This escape mode may be initiated by the NTD or flight crew. The NTD will direct that the orbiter access arm (OAA) be returned to its position at the crew module hatch. The fire/rescue crew will be dispatched if the NTD decides it is safe to do so. Escape from the shuttle vehicle and the pad is performed by the crew. This procedure is practiced in trainers and mockups in Houston and rehearsed during terminal countdown demonstration test (TCDT) at KSC. Because crew complement varies from flight to flight, each crew must develop their own particular procedures. Using a buddy system is strongly recommended. Egressing the shuttle along the OAA and across the pad 195 ft level to the slidewire baskets through the water deluge fire suppression system is a hazardous operation. Given the very real potential of fire, toxic vapors, and explosion, flight crews must be well-trained and prepared.

Mode 2 – Aided Escape

Aided escape is initiated by the NTD, flight crew, or closeout crew. This mode is used when the closeout crew is still on the pad. The closeout crew leader is responsible for ensuring that all personnel egress from the shuttle and proceed along the prescribed escape route to a safe area. The NTD will also alert the fire/rescue crew. Injured personnel will be assisted/carried along the escape route, and basic first aid will be rendered if required. The closeout crew leader keeps the NTD informed of medical conditions and egress/escape progress.

Mode 3 - Aided Escape

Initiated by the NTD or flight crew, this mode is used after the closeout crew has departed, and a contingency occurs that requires assistance. The OAA is repositioned, and the fire/rescue crew proceeds to the pad to assist the flight crew. The actual egress/escape is similar to the Mode 2 operation, except the fire/rescue crew substitutes for the closeout crew.

Mode 4 – Aided Escape

This mode is initiated by the NTD, closeout crew, or flight crew. It involves a contingency

arbitrar access and 10 AA) he towned to its president at the care module back in the dentities at the care module back in the dentities which and the part is performed to the shuffle vehicle and the part is performed to the care. This protection is performed in halons and increased in Housen and elements to the second reaction of the care is performed in halons at KSC. Percesse care comparents to the care there is begin to the towner and a performed in the second of the towner and the second second is a factor of the towner to the second reaction protections. Using a body in the factor is the towner the part of the second is a modely module and a most of the second is a second the towner the part of the fact to the ship where the towner the part of the second is a second the very and presented of the second is a sized the very and presented of the towner to an expression and an equilation of the towner to the ship where the towner the part of the definition to the ship way and presented of the towner to an address the very and presented of the towner to the ship way and explores the towner spect towner to an address the very and presented of the towner to the ship way and explores the towner spect towner to the ship way and the towner spect towner to the ship way and the spectrum of the

Model - Mided Pscape

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In summary, launch aborts may range from a scrub/turnaround to a complex rescue scenario. Crews must be very familiar with all hardware and procedures. This requires training and practice. Prior to any launch pad evolution, a careful review of emergency procedures is warranted.

writerly safing procedure and crew oppear, assisted by the chaevar crew. A fully fucied shurtle on the taunch and may present an extremely bacardions situation it toxic vapors, far, or structured damage are present. A faunch about after 9554E start is automatically controlled by the ground launch sequences (GLS). The most serious based here is the presence of excess hydrogen, resulting in a hydrogen time, which is invisible in the ope and yetry dangerous. This situation occurred during a faunch attempt for STS-41D.

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6.2 ASCENT ABORTS

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		EIN	15	
~~		TTT 4	10	

Performance Aborts	6.2-1
Systems Aborts	6.2-3
Range Safety	6.2-4

Events that require an ascent abort can be generally grouped into performance and systems failures. Flight Rules that govern these two types of scenarios are incorporated into various real-time MCC calls, along with the NO COMM MODE BOUNDARIES and the SYS FLIGHT RULES cue cards.

Performance Aborts

The amount of performance lost when a shuttle engine loses thrust or fails is directly related to the time of the problem. Early engine degradation or failure while the shuttle is heavy with fuel may preclude achieving a safe orbit. Late engine problems may result in no underspeed at all. Fortunately, it is not necessary to fly all the way to main engine cutoff (MECO) to find out how large the underspeed will be. By using a computer program called the abort region determinator (ARD), MCC can predict the underspeed that will result from any performance problem. Thus, the MCC can immediately determine whether the desired or even a safe orbit can be achieved. If a safe orbit cannot be achieved, some type of abort will be required.

There are two basic types of ascent abort modes, intact and contingency. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit crew survival following more severe failures when an intact abort is not possible. A contingency abort will usually result in a crew bailout.

For cases where the orbiter comes close to achieving normal orbit, the abort might simply consist of going to a lower, but perfectly safe, orbit. This is called an abort to orbit (ATO).

If even a low orbit cannot be achieved, an abort once around (AOA) may be used. The orbiter is placed into a suborbital trajectory leading to a landing after a single revolution around the Earth.

The next available abort mode, if performance does not permit an AOA, is a transoceanic abort landing (TAL), which results in landing on a runway in Europe or Africa.

Finally, for intact aborts, if an engine fails after lift-off and before TAL is possible, a return to launch site (RTLS) abort would be performed.

During powered flight, the crew tracks vehicle present abort capability by MCC voice calls. If communications are lost, the NO COMM MODE BOUNDARIES card provides a summary of ascent abort mode capability.

NEG RETURN (104)	8300	2 ENG BYD (104) 5900
PRESS TO ATO (104)	10300	ABORT TAL BYD (5)
NEG MRN (104)	11000	EO VI SE OPS 3 BYD (109) (5) SE BYD (104) (5)
PRESS TO MECO (104)	12200	
SE OPS 3 BYD (109)	12600	2 ENG BEN (104) 6500
SE BYD (104)	13800	ABORT TAL BEN (2)
NEG BEN (104)	15100	EO VI SE OPS 3 BYD (109) (12)
SE PRESS (104)	17200	SE OPS 3 BEN (109) (11) SE BYD (104) (5)
LAST PRE MECO TAL	23000	SE BEN (109) (2)
LAST TAL		
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BYD	24300	2 ENG MRN (104) 7600
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A REAL PROPERTY CONTRA		
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NO COMM MODE BOUNDARIES Cue Card

This card does not reflect off-nominal performance such as a stuck throttle. Only the ARD can calculate abort mode boundaries based on actual performance. The ARD takes real-time performance into account when predicting realtime mode boundaries.

The abort mode boundaries are flight specific. Times change significantly because of differences in mass properties, environmental modeling, and performance characteristics. Boundary names may also change. For example, some missions will not have a Press to ATO boundary. Also, TAL sites are mission specific. Higher inclination flights require a different philosophy of calls and checklist mode boundaries than lower inclination flights.

A generic discussion of mode boundaries for a low-inclination flight is presented here. Flight-specific data is available from the Flight Dynamics Officers (FDO).

Two-Engine TAL

Two-engine TAL is usually the first mode boundary reached that allows a downrange abort. It is the earliest inertial velocity (V_1) , or time in the trajectory at which AUTO guidance with 104% throttles may be used to successfully complete a TAL abort to the designated primary TAL landing site with two functioning engines. There is usually an overlap of RTLS and TAL capability. TAL is the preferred abort mode for engine failures in this overlap region, because single-engine completion capability is attained much earlier for TAL than RTLS. For severe systems failures in this overlap region, an RTLS may be preferred over TAL, because an RTLS will get the crew on the ground quicker than a TAL. The MCC voice call for this boundary usually has the TAL site name included in it (e.g., Two Engine Ben Guerir).

Negative Return

The latest V_1 or time in the trajectory at which AUTO guidance may be used to successfully complete an RTLS abort is NEGATIVE RETURN. Past this V_1 , the orbiter will have too much downrange energy to successfully return to KSC. If there is an abort gap between NEGATIVE RETURN and TWO ENGINE TAL, the calls will be based on throttling the good engine(s) to maximum throttle - 109%.

Press to ATO

This boundary represents the earliest engine out V_1 or time in the trajectory at which the orbiter can achieve the design underspeed at MECO. The constraints on design underspeed are ET impact, minimum performance, minimum altitude, contingency c.g. envelope protection, and minimum net positive suction pressure (NPSP) for the main engines. This boundary occurs on most missions and requires a pre-

MECO OMS dump (ATO) to achieve the design underspeed.

Press to MECO

This is earliest engine out V_1 in the trajectory where the orbiter can reach the design underspeed (see Press to ATO for design underspeed constraints) at MECO without a pre-MECO abort selection.

SE OPS 3 (TAL site) 109

The single-engine (SE) OPS 3 boundary represents the point in the ascent where two engines can fail and the flight will continue the ascent to MECO for an OPS 3 entry instead of an OPS 6 entry.

The SE OPS 3 boundary is a function of Bermuda/east coast abort landing (BDA/ ECAL) capability, emergency landing site (ELS) capability, and the ability to target a TAL or ELS without descending below 265,000 feet during powered flight (minimum droop altitude). Going below the minimum droop altitude violates ET heating constraints, and loss of vehicle is expected. Although European ELSs can be used for determining the SE OPS 3 boundary, typical ELSs are islands well short of the planned TAL site, such that single-engine runway capability occurs as early as possible in the powered trajectory. Depending on inclination, the island runways used are Lajes, Azores; Las Palmas, Canary Islands; and Amilcar Cabral, Cape Verde Islands.

In case droop capability comes before the last possible BDA/ECAL opportunity, SE OPS 3 will be called on at the earliest of the following: last BDA/ECAL, first ELS, or single-engine limits to an augmented contingency landing site (ACLS). In any case, capability to a runway exists for all these boundaries.

If BDA/ECAL capability does not overlap droop capability or there is no BDA/ECAL capability, the SE OPS 3 boundary may not ensure runway capability because the boundary will be called solely on the minimum droop altitude, without regard to TAL/ELS runway capability. A bailout likely will be necessary.

Single Engine TAL (104)

The SE TAL 104% boundary represents the lowest V_1 or time where AUTO guidance with 104% throttles can achieve the desired TAL site range-velocity target line with the simultaneous failure of two main engines.

Both in-plane and out-of-plane TAL sites may be used. This complicates abort mode determination, and the TAL REDESIGNATION cue card, along with MCC calls, will be required. This card is used for sequential engine failures and indicates to the crew which TAL site is attainable.

1ST E.O. VI	7700	7800	7900	8000	8100	8200	8300
SE OPS 3 BEN (109) (11)	11200	11200	11200	11300	11300	11300	11300
SE BEN (104) (2)	15900	15900	15800	15700	15600	15600	15500
SE MININ (104) (3)	17600	17500	17400	17300	17200	17000	16900
			1.	1000			
1ST E.O. VI	8400	8500	8600	8700	8800	8900	9000
SE OPS 3 BEN (109) (11)	11400	11400	11400	11400	11400	11500	11500
SE BEN (104) (2)	15400	15400	15300	15200	15200	15100	15100
SE MHN (104) (3)	16800	16700	16600	16500	16500	16400	16400
The Lord Street Man	12/22/1	and all	an the	120.00		332.00	
1ST E.O. VI	9100	9200	9300	9400	9500	9600	9700
SE OPS 3 BEN (109) (11)	11500	11500	11500	11500	11600	11600	11600
SE BEN (104) (2)	15100	15000	15000	15000	14900	14900	14900
SE MHN (104) (3)	16400	16400	16400	16400	16500	16500	16500
iyate broose gri	TERT		10.91	1.1.2		210.77	ia file
1ST E.O. VI	9800	9900	10000	10100	10200	10300	1.15
SE OPS 3 BEN (109) (11)	11600	11600	11600	11700	11700	11720	1.1
SE BEN (104) (2)	14900	14900	14700	14600	14500	14400	
SEMHN (104) (3)	16600	16600	16700	16700	16700	16800	1000
					-		0.42

MRN TAL REDESIGNATION Cue Card

As an example, if a TAL to MORON (MRN) has been initiated because of an engine failure at V_1 = 7830 fps, the new SE OPS 3 and single-engine TAL boundaries would be:

- 11,200 SE OPS 3 to Ben Guerir (BEN)
- 15,900 SE to Ben Guerir (BEN)
- 17,500 SE to MORON (MRN).

These velocities assume 109% or 104% throttle, as specified in parentheses, is selected on the remaining engine. These numbers are entered on the NO COMM MODE BOUNDARIES card.

NOTE

If a TAL site redesignation is required, it must be quickly accomplished on SPEC 50 to begin heading to the selected site, thus reducing crossrange during the entry phase.

WARNING

This redesignation must not be done just prior to or during the roll to heads-up maneuver; otherwise, an LOC can happen.

Single-Engine Press

Single-engine press is the lowest V_1 or time in the trajectory after which the critical underspeed can be attained with two simultaneous engine failures. Critical underspeed is the same as design underspeed minus the ET impact and NPSP constraints. Other criteria may be found in the Flight Rules.

Last Pre-MECO TAL

This boundary is the latest V_1 or time in the trajectory, with a single-engine failure, that AUTO guidance can be used to achieve the designated TAL landing site range/velocity (R-V) line. For such a late TAL declaration, the engines are throttled down at TAL initiation to provide for a longer pre-MECO OMS dump. LAST pre-MECO TAL is normally not called out by the MCC.

Last TAL

Last TAL is the highest MECO velocity acceptable for successful completion of a TAL entry to a TAL site or an ELS. This abort option is applicable to the early MECOs where V_1 is below the AOA range. LAST TAL is not an MCC callout.

Systems Aborts

The SYS FLIGHT RULES cue card summarizes the Flight Rules requiring RTLS and TAL selection in response to critical systems failures.

In most cases, additional insight provided by MCC is necessary to accurately and fully diagnose a failure and select the best response.

In the event of sudden multiple failures, help by MCC is critical. For COMM loss, however, only the SYS FLIGHT RULES cue card is available.

	RTLS	TAL
OMS - 2 He TKs	and the second se	
- 1 OX & FU TKS (diff pods)	Contraction of the	X
- 2 OX or 2 FU TKS		X
APU/HYD — Impending loss of all capability	×	X
CABIN LEAK (- EQ dP/dT > .15)	×	x
$CRYO - ALL O_2 (H_2)$	x	×
2 FREON LOOPS ↓	x	x
2 MAIN BUSES ↓	x	
THERMAL WINDOW PANE	X	

SYS FLIGHT RULES Card OMS Capability

A severe loss of OMS capability can make it impossible to continue uphill and deorbit. For example, loss of two propellant tanks results in insufficient propellant to get to orbit. In this case, TAL would be required.

APU/HYD

With the impending loss of all hydraulics, a trajectory option with minimum time to the ground is desired. This enhances the potential to land prior to a complete loss of hydraulics.

Cabin Leak

Loss of cabin pressure integrity impacts both breathing oxygen and equipment cooling. A minimum time to the ground option is required.

Cryo

Loss of cryo O2 or H2 will result in a loss of fuel cells and all electrical power. A minimum time to the ground option is required.

Freon Loops

Losing both Freon loops will eventually result in loss of all three fuel cells due to lack of cooling. Since this is time critical, RTLS is preferable over TAL.

Main Buses

Two main bus failures preclude ET door closure. Since TAL entry trajectories are thermally severe, RTLS is preferred. If RTLS is no longer possible (past NEGATIVE RETURN), pressing uphill is preferable to TAL.

Thermal Window Pane

Heating during TAL entries is severe. With a thermal window pane failure, RTLS is preferable due to its more benign heating characteristics.

Range Safety

Launch vehicles convert vast amounts of chemical potential energy into equally vast amounts of kinetic energy to put their payloads into orbit. Despite all planning, design, and tests, the possibility that a malfunction could cause a vehicle to fly out of control toward a populated area must be considered. Range Safety's function is to terminate flights that are far enough out of normal bounds to endanger populated areas. During first stage, this is accomplished by remotely detonating explosive charges aboard the SRBs. During second stage, the responsibility for range safety is on the MCC/crew, with inputs from Range Safety at KSC.

To protect populated areas, impact limit lines are drawn around them. No lethal piece of a vehicle can land behind an impact limit line. Since termination would have to occur well before an impact limit line is reached, destruct lines are drawn inside the boundaries of the impact limit lines. A vehicle passing outside the boundaries of the destruct line would be subject to termination.

Controllability

During first-stage, trajectory deviations may lead to a violation of a destruct line by a shuttle that is still under control. It may be possible to return the vehicle toward its nominal trajectory or to safely execute an abort. Therefore, the Flight Director (FD) and Flight Dynamics Officer (FDO) are in voice communication with the Flight Control Officer (FCO) (formerly Range Safety Officer) during ascent. If the FCO detects a violation, the FDO and FD are immediately informed. The FD must determine whether the shuttle is controllable or uncontrollable, and inform the FCO. As long as the FD declares the shuttle controllable, the FCO takes no action to terminate the flight for trajectory deviations alone.

Range Safety Limit Avoidance

A deviation from nominal trajectory that is large enough to warrant FCO action must be corrected. First-stage options are:

- State vector update
- Select CSS (after 90 seconds MET)
- Engage BFS

In second stage, the options are:

- State vector update
- ATO selection
- Select CSS
- TAL or RTLS selection
- Engage BFS
- SSME manual cutoff. For loss of comm, FCO will send the ARM command as a cue for manual MECO.

Options are listed in order of priority. The priorities are established such that higher priority options preserve lower priority options and involve fewer new dangers to the crew and shuttle when possible.

6.3 RETURN TO LAUNCH SITE

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Powered RTLS	6.3-2
Gliding RTLS	6.3-6
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RTLS abort is designed to provide intact abort capability for a suborbital return of the shuttle to the KSC Shuttle Landing Facility (SLF). An RTLS abort may be declared for an engine failure after lift-off and prior to NEGATIVE RETURN.

In order to reach the SLF, the shuttle must reverse course and fly back the way it came. The turn to reverse course is called powered pitch around (PPA). Timing of this maneuver is critical. Engines must be shut down when the shuttle has exactly enough speed and altitude to glide to the SLF runway. Also, for safe separation, the ET must have no more than 2% propellant remaining. Excessive propellant will slosh and could cause the ET and shuttle to collide. Selection of an RTLS abort is driven by several factors. Heat loading on the ET restricts RTLS selection to no earlier than 2 minutes 30 seconds (2+30) after lift-off. For RTLS systems aborts, selection occurs at 3 minutes 40 seconds. Abort overlap allows either an RTLS or a TAL to be selected. When RTLS/TAL overlap exists, TAL may be the preferred mode, since a second engine failure can be accepted much earlier and still make the runway. Also, the powered flight phase of RTLS is several minutes longer, causing more exposure to some types of MPS/SSME failures. An RTLS however, gets the orbiter back on the ground sooner and is not as thermally stressful as a TAL.

Once the decision is made to initiate an RTLS abort, MCC will direct the crew to "Abort RTLS." The FD will also turn on the *ABORT* light on panel F6, using a switch on their console, as a backup to the voice call. Onboard, moving the *ABORT MODE* rotary switch to *RTLS* and depressing the Abort pushbutton reconfigures GNC software to RTLS. As a backup, the crew can enter OPS 601 PRO on any PASS keyboard.



Powered RTLS

Powered RTLS (PRTLS) begins when the abort is initiated and terminates at MECO. PRTLS guidance is designed to deliver the shuttle to a MECO location at the proper altitude (I-load), flight path angle, and speed (function of range).

Guidance during PRTLS is closed loop. Computed MECO conditions are compared to desired MECO targets to determine a miss vector. This vector is then used to compute corrections in steering and throttle commands.



RTLS TRAJ Display

RTLS CDR Abort initiated: after 2:30 (2 eng) at 3:40 (3 eng)	If CSS: ✓ Pc = [1 ✓ DUMP U	RTL Man Throttle <u>Man MECO</u> 04% (2 eng) / NCONVERGED	S PLT 69% (3 eng) GUIDANCE TABL	
ABORT RTLS	ENG OUT	OUTBOUND INITIAL 0	PITCHAROUND at % (8°/sec)	FLYBACK INITIAL 0
· OPS 601 PRO ·	Liftoff	60°	44%	64°
	:30	56°	47%	63°
✓ GUIDANCE STATUS on RTLS TRAJ	1:00	57°	47%	63°
* If GUID 'INHIB':	:30	56°	48%	62°
· ✓ UNCONVERGED GUID TABLE · WINDS	2:00	49°	51%	61°
MAN PPA per PRPLT • 50K /	:30	42°	51%	52°
After GUID CONVERGE	3:00	38°	52%	50°
* P,R/Y AUTO/AUTO THROTTLE * 20 /	:30	34°	53%	48°
After PPA: ✓ BFS ITEM 1 (*) 7 / ✓ Bugs, V _{rel} , Waypoint 1 SUBE /	4:00	Last RTLS	52%	46°
SPDBK @ 3000 FT /	✓ Pc AT · If Pi · G51 Pitchd	PPA + 20 sec c = 104% (2 er MAX THROT Iown: ✔ Pc →	ng): * - ITEM 4 * • 67%	



The crew monitors guidance using cue cards and CRT displays.

Should guidance not converge, the crew will see "GUID INHB" on the RTLS TRAJ display. MCC, in conjunction with the crew, will request CSS takeover if guidance does not converge within a reasonable time.

The primary display for PRTLS is RTLS TRAJ. Some of the information on this display comes directly from NAV and is independent of guidance. The central portion of the display is a plot of altitude versus horizontal component of $V_{\text{REL'}}$ with the zero-velocity point at the end of the top trajectory line to the left of the screen midpoint. Shuttle position is plotted with a triangle. Predictors are generated to show 30- and 60-second positions. Trajectory lines are approximations of a generic set of high and low dispersed trajectories for an engine out at lift-off and just before negative return.

On the left side of the BFS ASC TRAJ there is a scale for delta H dot and angle of attack (α). The delta H dot scale is not used operationally and is not trained. The scale is intended to pro

vide a "fly to" indication for controlling altitude rate during the RTLS profile. However, this scale is referenced to a canned RTLS profile and, therefore, is not very useful in most cases. The alpha scale is just a graphical representation of the NAV-derived angle of attack. This scale also is not used operationally and, therefore, is not trained. The middle of the scale has a mark at -4°, which was intended to provide a reference during ET SEP while trying to maintain an AOA of -4° for separation. However, the desired angle of attack for ET SEP is now -2°, so the scale does not provide a good visual cue for the separation.

Two guidelines at the left end of the lower TRAJ line depict the q-bar limit for ET SEP. The shuttle symbol should be between these two lines, while approaching MECO. The lower line represents q-bar at 1 psf and the upper line represents q-bar at 2 psf.

A delta range scale at the top of the display represents current glide range. Near MECO, the cutoff bug moves from right to left, passing the pitchdown points for 3-engine (PD3) and 2-engine (PD) PRTLS. The cutoff (CO) point indicates where MECO should occur to obtain proper glide range to the runway.

Digital readouts present useful data for monitoring performance. Additional readouts on the BFS RTLS TRAJ present computed values of sideslip (beta), angle of attack (alpha), total vehicle acceleration, attitude errors, and computed throttle command.



To function properly, guidance needs to know the shuttle's speed and time when an engine fails. Normally, the GPCs will capture this data, but the crew should also note the time. This becomes important later to determine key trajectory parameters.

NOTE

If CSS flight control is selected, manual throttle control must also be selected. This will require manual throttle down and shutdown.

Fuel Dissipation

After abort selection, the first phase is fuel dissipation. During fuel dissipation, the shuttle continues heading downrange at a fixed inertial thrust direction. Cyclical computations are performed to determine the proper time to initiate turnaround. Should the abort be declared near the NEGATIVE RETURN boundary, pitcharound may occur immediately with no fuel dissipation.

For the crew to fly fuel dissipation phase in CSS, they must know the proper pitch angle (theta) and when to pitch around. Using the time, the RTLS cue card engine fail UNCONVERGED **GUIDANCE** TABLE is entered and the appropriate theta and pitcharound propellant remaining are Theta is chosen to minimize determined. altitude loss while heading away from the runway. Once set, it remains constant through the fuel dissipation phase.

Powered Pitch Around

This turn changes shuttle attitude from headsdown going away from the launch site to headsup pointing toward the launch site by an approximately 60° to 70° pitchdown maneuver. Until zero relative velocity is reached, the shuttle is still moving away from the launch site. Powered pitch around is performed at 10° per second pitch rate in AUTO. This is a dramatic maneuver and is designed to prevent lofting while passing through vertical orientation.

> 6. EMERGENCY PROCEDURES 6.3 Return to Launch Site

Timing of powered pitch around is critical and must occur within a certain interval to ensure the shuttle arrives at MECO with the proper amount of fuel remaining and the proper energy. The crew monitors guidance using the GUID % to go on the RTLS TRAJ 2 display. The percentage displayed is the percent deviation of the predicted final mass from the RTLS mass target. When the percentage equals zero, PPA should occur.

Should guidance be unconverged, the crew should select CSS and manual throttle control and pitch around manually at the appropriate propellant remaining cue.

NOTE

It is much better to pitch around slightly early than slightly late as late pitcharounds may result in not reaching a nominal RTLS MECO state.

OMS Dump

OMS propellant onboard at launch is mission specific. Because the propellant is stored in tanks located near the back end of the shuttle, it causes the c.g. to be considerably aft of the point at which the shuttle is designed to fly. For aborts such as RTLS, this excess propellant is dumped.

The dump is actually a burn, using the OMS engines and possibly the aft RCS jets. For interconnected dumps, valves are reconfigured by the GPCs to allow OMS propellant to be burned through the RCS jets. When RTLS is selected, the OMS engines begin burning immediately. Smart Interconnect takes approximately 3 seconds to reconfigure and check the valves. Some missions have interconnected-inhibited dumps where the dump is through the OMS engines only.

Normally, RTLS dumps are a combination of 2 OMS engines and 24 aft RCS jets. The jets used are 4 +X jets and 20 null jets. The +X jets fire directly aft and produce no significant rotational movement. Null jets fire in opposite directions so that they cancel each other out. Dump times are mission specific and are depicted on the RTLS/TAL DUMPS cue card.



RTLS/TAL Dumps

When the dump is complete, OMS/RCS valves are automatically reconfigured by the GPCs in preparation for MECO. If required procedurally, the crew can secure one or both OMS engines by placing the *ARM/PRESS* switch in *OFF*.

Dump time-to-go (TTG) counts down to zero during RTLS dumps. During the dump, the interconnect can be inhibited or enabled by toggling ITEM 5.



OVERRIDE Display

Onboard failures, such as electrical or DPS problems, can cause serious OMS/RCS valve reconfiguration problems. "Smart Interconnect" Software should reconfigure the valves or inhibit some or all of the jets to prevent any serious problems.

Shuttle abort dumps are complex procedures and must be executed correctly in a time-critical situation. Consult the Ascent/Aborts Flight Procedures Handbook for additional information.

Flyback

This phase is part of PRTLS where the shuttle points back toward the runway. Guidance computes steering and throttle commands that direct the shuttle along the proper trajectory.

Should CSS control be required, the crew should stop the PPA maneuver at the initial flyback theta, as determined from the RTLS PLT UNCONVERGED GUIDANCE TABLE. The shuttle pitch attitude must then be adjusted to fly back along or parallel to the guidelines on the RTLS TRAJ display.

CAUTION

Do not allow the predictors to fall below the lower guideline during flyback. Recovery from this low altitude condition may be impossible.

In the area of high q-bar, the guidelines are very important to avoid structural overload or ET SEP problems. As the predictors reach the left edge of the display, control theta to fly between the guidelines until the delta-R bug begins to move.

Powered Pitchdown

To satisfy altitude and flight path angle constraints at MECO, a positive angle of attack of about 30° is required. However, to safely separate the ET, an alpha of -2° is necessary. The transition between these attitudes is called powered pitchdown.

The maneuver must be completed rapidly (5° to 8° per second) to avoid large sink rates, which could cause overheating or overstressing. Engines are throttled back to reduce trajectory impact. Should CSS be required when the bug reaches the appropriate pitchdown mark (PD3 or PD), the shuttle should be pitched down at 5° to 8° per second to alpha = -2°. At this point the crew should null beta. Simultaneously, the engines are manually throttled to 67 percent. These procedures are summarized on the RTLS CDR and PLT cue cards.

MECO and ET SEP

Because the MECO time has been fixed by the GPCs, an attitude of alpha = -2 must be held until the delta-R bug reaches the CO mark, and the engines are shut down either by the GPCs or manually. After shutdown, a mated coast phase occurs for approximately 13 seconds. During this phase, valves are closed, umbilicals retracted, and electrical connections deadfaced. The RCS jets control attitude.

The shuttle is then ready for ET SEP, which will occur automatically, provided certain constraints are within limits.

of the last	DESIGN TARGET	DESIGN TOLERANCES	VEHICLE LIMITS
Roll rate, P	0°	±1.25°/sec	20 > P > -20
Pitch rate, Q	25°/sec	±0.5°/sec	+.25 > Q > -20
Yaw rate, R	0°/sec	±0.5/sec	+20 > R > -20
Angle of attack, α	-2°	±.05°	$-1.5^\circ > \alpha > -89^\circ$
Side slip angle, β	0	±2°	+20 > β > -20
Roll angle Ø	0	±5°	None

RTLS ET Auto Separation Limits

These limits prevent separation in an unsafe attitude, which might cause shuttle/ET collision. If the parameters are not within limits, an ET SEP inhibit suspends the separation sequence until the out-of-limits is corrected or 6 seconds expire, whichever occurs first. The timer is necessary because of rapid q-bar buildup, which makes a safe separation impossible, regardless of attitude. Separation can be commanded manually using the ET *SEPARATION* switch and *ET SEP* pushbutton on panel C3.

Immediately after ET SEP, the DAP performs a translation and pitch maneuver to fly the shuttle away from the ET. This is accomplished by firing all of the shuttle's downfiring jets. The combination of four forward and six aft downfiring jets results in a simultaneous translation and rotation, which moves the shuttle up and away from the ET. Once the shuttle achieves an alpha $\geq +10^{\circ}$ and time from ET SEP ≥ 10 seconds, the GPCs mode to MM 602 and the glide portion of RTLS (GRTLS) begins.

In CSS and manual throttle, a manual MECO must be performed using the *MAIN ENGINE*

SHUT DOWN pushbuttons on panel C3. The alpha = -2 degree attitude must be maintained until ET SEP. This will require a small negative pitch rate due to H-dot increase, which causes alpha to become more positive. The -Z translation maneuver will occur automatically unless the CDR intervenes by moving the THC out of detent. If this is done, a manual -Z maneuver should be performed to ensure safe separation, and the pitch up maneuver to alpha \geq +10° must also be manually performed. Generally, it is preferable to allow the DAP to perform these maneuvers automatically.

Gliding RTLS

The gliding portion of RTLS is very similar to the final portions of entry, which are discussed in detail in Section 7. Only significant differences are presented here.

Post-MECO Dumps

After MECO and ET SEP, the remaining MPS propellants must be dumped to assist in c.g. control and, for the liquid hydrogen, to reduce potential fire hazard. The MPS dump sequences are very similar for the nominal, TAL, and RTLS modes. The LO2 and LH2 are dumped simultaneously to save time.

CDD

The RTLS MPS dump starts immediately upon transition to MM 602. LO2 is dumped through the main oxidizer valves in the main engines and the 8-inch fill/drain line on the starboard side of the orbiter. LH2 is dumped through the 1.5-inch backup dump line and the 8-inch fill/drain line on the orbiter port side aft. To ensure a rapid LH2 dump, the LH2 manifold is pressurized with helium.

The onboard software also allows a post-MECO dump of RCS propellant through the RCS jets to satisfy maximum tank landing weight constraints and c.g. control.

Guidance

During GRTLS, guidance manages the shuttle's energy state to arrive at the runway with sufficient energy to complete a safe landing. GRTLS guidance is divided into five phases:

851.cv5

- Alpha Recovery
- N₇ Hold
- Alpha Transition
- S-Turn
- GRTLS TAEM

CD/1	PLI
MECO MECO	MECO MECO
✓ MM602 (α > 100 and SEP + 10 sec)	KEAS = 77 ✓ SPDBK → 81%
✓ P,R/Y, SPDBK, BDY FLP -A UTO	✓ ET DOORS -Clos ed and latched (MECO + 1:30)
$\alpha = 50^{\circ}$ until ~ 1.80, maintain 2.20	✓ ET SEP, SRB SEP - AUTO
in a main they	Adjust seat
Adjust seat	✓ TACANS, INCORPORATE
	If KSC TACAN Fail:
· · ·	TACAN Ch 97X (OMN), ITEM 5 EXEC ·
H > 320 √ α vs Mach	G51 AIR DATA, INCORPORATE
V = 5 AIR DATA PROBES (two) - DEPLOY, (V He	eat) MM603 HYD MPS/TVC ISOL VLV (three) - CL
RUD, AIL TRIM	(Hold 5 sec) ✓ tb -CL
M = 3.2 ✓ SPDBK → 65%	H = 85K MLS (three) -ON
M = 2.7 L HUD PWR -ON	If Rwy 33(15): MLS CH (three) -6 (8)
TRIM PANEL -OFF	I/O RESET
RHC/PNL -ENABLE	M = 2.7 R HUD PWR -ON
IT M<2.5; P CSS for ADTA to G&C incorp *	TRIM PANEL -OFF
M = 2.0 Ensure ADTA to G&C else THETA limits	RHC/PNL -ENABLE
M = 0.9 P,H/Y - CSS, V SPDBK CMD vs POS	M = 0.9 VR FLT CNTLR PWR - ON
NWS-1	Lock Inertia Reels
POST LANDING: ENT POST LOS	H = 10K (OBV SIG TO SOL VLV - OP
ENT, POST LDG	LES Viere D
	POST LANDING ENT DOOT LOO

RTLS Post-MECO Procedures

6.3 Return to Launch Site

^{6.} EMERGENCY PROCEDURES

These phases provide for transition from a ballistic trajectory, through hypersonic gliding flight, to an energy management scheme designed to make the runway.

Alpha Recovery

Pullout from the ET SEP attitude must be accomplished quickly before aerodynamic forces build up to uncontrollable levels. To accomplish this, the shuttle maneuvers to a high (alpha = 50°) angle of attack using both RCS jets and aerodynamic controls.

Increasing dynamic pressure caused by the shuttle falling into the atmosphere causes more lift to be generated by the wings. The resultant lift produces a Z-axis acceleration (N_z). At about 1.65 g, the DAP starts to reduce alpha to hold an N_z of 2.2 g's. The shuttle N_z limit for RTLS is 2.0 - 2.5 g's (based on the vehicle's weight).

Roll jets are secured at q-bar = 10. Pitch jets are secured at q-bar = 40. Yaw jets are required until Mach = 1.0. When KEAS = 77, the speed brake is ramped open to about 81 percent to enhance lateral stability by allowing the elevons to be trimmed down. Below Mach = 0.95, the speed brake position is modulated by GRTLS TAEM guidance.

N_z Hold

Alpha is smoothly decreased to maintain the 2.2 g limit until H-dot is greater than -320 ft/sec. Excessive g-loading could cause structural damage and also dissipate excessive energy. The ADI pitch error needle displays N, error during this phase.

Alpha Transition

Upon termination of N, hold, alpha is changed to conform to a profile that is a function of Mach number. This profile provides the best vehicle control until active ranging begins in GRTLS TAEM. Also, a bank maneuver is performed, either to null any heading errors to the heading alignment cone (HAC) tangency point, or to dissipate excess energy by turning (S-turn) away from the HAC. The maximum bank angle is 45°. The ADI pitch error needle displays alpha error during alpha transition phase. Guidance can be manually downmoded to the straight-in or minimum entry point (MEP) HAC if required due to low energy.

To fly the alpha transition in CSS, the display in the upper left corner of VERT SIT 1 is used. The shuttle symbol initially appears in this portion of the display, which represents an alpha versus Mach number profile. The dashed line is the nominal profile, and the solid line is the q-bar limit.

The ENTRY ALPHA cue card can also be used for alpha transition. Since there are no procedures to initiate S-turns manually, ranging is accomplished by exercising the OTT options described in Section 7. The MCC can also request a GCA and accomplish S-turns by asking the crew to fly appropriate bank angles or headings.



GRTLS Vertical Situation 1 Display

S-Turn

An S-turn can be initiated in GRTLS TAEM or while still in alpha transition. S-turns increase the distance to be flown, thus decreasing energy. It is possible that more than one S-turn would be required. Starting and stopping of S-turns can be monitored using the E/W scale on VERT SIT 1.

GRTLS TAEM

This phase is essentially identical to normal entry TAEM, which is discussed in detail in Section 7. The main differences are that GRTLS TAEM starts at Mach = 3.2 and an alpha limiting corridor exists. SFOC-FL0884 Rev. B

The MPS/TVC ISOL valves must be closed by the crew before the low altitude/high maneuvering regions of GRTLS TAEM to prevent PRL. These valves must remain open until MPS dump completion at approximately Mach = 4.5.

To conserve power during ascent, the MLS LRUs are powered off. They must be turned on and communication established (I/O RESET) at about 85 k ft during GRTLS.

Postlanding procedures are the same as nominal end of mission, except that the hydraulic load test is not performed.

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6.4 TRANSOCEANIC ABORT LANDING

CONTENTS	No. of Street
Nominal Transoceanic Abort	MEDO
Landing	6.4-1
Post MECO Transoceanic Abort	
Landing	6.4-4

The purpose of a transoceanic abort landing (TAL) is to provide an intact abort capability for single-engine failures between 2 ENGINE TAL and PRESS TO ATO (MECO). It also offers an intact option for two engine failures much earlier than SINGLE ENGINE PRESS. TAL also supports system aborts that occur after NEGATIVE RETURN such as cabin leaks, cooling problems, or OMS propellant loss.

During a TAL abort, the shuttle flies an entry trajectory across the ocean to land on a missionspecific runway. Landing occurs approximately 40 minutes after launch. Powered flight guidance has the capability to target 13 different landing sites, which are selected based on runway length, weather, and orbital inclination. Landing sites near the nominal ascent ground-track are more efficient since crossranging requirements are reduced. Typically, only three TAL sites are supported for possible use on each mission.

Nominal Transoceanic Abort Landing

TAL is selected prior to MECO by placing the *ABORT MODE* rotary switch on panel F6 in *TAL* and pressing the *ABORT* pushbutton. Item entries on the OVERRIDE display (SPEC 51) may also be used to select TAL should the *ABORT MODE* switch fail. The crew should note the title of the ASCENT TRAJ display changes to TAL TRAJ. The shuttle indicator (triangle) and predictors should follow the upper trajectory line on BFS TAL TRAJ 2.

Abort Dump

When TAL is selected, an abort dump begins immediately. OMS propellant is usually dumped through the OMS engines plus 24 aft RCS jets interconnected to the OMS propellant tanks. The OMS/RCS interconnects are determined preflight via I-loads for each abort scenario. They may be enabled or inhibited by the crew if required. Some OMS propellant will be dumped in MM 304 prior to 0.05 g. This dump is performed primarily to increase separation from the ET.

If a TAL is initiated after an I-loaded velocity (dependent on two or three engines remaining), there will not be enough time to complete the OMS dump. For these cases, the remaining engines will be throttled down automatically to 67% to gain extra dump time.

The OMS dump should be stopped if helium pressure decreases to 2,000 psi to ensure helium will not be ingested into the RCS lines.

Guidance

At abort selection, TAL guidance begins steering the shuttle toward the selected landing site plane. Variable I-Y steering is used to bring crossrange to the TAL site within acceptable limits (approximately 500 n. mi.) at MECO.

The crew monitors guidance during TAL aborts using the TAL CDR and TAL PLT cue cards.

It is important to verify, using SPEC 50, that the correct landing site is selected.

Should a second engine fail during a TAL, the OMS dump will continue through the OMS engines, but the dump through the RCS will be terminated. The crew must push the two failed engine *MAIN* ENGINE SHUT DOWN pushbuttons on panel C3 to set the safing flag. The contingency dump must also be started using SPEC 51.

Trajectory droop, along with guidance convergence and main engine performance, are the deciding factors in defining the earliest single-engine TAL capability. Drooping below the 265 k ft limit will result in either an explosion due to ET heating or a loss of control. If two engines fail near the SE OPS 3 109 boundary, the crew should throttle up to 109 percent. Droop guidance will engage and pitch up to 60° on the ADI to minimize sink rate and enable the shuttle to remain above 265 k ft. When thrust-to-weight is greater than 1, the shuttle will begin to climb and accelerate downrange.







To lessen ET heating effects and to put the shuttle in the correct entry attitude at ET SEP, a roll to heads up is performed at an I-loaded reference velocity. If the shuttle is still in the heads down attitude when TAL is selected, roll to heads up will occur at the TAL I-loaded velocity. If the shuttle has already performed the nominal roll to heads up when TAL is selected, it will remain in the heads up attitude for the rest of powered flight. The roll is performed at 5° per second.

TAL MECO occurs about 2,800 n. mi. from the landing site. For inplane sites, very little banking for azimuth control is necessary if started as soon as possible after the first MM 304 pullout. Waiting to null out delta azimuth until late in the entry can severely reduce crossrange capability.

The MCC will recommend the best approach to the field. An overhead approach is preferred.

OPS Transition

TAL is a unique abort in that it requires transition to OPS 3 after MECO and ET SEP, which is time-critical. The PASS computers obtain this software from upper memory.

CAUTION

To prevent loss of control, engage BFS and type in OPS 301 PRO if the PASS does not mode into OPS 3 within 68 seconds.

Because OPS 3 software is now in PASS upper memory, a reduced wait time until engaging BFS on the OPS 3 transition is being pursued. The 68 seconds mentioned above is a holdover from when the OPS 3 software had to be loaded from the mass memory units (MMUs). The maximum time it would take to try and load the software after attempting both MMUs is 6-8 seconds.

About 3 minutes are available to complete the OPS transition between ET SEP and the start of dynamic pressure buildup depending on the altitude, flight path angle, and velocity at MECO. This period is critical. The shuttle is entering the atmosphere, and the TRANS DAP is not designed for atmospheric flight. All

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For high inclination missions, a crewinitiated (MAN MECO) post-MECO TAL is not an option. This is because, for high inclination missions, the post-MECO TAL landing sites are emergency landing sites (ELSs), and the program has decided to try for an AOA rather than land at an ELS.

MECO velocity takes into account the AV due to SSMII tailoff. This number is flight specific and depends upon inclination.

The boundaries chart shows approximate TAL site coverage for a range of early MBCO conditions. Using the real time downrange abort evaluator (DAE), the MCC will determine the appropriate site and communicate data to the crew. Cue card boundaries are used for loss of communications.

High Energy TAL

MICO velocities between approximately 24.5 k and 25.2 k ips may be too low for AOA capability (especially if the OMS propeliant has been dumped) and too high for auto guidance to make a TAL site. The only option in this attration is to about to an ELS or to bail out. For melinations c57°, a high-energy TAL procedure angles of attack, prebane, and OMS dumps to dissipate excess energy and to allow the orbiter to land at a TAL site from these MECO velocities.

Post MECO Dump

The high-energy TAL post-MLCO OMS dump, is similar to the TAL OMS dump, interconnected dumps are performed automatically univ in indicated regions.

Guidance

pon entry into MM 304, guidance will roll the unutie to heads up, if not there already.

procedures must be completed quickly and accurately. Ignore all systems problems unless they are extremely critical until correct entry flight control is available.

Post-MECO Dumps

An MPS dump similar to the RTLS dump begins automatically at MM 304. The TAL LH2 MPS dump is unpressurized.

Once in MM 304, the OMS dump restarts to ensure separation with the ET. This dump adds about 100 fps ΔV to the shuttle's energy. (Several missions have used 200 fps ΔV .) For post-MECO TALs, the dump also ensures orbiter landing weight, c.g., and tank landing weight constraints are met.

The FRCS null jet dump typically starts at MM 304 to help control X c.g. location.

An aft RCS dump is commenced at $V_{REL} = 9$ k fps. This dump reduces aft propellant to meet weight and c.g. constraints. The dump time is an I-load, which is usually 88 seconds. Should the aft RCS quantity be low, the dump can be inhibited using SPEC 51. For missions with forward X c.g. concerns, this dump will not be performed.

Entry

MM 304 is very similar to a normal end-ofmission entry (discussed in detail in Section 7) with the exception of the 43° initial angle of attack flown during the TAL pullout phase which protects for high wing leading edge temperatures.

The shortfield speed brake option is automatically selected for TAL. Should nominal speed brake be desired, an ITEM 39 (S/B) on SPEC 50 will be required.

Post MECO Transoceanic Abort Landing

An intact abort capability is available between $V_i \sim 21.5$ to 23 k fps (mission specific) and AOA capability by using the TAL entry software. The abort is declared after MECO. For late systems problems after last pre-MECO TAL, the crew performs a manual MECO at the specified

velocity using the MAIN ENGINE SHUT DOWN pushbuttons.

NOTE

For high inclination missions, a crewinitiated (MAN MECO) post-MECO TAL is not an option. This is because, for high inclination missions, the post-MECO TAL landing sites are emergency landing sites (ELSs), and the program has decided to try for an AOA rather than land at an ELS.

MECO velocity takes into account the ΔV due to SSME tailoff. This number is flight specific and depends upon inclination.

The boundaries chart shows approximate TAL site coverage for a range of early MECO conditions. Using the real time downrange abort evaluator (DAE), the MCC will determine the appropriate site and communicate data to the crew. Cue card boundaries are used for loss of communications.

High Energy TAL

MECO velocities between approximately 24.5 k and 25.2 k fps may be too low for AOA capability (especially if the OMS propellant has been dumped) and too high for auto guidance to make a TAL site. The only option in this situation is to abort to an ELS or to bail out. For inclinations <57°, a high-energy TAL procedure is also available. This procedure uses high angles of attack, prebank, and OMS dumps to dissipate excess energy and to allow the orbiter to land at a TAL site from these MECO velocities.

Post MECO Dump

The high-energy TAL post-MECO OMS dump is similar to the TAL OMS dump. Interconnected dumps are performed automatically only in indicated regions.

Guidance

Upon entry into MM 304, guidance will roll the shuttle to heads up, if not there already.

The crew should verify that the proper runway is selected. For low energy cases, low energy logic is required until the shuttle is within the trajectory lines on the ENTRY TRAJ display.

The abort once around (AOA) abort mode is used or cases where shortle performance has been but to such an extent that it is impressive to achieve a viable proit, or not enough OMS-1, OMS-2, and dearbst burns. ACA may also be used when a major systems feilure makes in necessary to land outckly.

In an AOA for a standard insertion, or a low performance direct insertion, one OMS burn is made to adjust the post MI CO proin such that a second burn will result in the orbitar deoreting and leasting is an AOA landing size. In an AOA for a systems failure during a nominal performance direct insertion, only the deorbit burn is required. Landing scenario about 1 hour and 45 minutes after late.

There are two AOA trajectories with several different options for each one, depending upon the reason for performing an AOA: steep AOA and shallow AOA.

Entry trajectory for the storp AGA is very similar to a nominal entry and is the pacterned trajectory due to thermai consideration. However, storp targets tequire more AV and therefore more propellant, shallow AOA results in a flatter trajectory, which places the shuttle closer to the skipout boundary and thermai limits. This is less desirable, but tequires less OMS propellant, which is important for severe underspeed cates or if both OMS beform terits have failed with propellant connecting above may blow doten.

Execution of an AOA is determined by an MCC cell and by checking the ONE-1 target solution against the OME-1/2 TGTRNG cure cord. If required, OME-1 targets are loaded lead humed After runway selection is verified, and guidance is converged, AUTO flight control may be reselected. The remaining high-energy TAL procedures are identical to the nominal TAL.

AOA can only be selected post MECO by crew relection of an AOA target set on the CMS MINV R display.

The Childs-1/2 targeting distription description of a properties OMD-1/2 target sets as a function of MECO professional. This can can assume no system activities but does account to any ATO during perfectioned pre-MECO. The case obtains the context target set by calculating outstal every HA a HP) and noting the assume of Odd propellant remaining. Context HA - HP is obtained from the OMS-1 MNVK EXEC display after MM 108 transition.

The OMS 1/2 TOTING our cand should be used in comparison with the OMS-2 TABASTING ourd, and source case requirements will prever for combinations of Jalhuers, MCC help of the required. In any case, MCC is jointe for all target selections as long as COMMEnter.

For all lights there is an ATO OM5 1 support of that will allow either an ATO AOA strip, AOA shallow, or minimum periors (MD8 Hp) OM5.2 This target set is released to as the common targets. The common terpost can be burned and the decision to abort AOA may be delayed until after OM5-1 for most cases. If AOA is selected after OM5-1, this crew depresses the hydraudic systems instead of shutting down the APDs. This slip avoids an APU shuttiown and restart. Running the APUs in LOW PRESS meteored of NORM PRESS, will cause APU built for entry.

6.5 ABORT ONCE AROUND

CONTENTS	
OMS-1	6.5-1
OMS-2	6.5-3
Entry	6.5-4

The abort once around (AOA) abort mode is used in cases where shuttle performance has been lost to such an extent that it is impossible to achieve a viable orbit, or not enough OMS propellant is available to accomplish the OMS-1, OMS-2, and deorbit burns. AOA may also be used when a major systems failure makes it necessary to land quickly.

In an AOA for a standard insertion, or a low performance direct insertion, one OMS burn is made to adjust the post MECO orbit such that a second burn will result in the orbiter deorbiting and landing at an AOA landing site. In an AOA for a systems failure during a nominal performance direct insertion, only the deorbit burn is required. Landing occurs about 1 hour and 45 minutes after lift-off.

There are two AOA trajectories with several different options for each one, depending upon the reason for performing an AOA: steep AOA and shallow AOA.

Entry trajectory for the steep AOA is very similar to a nominal entry and is the preferred trajectory due to thermal considerations. However, steep targets require more ΔV and therefore more propellant. Shallow AOA results in a flatter trajectory, which places the shuttle closer to the skipout boundary and thermal limits. This is less desirable, but requires less OMS propellant, which is important for severe underspeed cases or if both OMS helium tanks have failed with propellant quantities above max blowdown.

Execution of an AOA is determined by an MCC call and by checking the OMS-1 target solution against the OMS 1/2 TGTING cue card. If required, OMS-1 targets are loaded and burned.

After OMS-1, the desired OMS-2 targets are selected on the MNVR EXEC display. Then the software is moded to OPS 3 and the appropriate OMS-2 (deorbit) targets are loaded and burned. After the deorbit burn, an entry is flown that is very similar to the nominal end of mission.

OMS-1

AOA can only be selected post MECO by crew selection of an AOA target set on the OMS MNVR display.

The OMS-1/2 targeting chart provides the crew with information describing the appropriate OMS-1/2 target sets as a function of MECO underspeed. This cue card assumes no system failures but does account for any ATO dump performed pre-MECO. The crew obtains the correct target set by calculating orbital energy (HA + HP) and noting the amount of OMS propellant remaining. Current HA + HP is obtained from the OMS-1 MNVR EXEC display after MM 104 transition.

The OMS 1/2 TGTING cue card should be used in conjunction with the OMS-2 TARGETING card, and worst case requirements will prevail. For combinations of failures, MCC help will be required. In any case, MCC is prime for all target selections as long as COMM exists.

For all flights there is an ATO OMS-1 target set that will allow either an ATO, AOA steep, AOA shallow, or minimum perigee (MIN Hp) OMS-2. This target set is referred to as the common targets. The common targets can be burned, and the decision to abort AOA may be delayed until after OMS-1 for most cases. If AOA is selected after OMS-1, the crew depresses the hydraulic systems instead of shutting down the APUs. This step avoids an APU shutdown and restart. Running the APUs in LOW PRESS instead of NORM PRESS will conserve APU fuel for entry.

> 6. EMERGENCY PROCEDURES 6.5 Abort Once Around



Execution of an AOA is determined by an Aucall and by directing the OMD-1 surger solution against the OMS 1/2 TOTING, one card. Is required OMS-1 surgers are invoked and bureed

OMS 2 TARGETING (DIR INSERTION)

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FAILURE	OMS 2 TARGET		DL	JAL
OMS – 2 N2 TKs (Perform burn Single OMS Eng)	NOM	POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN SH
OMS - 2 OMS ENGS - 1 He TK - 2 He TKS - 1 PRPLT TK- EPS - MNA & B, MNB & C MNA & C ET SEP	PEG 7; TTA = 1 CUTOFF HP = 85	95 90 85 80 75 70 65 60 55 50	37.6 38.2 39.9 41.8 43.8 45.7 47.0 47.9 48.4 49.0	
OMS - 2 OX or 2 FU TKs - 1 OX & 1 FU TK	AOA-S		SIN	
diff PODs 2 FREON LOOPS (Accum Qt	V AOA	POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN SH
$(\downarrow \text{ and decr) and/or Flow }(\downarrow)]$ 2 H2O LOOPS CABIN LEAK (-EQ dP/dT \ge .08)	certain system	95 90 85 80 75	33.1 33.8 35.5 37.4 39.4	100
APU/HYD - impending loss of all capability	AOA	65 60 55	41.3 42.6 43.5 43.9	1.
CRYO - All O2(H2)	AOA	50	44.6	1
C	MS	LEFT OMS	GAGE QTY (%)	
He %	He %	30	40	50
4800 87.8	2890 40	30 30	5 35 37	32

2090 20

1690 10

1290 0

ava	Includes	8.8 % Unusable	REQUIRED	pod)
POST	ATO OMS 2 &	MIN HP OMS 2 &	AOA STEEP	AOA SHALLOW
DMS 1	STEEP D/O	SHALLOW D/O	D/D BURN	D/O BURN
HP	BURN (%)	BURN (%)	(%)	(%)
95	37.6	22.6	41.9	26.5
90	38.2	19.1	39.0	22.1
85	39.9	17.5	36.9	19.0
80	41.8	17.3	34.4	16.0
75	43.8	18.7	31.2	13.0
70	45.7	20.9	27.9	10.4
65	47.0	22.3	25.3	8.8
60	47.9	23.6	24.3	8.8
55	48.4	24.7	25.5	8.8

ATO

NOTE

These tables apply only af

POST OMS 1 HP	ATO OMS 2 & STEEP D/O BURN (%)	MIN HP OMS 2 & SHALLOW D/O BURN (%)	AOA STEEP D/O BURN (%)	AOA SHALLOW D/O BURN (%)
95 90	33.1 33.8	18.2	37.5	22.1
85	35.5	13.1	32.5	14.6
80	37.4	12.9	30.0	11.6
70	41.3	16.5	23.5	6.0
65	42.6	17.9	20.9	4.4
55	43.5	19.2 20.3	19.9	4.4
50	44.6	21.5	21.3	4.4



Post-ATO(1) OMS Required

OMS-2

After OMS-1 is burned, the OMS-2 TARGET-ING cue card is checked to determine the appropriate OMS-2 targets. Additionally, the OMS REQUIRED card is used to determine the appropriate abort mode in the event of an OMS propellant shortage or to confirm that sufficient OMS propellant is available for completion of the planned abort mode.

4090 70

3690 60

3290 50

OMS targeting options are complex and vary greatly from flight to flight. For a complete explanation of targets, refer to the Ascent/ Aborts Flight Procedures Handbook.

For all AOA aborts, deorbit targets are called up in OPS 1 and carried across the transition to OPS 3. Targets are not loaded until after the OPS 3 transition because of different guidance targeting logic. Where the OMS-1 maneuver (if required) establishes a temporary orbital trajectory, OMS-2 is a deorbit burn.

AOA software computes the amount of excess OMS that may be burned out of plane during the deorbit maneuver. The crew can change this amount through keyboard entries on the OMS MNVR EXEC display.

Once the appropriate AOA OMS-2 targets are loaded, burn TIG may need to be adjusted to correct range from entry interface (REI). The FDF checklist provides the procedure for TIG adjust. The MCC may recommend a TIG that has already been adjusted.

If the key-in AOA targets are used, an AOA target set should still be called up in OPS 1

using Item 35 on the OMS MNVR display to establish the AOA Kalman filter covariance matrix. The key-in AOA targets can then be entered and ultimately loaded in OPS 3.

Entry

After the OMS-2 burn, the orbiter is maneuvered to an EI-5 attitude, which is similar to the nominal entry attitude. If AOA shallow targets were burned, a prebank will be required to ensure atmospheric capture.

The software transition from OPS 1 to OPS 3 will automatically load landing site data for an AOA. Included are data for the runways shown on the HORIZ SIT SPEC 50, an associated set of TACAN stations, and MLS data for the primary and secondary runways. Potential AOA landing sites are Edwards Air Force Base, California; Kennedy Space Center, Florida; and Northrup Strip, New Mexico. The crew should verify that the appropriate site and runway are selected.

The entry and landing phase of an AOA is similar to the normal entry and landing discussed in Section 7.

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could accessing options are complex and vary generity from finish to flight. For a complex explanation of surgets, roke to the Access about Flight Procedures Enablished

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6.6 ABORT TO ORBIT

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OMS-1	6.6-1
OMS-2	6.6-1

ATO aborts are designed to achieve a safe orbit that is lower than the nominal orbit. This requires less OMS propellant and allows time for problem evaluation to determine whether an early return is required or additional burns can be performed to raise the orbit and continue the mission. ATO may be selected for either a performance shortfall or certain systems failures.

Powered Flight

ATO is selected pre-MECO by using the *ABORT MODE* rotary switch or by item entry on SPEC 51. Primarily, pre-MECO ATO selection provides an OMS dump, switches to abort MECO targets (usually the same as nominal), and may enable variable I-Y steering to reduce inclination. The crew monitors ascent performance and keeps abreast of abort mode capability using the NO COMM MODE BOUNDARIES cue card, along with calls from the MCC.

ATO procedures during powered flight, with the exception of the pre-MECO OMS dump, are identical to nominal ascent, which is discussed in Section 7.

The only not they make moneths

The procedures are separated into COMTEN-SERCY ABORT and RFLS CONTENSANCY one cards. They are further subdivided nonevent interfines and color-coded for casier are for detailed precedures, the Ascent/Aborts light Procedures Hamdbook or the Continentor Aborts 2002 Manual should be used. This ection describes the basic information opplicable to all contingency aborts, and is finided note during major phases. Forward light, ET Separation, and Entry.

OMS-1

If possible, ATO abort is declared after MECO to ensure that other downmode options are available as long as possible. ATO OMS-1 targets are automatically called up if an ATO is declared either pre-MECO or pre-OMS 1. This may be a common target set from which either an AOA deorbit burn or an ATO circularization burn can be performed at OMS-2. The final decision can thus be delayed until after OMS-1 is completed.

OMS-1 targeting is performed using the same procedures and cue cards as AOA. These are discussed in Section 6.5. To provide a fuelefficient ATO or AOA burn, OMS-1 is initiated at time to apogee (TTA) equals 2 minutes, but no earlier than MECO + 2 minutes.

OMS-2

The ATO OMS-2 burn is performed using nominal Ascent Checklist and cue card procedures. Proper targets are selected and loaded, the shuttle is maneuvered to burn attitude, and the burn is executed.

After completion of both ATO OMS burns, the orbiter should be in approximately a 105 n. mi. circular orbit. Once this safe orbit is attained, mission operations may be continued for at least 1 day. Additional burns may be used to raise the orbit or the mission may be ended early.

OMS-2 targeting for ATO is very similar to AOA, which is discussed in Section 6.5.

required. If, AL landing sites are strategically incased along the east coars of the Uniter States These sites are studieble on messions with inclinations grower state SF. On messions with mellinations are studieble to messions with mellinations are studied to mession with inclinations are studied to react a strategically to land at Bermania a unless the weblick is already on a TAL about that crosses the UDA would be plane the source plane and parts. The years sterring these occurs on liness TALs provides the plane to bermands. The vehicle to strate the plane to bermands. The vehicle her strate sterring the occurs on liness TALs provides the plane to bermands. The vehicle her strate to BOA would be plane to bermands. The vehicle her growther the state is bermade. The vehicle her growther the state is bernard. The vehicle her growther the state is bernard. The vehicle her growther the state is bernard. The vehicle her growther the state her state is been as a state when the state is the state is bernard. The vehicle her growther her the state her become to be bound in the state when the state is been been been been been been and to be the bound of the state her book and to be the book as the bound of the book of book and to be the book as the book of the book of book and to be

6.7 CONTINGENCY ABORT

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Three-Engine-Out Automation	6.7-2
ET Separation	6.7-2
Entry	6.7-3

During ascent, a contingency abort is performed when the orbiter's thrust-to-weight ratio is less than that needed to achieve a safe orbit or an intact abort, due to multiple engine failures. The purpose of a contingency abort is to guide the orbiter to a safe gliding flight condition, where bailout or a landing can be performed. Currently, two engine-out contingency aborts are automated for both powered flight and the entry pullout. Beginning with OI-25 threeengine-out contingency aborts were automated. The OI-25 software has the capability to be "noopted"; reverting it back to manual contingency abort procedures for ET separation and maneuver to entry angle of attack until MM 602. However, this software is not expected to be noopted. Contingency abort procedures are very dynamic flight modes that take the orbiter to the limits of its structural and flight control envelope. For certain cases, especially high altitude and low velocity, the resultant entry may not be survivable.

Contingency abort procedures are outlined on the Contingency Abort cue cards. These procedures are designed to protect the orbiter from exceeding certain limits:

- -bar 800 psf
- N_z 3.9 g
- Elevon/body flap hinge moments

The procedures are separated into CONTIN-GENCY ABORT and RTLS CONTINGENCY cue cards. They are further subdivided into event timelines and color-coded for easier use. For detailed procedures, the Ascent/Aborts Flight Procedures Handbook or the Contingency Aborts 2102 Manual should be used. This section describes the basic information applicable to all contingency aborts, and is divided into three major phases: Powered Flight, ET Separation, and Entry. The PASS is moded to OPS 6 (RTLS) during most contingency abort procedures. OPS 6 provides the entry guidance and flight control needed for contingency aborts. The BFS does not support contingency aborts because of several restrictions, including no single-engine roll control, no two- or three-engine-out automated software, and no CSS until post-ET separation.

Powered Flight

Should two SSMEs fail, the remaining thrust is used to reduce entry sink rate. Different procedures are used, depending on when the engine failure occurs. For early failures, when the orbiter has a large positive H-dot, the thrust vector is pointed toward the horizon to prevent further lofting. This increases downrange velocity and helps reduce severity of the entry pullout. At an inertial velocity between approximately 7,000 fps and 12,000 fps, a vertical thrust vector is used to counter gravity losses, which shallows the flight path angle and improves entry conditions. At inertial velocities greater than about 12,000 fps, the orbiter may have enough energy to continue to a downrange site.

If two engines fail prior to the SE OPS 3 boundary while the orbiter is within a predetermined velocity envelope, yaw steering of 45° can be performed for an east coast abort landing (ECAL) or Bermuda (BDA) landing. inclination missions use ECAL High procedures, while low and mid-inclination missions use BDA procedures. ECAL and BDA landing sites are available during certain portions of ascent, should a contingency abort be required. ECAL landing sites are strategically located along the east coast of the United States. These sites are available on missions with inclinations greater than 50°. On missions with inclinations less than 40° Bermuda is available. For due east missions, there is no capability to land at Bermuda unless the vehicle is already on a TAL abort that crosses the BDA window (which is out of plane and north). The yaw steering that occurs on these TALs provides the plane change required to reduce the entry cross range to Bermuda. The velocity for a BDA landing is mission dependent but generally ranges from 9 k fps to 12 k fps for BDA and 6 k fps to 12 k fps for ECAL. The powered flight vaw steering for these aborts is open loop.
There is no range-velocity (R-V) target line being attempted, just a reduction in cross range to the site. Yaw steering generally increases entry pullout loads by approximately 0.1 g.

Powered flight is also used to dump OMS propellant. This reduces weight and moves the c.g. forward. Reducing weight decreases the peak q-bar during pullout, while more forward c.g.'s reduce elevon and body flap deflection required for pullout. This helps prevent aerosurface saturation and possible actuator stall.

The heads-up roll orients the bottom of the orbiter/ET into the velocity vector, which is generally the attitude desired for ET SEP and entry.

Three-Engine-Out Automation

Three-engine-out guidance initiates automatically when MECO confirmed is set and color is displayed on the PFS Ascent/RTLS Traj; no item entries are required. If no color is displayed, contingency guidance has determined that either an OPS 3 entry or RTLS runway can be reached without contingency maneuvering. The primary goal is to maneuver to a safe ET separation position, separate from the tank, and subsequently maneuver to entry attitude via the shortest path. The following events occur automatically:

- RTLS abort declaration (if not previously selected)
- Maneuver to ET separation attitude (if required)
 - ET separation
- Post-separation -Z translation
 - Interconnected OMS dump (if required)
 - Inhibit FRCS dump (if required)
 - MM 602 transition

ET Separation

Safe ET SEP is a function of alpha and q-bar. As the shuttle descends, q-bar increases and ET SEP must be performed prior to 10 psf.

At pressures above 10 psf, the ET may recontact the orbiter. Between 2 and 10 psf, the shuttle must be at a small negative (about -2°) angle of attack to ensure successful separation. This is the same technique used for RTLS ET SEP. At less than 2 psf, larger angles of attack are acceptable, but the -Z translation is optimized to help prevent recontact.



High sink rates during many contingency abort scenarios result in rapid entry into the atmosphere and, therefore, a rapid q-bar buildup. In most of these cases, there is not enough time for an RTLS-type PPD and a normal mated coast separation sequence. A fast SEP is performed instead, which takes about 5 seconds. This fast SEP can be performed in one of seven ways, depending on the vehicle attitude and q-bar at the time SEP is required. The first is the immediate, manually initiated fast SEP where no time is available to maneuver to a better attitude. The second is an alpha -2 fast SEP where there is time to achieve the attitude before q-bar exceeds 10 psf. The third is rate fast SEP where the separation is commanded while at a high angle of attack and a -4° per second pitch rate. This technique allows separation to be delayed as long as possible and extends the time available for powered flight. It is initiated when EAS is greater than 10 and increasing (q-bar of about 0.7 psf). The ET SEP occurs prior to the 2 psf limit for high alpha separations. Because the shuttle is near the alpha required for entry, the -4° per second pitch rate needs only to be slowed as the proper alpha is reached. Maneuvering the shuttle to a negative alpha for separation would require a second pitch maneuver to recover back to the entry alpha.

The pitch rate used for fast SEP is a compromise between a rapid pitchdown and the need to maintain control and slow/reverse the rate after SEP. The fourth type of fast SEP is (SRB) PC < 50, that is used only in first stage when the entire stack (SRB and ET) is separated as a whole at SRB thrust tail-off. The fifth is an attitudeindependent SEP where q-bar is low enough to allow the separation to occur in any attitude with zero rates. The sixth is the alpha 125 separation, used when high q-bar prevents a pitchdown maneuver to alpha -2. In this case, the vehicle is pitched up to an alpha of 125° for ET separation, then pitched back down to entry alpha. Last is the emergency separation, which is commanded at KEAS >77 any time the maneuver to ET separation attitude fails. This separation is commanded immediately when EAS exceeds 77 knots, regardless of attitude and rates.

The GPCs will automatically mode to MM 602 after structural separation, when close to entry attitude or >77 KEAS. After MM 602 transition, V_{en} is displayed as Mach number on the AMI.

Entry

The powered flight, mated coast, and ET SEP portions of contingency aborts are designed to deliver the orbiter to acceptable entry conditions without loss of control. Entry phases include:

- Alpha recovery
- N, hold/pullout
- Alpha-Mach
- ECAL/BDA landing or bailout

In general, reducing ET SEP altitude and H-dot will improve entry conditions. Any errors occurring in powered flight or ET SEP will result in a more stressful entry.

Alpha Recovery

Upon ET SEP completion, the orbiter is maneuvered to an alpha that maximizes lift and drag in a manner similar to GRTLS. The appropriate alpha is a function of Mach number and trim but lies in the range of 20° to 58°.

In some cases, alpha recovery is accomplished by stopping the -4° per second pitch rate at the appropriate alpha. Because the alpha tape on the AMI pegs at 60°, a maximum alpha of 58° is used.

The body flap and speed brake are set during the alpha recovery phase before the critical pullout begins. The speed brake and body flap affect hinge moment loads on the elevons. A body flap versus mach schedule is developed for each mission as a function of vehicle weight, c.g. and OMS load. The speed brake is left in auto unless the N, hold is entered below mach three. If below mach three, the crew opens the speed brake to 65%.

N₇ Hold/Pullout

Orbiter H-dot will continue to decrease (more negative trend) throughout alpha recovery until sufficient q-bar and the resultant lift are developed for equilibrium flight. As lift increases, N, will also increase. When $N_c = 1.0$, the orbiter is developing enough lift to support its own weight, and H-dot will begin to increase (more positive trend). The maximum negative H-dot is a good indicator of the severity of the entry. It is also used to calculate N, required for pullout, using the equation:

 N_z target = -H-dot/1000 + 0.65 at $_{\sim}$ = 1.0.

This N, target is calculated by the GPCs and displayed on VERT SIT. The N, hold/pullout is flown in AUTO, which significantly increases chances of survival. N, target is a compromise between structural limits and q-bar limits. The structural load factor limit is actually a function of orbiter weight and wing root bending moment, but the software currently will not target more than 3.9 g. Simulator tests show that q-bar over 800 psf often leads to loss of control. However, this limit is scenario- and mission-dependent.

Load factor continues to increase until within approximately 0.4 g of N, target. A pitchdown is then initiated to hold N, target. The AMI acceleration tape is scaled in g's in MM 602, with 10 = 1 g, 20 = 2 g, and 30 = 3 g. As alpha is reduced while holding a constant g, q-bar will continue to increase until after the sink rate is stopped. When H-dot is positive, pullout is complete, and g load is reduced. The crew can then mode the body flap to AUTO and monitor the alpha/Mach schedule. The N, hold/pullout is the most critical phase of contingency aborts. Even if flown perfectly, some profiles will exceed structural, temperature, or flight control limits. Target N, must be accurately flown.

Most regions of the contingency abort profile have adequate flight control margins. However, there are some regions where even flying the maximum structural load factor limit during N, hold will not prevent q-bar from exceeding 800 psf, possibly stalling the elevons, and losing control.

Flight control gains were designed for a maximum q-bar of 375 psf. Loss of control results from a number of factors. In some cases, aerodynamic moments are so large that the orbiter rates cannot be controlled, even at maximum aerosurface deflection and with maximum jet firings. Additionally, in some cases the aerosurface loads are so large that the actuators cannot drive the surfaces. This is called actuator stall. Sometimes these control problems can be avoided by flying a higher g-level during pullout, but the best technique is to follow the contingency abort procedures explicitly and engage the AUTO system where it has the capability to execute critical maneuvers.

Alpha-Mach

The crew monitors the alpha-mach phase by making sure the vehicle is at the proper alpha for the Mach number. This information is in a table on the Contingency Abort Entry cue card.

Automated ECAL

Starting with OI-28, Item 1 (centered at the bottom of the MM 602 TRAJ) will enable/disable the automated ECAL logic. This item entry is initialized enabled (ENA) when the contingency abort flag is ON, and will require no action.

Entry ECAL energy and g's will be managed with AUTO FCS in OPS 602 and 603 with pitch and bank. For automated ECAL, the alpha range is 20° to 58° , while the bank range is 0° to 70° .

Bailout

An attitude hold mode in MM 603 allows the crew to stabilize the orbiter in gliding flight using the AUTO DAP functions. It is armed when Mach is less than 1.0, the *ABORT MODE* rotary switch is placed to *ATO*, and the *ABORT* pushbutton is pressed.

Guidance snapshots current airspeed and roll angle and attempts to hold both constant. The crew should stabilize the orbiter at 185 to 195 KEAS and zero roll angle, then abort MODE switch to ATO, press ABORT PBI, and select *PITCH* and *ROLL/YAW AUTO*. If a new airspeed or roll attitude is desired, select CSS, fly to the appropriate parameters, and reselect AUTO.

Once attitude hold is established, a middeck MS depressurizes the crew module using the emergency vent handle. When cabin pressure is equalized, the hatch is jettisoned, the escape pole is extended, and bailout is commenced.

EMERGENCY PROCEDURES
 6.7 Contingency Abort

6.8 SYSTEMS FAILURES

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Depending on flight phase, various Flight Data File documents are used to diagnose, correct, and reconfigure malfunctions of orbiter systems.

- Cue Cards
- Pocket Checklists
- Malfunction Book
- Payload Systems

Dynamic phases of flight, such as ascent and entry, do not allow leisurely identification and correction of malfunctions. The CDR and PLT flip books, along with the Ascent/Entry Systems book are designed to allow quick response to certain critical malfunctions in order to safe the affected system.

Procedures in the Ascent, Orbit, and Entry Pocket Checklists (PCL) are designed to safe critical systems where malfunctions require a response in less than 5 minutes. Three separate books are used, since actions vary significantly depending upon the flight phase.

On orbit, with the exception of certain systems such as cabin pressurization, most malfunctions can be thoroughly investigated and isolated, and backup systems can be activated. The Malfunction Book provides step-by-step procedures that have been developed to allow a very structured, methodical approach to correcting systems failures. Because each mission is unique, one or more Payload Systems procedures will be flown to allow the crew to troubleshoot various payload malfunctions.

None of these procedures relieves the crew from understanding how various orbiter and payload systems work and what failures may occur. This in-depth knowledge across a broad range of systems allows a well-trained crew to be confident that nearly all credible malfunctions can be handled without compromising safety or mission success.

The philosophy behind all emergency procedures for the orbiter separates into three categories:

- Detect and confirm the malfunction.
- Ensure a safe configuration.
- Attempt to correct the malfunction or reconfigure to optimize remaining systems.

Many orbiter malfunctions are accompanied by some type of caution and warning alarm. These are designed to help the crew identify the system involved and direct them to the correct procedure. Almost all emergency procedures titles reflect either a hardware caution and warning light or a software fault detection annunciation (FDA) message. It is extremely important to confirm the malfunction with whatever data is available. Sources of data may include dedicated displays, related system malfunctions, or an inventory of failed equipment. Mission Control is often able to provide confirmation, since a great deal more data is available on the ground, and highly trained and knowledgeable controllers are dedicated to each system.

Malfunction confirmation may be complicated by previous failures. Also, the caution and warning system cannot distinguish real failures from sensor failures. Thus, identification of the malfunction and selection of the correct procedure are sometimes difficult. Only through study, training, and practice in simulators can crewmembers develop the capability to quickly and accurately detect and confirm malfunctions in a vehicle as complex as the orbiter.

Once a malfunction has been identified and the proper procedure selected, the crew takes certain well-defined steps to put the orbiter into a safe configuration. An example is pressing the appropriate MAIN ENGINE SHUT DOWN pushbuttons after a second engine failure to establish single engine roll control. Due to the redundancy of most onboard systems, no immediate action should be required for most single and many dual failures. However, if multiple failures occur, there may be very little time to switch to alternative systems or take the necessary steps to prevent loss of control. In multiple failure cases, the crew must keep in mind the interaction of different systems and prioritize their responses.

Most malfunction procedures involve correcting a malfunction to recover lost capability or remaining systems. In general, switching to backup systems, inter-connecting to components of other systems, or securing some remaining systems to reduce heat loads or power consumption are methods used by the crew.

On orbit, it may be possible to perform in-flight maintenance (IFM) to install replacement components or reconfigure systems. An IFM Checklist covers many of these pre-planned activities. A dedicated team of IFM specialists supports each mission and responds to MCC in the event an IFM procedure is contemplated. Mission Control also excels at developing new procedures in real time to deal with unexpected malfunctions. This capability is frequently exercised during simulations.

This section discusses malfunction signatures and confirming cues for some of the malfunctions that may be encountered during training and in flight. Brief summaries of actions required for safing and reconfiguration are also presented. For more detailed malfunction information, refer to Flight Data File books, Flight Procedures Handbooks, and System Workbooks.

APU/Hydraulics

The APU/HYD cue cards and PCL are used to provide response to APU and HYD malfunctions. During ascent, unless the APU or hydraulic failure could cause a catastrophe, the system will not be shut down until after MECO to avoid interrupting hydraulic power to the main engines. Loss of a hydraulic system in powered flight will result in an SSME hydraulic lock-up. Loss of two hydraulic systems in powered flight will result in two SSME hydraulic lock-ups, one of which will have no thrust vector control (TVC).

APU Failure

- Hydraulic pressure goes to zero
- APU speed goes to zero
- APU SPD HI/LOW message
- MASTER ALARM
- APU OVERSPEED/UNDERSPEED light on F7
- Accumulator pressure decrease to ~2600 psia
- HYD PRESS light on F7

Specific software and hardware caution and warnings occurring at the time of failure inform the crew if the shutdown was due to an overspeed or underspeed. MCC uses additional telemetry data to confirm the type of shutdown.

To safe the system, the crew performs the APU SHUTDOWN procedures to remove the start command, close fuel tank isolation valves, and remove power from the APU controller. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending upon flight phase. If sensor problems are involved, reconfiguration of PRL may be required.

If APU shutdown was due to an underspeed, a restart may be attempted after completion of the APU COOLDOWN procedure. An APU that shut down due to an overspeed will <u>never</u> be restarted.

Hydraulic System Failure

- Pressure decrease on both CRT and meter (independent sensors)
- APU speed good
- MASTER ALARM
- HYD PRESS light
- HYD PRESS message
- Accumulator pressure drops to ~2600 psia

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Two of the three pressure sensors in each hydraulic system can be seen onboard. MCC receives data from all three sensors. If the hydraulic failure is confirmed, the APU will be shut down to prevent additional damage. The remaining APUs may be taken to high speed and auto shutdown inhibited, depending on flight phase.

Partial hydraulic failure due to a degraded pump or line blockage may produce pressure fluctuations. For ascent, the system is allowed to operate as long as sufficient pressure is available to keep a main engine from going into hydraulic lockup (~1200 psi). During other flight phases, the hydraulic system is taken to low pressure in an attempt to restore stable operation and to ensure that the aerosurface switching valve has selected a "good" hydraulic system for aerosurface actuation. If the system is stable in low pressure, the APU is kept running until an appropriate shutdown time. If the system is required for critical functions such as landing, the system may be returned to normal pressure.

Hydraulic Leaks

- Unexpected drop in reservoir quantity
- SM ALERT
- SM2 HYD QTY message

During powered flight, the system is left in normal pressure to prevent SSME hydraulic lockup. At other times, the system is taken to low pressure to reduce leak rate. Normal pressure may be reselected if required. MCC determines leak rate and decides whether or not the system may be returned to normal pressure.

APU Fuel/Nitrogen Leaks

- Unexpected decrease in fuel quantity
- SM ALERT
- SM2 APU FUEL QTY message
- Difference in fuel quantity among APUs
- Decrease in fuel pressure

Since fuel and nitrogen leaks are indistinguishable until very low levels are reached, crew response is to assume a fuel leak (worst case). No action is required pre-MECO unless the APU shuts down. For other flight phases, the APU is shut down and the fuel tank isolation valves closed to attempt to isolate the leak. If isolated, the APU is only started for critical operations. If non-isolatable, the APU is restarted and run to fuel depletion. This prevents damage in the aft compartment from leaking hydrazine, which is very corrosive.

Water Quantity Low

- Abnormal decrease in water boiler quantity
- SM ALERT
- SM2 W/B QTY message

Water spray boiler nitrogen or water leaks, as well as excessive spraying by a faulty water spray boiler controller can cause an abnormal decrease in water boiler quantity.

MCC can detect excessive spraying, but in any case, the crew should switch to the alternate controller. If switching controllers does not work, boiler power is cycled to reduce water usage. MCC will determine when and if APU shutdown is required, depending on mission phase.

For a water leak, switching controllers will not help, and APU cooling will be lost when the quantity reaches zero. The APU will then overheat within 4 minutes. Nitrogen leaks allow cooling for a short time even after water quantity reads zero. W/B QTY is a PVT calculation.

APU Shifts to High Speed

- APU rpm increases to 113%
- APU SPD HI Fault message
- SM ALERT

An APU shift to high speed can be caused by an APU controller electronic malfunction or an open failure of the Primary Control Valve. The crew will take APU control to high-speed to ensure proper controller logic for high-speed control. If rpm does not shift when the controller is taken to high speed, the failure is real. The APU will be shut down as soon as possible post MECO as long as two other APUs are working properly. APU auto shutdown

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must not be inhibited on an APU that has shifted to high-speed since auto shutdown via the fuel tank isolation valves is the only protection from APU overspeed if both control valves were to fail open.

Hydraulic Fluid/Lube Oil Overtemp

- High hydraulic fluid temp
- High lube oil temp
- MASTER ALARM
- APU TEMP light on F7
- SM ALERT
- APU TEMP message
- HYD RSVR T message

Excessive hydraulic fluid temperature (>230° F) or lube oil temperature (>290° F) are signatures of inadequate cooling. This may be caused by mechanical problems or a water spray boiler malfunction. The crew should switch boiler controllers first. If APU temperatures decrease, then the problem was in the controller. If temperatures continue to rise, APU shutdown may be required.

An APU will run for 4 to 5 minutes without lube oil cooling. Shutdown and restart may be possible if the APU is required for critical maneuvers. Although the system is not limited in run time for excessive hydraulic temperatures, the system may be taken to low pressure or shutdown in order to maintain the hydraulic fluid below limits that may cause system seal degradation if exceeded.

Fuel Tank Valve Overtemp

- High valve temperature
- SM ALERT
- FU TK VLV APU message

When the fuel tank isolation solenoid valves are powered open without fuel flow for cooling, excessive heating can occur. High temperatures may cause hydrazine detonation. The crew should verify the fuel tank isolation valve switch is closed, then open the appropriate circuit breaker on panel R2 to remove power from the valve solenoid.

Priority Rate Limiting

- Possible differing hydraulic pressure on CRT and meter
- SM ALERT
- PRL DLMA message
- APU accumulator pressure
- APU speed

Pressure (or sensor) differences within a particular hydraulic system may cause the PRL software to be confused. MCC can see all three sensors in each hydraulic system and will assist the crew with proper actions. The first action is to use confirming cues to determine if the APU is running. Once APU status is known, the crew should verify all good systems are selected for PRL by executing appropriate item entries on the OVERRIDE (SPEC 51) display.

Switching Valve Failure

- MCC call
- Control problems

This failure can prevent the hydraulic systems from operating a control surface. The crew can cycle the affected system hydraulic pressure between *LOW* and *NORM* to attempt to reset the valve upon MCC direction. The other option is to deselect one or more hydraulic system in the PRL software and operate on reduced PRL rates. This will reduce the loads on the good APU(s). This procedure is also performed only at MCC direction.

Uncommanded Brake Pressure

- Brake pressure greater than zero in flight
- SM ALERT
- SMO BRAKE P message

Since brake pressure is measured downstream of the brake/skid control module, there is no way to determine which hydraulic system is responsible. Landing with pressure greater than 200 psi in the braking system can cause the wheels to be locked at touchdown. This will cause one or more tires to fail, resulting in

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directional control problems and possible loss of control. Nominally, none of the three brake isolation valves will be open prior to weight on wheels (WOW) or main gear touchdown. Therefore, there should be no concern for this problem. However, if the hydraulic system 2 brake isolation valve must be opened prior to WOW for nose gear deploy redundancy, there is potential to get uncommanded brake pressure. To correct this problem, the PLT must close brake isolation valve 2 as soon as possible after gear deploy and before WOW. This will allow for the pressure to bleed down.

The crew should close the appropriate isolation valves, then reopen them after nose gear touchdown. Since hydraulic system 1 supplies power for nosewheel steering, this procedure is modified for certain cases, and isolation valve 1 is reopened at main gear touchdown.

Communications

The orbiter communications system is extensive and complex. A great deal of redundancy exists, and the system has been very reliable. For normal operations, MCC commands system reconfigurations. Loss of communication can occur for reasons other than onboard equipment, such as ground station or satellite problems and antenna blockage. The crew should consider this possibility as well as their current communication mode, comm panel configuration, and position over the ground prior to executing lost communication procedures.

ICOM Lost

• Inability to communicate using ICOM

The procedure for ICOM lost will have the backup audio terminal unit (ATU) selected via the POSITIONS control switch. Positions with backup ATU include commander (CDR/left), pilot (PLT/right), mission specialist (MS), and airlock (AL). At other positions, or if alternate position doesn't regain ICOM, the alternate audio central control unit is selected via panel C3. If these actions do not regain ICOM, a different ATU, crew communications umbilical (CCU) connection, or headset/handheld mic may be required to regain ICOM.

Comm Lost

- ICOM operating properly
- S-band comm lost on multiple panels
- UHF comm status

The crew should first select ACCU alternate power. If this is unsuccessful, S-band PM panel C3 controls are verified and the crew switches the *S-BAND PM CONTROL* switch to *PANEL*, then back to *COMMAND*. This causes the Sband PM system to attempt to operate as specified by the panel A1L switches. If this corrects the problem, one of the originally selected S-band subsystems has malfunctioned.

CAUTION

Panel A1L switches must be set up for the current comm mode (including proper NSP configurations).

To troubleshoot antenna problems, manual antenna selection is attempted, using the SIGNAL STRENGTH meter and SM OPS 201 ANTENNA display to monitor signal strength. If comm is not restored, the *ANTENNA* rotary switch on panel C3 is returned to *GPC*, and TDRS mode is configured since it provides the greatest coverage.

An in-flight maintenance procedure is available to bypass a completely failed ACCU.

Finally, the procedure provides steps to determine if MCC can uplink to a GNC GPC for state vector updates. If comm is not regained, the crew may have to deorbit without MCC direction to preserve IMU alignment entry limits.

UHF Lost

• Unable to communicate on UHF

The crew first turns off the UHF squelch system to ensure good signal reception, then an alternate ACCU power source is selected.

Three frequencies are available (259.7, 296.8, and GUARD). All should be tried. GUARD is an international UHF frequency that is only used in emergencies.

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Since the UHF antenna is located on the orbiter's belly, a roll to heads up is performed to ensure optimum antenna gain.

Finally, an in-flight maintenance procedure may be performed to bypass the UHF power amplifier. If successful, a low power transmit mode will be available.

Cryo

The cryo O2 and H2 systems provide reactants to the fuel cells from tanks located under the payload bay. The cryo O2 system also supplies oxygen to the crew module for metabolic use and also for direct breathing while using the LES helmets.

Leaks

- MASTER ALARM
- O2 (H2) PRESS light (F7 matrix)
- SM ALERT
- CRYO O2 (H2) MANF message
- CRYO O2 (H2) PRES message
- Decreasing tank pressure
- Decreasing manifold pressure
- MCC call

If a cryo leak is detected, the location of the leak must first be determined, then steps must be taken to isolate the leak. If pressure decreases in only one tank, a tank leak is indicated. Check valves should prevent the other tanks from losing cryo through a leaking tank. Some cryo in the leaking tank may still be usable, depending on the leak rate. Mission duration may be affected.

A pressure decrease in all tanks requires closing the manifold isolation valves to isolate the leak. Once a potential leak area is isolated to a single manifold, additional troubleshooting may allow further isolation to either the PCS system or an individual fuel cell. Should the leak be in the manifold feeding a fuel cell or in the fuel cell itself, a shutdown and powerdown may be required. Mission duration may be affected, depending on leak location and the mission cryo quantity requirements.

Heater Problems

- MASTER ALARM
- O2 (H2) PRESS light (F7 matrix)
- O2 HEATER TEMP light (F7 matrix)
- CRYO O2 (H2) PRES message
- CRYO O2 HTR message
- High tank temperature
- High tank pressure
- High heater temperature

Cryo heaters can fail on or off. A heater can also have a short. If an O2 heater has a short, it should cause the O2 current sensor logic to trip and disable the heater.

A failed "on" heater may result in high tank temperature or pressure, requiring the affected heater to be turned off. A failed "off" heater can be caused by a control problem or a failure of the heater itself. MCC normally will alert the crew to these conditions. Redundant heaters are used if a heater problem is present. For control problems, a manual heater control procedure can be used.

Failure of heaters in two tanks indicates a paired logic problem. For this case, each tank's heaters must be operated individually to determine the location of the failure.

Data Processing System

Hardware and software DPS problems are normally detected by monitoring software and annunciated by the caution and warning system. Failure signatures are presented in a table in this section. Once the failure is identified, the appropriate procedure is worked. The impact of a single DPS failure in other systems is normally a loss of redundancy rather than a loss of capability.

	CAL	ITION & WARNING	s jaosedure i	Kev safur stable is ca
FAILURE	HARDWARE	SOFTWARE	PROCEDURE	COMMENTS
Fail to Sync	GPC light CAM lights	GPC Fail message Down arrow on SYS SUMM Failed GPC issues fail mes- sages against the good GPCs GPC continues to drive its CRT	GPC Fail	GPC continues to run and send commands over the data buses Mode tb will be RUN and Output tb is grey
Fail to Halt	BP Output tb BP Mode tb CAM lights GPC light CRT Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Dead GPC, no commands
Fail to Quit	GPC light CAM lights CRT Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Like fail to halt, except Mode and Output tb's do not turn barberpole (BP)
PASS Total Set Split	All PASS GPCs st GPC issues fail me diagonal CAM ligh	op talking to each other, each essages against the others, ts lit, BFS standalone	BFS Engage	Engage should be done with 10 sec for Ascent, 45 sec for Entry
Generic PASS Fatal Software Error	Fail to quit or halt of PASS driven CRTs standalone	on all four GPCs simultaneously/all s Big X and poll fail/BFS	BFS Engage	Engage should be done within 10 sec for Ascent, 45 sec for Entry
Power Fail	Bp Output tb Bp Mode tb CRT Big X Poll Fail	GPC Fail message Down arrow on SYS SUMM	GPC Fail	Like fail to halt, but no CAM lights or F7 GPC light
I/O Term B fails on	Bp Output tb	Down arrow on SYS SUMM for FF and FA FF and FA I/O Error messages	GPC Fail	GPC running, but commands inhibited on flight critical data buses
I/O Term A fails on	Angen John and an	Down arrow on SYS SUMM for PL1 and PL2 PL1 and 2 I/O Error messages	BFS or SM GPC Fail	GPC running, but commands inhibited on payload and launch data buses
MDM I/O Error at MDM	Varies with MDM	I/O Error message (PASS & BFS) Down arrow on PASS SYS SUMM Down arrow on BFS SYS SUMM	MDM I/O Error	GPC good, MDM lost, Port mode may recover
MDM I/O Error at GPC	Varies with MDM	PASS I/O Error message BFS BCE String PASS message Down arrow on PASS for failed MDM M's on BFS SYS SUMM for FF and FA	MDM I/O Error	Port mode will cause loss of other MDM on string trade-off case)
Component comm problems	na kontero del an	BCE String x message M's on PFS and BFS SYS SUMM	BCE String X	Use Ref Data book to find parameters lost and verify signature
OI MDM/DSC Fail	Varies with MDM/DSC	M's on SYS SUMM for MDM L's on SYS SUMM for DSC I/O Error PCM annunciated by BFS for PCM port problem or MDM problem PASS SM machine will annunciate S62 BCE BYP of X or QA MSG	I/O Error PCM	gʻabas Nosi dagecone no miko mov adaj et si kolis ra- MDa konsidili dogarito at parlenda at oparito da sona prilo datero dal

permitted.

DPS Failure Signatures

Key safing steps in each procedure are used to prevent commands to good systems from bad computers and prevent good computers from using data from bad components. To correct transient errors, an I/O RESET or power cycle is attempted. For port-dependent failures, the port mode procedure may allow communications to be resumed using alternate ports and a different data bus.

During ascent or entry, when certain DPS failures affect more than one flight-critical string, the MULTI DATA PATH cue card is used to identify failure effects and determine crew actions. For some multiple failures, when Flight Rules allow, the DPS can be reconfigured using the RESTRING cue card. This procedure allows good GPCs to take over flight-critical buses and components that are lost after one or more GPC failures.

Set Splits

Since the GPCs run in a redundant set during ascent, entry, and some on-orbit operations, it is possible for one or more PASS GPCs to split apart from the rest of the set and continue running. Various combinations are possible, but in all cases it is imperative to determine if a good PASS set exists. A good set must include:

- 1 IMU
- 2 RGAs
- 2 AAs
- 2 FCS channels

Restring or BFS engage is required if a good set does not exist.

NOTE

See section 6.9 for GPC set splits during ascent.

BFS Engage

For unrecoverable PASS failures, the BFS is available to take over orbiter control. Monitoring of BFS and GNC systems status prior to engage is required to ensure the BFS is capable of control. For a successful BFS engage, the BFS must have a good nav state and be able to communicate with/command:

- 1 IMU
- 1 RGA
- 1 AA (for 1st stage)
- 2 FCS channels
- 1 ADTA

BFS Failures

For most transient failures, the BFS will automatically attempt a software restart. If this is successful, operations will continue, and a GPC BITE message will be issued. A Halt transient results in the BFS restarting in OPS 0, and it must be moded to the appropriate OPS by the crew. For these transient failures, however, the BFS should be considered "suspect" for engage. This means that it should only be engaged for emergency situations for total PASS failures.

Total BFS GPC failures present a signature similar to a PASS GPC FAIL. The crew should see barberpole *OUTPUT* and *MODE* talkbacks, a big X on the BFS CRT, and a POLL FAIL message.

Actions for BFS failures are listed in the appropriate FDF procedures. Since the BFS also controls several systems during ascent and entry, the crew may be required to take manual control of communications or ECLSS equipment. The following table lists some commands issued by the BFS:

SYSTEM	COMMAND	MAJOR MODE
ECLSS	FES on	103
Down men	NH3 on	603, 305
СОММ	SPC to TDRS	104
	Antenna	Ops 1, 6, 3
and the second of	Other SPCs to ground stations for lost comm	Ops 1, 6, 3

BFS Commands Over Payload Buses

Environmental Control and Life Support System

Environmental control and life support system (ECLSS) malfunction procedures cover the four subsystems of pressurization, air revitalization, active thermal control, and supply/waste water. Since the ECLSS is highly redundant, the normal response to failures is to switch to the alternate system.

Cabin Pressure

- Klaxon
- MASTER ALARM
- Cabin pressure meter
- dP/dT meter
- SM SYS SUMM
- High O2 or N2 flow
- CABIN ATM light (F7 matrix)

Crew reaction to cabin leaks consists of four basic steps: assess magnitude of the leak, attempt leak isolation through system reconfiguration, power down, and prepare for deorbit.

The crew first closes cabin relief isolation valves and uses available data sources (CRT displays and meters) to verify the leak. If a leak is confirmed, the leak rate determines whether an ascent abort or an emergency deorbit is required. If enough time is available, additional leak isolation procedures are attempted.

An unexpected cabin pressure increase could be caused by either a PCS leak or a malfunction in the PCS control system. Flight Data File procedures are used to secure the PCS and isolate the failure. An early deorbit may be required for a non-isolatable leak to prevent O2 or N2 depletion. PCS leaks may be either internal or external to the crew module.

Pump/Fan Failures

- Rapid drop in flow rate
- Pressure differential in loop
- Rising temperatures
- MASTER ALARM
- Hardware caution and warning
- Fault messages

The normal response is to switch to an alternate pump/fan; however, during powered flight only avionics bay fans and Freon pumps are switched. This prevents electrical transients. Should avionics bay temperatures exceed limits, activation of the alternate water loop is also permitted.

Water/Freon Leaks

- Decrease in flow rate
- Change in accumulator pressure
- Decrease in pump delta pressure
- MASTER ALARM
- Hardware caution and warning
- Fault messages

Depletion of fluid makes the loop unavailable for cooling. An early deorbit should be expected. On ascent, an abort may be required for the loss of two H2O loops or two Freon loops.

Fire

- Siren
- Master alarm
- SMOKE DETECTION lights on panel L1
- Fault messages
- Smoke concentration on CRT display

If a fire is confirmed by checking the smoke concentration on the CRT display, the crew must protect themselves with helmets using the helmet retention assembly (HRA), then take steps to extinguish the fire. Either a built-in or a portable Halon bottle is discharged to extinguish the fire.

Once the fire is under control, the WCS charcoal filter, ATCO, and LiOH canisters are used to clear the cabin atmosphere of combustion products. If the crew cannot purify the atmosphere to a safe level, then an early deorbit will be required, since the orbiter N2 supply is insufficient to maintain cabin PPO2 below flammability limits for more than 4 to 8 hours while the crew is wearing helmets and exhaling oxygen-rich air.

Cooling Loss

Loss of one or more heat rejection systems (radiators, FES, NH3 boiler) requires a reconfiguration to make up for lost cooling capability while troubleshooting. A powerdown may be required. For severe cooling loss, an early deorbit may be performed.

Electrical Power System

The orbiter EPS configuration during all flight phases is for all buses to be powered and operating independently. Payload and other considerations may mandate bus ties during orbit operations. EPS malfunctions that require an immediate response include reactant valves, fuel cells, major dc buses, dc-ac inverters, and ac motors. Cryo-related problems are discussed in the Cryo section.

Shorts

- High amps
- Low volts
- Hardware caution and warning (F7 lights)
- MASTER ALARM
- Fault messages
- CRT displays
- F9 meter

For a confirmed short, power is removed from the affected bus. Circuit protection equipment built into the orbiter may also react to large shorts by tripping RPCs, blowing fuses, or popping circuit breakers.

Most bus shorts are characterized by high current and low voltage. Each bus failure has a particular signature that should be learned through practice in failure recognition in the Single System Trainer (SST). It is important to be able to react quickly and correctly to electrical shorts, particularly during critical flight phases.

CAUTION

Never tie a good bus to a shorted bus while executing malfunction procedures.

Bus Losses

- Bus loss ID in FDF
- Fault messages
- Hardware caution and warning

The following table is an abbreviated list of cues for certain bus losses. When the bus loss is confirmed, an attempt may be made to recover the bus, depending on flight phase, criticality, and the type of failure. If the bus cannot be regained, FDF bus loss actions must be completed to reconfigure and safe systems.

BUS	SIGNATURE
Main	MAST ALARM Hardware caution & warning MAIN BUS UNDERVOLT light and other lights on F7 matrix
	Fault messages MN volts = 0 CRT loss FC amps = 0
FPC	MASTER ALARM Hardware caution & warning AC VOLTAGE light, FUEL CELL PUMP light Fault messages AC volts = 0 AC amps = 0 MN volts good
structure as	CRT loss Pump/motors
AC	MASTER ALARM Hardware caution & warning AC VOLTAGE light, other F7 lights Fault messages AC volts low AC amps low Pumps/motors
ESS	MASTER ALARM Hardware caution & warning Fault messages ESS volts low Bus loss ID FUEL CELL PUMP light on F7 matrix
CNTL	Control bus losses are difficult to diagnose. The signature could range from no indications to: SM Alert Fault messages, including SM CNTL/ESS V CNTL volts low Bus loss ID
Panel/	Equipment loss
Sub bus	Bus loss ID

Abbreviated Bus Loss Signatures

Fuel Cell Reactant Valves

- MASTER ALARM
- SM ALERT
- FUEL CELL REAC light on panel F7
- FC REAC message
- FC COOL P message

If a reactant valve failure annunciates, the PLT should quickly attempt to reopen the valve and bus tie in order to prevent fuel cell loss and a subsequent main bus loss. For confirmed reactant valve failures, the affected fuel cell must be shutdown. If an O2 or H2 reactant valve fails closed, the fuel cell will fail from lack of fuel within 90 or 30 seconds, respectively.

Fuel Cell Cooling Loss

- MASTER ALARM
- FUEL CELL PUMP light (F7 matrix)
- FC PUMP message
- FC coolant pump DP talkback barberpole

Fuel cell cooling can be lost for several reasons, including: coolant pump failure, AC bus loss, ECU failure, ESS bus loss, or a fuel cell coolant leak. The fuel cell temperature signatures vary with each failure, but in general, the fuel cell must be secured within 9 minutes to prevent stack overheating. To troubleshoot fuel cell cooling problems, use the following rules of thumb, although each is not applicable in all cases.

- If the coolant pump is not running, EXIT T should increase if the H2 pump is running.
- If the coolant pump and the H2 pump are not running, STACK T will decrease. EXIT T will increase slightly and stabilize.
- Combined coolant/H2 pump failures may be an indication of an ECU malfunction, or an AC problem affecting both motors.
- Steadily increasing STACK T and EXIT T are indications of a real fuel cell cooling problem.

Fuel Cell Internal Short

- Low fuel cell volts
- Low MN volts
- Reduced FC amps
- Increasing STACK T
- Increased reactant flow
- Fuel cell performance degraded

For this case, the MN BUS UNDERVOLTS procedure is used. The fuel cell is shut down after dropping the affected bus. For a confirmed fuel cell short, the main bus may be regained using the BUS TIE procedure.

Fuel Cell Crossover

- SM ALERT
- FC DELTA V message
- Increasing STACK T and EXIT T
- Decrease in FC volts

The FC DELTA V procedure is used to bus tie and safe the fuel cell.

Fuel Cell Shutdown

If a shutdown is required due to a failure or malfunction, the FC SHUTDOWN procedure is used. Upon completion, the appropriate LOSS OF 1 FC powerdown should be performed.

Should a second fuel cell shutdown be required, the 2ND FC SHUTDN procedure is used. In this case, some powerdown is required prior to fuel cell shutdown to prevent excessive loads on the single remaining fuel cell. During ascent, one FC cannot support the load of three main buses, so one main bus will have to be dropped. As before, a LOSS OF 2ND FC powerdown would be performed after the fuel cell is shut down.

Dual Gas Regulator

- SM ALERT
- FC COOL P message
- Reduction or increase in coolant loop pressure

Pressure that is either too high or too low will cause the fuel cell to operate incorrectly, and a shutdown will be required. The BUS TIE procedure is used to prevent loss of an MN bus. Time available before shutdown of the fuel cell varies depending upon the severity of the pressure problem.

Powerdowns

Powerdowns are performed to reduce electrical power consumption and reduce heat loads. The appropriate ascent, orbit, or entry FDF procedure is used. These procedures are designed specifically for each flight phase.

Guidance, Navigation, and Control

The most serious failures in GNC systems are those that affect flight control. It is imperative that the crew manage the flight control system properly in a highly augmented vehicle such as the orbiter. Since stability is negative in many flight regimes, failures in the flight control systems can rapidly deteriorate into a loss of control.

FCS Channel

- MASTER ALARM
- FCS CHANNEL light on panel F7
- FCS CH message
- Down arrow on GNC SYS SUMM
- Down arrows on SPEC 53 CONTROLS display
- MCC call

Due to system redundancy, no action is required for the first failure. A second failure on the same effector requires the crew to place the remaining channels to *OVERRIDE*. This prevents a good channel from being bypassed in the event of a third failure.

Sensor Failures/Dilemmas

- SM ALERT or Master Alarm
- Fault message
- Down arrow, "?," or M on GNC SYS SUMM
- Down arrow, "?," or M on sensor displays

For single sensor failures or commfaults, redundancy should allow the good systems to continue to provide data without impacting control system performance. A second or third failure may confuse the FDIR selection filter, requiring crew intervention. MCC can generally resolve sensor dilemmas quickly, using the additional data available in the telemetry stream.

Mechanical

Malfunctions in orbiter mechanically actuated systems such as payload bay doors and latches can be electrical, mechanical, or DPS related. Since many of these systems are critical for entry, it is important to understand each system and troubleshoot correctly.

Motor Failure

All orbiter mechanical systems have two motors for redundancy, and all systems can drive with just one motor. Motor failures can occur due to power failures, control logic failures, software failures, or jams. Failure of a single motor doubles actuation time for the system. Failure of both motors precludes actuation. Workarounds, IFM, and, as a last resort, EVA procedures are available to restore capabilities on some systems.

Indicators

Microswitch failures can prevent automatic system operation or give false indications of a malfunction. Individual readouts of paired microswitches on most mechanical systems allow the crew or MCC to determine actual status of the system and its associated talkback indicators.

Main Propulsion System

MPS failures during ascent can cause degraded performance that may result in an abort. Most cue card procedures must be executed quickly to safe systems and protect against additional failures. Close crew coordination is required, especially where an ascent abort must be executed.

Engine Failure

- MASTER ALARM
- Red *MAIN ENGINE STATUS* light on panel F7

- SSME FAIL message
- Pc goes to zero
- Change in acceleration
- Reduced helium flow. (Helium flow increases during shutdown and then decreases to zero post shutdown)
- MCC call

The most important step following an engine failure is to ensure the GPCs know that an engine has failed. This is checked by verifying that an SSME FAIL message has annunciated. If the SSME FAIL message has not been annunciated, the crew must push the appropriate *MAIN ENGINE SHUT DOWN* pushbutton to mode guidance.

For any SSME failure, the PLT places the *AC BUS SENSOR* switches to the off position. This protects against other electrical failures causing an engine shutdown. AC bus sensors are also taken off for AC power problems during ascent and entry, and for loss of main engine controller redundancy.

Helium Leak

- SM ALERT
- MPS HE message
- HE dP/dT > 20
- Down arrow on BFS GNC SYS SUMM 1
- HE tank pressure lower than other engine tanks
- HE Reg A^{\uparrow} or B^{\uparrow} (may be present)

Early in ascent, a cue card isolation procedure is used to secure one He leg at a time. If the leak is isolated, the bad valve is kept closed and MCC evaluates He remaining to determine if a safe shutdown will occur at MECO. It may be necessary to interconnect the pneumatic helium system. Failures later in ascent may require a shutdown using the shutdown pushbutton only if there is insufficient time for leak isolation. A pushbutton shutdown requires less Helium than a pneumatic shutdown, since hydraulic pressure is used to actuate some SSME valves. If a leak cannot be isolated, helium from a previously failed engine may be used as a source of additional helium to prevent a second engine failure. The engine will fail when helium is depleted. Limits must be enabled to ensure a safe shutdown. An early crew-initiated shutdown could also be required, depending on leak rate. MCC will analyze leak rate and recommend action if comm is available. Without comm, the crew uses the procedures on the MPS cue card.

Data Path Failure

- Engine Pc goes to zero
- SM ALERT
- SSME DATA message
- Yellow *MAIN ENGINE STATUS* light on panel F7
- Acceleration cues
- Helium flow
- MCC call

The onboard software automatically inhibits limits for a data path failure. If the engine is still running, the crew re-enables limits and continues monitoring ascent. If the engine has failed, the shutdown pushbutton must be pressed to mode guidance for the engine failure.

Stuck Throttle

- SM ALERT
- Yellow MAIN ENGINE STATUS light on panel F7
- Static engine Pc
- SSME CMD (HYD, ELEC) message
- MCC call

SSME Pc is frozen in its last position for command path failure, loss of a hydraulic system, computer or sensor failures, and drifting valves. Procedures for these malfunctions are found on the MPS CMD/HYD/ELEC cue card. Engines with command path failures must always be shut down manually using the MPS controller ac power switches. After shutdown, the shutdown pushbutton is depressed to set discretes that allow software to recognize an engine failure. This is called an AC/PB shutdown. A single engine with a hydraulic or electric lockup will be shut down only if first stage performance is low, and three engines are running.

For single stuck throttle, shutdown time varies for nominal ascent, TAL, and RTLS. The engine is usually shut down shortly before normal MECO to preserve the maximum amount of performance.

If two SSME throttles are stuck due to command path failures, they are shut down one at a time near MECO. The MPS *ENGINE POWER* switches (*AC 1, 2,* and 3) must be used for shutdown, followed by the *MAIN ENGINE SHUT DOWN* pushbuttons (AC/PB shutdown).

Two hydraulic or two electric lockups will cause the orbiter to exceed three g's in the latter part of ascent. One engine is shut down per the cue card or MCC call to prevent vehicle overstress.

Mixed failures require one engine to be shut down near MECO according to the following failure priority:

- 1. Command
- 2. Hydraulic
- 3. Electric

ET SEP Inhibit

- MAIN ENGINE STATUS lights remain on panel F7
- SM ALERT
- SEP INH message

This malfunction can be caused by excessive rates or a feedline disconnect failure. If rates are the problem, the crew damps them manually and allows the automatic separation sequence to occur. Feedline disconnect failures require the crew to execute a manual separation 6 minutes after MECO. For performance problems or aborts, a separation may be performed sooner.

ET SEP Switch

- SM ALERT
- ET SEP MAN message
- ET SEP AUTO message (RTLS)

The software automatically defaults to a crewinitiated ET SEP if this switch fails to *MANUAL*, except for RTLS aborts where the default is *AUTO*. The switch is overridden using an item number on SPEC 51.

MECO Confirm

- No auto ET SEP
- Glareshield DAP lights remain on
- Panel C3 ORBITAL DAP lights remain off
- No software mode transition

A failure of the software to confirm MECO prevents an auto ET SEP. The crew can set a MECO confirm flag in the software by simultaneously pushing all three engine shutdown pushbuttons, providing no other failures have occurred. The MECO confirm flag may also be set by manually moding the software via an OPS 104 PRO.

Orbital Maneuvering System/Reaction Control System

Failures in the OMS/RCS are handled using procedures tailored for the current flight phase. For ascent, achieving a safe orbit while maintaining deorbit propellant margins is the primary concern. On orbit, maintaining at least two deorbit capabilities drive the procedures. During entry, vehicle control is paramount.

Leaks

- Helium pressure decrease, propellant quantity decrease
- MCC call
- MASTER ALARM
- OMS or RCS light on panel F7
- Leak message

^{6.} EMERGENCY PROCEDURES

Leaks must first be confirmed, using independent CRT and meter indications, since sensor failures may cause false annunciation. Once confirmed, the crew attempts to isolate the leak by securing the affected system. Control requirements drive the procedure to be used.

Helium tank leaks are identified by a continual He pressure decrease after the system has been secured. For this case, propellant is burned from the affected system to achieve blowdown capability. This amount of propellant remaining (39 percent OMS, 22 percent RCS) allows degraded use of the system even though the remaining helium is depleted.

A helium leg leak can be identified by the He pressure stabilizing after the system has been secured. In this case, the helium isolation valves are manually operated to maintain pressure in the propellant tanks.

If propellant tank pressure continues to decrease when the system is secured, a tank leak is indicated (RCS tank leaks in MM 304 are identified by propellant tank pressure diverging from good tank when the system is secured). The system should be used as long as possible, then crossfeed is established to the other system prior to tank depletion. A burn may be performed to deplete the affected propellant tank, preventing leakage into the OMS/RCS pod where the corrosive propellants could damage other systems.

RCS manifold leaks and leg leaks are indicated by a pressure drop in the individual manifold or manifold pairs after leak isolation. In general, the leaking manifold/leg will be left secured and operations will be continued using the good systems.

Regulator Failed High

- Pressure increase in OMS/RCS system
- MASTER ALARM
- OMS or RCS light on panel F7
- OMS or RCS TK P message

He isolation valves are closed per the appropriate procedure and troubleshooting performed to isolate the bad regulator.

OMS Engine/Propellant Failure

- MASTER ALARM
- Drop in OMS Pc and/or increase in OMS injector temperature
- Reduced acceleration
- Down arrow on MNVR display
- OMS ENG PC message
- OMS light on panel F7

Depending on flight phase, the appropriate OMS BURN MONITOR cue card is used. Engine oxidizer/fuel inlet pressure is analyzed to determine whether the failure is real and if it was caused by a propellant problem upstream of the engine (PRPLT FAIL) or problems within the engine itself (ENG FAIL).

For engine failures, the remaining propellant can be used by the other engine or the RCS by setting up a crossfeed/interconnect. Propellant failures are more severe, since the remaining propellant is probably unusable. In some cases, where a partial blockage exists, it may be possible to feed the RCS jets using the remaining OMS propellant due to the reduced flow rate requirements.

RCS Jet Failures

- MASTER ALARM
- RCS light on panel F7
- RCS XJET FAIL message
- GNC SYS SUMM indications
- SPEC 23 RCS display indications

Jets can fail off, on, or leak. False annunciations may also occur.

For a failed "on" jet, the RCS manifold must be quickly secured to prevent propellant depletion. If the failure was real, pressure will decrease in the affected manifold.

Since the RCS jets have a great deal of redundancy, a single failed off jet usually has no major effect. The remaining jets take over per the software jet select priority. MCC will examine the telemetry data to determine whether the failure is a transducer or an actual jet problem. If required, the jet may be reselected so that the DAP will attempt to fire it again.

When a jet fail leak is annunciated, the crew and MCC examine available data to determine if the leak is real or an instrumentation problem. For actual leaks, the appropriate manifold is secured only if the leak is large enough to cause a quantity divergence.

Interconnect/Crossfeed

Crossfeed valves and lines allow crossfeeds between the left and right OMS pods or left and right RCS pods. The crossfeed valves and lines also allow the OMS and RCS systems to be inter-connected. Placing the OMS/RCS switches in *GPC* allows the software to automatically reconfigure these valves and establish OMS/RCS interconnects for abort dumps and RCS crossfeed for large RCS leaks. The software will also automatically deselect manifolds and reconfigure the system for DPS and electrical failures for some ascent aborts.

Generally, the automatic reconfiguration can handle single failures and some multiple failures for ascent aborts. The crew must ensure that valves are configured correctly to prevent inadvertent propellant depletion or loss of control. When the systems are being operated in an interconnect or crossfeed mode, failure isolation becomes much more complex. If conditions permit, it is better to secure the OMS/RCS systems entirely prior to attempting trouble-shooting procedures.

OMS Gimbal

- MASTER ALARM
- OMS TVC light on panel F7
- OMS GMBL message
- Downmode to secondary gimbal

Either a gimbal failure or its data path cause this annunciation. For either case, operation on the secondary gimbal is initiated. A second gimbal failure may require securing the OMS engine if control problems exist. Should the OMS engine be pointed near the orbiter's c.g., then the RCS and the remaining OMS engine may be able to maintain control.

A gimbal failure that occurs while a burn is not being performed may be overcome if the remaining gimbal system can be used to position the engine through the c.g. Gimbal power is then removed via an item entry on the MNVR display. The procedure protects against additional failures that might make the engine unusable.

6.9 MULTIPLE FAILURE SCENARIOS

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This section briefly describes multiple failures that may be encountered during training. Although the potential for these failures in flight is very low, they allow flight crews and MCC personnel to exercise their knowledge of orbiter systems. For each case, crew actions are noted after the multiple failure is discussed.

MPS He Leak with APC/ALC Failure

A failure of APC 4 (5,6) or ALC 1 (2,3) causes the A helium isolation valve on the L (C,R) main engine to close. Should a helium leak subsequently occur, and isolation procedures are attempted, closing the B helium isolation valve on the affected engine would result in an unplanned engine shutdown.

With an APC/ALC failure during powered flight, helium leak isolation must not be performed on the affected engine. A helpful cue that an APC has failed is the ullage pressure indication directly below the Helium dp/dt readout on BFS GNC SYS SUMM. With an APC/ALC down, LH2 ullage pressure reads 12.0, and LO2 ullage pressure reads 0.0 for the affected engine.

Set Splits During Ascent

GPC set splits during ascent (2V1V1 or 2V2) can cause control problems, inhibit ET SEP, or cause MPS command and data path problems. Because of this, should a set split occur during ascent, BFS engage may be required to prevent a loss of control, to regain throttling, or ensure a safe ET SEP. Flight Rules permit reconfiguring the PASS GPCs after the set split if certain very specific conditions are met. However, because of time criticality during powered ascent, there may not be enough time to reconfigure the set to ensure vehicle safety. In these cases, a BFS engage should be performed.

Stuck Throttle in the Bucket

MCC uses the ARD to evaluate uphill capability for this case. Depending on throttle level and actual performance, it may be possible to continue into orbit. If not, the downmode preference is TAL, followed by RTLS. This is a real-time call that can be made only by the MCC. A restring may also be performed in some cases if it will recover the stuck throttle.

Second Hydraulic Failure and 1 SSME Failed

Loss of two APUs or hydraulic systems during ascent causes a loss of TVC on one SSME. If another engine fails, the non-gimbaling engine may have to be shut down also to prevent loss of control. Simulations have demonstrated a high probability of control problems with two engines running and one non-gimbaling.

Two APUs/Hydraulic Systems

Loss of two hydraulic systems will affect flight control for landing, since aerosurface rates are reduced. Abrupt maneuvers should be avoided to prevent control system saturation.

APU 1 and Multiple Prox Box Failures

Either hydraulic system 1 or one of the landing gear proximity boxes is required to deploy the landing gear. APU 1 provides power for hydraulic system 1, which performs hydraulic gear deploy. Pyrotechnic backup is provided by either prox box. One of these three systems is required for a successful gear deploy. If two of these systems are failed, attempts will be made to recover at least one of them by repowering failed buses, resetting RPCs/circuit breakers, using a hydraulic circulation pump or restarting APU 1. Failure of both prox boxes results in all landing gear talkbacks remaining barberpoled. Gear deployment verification may not be possible via physical cues.

NOTE

Bailout is preferred over a gear-up landing attempt.

Two Freon/Water Loops

Loss of cooling capability requires an emergency deorbit. Procedures are contained in the FDF CONTINGENCY DEORBIT PREP or the SYSTEMS AOA books for losses during ascent. It is extremely important to understand the related powerdown procedures for these cases and perform them expeditiously. Successful entry and landing depend on proper execution of the powerdowns.

Total Loss of FES

Complete loss of the FES during ascent requires an emergency payload bay door opening to obtain adequate cooling. Either the BFS or an SM GPC is used, depending on urgency and what other malfunctions are present.

If the FES has failed on orbit, the payload bay doors will be closed as late as safely possible prior to entry. The ammonia boiler will be activated as soon as possible for cooling during entry. Minimum acceleration of 0.05 g is required for ammonia boiler operation. Due to entry heating and lack of cooling with a FES failure, orbiter temperatures will rise to high levels between payload bay door closing and ammonia boiler activation.

Total Loss of FES with BFS Failure

In order to accomplish emergency payload bay door opening with BFS failed, it will be necessary to either IPL a new BFS machine using the BFS GPC IPL procedure in the Ascent Pocket Checklist or transition a PASS GPC to SM OPS 2 using nominal post insertion procedures. MCC and the crew will work together to pick the best course of action depending on the time available, progress through post insertion when failures occur, and other system failures.

Two Fuel Cells

On orbit, all three main buses may be tied upon completion of the LOSS OF 2 FC POWER-DOWN. During ascent or entry, the cue card or Pocket Checklist powerdown is performed, but one main bus will remain unpowered to prevent overloading the remaining fuel cell.

Both OMS

RCS is used to perform the remaining ascent and deorbit burns. If RCS is insufficient to accomplish a safe orbit insertion or deorbit, then RCS capability will be used to obtain the best performance possible. A staged deorbit burn using aerobraking to provide some of the deorbit deceleration may be possible.

OMS/RCS Leak with DPS/EPS Failures

Electrical failures affect the capability to operate the motor-driven OMS/RCS valves, and DPS failures affect software commands to the valves. EPS failures especially compromise leak isolation capability. If time permits, the OMS/RCS sliderule is used to determine which valves are operational for various failures. Some workarounds are available.

To work around a tank isolation valve that cannot be closed, the corresponding helium isolation valve should be closed. As pressure decreases in the affected propellant tank, flow will occur preferentially from another higher pressure tank.

During entry after q-bar = 20 psf, to attempt leak isolation, NO YAW JET may be temporarily selected and the entire RCS system secured. Even though some valves may remain open due to DPS/EPS failures, it still may be possible to isolate the leak if no jet fire commands are issued.

indication directly below the Felium dp/ readout on BFS GNC SYS SUMM. With APC/ALC down, LH2 ullage pressure real 12.0, and LO2 ullage pressure reads 0.0 for 8 affected engine.

NOTE

Although NO Y JET is certified at q-bar = 20 psf, it would be best if the RCS system is not secured until q-bar = 40 psf. Before q-bar = 40 psf, it is possible for a pitch jet to fire. With an RCS system only partially secured due to an EPS failure, evacuated tank legs are possible. This would complicate leak analysis due to a jet firing.

For some control bus failures, it is possible to actuate OMS/RCS valves using GPC commands. The master crossfeed, automatic crossfeed, or a software read/write procedure is used to command the valve.

MDM failures can cause the GPCs to lose RCS status information. This may result in good jets being declared failed or unavailable by the RM software. Using item entries on SPEC 23, it may be possible to override the software to the correct status and regain RCS jets or prevent firing a failed jet or jets on a failed manifold.

MPS Switches

The six ENGINE POWER switches and the six He ISOLATION switches are located in adjacent rows on panel R2. The switches are very similar, except for a yellow band sround the six power switches. Caution should be exercised during MPS beliam leak isolation or ESME shutdown procedures.

Fuel Cell Reactant Valves

Because of panel design, which represents a schematic of the PRSD and PC systems, the PLEL CELL REAC valve switches are arranged in a 1-3-2 order (1 on top, 3 in the middle 2 on the bottom) of panel R1. Closing the incorrect reactant waive results in the loss of a second fuel cell and possibly two main buses.

Cryo Leak with Failed Manifold Valve

A bus tie and fuel cell shutdown may be required to isolate the leak. The PCS systems may also be secured individually to assist in leak isolation. The manifold valve may be closed if the failed bus can be temporarily powered or an IFM performed. If the valve cannot be closed or the leak isolated, then two fuel cells will be lost when the cryo H2 or O2 is depleted. Emergency deorbit or ascent abort may be required, depending on leak rate.

BFS Self Engage

While this is not a multiple failure per sé, certain failure modes of the Backup Flight Controller and the BFS GPC can put the BFS one failure away from self engage. Should this occur, the crew must be aware that moving the BFS *OUTPUT* switch out of *BACKUP* could result in a self engage. This is a condition where the BFS will engage but the PASS does not shut down.

The PL BAY DOOR SYS ENABLE surfaces on used during PLED opening/desing. The PL DAT MICH PWR SYS switches are used for other mechanical systems in the PLS (such as radiation) PRLAS, 1345, etc). A careful provedure crosscheck will avoid problems.

HYD Press and APU Controller Power Switches

The HYD MAIN PUMP and APU CNTLR PAR excitations look similar and are in adjacent rows on pained 82. It is easy to confuse these two soutches during the APU shutdown procedure or when talang a hydrautic protein in LOW PRES.

OMS Kit

OATS KIT switches are on the left side of panel OS. It is easy to combine the OATS KIT switches with the LEFT OMS switches. The OMS KIT switches are inconstance.

6.10 SWITCH AND PANEL CAUTIONS

CONTENTS

MPS Switches	6.10-1
Fuel Cell Reactant Valves	6.10-1
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HYD Press and APU Controller	
Power Switches	6.10-1
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Because the design of some orbiter controls is very similar, when they are placed in close proximity, inadvertent actuation can occur. Training, along with close attention during high workload tasks, will minimize these problems. This section discusses several potential areas where crewmembers should exercise caution to avoid pitfalls. By being aware that these situations exist, crewmembers can execute time-critical procedures confidently.

MPS Switches

The six *ENGINE POWER* switches and the six *He ISOLATION* switches are located in adjacent rows on panel R2. The switches are very similar, except for a yellow band around the six power switches. Caution should be exercised during MPS helium leak isolation or SSME shutdown procedures.

Fuel Cell Reactant Valves

Because of panel design, which represents a schematic of the PRSD and FC systems, the *FUEL CELL REAC* valve switches are arranged in a 1-3-2 order (1 on top, 3 in the middle, 2 on the bottom) on panel R1. Closing the incorrect reactant valve results in the loss of a second fuel cell and possibly two main buses.

CRT Power Switch

The *CRT POWER* switches on panel C2 are adjacent to the *MAJOR FUNC* switch. This makes it relatively easy to power off a CRT when intending to switch major functions. If this occurs, simply power the CRT back ON, inform MCC of the incorrect switch throw, and continue.

GPC/MDM

During ascent and entry, the GPC and MDM switches on panel O6 are very difficult to reach. They are also hard for the CDR to see when wearing a launch/entry suit helmet. When executing DPS malfunction procedures, it is important to ensure the correct switch is actuated. One technique is to have the MS2 verify that the CDR has selected the correct switch prior to actuation.

PLB Mech Power/Enable

These switches are located adjacent to each other on panel R13L and perform entirely different functions. Because of their similar nomenclature and same appearance, they are easily confused. The *PL BAY DOOR SYS ENABLE* switches are used during PLBD opening/closing. The *PL BAY MECH PWR SYS* switches are used for other mechanical systems in the PLB (such as radiators, PRLAs, RMS, etc). A careful procedure crosscheck will avoid problems.

HYD Press and APU Controller Power Switches

The *HYD MAIN PUMP* and APU *CNTLR PWR* switches look similar and are in adjacent rows on panel R2. It is easy to confuse these two switches during the APU shutdown procedure or when taking a hydraulic system to LOW PRESS.

OMS Kit

OMS KIT switches are on the left side of panel O8. It is easy to confuse the *OMS KIT* switches with the *LEFT OMS* switches. The OMS KIT switches are inoperative.

6.11 SYSTEMS FAILURE SUMMARY

This section summarizes actual, in-flight failures that have occurred in the shuttle program. It includes major systems and selected repeat failures important to the crew. The purpose is to give crewmembers a feel for the type and severity of equipment failures and their potential impact on operations. Complete lists of anomalies and failures for both flight and ground operations are available from the Orbiter Project Office.



Systems Feiling Summery Chart

SYSTEM	FAILURE	CAUSE
APU/HYD	APU lube oil temp high	WSB ice
	Two APUs underspeed shutdown	Hydrazine leak and fire
	APU shifted to high speed	Failed control valve
	Hydraulic leak on entry	Leak in pump hose
	APU underspeed - FCS checkout	Valve contamination
COMM	Loss of KU antenna gimbal and stow control	Loose screw and circuit burnout
	TAGS jam	Paper jam
CRYO	O2 leak	PCS O2 restrictor installed backwards
DPS	GPC 2 quit	CPU timing
	RS split	Chip problem
	BFS failed pre-launch	Failed string tracking
	GPC 1 and 2 failed	Contamination
	GPC 5 failed	Engage term errors
	GPC 4 failed on orbit	Failed to sync; changed on orbit
	MDM OF3 failed pre-launch	Component contamination
	MDM port failure	Power supply fail
	MDM failure pre-launch	I/O errors
	MDM card problems	Card fail
ECLSS	FES shutdown	Ice, temp transducer, or thermal transient
EPS	Hum Sep signal conditioner B circuit breaker popped	Wire bundles short
	TAGS cable arcing	Cable short
	Fuel cell 1 failed	H2 pump fail due to blockage
	Fuel cells produced excessive hydrogen	H2 entrainment in new filter screen
	High drift rates	IMU failed
GNC	IMU cage	•
	IMU failed	Power supply failed (9)
	Sourious IMU accelerometer output	Accewlerometer component shift
	3 de/sec vehicle vaw rate during crew sleep	Bad state vector uplink
	Badar altimeter loss of lock/intermittent lock/fail	Transmission system malfunction
	TACAN no lock up or biases	Low receiver sensitivity
Mechanical	Air data problems	Thermal warning
Systems	PI BD would not close	 Inemia waiping Inadequate brake essekility
	Brake damage on landing	Inadequate brake capability
	Thermal blanket and PLBD seal dislodged	- Unknown wanting avenueted
MPS	Pad abort after SSME start	Onknown; venting suspected
WI O		Engine valve slow to open
	· Launch Scrub	Various component failure, including H2 leakage
The States	• 14 000 lbs of LOO drained from ET are lower	Operator orror
	Launch held due to strange LO2 temp	
	indications in engine	
		and the second
	Orbiter ET/SRB structural breakup	Bight SBB lower field joint humbrough
	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO	Right SRB lower field joint burnthrough Failed sensor
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight	Right SRB lower field joint burnthrough Failed sensor
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight Left OMS pod burnthrough	Right SRB lower field joint burnthrough Failed sensor Launch stresses APU detention and fire
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight Left OMS pod burnthrough Loss of verniers	Right SRB lower field joint burnthrough Failed sensor Launch stresses APU detonation and fire SEL and SEB loade
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight Left OMS pod burnthrough Loss of verniers RCS iet failed off	Right SRB lower field joint burnthrough Failed sensor Launch stresses APU detonation and fire F5L and F5R leak Over the folder of the
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight Left OMS pod burnthrough Loss of verniers RCS jet failed off RCS jet failed leak	Right SRB lower field joint burnthrough Failed sensor Launch stresses APU detonation and fire F5L and F5R leak OX valve failed/clogged Pc tube/ main poppet at individue insect
OMS/RCS	Orbiter ET/SRB structural breakup SSME failed (auto shutdown) ATO OMS cracks discovered post flight Left OMS pod burnthrough Loss of verniers RCS jet failed off RCS jet failed leak BCS Reg leak	Right SRB lower field joint burnthrough Failed sensor Launch stresses APU detonation and fire F5L and F5R leak OX valve failed/clogged Pc tube/ main poppet stuck/He ingestion Leaks

Systems Failure Summary Chart

7. TRAJECTORY MANAGEMENT AND FLIGHT CHARACTERISTICS

CONTENTS 7.1 ASCENT..... 7.1-1 7.2 ORBIT..... 7.2-1 7.3 ENTRY 7.3-1 TERMINAL AREA ENERGY 7.4 MANAGEMENT AND APPROACH, LANDING, AND ROLLOUT (OPS 305) 7.4-1

This section presents space shuttle flight characteristics and trajectory management during powered flight, on orbit, reentry into the atmosphere, approach, landing, and rollout. Some guidance and navigation information is included so the crewmember will be acquainted with the parameters that are important in influencing flight control. Much of the information was supplied by crewmembers who have flown the space shuttle. Additional information was derived from simulator runs in the Shuttle Mission Simulator, Shuttle Engineering Simulator, and Vertical Motion Simulator.

For each flight phase (ascent, orbit, entry), manual control techniques are presented, along with information on vehicle handling qualities, performance monitoring, and takeover criteria.

For detailed information on these subjects, consult the appropriate Flight Procedures Handbooks, Flight Data Files, or Flight Rules.

Each subsection discusses the primary controls and displays used during each flight phase. When used, external devices, such as runway lighting, ball-bar, and aimpoints, are integrated with the flight crew techniques in order to present a coordinated picture to the crewmember.

Where the backup flight system (BFS) differs from the primary avionics system software (PASS), (also called primary flight system (PFS)), BFS characteristics are discussed separately. This generally applies to ascent and entry flight phases, because the BFS has limited capability on orbit.

Each subsection concludes with rules of thumb.

the manual trajectory plot with altitude on the y-axis and relative vehicity (V₂₀) on the X-axis. Altitude acate is from 0 to 170,000 ft and velocity from 0 to 5,000 (ps. Tech marks on the profile show attitude director addicator (ADD) place attitudes at appropriate relevance points. Orbiter state (from NAV) is displayed by a moving triangle with a 20 sec predictor chicle an appreciate scile is marked with speeds, and the current knots expression without the speeds, and the current knots expression indicator (KEAS) is shown by a triangle. A staging (57G) tick mark denotes manual orbit for SKB SEP.

The BPS ASCENT TRAJ I deplay, slong with the about cut cands, is used to mention firststone trajectory.

Teen CRT displays are available in second atage and brith are used for respectory monitoring. The PES ASCENT TRAJ is a plot of altitude ve Vaco a Correct webside atom is indicated by a marking triangle with 30 and 60 are producted. NAV. BES ASCENT TRAFT is accommenced to implement at minimum to any in another (Millish 101. The provide expressions a normal second interesting with statistic variation detects (W) is the area. Addition scale competition 147000 is 125000 fb and venerity from 52000 to 25000 ps. Both PISs and BPS displays bave tick stars in the last returns to have base (W) of 150 bounding and the point (OO) scales no action is instructed for a single-graphic failure. The action that part of the profile. The represents a Toling part of the profile. The represents a Tolrepresented V, scale from 25, the is 26,000 fps with a context V, is indicated by a moving triangle determine by reading A vertices scale merided in used ing factors (Q) has at the MIECO vertexity.

7.1 ASCENT

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Backup Flight System	7.1-8
Sensory Cues	7.1-9
Ascent Rules of Thumb	7.1-11

Powered Flight

During powered flight, the crew monitors orbiter performance and system status using dedicated displays, CRT displays, and cue cards. This section describes the displays used, the monitoring task, takeover criteria, and manual control.

CRT Displays

Several types of CRT displays are used to monitor vehicle performance during powered flight. For a more detailed description of the displays presented here, refer to the Flight Procedures Handbook and DPS Dictionary.

GNC TRAJ Displays

In first stage, BFS ASCENT TRAJ 1 displays a nominal trajectory plot with altitude on the y-axis and relative velocity (V_{REL}) on the X-axis. Altitude scale is from 0 to 170,000 ft and velocity from 0 to 5,000 fps. Tick marks on the profile show attitude director indicator (ADI) pitch attitudes at appropriate reference points. Orbiter state (from NAV) is displayed by a moving triangle with a 20 sec predictor circle. An airspeed scale is marked with speeds, and the current knots equivalent airspeed (KEAS) is shown by a triangle. A staging (STG) tick mark denotes maximum q-bar for SRB SEP.

The BFS ASCENT TRAJ 1 display, along with the ascent cue cards, is used to monitor firststage trajectory.

Two CRT displays are available in second stage, and both are used for trajectory monitoring. The PFS ASCENT TRAJ is a plot of altitude vs V_{REL} . Current vehicle state is indicated by a moving triangle with 30 and 60 sec predictors.



BFS Ascent TRAJ 1 CRT



PFS Ascent TRAJ

Both altitude and velocity data are supplied by NAV. BFS ASCENT TRAJ 2 is automatically displayed at transition to major mode (MM) 103. The profile represents a nominal second stage ascent with altitude vs inertial velocity (V₁) as the axes. Altitude scale ranges from 140,000 to 525,000 ft and velocity from 5,000 to 26,000 fps. Both PFS and BFS displays have tick marks at the last return-to-launch-site (RTLS) boundary and the point (GO) where no action is required for a single-engine failure. The BFS TRAJ 2 has a short line roughly parallel to the last part of the profile. This represents a TAL TRAJ for an engine failure at the earliest TAL opportunity. Also on the BFS display is an expanded V, scale from 25,000 to 26,000 fps with a cutoff (CO) tick at the MECO velocity. Current V is indicated by a moving triangle driven by NAV. A vertical scale marked in total load factor (g) ranges from 2.0 to 3.5 g with current value indicated by a triangle.



BFS Ascent TRAJ 2 CRT

The orbiter symbol and predictors should track the appropriate profile through MECO. Other monitoring items are:

- ΔH-dot: used to ensure proper H-dot at MECO
- V₁: used to monitor proper MECO velocity
- g: used to monitor throttling.

NOTE

TRAJ DISPLAY titles change to include the abort mode when an ascent abort is executed.

GNC SYS SUMM Displays

GNC SYS SUMM displays are the principal means of monitoring flight-critical systems. They should be scanned frequently during ascent to verify system status and aid in determining causes for alarms. The BFS also supports a THERMAL display and two SM SYS SUMM displays. These are accessed by placing the BFS CRT *MAJ FUNC* switch to *SM*. These displays should also be scanned frequently to detect impending system problems and are also used to deal with orbiter systems problems during ascent. CRT displays are presented in Appendix B.

OVERRIDE Display

The OVERRIDE display (SPEC 51) allows the crew to deselect/reselect certain line replaceable units (LRUs) to solve a redundancy management (RM) dilemma or to force RM to

consider a previously deselected LRU. The OVERRIDE display also contains various software switches that may be used to override dedicated switch failures, controls for OMS and reaction control system (RCS) dumps, and several other additional functions.

Dedicated Displays

Dedicated displays are also used during ascent to monitor shuttle performance.

The attitude director indicator (ADI) displays attitude, rates, and error information and is used in combination with the CRT displays and cue cards. ADI attitude depends upon the position of the *ADI ATTITUDE* switch on panel F6 or F8. Switch positions are:

- *REF*: reference frame based on nominal launch azimuth at lift-off (can be redefined)
- *LVLH*: Earth-referenced pitch/roll (local vertical local horizontal)
 - *INRTL*: referenced to Mean of 1950 (M50) inertial frame (see Section 2.13 for reference frame definitions).

ADI rates are body rates driven by the rate gyro assemblies (RGAs). Scaling depends on the position of the *ADI RATE* switch. Switch positions are:

- *HIGH*: 10° per second
- MED: 5° per second
- LOW: 1° per second.

ADI errors are the difference between actual and commanded body attitude. Scaling is controlled by the *ADI ERROR* switch.

- *HIGH*: 10°
- MED: 5°
- LOW: 1°

The available scaling of ADI errors and rates is used to tailor vehicle displays for the sensitivity appropriate in each flight phase. If guidance is unconverged, the error needles will be stowed. An OFF flag is displayed for invalid or missing data.



Attitude Director Indicator

CAUTION

ADI malfunctions can occur without tripping the OFF flag. Crosscheck other displays during ascent to confirm performance is appropriate for the displayed attitude.

The horizontal situation indicator (HSI) is used to monitor AUTO guidance and provide information needed by the crew to fly manually. HSIs provide a geometric view of orbiter location with respect to various NAV points. During powered flight, the HSI displays data relative to the target insertion orbit.

North on the compass card is the desired insertion plane. Heading of the body +X axis with respect to desired insertion plane is read at the lubber line. The difference between current heading and north is vehicle yaw. A course pointer indicates heading of V_{REL} , while the course deviation indicator shows estimated sideslip (the angle between body X-axis and V_{REL}). The primary bearing pointer indicates

heading to the selected runway for TAL and RTLS aborts only. It is not driven in first stage. Heading of V_1 with respect to target insertion plane is indicated by the secondary bearing pointer.

The Alpha/Mach Indicator (AMI) is driven by NAV during powered flight. ALPHA displays angle of attack, and ACCEL displays acceleration (computed thrust/weight) in second stage. The ALPHA tape is not driven in first stage.

M/VEL displays magnitude of V_{REL} in first stage, then V_1 in second stage, while equivalent airspeed (EAS) shows equivalent airspeed throughout powered flight. EAS is an indirect indication of q-bar.

The Altitude/Vertical Velocity Indicator (AVVI) is driven by NAV during powered flight. ALT is displayed with respect to the selected runway. ALT RATE (H-dot) is the radial component of V_i .

Pushbutton indicators on the glare shield on panels F2 and F4 indicate status of *PITCH*, *ROLL/YAW*, and *SPD BK/THROT*. Lights within the pushbuttons correspond to control modes. The *BODY FLAP* pushbutton light also indicates the status of the main propulsion system (MPS) dump sequence post-MECO. The light comes on when the MPS dump is started and goes out when the dump is complete. All other pushbuttons extinguish at space shuttle main engine (SSME) zero thrust (MECO confirmed +3.75 sec). The *BFC* light illuminates when the BFS is engaged and flashes when the BFS is standalone.

Powered Flight Monitoring

Sequential SSME start is monitored on the chamber pressure (Pc) gauges on panel F7. After solid rocket booster (SRB) ignition (about 7 seconds after SSME start) the orbiter should perform a vertical rise for about 8 seconds, followed by a combination roll, pitch, and yaw maneuver onto the launch azimuth. Roll attitude on the ADI should be 180° upon completion. Switch ADI ATT from REF to LVLH after the roll is complete to obtain proper pitch/roll attitude information. REF is used for lift-offs to avoid large ADI movements at the LVLH 90° pitch singularity.

Throughout first stage, the crew monitors the parameters listed on the ASCENT ADI cue card (especially attitude) and also vehicle rates. Some deviation of the error needles during first stage can be expected due to load relief, but the error needles may not recenter precisely and veto differences in the load relief flight software and error needle display software logic. Guidance will turn the vehicle into unexpected winds to reduce aerodynamic loading during the load relief phase. The crew will be briefed on expected dynamic response prior to launch.

ASCENT ADI - NOMINAL



ASCENT ADI Cue Card

SSME throttle-down at 20 to 30 seconds and throttle-up at about 60 seconds is monitored on the Pc gauges. Throttle command (T) is displayed digitally on the BFS ASCENT TRAJ, which also displays the only trajectory information in first stage. Second stage follows SRB SEP. CRT displays should change to MM 103, and AMI/AVVI tapes display inertial velocity. Monitor closed loop guidance convergence by noting that the time of main engine cutoff (TMECO) on the PFS and BFS CRT displays is within a few seconds of the expected MECO time.

The BFS ASCENT TRAJ 2 and the dedicated displays are used to monitor trajectory during second stage. Continue to compare displayed data with the ASCENT ADI cue card. The PFS ASCENT TRAJ is primarily used during an RTLS.

The crew must be continuously aware of the orbiter's abort mode status. Boundaries are monitored by Mission Control Center (MCC) based on tracking data and projected vehicle performance capability as computed by the abort region determinator (ARD) program. Boundaries are transmitted to the crew by the capsule communicator (CAPCOM), but the crew should use the NO COMM MODE BOUNDARY cue card to maintain onboard status if communications with MCC are lost. Boundaries listed on the CONTINGENCY ABORT cue cards should also be monitored.

Contraction of the second second		
NEG RETURN (104)	8100	2 ENG ZZA (104) 5700
PRESS TO ATO (104)	9400	ABORT TAL ZZA (4)
SE OPS 3 ZZA (109)	11600	SE OPS 3 ZZA (109) (13)
SE ZZA (104)	13200	SE ZZA (104) (4)
PRESS TO MECO (104)	14000	2 ENG MRN (104) 5600
SE PRESS (104)	17900	ABORT TAL MRN (3)
NEG BEN (104)	18000	SE OPS MRN (109) (12)
NEG MRN (104)	20500	SE MRN (104) (3)
LAST PRE MECO TAL	23000	2 ENG BEN (104) 5600
IAST TAL	23900	ABORT TAL BEN (2)
FFA	24100	FOVI
ESN	24900	
ZZA	25000	SE OPS 3 BEN (109) (11)
ккі	25100	SE BEN (104) (2)
strant a share of the second strange	and me	867.cvs

NO COMM MODE BOUNDARY Cue Card

About 60 seconds prior to MECO, 3 g throttling commences and is monitored on the Pc gauges and CRT displays. MECO should be observed at guidance predicted TMECO and near the design MECO velocity on the AMI. All three red MAIN ENGINE STATUS lights on panel F7 will come on for a nominal MECO, and the ORBITAL DAP pushbutton lights on panel C3 will illuminate when MECO confirmed is set in the GPC software.

AUTO ET SEP should occur at MECO +18 seconds and is indicated by the red *MAIN ENGINE STATUS* lights going out. A SEP INH message indicates vehicle rate in any axis exceeds 0.7° per second or failure of a feedline disconnect valve to close. For rate exceedance, wait for rates to damp, and separation (SEP) will occur automatically. Feedline disconnect failure is handled using cue card and checklist procedures to perform a delayed ET sep..

After external tank separation (ET SEP), an automatic -Z translation occurs to obtain -4 ft/sec DV and move the orbiter away from the external tank. Upon completion, the crew should observe software transition to MM 104 by the appearance of the MNVR displays on the CRTs.

Takeover Criteria

During powered flight, the crew should be prepared to take whatever action is necessary in off-nominal situations in order to preserve safety and mission success. The Flight Rules define potential takeover criteria. These rules are built into the Flight Data File cue cards and checklists.

The most serious situations involve control problems. In many cases, these are time-critical and an FCS downmode (control stick steering (CSS) or BFS engage) must be rapidly performed. Downmode is an onboard decision that may be made for:

- Impending loss of control
- Failure of an expected maneuver to occur
- Unexplained attitude/rate excursions or undamped oscillatory motions.

If the roll maneuver is not initiated as scheduled, auto guidance is considered no-go, and a BFS engage should be performed.

Throughout first-stage flight, rate excursions are a parameter requiring crew action. Prior to 90 seconds, if pitch or yaw rates exceed 5° per second, the crew should engage BFS. After 90 seconds, the crew should select CSS, followed, if necessary, by BFS engage.

CAUTION

With manual throttle control selected, an automatic guided MECO will not occur. To obtain the correct MECO velocity, the main engines must be shut down manually. In low performance cases, a low-level shutdown may occur prior to the planned MECO velocity.

After staging, if TMECO has not converged within 10 seconds, MCC should be consulted. In a NO COMM situation, CSS and manual throttle should be selected.

To avoid violation of range safety limits, CSS takeover may be required. MCC will provide yaw steering commands to allow the crew to fly away from limit lines. Trajectory deviations of such magnitude to require takeover are extremely unlikely. Potential causes are:

- Faulty onboard NAV
- Erroneous guidance
- Launch day winds
- SRB dispersions.

Range safety agreements for first-stage deviations allow for limit exceedance as long as control is maintained.

As the orbiter approaches 3-g acceleration, throttling commands and SSME throttle-down should be observed. If this does not occur, manual throttling must be performed using the pilot's speed brake/thrust controller (SBTC) to ensure vehicle loads do not exceed design limit constraints.

Any time the AUTO guidance is unacceptable for vehicle attitude control, it should not be allowed to control the main engines. Manual throttle should be selected whenever CSS takeover is initiated. Automatic guided MECO is inhibited with manual throttles selected. If MCC predicted TMECO is 2 seconds different than onboard predicted TMECO, a manual SSME shutdown will be initiated on the groundcomputed value.

The MCC abort region determinator (ARD) program is the prime tool for determining abort capabilities. The onboard NO COMM MODE BOUNDARIES cue card lists inertial velocity values that define flight design mode boundaries computed prior to flight using predicted ascent performance and including ground rule flight performance reserves. The ARD is a real-time computational system designed to handle:

- One or more SSME failures at any time
- Performance dispersions visible in the vehicle state
- Performance dispersions not visible in the vehicle state
- SSME mixture ratio changes.

Multiple or single-engine abort capabilities are determined throughout ascent for any combination of these failures using ground radar tracking or telemetry of current vehicle state. A discussion of performance boundaries is presented in Section 6.

Should the translational hand controller (THC) be moved out of detent post-MECO and prior to the completion of the -Z ET SEP maneuver, the maneuver will be inhibited (terminated if in progress) with no moding to MM 104. If for any reason the -Z maneuver is not completed either automatically or manually, the crew can manually mode to MM 104 by keying in OPS 104 PRO.

Manual Control

Manual control during powered flight is selected by depressing either the *PITCH* or *ROLL/YAW CSS* pushbutton indicator on the eyebrow panel. Any pushbutton indicator gives CSS in all axes to both commander (CDR) and pilot (PLT) RHCs. If CSS is selected, manual throttles should also be selected. The PLT can select manual throttle by depressing the red button on the left SBTC and moving the lever to match current commanded throttle setting within 4 percent. As throttle level is matched, the *MAN SPD BK/THROT* light on the eyebrow panel will illuminate, indicating SSME throttling is completely controlled by the PLT's SBTC. Pushing either *SPD BK/THROT* pushbutton on the eyebrow panel will return control to auto throttle.

The control system in powered flight is rate control, attitude hold, with a maximum rate of about 12° per second in pitch and roll, and about 6° per second in yaw. If both RHCs are out of detent at the same time, the commands are summed.

To fly to a nominal MECO in CSS, the trajectory displays and the ASCENT ADI cue card are the prime tools. Displayed data are only as good as the NAV state, so the crew must confirm NAV state with MCC at takeover. Maintaining roll at 180° and commanding yaw to keep V_1 (HSI secondary bearing pointer) on the nose is the most efficient yaw profile. Use the ASCENT ADI cue card to confirm MECO velocity and H-dot.

The BFS ASCENT TRAJ display provides performance information. Keep the current state (triangle) and the two predictors on the TRAJ line and make small (less than 5°) attitude changes. Observe the results prior to making another correction. If BFS guidance is good, BFS digital information can be used to fly the ascent profile.

Since H-dot at MECO is extremely critical, concentrate on controlling H-dot rather than altitude within 90 seconds of MECO. Attempt to achieve the nominal H-dot shown on the ASCENT ADI cue card. This will result in a nominal H-dot at MECO, although errors of ± 100 fps are usually acceptable.

Whenever the CDR is flying CSS, the PLT should take manual throttle control. Maintain full throttle up to 3 g, then reduce SSME thrust to maintain 3 g. Coordinate with the CDR, since thrust changes affect attitude control. Lead target MECO by about 150 fps to allow for system lag time plus SSME tailoff. Perform manual shutdown by depressing all three shutdown pushbuttons on panel C3. This procedure should result in achieving desired V_1 at MECO.

Insertion OMS Burns

Monitoring and Targeting

To monitor insertion OMS burns (OMS 1 and/or OMS 2), the MNVR EXEC display and BFS GNC SYS SUMM 2 are used in addition to the ADI. These displays are available in both PASS and BFS in similar formats. The MNVR EXEC display provides digital data to target and monitor orbital maneuvering system (OMS) burns. MNVR EXEC is an interactive display requiring keyboard inputs from the crew, as well as monitoring prior to and during burns. Current HA and HP are used in conjunction with the OMS 1/2 TGTING cue card to determine which OMS targets should be used. Each mission has a flight-specific card, which the crew must understand thoroughly. The MNVR display is described in detail in Section 2.18.

After the crew loads the appropriate targets, the GPC software will compute a burn solution. The target set and burn solution can be checked by comparing data on the CRT display with the expected solution listed in the OMS targeting section of the ascent check list or OMS maneuver pads.

1041/ OMS OMS BOTH 1*	1 MNVR EXEC	1 000/00:40:23 000/00:15:37
L 2	BURN ATT	1
2	24 P 093	AUTOT 0
DCC CPI A	25 D 105	TCO 0.00
C TU DOLL 100	25 F 195	100 0:00
S IV ROLL 100	20 1 300	UCO V .
TRIM LOAD	MINVR 274	VGO X +
6 P [-]0.1		¥ +
7 LY[-]5.7	REI 4366	Z +
8 RY[-]5.7	TFF 24:40	
9 WT <u>217047</u>	GMBL	HA HP
10 TIG	L R	TGT 130 +129
1 : : .	P +0.4 +0.4	CUR 130 + 9
TGT PEG 4	Y +5.8 +5.8	
14 C1	monthly first a	
15 C2 [-]	PRI 28* 29*	35 ABORT TGT
16 HT	SEC 30 31	
17 00	OFF 32 33	FWD PCS
17 01	OFF 32 33	PHD ACS
18 PRPLT[-]	CHIDI - CHI - 24	ARM 30
TGT PEG 7	GMBL CK 34	DOMP 37
19 AVX [-]	And Andre March 1999	OFF 38*
20 AVY [+]		SURF DRIVE
21 AVZ [-]		ON 39
ET 140 [-]		000 10+

MNVR Display

For a quick check, scan ĐVTOT, TGO, apogee altitude (HA) and perigee altitude (HP), burn attitude, and time of ignition (TIG) to make sure they are reasonable. Before executing a burn, automatic maneuvers to the inertial burn attitude may be performed using ITEM 27. Prior to executing the burn, crosscheck the attitude with the ADI and compare PFS and BFS solutions.

NOTE

Burn attitudes on the MNVR display are inertial, and the *ADI MODE* switch must be in *INRTL* for a proper crosscheck of orbiter burn attitude.

The ADI is used for OMS burns in a similar fashion to its use during powered flight. BFS GNC SYS SUMM 2 is used to monitor the OMS system during insertion OMS burns.

Once the targets are loaded, and a solution is available, the crew follows ASCENT CHECKLIST/OMS Burn cue card procedures to prepare for and execute the burn. When in the correct burn attitude, error needles should be centered, and the ADI inertial attitude and commanded attitude on the MNVR display should match.

CAUTION

Maneuvering to burn attitude should be delayed if the DAP has failed to maintain the orbiter within 10° of the ET SEP attitude during the -Z translation. This will avoid recontact with the ET.

Provided perigee is high enough to remain in orbit for a few revolutions, cutoff conditions of an ascent OMS burn are relatively unconstrained compared to a deorbit burn. Achieving the planned orbit is a mission success issue. Reaching an orbit above minimum HP is a safety issue. For failures during insertion OMS burns, the crew will downmode from 2 OMS to 1 OMS to + X RCS to forward RCS as necessary to reach at least minimum HP. Downmode procedures are listed on the INSERTION OMS BURN cue cards.

Manual Control

Takeover criteria and manual flight characteristics during insertion OMS burns are similar to those encountered during deorbit burns. Refer to Section 7.3 for a more detailed discussion of OMS burn takeover criteria and flight characteristics.

Insertion OMS burns for ascent aborts are discussed in Section 6.2. Some special situations encountered during insertion OMS burns are discussed here.

Backup Flight System

The BFS is unique software contained in a single GPC that supports nominal ascent and most shuttle aborts. The BFS can be engaged at any time after lift-off. Once engaged, it is irreversible until the orbiter is in orbit or back on the ground.

BFS state vector degrades very rapidly during powered flight if the BFS is standalone, since it is propagated using the last known DV from the inertial measurement units (IMUs). Therefore, if the PASS were to fail, BFS engage must be performed within 10 seconds to ensure the vehicle will remain under control.

BFS engage criteria are listed in the Flight Rules and summarized on the DPS cue cards. They include:

- Loss of redundant set
- Loss of PASS capability to control the vehicle due to general purpose computer (GPC)/multiplexer/demultiplexer (MDM)/ LRU failures
- Loss of control due to divergent trajectory
- Roll maneuver not initiated as scheduled.

There are a number of functional differences between the PASS and the BFS:

- No manual control during powered flight.
- No manual throttling.
- BFS does not support contingency aborts.
- No single-engine roll control.
- BFS runs pre-engage in parallel with PASS although not in control of the orbiter.
- BFS has only one memory load. Unique ascent and entry requirements are merged into one common set of guidance requirements.

- When BFS is engaged, it takes command of all flight-critical buses.
- When BFS is engaged, two CRTs are driven unless additional CRTs are assigned with keyboard inputs.
- The BFS can drive all four CRTs simultaneously while the PASS is limited to three.
- BFS performs limited SM functions while PASS does not.
- The ADI and HSI are the only dedicated displays driven in powered flight. The AMI and AVVI are frozen and display OFF flags.
- Post ET SEP, only AUTO -Z translation is available. In the TRANS DAP, attitude maneuvers are manual only.
- OMS burn attitude must be controlled manually.

Sensory Cues

Prelaunch, SSME gimbal checks can be felt through the shuttle structure.

First stage is characterized by a rapid g buildup to slightly over 2 g, accompanied by a great deal of noise and vibration. Instruments and CRT displays can be monitored, but precise tasks are difficult.

SRB SEP results in a large amount of flame across the windows from the SRB separation motors. When the flame disappears, forward windows appear to be coated with residue, making them nearly opaque at certain Sun angles.

At SRB SEP, g-load undergoes a nearly instantaneous reduction from 2.3 g to 1.0 g, coupled with a significant reduction in both noise and vibration. Since the orbiter is above most of the atmosphere, many crewmembers have remarked that it seems to stop accelerating.



Vehicle Acceleration During Ascent

During second stage, g-load builds very gradually until 3 g's are reached and the SSMEs throttle to maintain 3 g.

A good fit of the pressure suit and harness is very important to avoid discomfort during ascent, particularly at high g loads. Centrifuge runs with actual flight equipment should be performed to ensure proper adjustment.

Some crewmembers report that the eye position in an actual orbiter differs from that encountered in the SMS. Checking seat position in an actual orbiter prior to flight is recommended for first time flight deck crewmembers.

MECO results in g-load decreasing rapidly to zero. Indication of MECO is limited to observing the red SSME status lights, Pc meter readings dropping to 0, and g-reduction. Some crews have reported an audible thump at ET SEP which could be caused by the explosive severing of the forward attach fitting. Other crews noted that ET SEP had occurred by extinguishment of the SSME status lights.

When the forward RCS jets fire to perform the -Z translation, their ignition is accompanied by a loud boom (just like "cannons" according to some crewmembers). Aft jets produce a noticeable structural vibration, but no sound. The OMS engines do not produce sounds, but the thrust can be noted by unrestrained objects translating aft in the cabin.

Night launches are a special case. The SRB and SSME plumes appear to reflect off the air molecules and produce a "pulsing" light that is most pronounced through the overhead windows, but can be seen through the front windows also.
Ascent Rules of Thumb

- At L/O, check Auto FCS
- Monitor roll program on the ADI and BFS ASCENT TRAJ display.
- Before L/O +90 seconds, BFS engage is the crew's only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.
- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS TRAJ displays. The shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.

- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.
- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the BFS MECO cutoff bug or planned MECO V₁ minus 150 fps.
- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

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Passive Thermal Control (PIC)

This is another inertial attitude rotation ecour the + or -X axis, but it maturations the sum in the Y-Z plane. The result is even warming of the orbiter, PTC is sometimes called the "barbers" thode. It is used to mere various payourd thermal constraints.

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A stable atching controlled by balancing differential gravitational and aerodynamic border. The KCS is not used. Combined torces are very small, and only a few stable attitudes core these are difficult to establish and very, arcording to elabade, auctimation, time or year, and many other variables. Goardry gradient is used to conserve propelland us to bubblet RCS fieldings during coltain payland tests and experiments.

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7.2 ORBIT

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Attitude Control

Orbiter attitude is primarily controlled automatically using either inertial attitude hold or track mode. The universal pointing (UNIV PTG) display, combined with the digital autopilot (DAP) display and control panel C3 are used for automatic attitude control. For manual attitude control, the RHC is also used.

Orbit flight control software includes the RCS DAP, OMS TVC DAP, an attitude processor to calculate vehicle attitude, and logic to govern which DAP is selected. Attitudes calculated by the attitude processor are displayed on the ADI and UNIV PTG. Vehicle attitude is used by the DAP to determine attitude and rate errors.

As part of mission planning, an attitude timeline (ATL) is generated. While the Flight Plan is being developed, the ATL is also developed using information about payloads, experiments, and other constraints. An ATL is produced for both the Basic and Final versions of the Flight Plan. When complete, the ATL is incorporated into the Flight Plan, although it is not usually flown. Missions with large numbers of timecritical maneuvers may carry the ATL onboard and use it to perform maneuvers.

Common Attitudes

While each shuttle mission is unique, some attitudes are used frequently and are briefly described in this section.

Top/Bottom Sun

These are inertial attitudes that point either the +Z or -Z body axis at the Sun. They are normally used for thermal control of payloads. Obviously, a rotation angle about the pointing axis must be defined to constrain the attitude. This is usually flight-specific and is driven by look angles, communications coverage, or other constraints.

Tail Sun

Another inertial attitude, but with the -X axis pointed toward the Sun. This is one of the coldest attitudes.

Nose Sun

Opposite to tail Sun. A semi-cold attitude used to cool the aft section of the orbiter or to warm the nose area, particularly the nose wheelwell.

Deorbit Prep Tail Sun

A special case of the tail Sun attitude designed to "cold soak" the radiators prior to entry. This is a track attitude using body vector of pitch = 184° , yaw = 0° , and OMICRON either 90° or 270° .

Tail Sun Rotation

The coldest attitude for the payload bay. This is an inertial attitude that keeps the -X axis pointed at the Sun while phasing rotation to keep the payload bay pointed away from the Earth. It is used for thermal bending tests or to meet specific payload requirements.

Passive Thermal Control (PTC)

This is another inertial attitude rotation about the + or -X axis, but it maintains the Sun in the Y-Z plane. The result is even warming of the orbiter. PTC is sometimes called the "barbecue" mode. It is used to meet various payload thermal constraints.

Gravity Gradient

A stable attitude controlled by balancing differential gravitational and aerodynamic forces. The RCS is not used. Combined forces are very small, and only a few stable attitudes exist. These are difficult to establish and vary according to altitude, inclination, time of year, and many other variables. Gravity gradient is used to conserve propellant or to inhibit RCS firings during certain payload tests and experiments.

Local Vertical Local Horizontal (LVLH)

This attitude maintains a constant orbiter orientation to the earth. Typically, the -Z axis is pointed at the center of the earth with the +Y axis aligned with the -H bar. For circular orbits,

the X axis will be along the velocity vector. The –ZLV (payload bay to the earth) attitude provides excellent extended earth viewing for the crew and PLB experiments.

Displays

Attitude data for the attitude processor are provided by the inertial measurement units (IMUs). Rate data are derived from the IMUs by dividing attitude delta by the time interval between attitude measurements.

ADIs provide an analog attitude display relative to three selectable reference frames. These are selectable via the *ADI ATTITUDE* switch. Inertial (*INRTL*) and reference (*REF*) positions represent inertial reference frames. Local vertical/local horizontal (*LVLH*) represents the orbiter in a fixed position relative to a rotating reference frame.

In addition to the forward ADIs, which always operate in the +X sense, the aft ADI may operate in either a -X or -Z sense. Selection is made using the *ADI SENSE* switch. This allows proper orientation, depending on whether the crewmember is viewing through the payload bay (-X) windows (W 9/10) or the overhead (-Z) windows (W 7/8).

The ADIs also display attitude errors that are calculated from the difference between current attitude and required attitude. The error needles are mechanized to indicate a "fly-to" sense. Rate needles are also fly-to. To correct attitude or rate errors, the RHC is deflected in the direction indicated by the needle.

Control

Attitude control on-orbit is provided by the RCS. The RCS is designed to control the orbiter independently in each of three axes. Minimum on/off cycle time for the jets is 80 milliseconds. Vernier jets (25 lb thrust) are normally used on orbit for attitude control since the primary jets (870 lb thrust) use more propellant for fine attitude control. Primary jets are used for translation and higher rate attitude maneuvers. ALT PRCS DAP uses the primary jets but limits the number, duration, and spacing of jet firings to achieve attitude control and RMS loading similar to vernier jets. OI-23 added notch filter capability. Simply stated, notch filtering allows the crew to select different frequencies to attenuate. This new capability was driven by the previous need for extensive preflight stability analysis in regard to the acceptable RMS/payload position envelope. Without notch filtering, the DAP may tend to excite rather than damp attitude oscillations caused by an unstable RMS/payload position.

For OMS burns, the OMS TVC DAP controls OMS engine gimballing, allowing OMS engine thrust vectors to be independently pointed several degrees in any direction relative to the orbiter c.g. This allows complete attitude control with the OMS engines alone during normal twoengine burns. For single-engine OMS burns, the RCS is used for roll control. The OMS TVC DAP also contains an RCS "wraparound" capability. If the attitude error exceeds 10° in pitch or yaw, or 5° in roll during an OMS burn, RCS jets are fired to correct the attitude.

DAP Configuration

The DAP uses current attitude to determine attitude and rate errors.

Rotation rates and deadbands are functions of DAP configuration. Values may be changed on orbit using SPEC 20 DAP CONFIG. For convenience, each planned DAP configuration is assigned a number. The crew uses these numbers, which are called out in flight data file procedures, to select the proper DAP mode for maneuvers. Typically, DAP A has lower rates and smaller deadbands than DAP B. Wide deadbands minimize propellant usage, while smaller deadbands allow more precision in executing maneuvers or holding attitude.

Attitude Control

Rotation and pointing maneuvers are required to achieve correct attitudes for deployments, onorbit burns, star tracker operations, thermal control, flyarounds during proximity operations, and pointing.

The RCS controls rotation independently in three axes. Jets are appropriately located and oriented to provide this control. Two independent sets of jets, primary (PRI) and vernier (VERN) are capable of attitude control. Most on-orbit rotation maneuvers are performed with the VERN jets.

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2011/ /	UNIV PIG	2 00	0/02:44:58
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13 ALT[]0.0	REQD 304.04	139.80	342.99
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14 BODY VECTOR 3	RATE - 0.266	5 - 0.367	+ 0.443
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16 Y 0.00			
17 OM 270 00			
17 OM 270.00			

UNIV PTG Display

The UNIV PTG display is used to control automatic attitude maneuvers input by the crew. By entering data on the UNIV PTG display, the crew can command automatic maneuvers to point a specific body axis at a specified target, maneuver to a predetermined attitude, rotate about a specified body axis, or maintain attitude hold. The UNIV PTG display also shows attitude information, errors, and completion time for current maneuvers. Types of automatic attitude maneuvers are presented in the following summaries.

To perform an automatic maneuver, the crew first enters the required data on the UNIV PTG display for the desired maneuver. To start the maneuver at a set time, that time is also entered on the UNIV PTG display. After checking the data, the crew enters an Item 18, 19, or 20, as appropriate, to start the maneuver. With AUTO DAP selected, an auto maneuver will begin at the set time or as soon as Item 18, 19, or 20 is entered if the maneuver start time is in the past. Item 21 is used to cancel a maneuver.

Maneuver

The maneuver (MNVR) option is used to maneuver the orbiter from current attitude to a new inertial attitude specified on UNIV PTG. AUTO maneuvers are three-axis at the rate specified on SPEC 20. Maximum acceptable error in any axis is the SPEC 20 attitude deadband (ATT DB). Total error, displayed on UNIV PTG, is the difference between required and current attitude. Allowable rate error in any axis is specified by the rate deadband (RATE DB) on SPEC 20. When the flight control software determines the orbiter is at the required attitude, attitude hold is initiated.

NOTE

Manually maneuvering away from a commanded attitude is possible. However, the DAP will return the orbiter to the commanded attitude when AUTO is reselected.

Track

The track (TRK) option is by far the most complex in universal pointing software. There are six subcases: orbital object tracking, center of Earth, Earth-relative target, center of Sun, celestial target (e.g., planet, Moon), and navigation star target. Each subcase is selected by a target ID (TGT ID) on UNIV PTG. The TGT ID is the line of sight or target vector from the orbiter c.g. to one of the defined targets.

The track option is used in conjunction with a body pointing vector, which is centered at the orbiter c.g. and is defined by a pitch and yaw combination. These angles are referenced to the orbiter +X axis.

Track software allows the crew to point a specified body vector at one of the defined targets. Attitude is not completely constrained until body orientation about the body pointing vector has been specified. Rotation about the body pointing vector is called OMICRON. By selecting a pitch, yaw, and OMICRON, a body pointing vector and the orbiter's orientation with respect to that vector are specified.

When a TRK option is initiated, TRK software performs a three-axis maneuver at the rate specified by the current DAP, then begins active track of the target. TRK subcases perform the following functions:

Orbital object tracking (TGT ID = 1)

State vectors of the orbiter and another orbiting target are used to determine a relative target vector. The target state vector is maintained by the REL NAV software. This mode is used postdeploy to track a payload. It is also used extensively during rendezvous operations.

NOTE

It is important to have REL NAV (RNDZ NAV) enabled (SPEC 33, ITEM 1) prior to tracking another orbiting body. It is also important to disable a TGT ID = 1 prior to OPS 8 or OPS 3 transition. Although UNIV PTG remains active in OPS 8, REL NAV does not. Excessive fuel usage could occur due to universal pointing chasing a stale state vector.

Center of Earth (TGT ID = 2)

Selected body vector is pointed at the Earth, with orientation specified by OMICRON, and maintained. This is, in effect, an LVLH attitude hold, requiring the orbiter to establish a small rotation rate that matches orbital rate. Center of Earth tracking is frequently used on orbit for normal operations that do not require specific attitudes.

Earth-relative target (TGT ID = 3)

Latitude, longitude, and altitude of an Earth target are entered on UNIV PTG. This determines target line of sight from the orbiter. TRK maintains this attitude. Latitude and longitude are entered in degrees. Altitude is entered in nautical miles. Typically, primary jets will be required to maintain this track as the orbiter flies over the target.

Center of Sun (TGT ID = 4)

Present values of right ascension (RA) and declination (DEC) are used to determine line of sight to the center of the Sun. TRK then maintains the proper attitude. RA and DEC on the UNIV PTG display are updated with each new recall of TGT ID=4 as the Sun RA and DEC change. This mode is used primarily for thermal control.

Celestial target (TGT ID = 5)

RA and DEC of a desired celestial object are entered. TRK will then point the defined body vector at this target and commence tracking it. An astronomical target can be tracked in this mode to point specific instruments. It may also be used during payload deployment to provide illumination or shading.

Navigation star target (TGT ID = 11-110)

TRK software contains the RA and DEC of 100 navigation stars that are defined by a number (11-110). Selecting a particular star and defining a body vector allows TRK to point the body vector at the star and track it. Obviously, this mode can be used for star sightings. It may also be used to point instruments.

Rotation

The rotation (ROT) option takes the body vector defined by pitch and yaw and initiates a rate (specified on DAP CONFIG, SPEC 20) about it.

NOTE

Transitioning to OPS 8 with an active rotation continues the rotation. Ensure correct DISC RATE is selected prior to transition, since neither UNIV PTG nor DAP CONFIG (SPEC 20) is available.

Cancel

Executing the cancel (CNCL) item on UNIV PTG snapshots and maintains current inertial attitude. All other current and future options (MNVR, TRK, ROT) are terminated. CNCL is selected automatically when entering OPS 2 from any OPS except OPS 8. Otherwise, the crew must select CNCL via an ITEM entry.

Manual Attitude Control

The RHC controls roll, pitch, and yaw movements on orbit with the OMS and RCS. Flight characteristics depend totally on DAP configuration. Various DAP configurations have been optimized for certain tasks, using off-line simulation. With the DAP mode in INRTL, and DISC RATE selected on panel C3 or A6U, deflecting the RHC out of detent fires appropriate RCS jets until an angular rate is achieved in that axis equal to the rate specified in the DAP CONFIG display (SPEC 20). Different rates may be specified for DAP A and B, and for PRI or VERN jets. When the rate is achieved, the jets are turned off until the RHC is returned to detent or deflected in another axis. lets also fire to maintain attitude or rates within selected DAP CONFIG deadbands. Returning the RHC to detent snapshots the attitude, and jets are fired to stop rates and hold the snapshot attitude.

Deflecting the RHC beyond the soft stop causes jets to fire continuously, producing a constant angular acceleration. When the RHC is repositioned inside the soft stop, jets are turned off, but rates continue until the RHC is returned to detent.

With *PULSE* selected, RHC deflection fires jets to achieve the angular rate change specified by rotational pulse (ROT PLS) on SPEC 20. *PULSE* is also a free drift mode.

For manual rotation maneuvers, modes generally used are:

- *INRTL DISC* for inertial attitude hold and small attitude maneuvers
- INRTL PULSE for large manual maneuvers

High Rate Attitude Maneuvers

To quickly maneuver to attitude in an emergency, a high maneuver rate may be required. Bump the RHC past the soft stop and back within the soft stop several times until the desired rate is achieved, being careful not to let the RHC return to detent. Stop the maneuver by returning the RHC to the detent. It will be necessary to lead the desired attitude by an amount proportional to the rotation rate.

Flying Techniques for COAS /HUD Calibrations and COAS IMU Alignments

To perform a COAS (or HUD) calibration or IMU alignment, the orbiter must be maneuvered manually to align the COAS reticle (or HUD test pattern) with a preselected star. The largest portion of the maneuver will be performed using a coarse control DAP with rates and deadbands selected to minimize maneuver time without exceeding propellant allotments.

Once the star is near the center of the COAS reticle, the crew must switch to a DAP optimized for fine attitude control. A vernier DAP will provide the finest attitude control with minimum fuel consumption.

Patience is very important when attempting to center the star in the COAS reticle. After making an RHC input, wait until movement is noticed, and the star is near the desired position before releasing the RHC. This will minimize jet firings and fuel consumption. The coarse control DAP will usually allow higher maneuver rates than the fine control DAP. The higher rates require more time to start and stop so pilots will notice a requirement to lead RHC inputs when using the coarse control DAP (i.e., return the RHC to the center detent slightly before the star reaches the desired position in the COAS reticle).

Translation

Orbit translation maneuvers can be conducted using the OMS engines or RCS jets. The OMS engines are usually used for larger maneuvers. Burn targets for preplanned orbit OMS or RCS burns are normally transmitted to the crew from Mission Control. The crew will then load those (or verify auto-loaded) targets and execute the burn at the appropriate time. OMS/RCS burn monitoring and control for orbit burns is similar to that discussed in Section 7.3.

RCS Translation

The RCS is used to control translation when small velocity changes are required. For example, the RCS might be used for the initial maneuvers used to separate from a payload after deploy. In these situations, the CDR/PLT uses the THC and DAP panel to transmit control commands to the GPCs and ultimately to the RCS jets.

Translation flight characteristics depend on DAP panel configuration and the DAP parameters listed on the DAP CONFIG display. DAP parameters are optimized for planned tasks preflight, using off-line simulation.

THC deflection with *PULSE* selected on the *ORBITAL DAP* panel fires jets to cause a velocity change as specified on SPEC 20. Selecting *NORM* allows continuous acceleration as long as the THC is deflected. *HIGH Z* is a submode available for +Z translations only. Selection of this submode fires all nine up-firing jets and should be used only in an emergency.

LOW Z is a submode that allows +Z translations by firing +X and -X jets simultaneously to minimize payload/Space Station pluming. LOW Z translations also affect pitch and roll, since upfiring jets are inhibited. There are significant translational cross-coupling effects in this mode.

Rendezvous/Proximity Operations

Rendezvous and proximity operations require coordinated attitude and translation maneuvers to join with or maintain position relative to another orbiting object. This section covers some of the tasks and problem areas encountered during rendezvous and proximity operations along with some suggested techniques. The normal rendezvous sequence is presented in the orbit mission events summary in Section 5. For a more detailed discussion of Rendezvous/Proximity Operations, refer to the Flight Procedures Handbook.

Plume Impingement

For translations near targets, there is a concern about contamination and also the resultant induced body rates and torques caused by an RCS jet plume striking the target. Certain types of payloads may be sensitive to propellant molecules. For example, a payload with delicate optical equipment could be damaged by an intense blast from an RCS jet at a short distance. Selecting which jets to fire, as well as distance and orientation of the orbiter with respect to the target, may be adjusted to reduce contamination.

Nearly all payloads are sensitive to the overpressure and resultant body rates/torques caused by an RCS jet firing at close range. Usually, a sphere of influence is identified, and no upfiring jet firings at the target are allowed within it; typically, 200 ft to grapple range from the target.

Braking Techniques

Braking is used to reduce relative velocity between the orbiter and a target. Three techniques will be discussed: normal Z, low Z, and orbital mechanics effects.

Normal Z axis technique uses upfiring jets to generate braking in a +Z direction. Since the jets pointing toward the target provide the braking force, plume impingement is a concern.

Low Z reduces plume impingement by using the cant of the +X jets and scarfing (design of the nozzle) of the -X jets to produce a resultant force in the +Z direction. Jet firing is controlled by the DAP to produce a near zero force in X axis direction. Low Z braking can use up to 12 times the amount of propellant as normal Z. This mode should only be used where plume impingement must be minimized. When in low Z, Y-axis jet firings induce higher closing rates, requiring expensive braking maneuvers.

CAUTION

Due to severe cross-coupling effects, minimize Y-axis translations when flying in low Z mode.

Orbital mechanics may provide small separation forces for various approaches. This may be used effectively for plume-sensitive targets and to help minimize propellant usage. The best illustration of this concept is the +R-bar approach, where "natural" braking (slowing of the orbiter) lessens the requirement for +Z thrusting.

Stationkeeping

Stationkeeping is the technique used to maintain the orbiter at a desired relative position, attitude, and attitude rate with respect to a target vehicle. When stable in a stationkeeping position, the crew has time to obtain navigation information and determine and set up approach maneuvers. Stationkeeping most commonly is performed on the target's velocity vector (V-bar) or the radius vector of the target to the center of the Earth (R-bar).

V-bar stationkeeping can be accomplished either ahead of (+V-bar) or behind (-V bar) the target. The only completely stable stationkeeping position is on the target's V-bar.



V-Bar Stationkeeping

This results in the most efficient type of stationkeeping because minimal propellant is required to maintain the orbiter at the same altitude and coplanar with the target. At about 1,000 ft on the V-bar, position can be maintained for about 100 pounds of propellant per orbit, using optimum techniques.

Similarly, R-bar stationkeeping can occur either below (+R-bar) or above (-R-bar) the target.



R-Bar Stationkeeping

This is an unstable configuration, since orbital mechanics effects will result in the orbiter and target changing their relative positions over an extended period. R-bar stationkeeping is more complex and requires higher propellant usage. About 0.5 lb/ft range per rev, above and beyond V-bar usage, is required.

ISS docking flights nominally involve +R-bar stationkeeping at various ranges to either set up approach timing or to correct shuttle/station attitude misalignment.

Stationkeeping position is maintained using the COAS, rendezvous radar, lasers, and CCTV triangulation. The crew must judge when attitude and translation corrections are necessary and make corrections manually. Typically, attitude is controlled by UNIV PTG so the crew has only translation corrections to maintain position.

For convenience, stationkeeping operations are classified by range (close in, short, medium, and long). There are significant differences between techniques used at different ranges.

RANGE	DISTANCE
Close in	35 - 200 ft
Short	200 - 1000 ft
Medium	8 miles
Long	40 miles

Stationkeeping Ranges

Close In

Close in techniques are required after the orbiter has achieved a stable position near the target. Alignment with the desired target axis may or may not have been completed. Orbital mechanics effects are minimal, and flying is done using a combination of out-the-window and CCTV cues. Most payloads will be below the RCS plume impingement area, so NORM Z operations can be performed. Very large payloads may require use of LOW Z. Also, if the payload drifts too far forward or aft, LOW Z may be required to avoid plume impingement. Close in stationkeeping requires constant attention by the crew. A flyaround or matching the target's rates may be required to effect a capture.

Short Range

Short range techniques are used after the orbiter is positioned on the desired target axis or

immediately after target deploy. Orbital mechanics effects cannot be ignored, and plume impingement must be considered. The primary tasks are matching attitude rates and translating to maintain correct relative position on the desired target axis. These require visual translation guidance techniques that can be described by three types of targets: inertially stabilized, fixed in LVLH frame, and arbitrary rate. Inertially stabilized targets usually have some type of control system or are spin-stabilized. To keep the same relative geometry, the orbiter must also maintain inertial hold. This requires a constant translation to stay on the desired axis and maintain desired range. Procedurally, UNIV PTG and the DAP are used to automatically maintain inertial hold, while the crew uses the THC to remain on the target axis at the desired range.





872.cvs

873.cvs

Stationkeeping WRT inertially stabilized target





LVLH frame)

LVLH Stationkeeping

Some targets may be maintaining a constant attitude relative to the LVLH reference frame and therefore rotating in the inertial frame at orbit rate. The target may have an active or passive (gravity gradient) control system.

The orbiter maintains a fixed position and attitude with respect to the target LVLH reference frame. Procedurally, UNIV PTG or LVLH is used to automatically control attitude, and translation is controlled manually. Since LVLH stationkeeping is much more stable than inertial, fewer translation inputs are required to maintain position.

Should the target lose its control system, causing it to rotate at an arbitrary rate about a principal axis of inertia, stationkeeping becomes more difficult. Either an inertial or LVLH mode may be used, depending on the situation.

Medium Range

Medium range stationkeeping may be required long-term payload checkout or during Operations are usually autoactivation. matically controlled using NAV state data. The position should provide relative radar information. One AUTO technique, called a "football," attempts to keep the orbiter within some predefined boundary centered at some range on the V-bar. When the orbiter approaches a boundary, a maneuver is performed to drive it back to the center. This is repeated as required. Orbital mechanics effects can be used to maintain the "football" with minimal maneuvering required.

Long Range

Long range stationkeeping is typically done at 40 n. mi. This is usually done to support a possible rendezvous at some later time in the mission (similar to HST deploy). This stationkeeping is usually maintained by ground targeted coelliptic (NSR burns) and is done on the V-bar.

Techniques

Whenever possible, use the DAP and UNIV PTG to automatically maintain attitude. Select vernier jets for attitude control to conserve fuel. Aim for an "ideal" target position in the -Z COAS reticle. At 1,000 ft, the target should be 2.5° low. This places the orbiter c.g. on the V-bar, since the c.g. is aft of the COAS position. At 500 ft, the target should be at the bottom of the COAS, and at 200 ft, it should be 13° below the center of the COAS.



COAS Sight Picture

Translate using the THC to maintain this position. Small inputs and patience are essential. Use the smallest translational pulse size available. Use vernier jets for attitude control. Maintain the payload in an imaginary box, sized to reflect attitude deadbands, about the "ideal" position and translate only when the target moves out of the box.

This will reduce fuel consumption and take maximum advantage of orbital mechanics effects.

Use radar and REL NAV (SPEC 33) to maintain distance and range rate.

NOTE

The tendency is to focus on keeping target position fixed in the COAS. A good scan and crew coordination are necessary to control range rate and maintain distance.

Transition

Transitions are maneuvers that maintain the orbiter at a constant distance from the target while it moves from one position to another. The orbiter will continue pointing a specified body vector (usually -Z) at the target. In contrast to a flyaround, which requires the orbiter to actually fly around the target in an inertial sense, a transition involves moving the orbiter around the target in a target-centered, rotating LVLH reference frame without regard to the target's inertial attitude. Transitions can be completed by placing the orbiter in inertial attitude hold with the -Z axis pointed toward the target (inertial stationkeeping), or by pitching the orbiter (tail up or tail down).

Flying a transition from the V-bar to the R-bar in 90° of orbit using a pitch maneuver is equivalent to a 90° in-plane flyaround about an inertial hold target. Which transition is selected depends on propellant concerns (inertial) or time concerns (rotational pitch).

Separation

Translating away from another object requires establishing an opening rate between the bodies. Usually, relative state vectors are well known, and a planned sequence can be followed to minimize propellant usage. However, payload sensitivity to plume impingement and unknown payload control system characteristics tend to complicate separation maneuvers. Long and short term recontact must be considered; therefore, some separation sequences require multiple separation maneuvers. Separation is usually performed in two stages. A small separation burn (< 1 fps) is performed to start opening, then a larger burn is performed when the orbiter is further away. The second burn typically occurs 22 minutes after the first burn.

Cross-Coupling Effects

Because the thrust of the RCS jets is not through the orbiter c.g., commanded translation/rotation maneuvers in one axis tend to induce motion in other axes. This effect is called "cross-coupling," and it can have a significant impact during rendezvous terminal phase and proximity operations.

With the orbiter on the target V-bar, tail-to-Earth, and payload bay toward target, the crew should be aware of cross-coupling effects as follows:

- NORM ROLL: affects every degree of freedom. Much worse in LOW Z than NORM Z.
- LOW Z and NORM ±X: induces significant braking (+Z) translations, requiring closing rate to be reestablished and pitch cross-coupling. May look like translation in the COAS. When flying Prox Ops, use the 1 to 5 Rule: 1 +Z input for every 5 ±X inputs
- NORM -Z: significant +X translation. Same effect in LOW Z.
- LOW Z +Z: major negative pitch if in free drift. In attitude hold, translation pulse loses half its force due to counteraction of attitude firings.
- LOW Z ± Y: in attitude hold, major closing (-Z) rates induced, more than half the size of commanded Y-axis translation.
- ROLL/PITCH deadbanding: in NORM jets, induces a small opening (+Z) rate. In LOW Z, causes a major closing (-Z rate). Minus pitch also produces a significant +X translation when in LOW Z.
- TAIL ONLY: an off-nominal control mode used to conserve forward RCS propellant. Pitch maneuvers induce a powerful Z translation and a significant +X translation. Yaw induces a powerful Y translation and noticeable X and Z translations. All other control mode effects are identical to normal control (NOSE and TAIL).
- NOSE ONLY: for pitch, translational effects are mirror image of TAIL ONLY, except no X effects. Yaw is also opposite to TAIL ONLY, but significantly reduced.



These effects point out the requirements for patience after performing translation pulses. Crewmembers should observe the line of sight motion after deadbanding (keep ADI rate needles and UNIV PTG in scan) and not be misled by initial line of sight rates. Rotationinduced components must be understood. Techniques are developed through practice in simulation facilities.

Vernier jets, when used for attitude control, induce their own cross-coupling effects. Even though verniers produce much smaller forces than primary jets, their geometry is even more awkward. All vernier firings induce translational cross-coupling of roughly equivalent size in the -Z direction. The firings do not randomly cancel out; rather, they accumulate in one body direction. This can induce significant downtrack errors in orbiter position that are important during rendezvous over long periods.

Crew monitoring or performance is required information necessary to monitor and control the vehicle during the deorth Lum and entry planes of guidance. This task consists of monitoring vehicle displays to determine if guidance, navigation and flight control are performing cornerity and taking active if required to ensure a sale handing. An in depth knowledge of how these systems work, along with an understanding of the reference respectory and orbiter flight control system (FCS) will enable crewissentiers to navignize alfnominal statistics, and correct them before sectors performance or control problems develop

Takeyver

Takenver rules and criteria are described in the Flight Rules Interpretation of onboard intermation will ald the crew in their usersament of when to manuely biservers. From the available information, the cruw assesses the performance of the automatic guidance system and remains prepared to take over with number guidance for off-monianal situations. Some of the conditions requiring crew takeners are Pitch/yaw deadbanding in LOW Z, or vernier attitude control during PROX OPS can quickly introduce a -Z translation (closing rate). Expending about 35 - 40 lb of RCS propellant to maintain attitude using vernier jets results in a cross-coupling translation of 1 fps in the -Z direction. AVG G on REL NAV (SPEC 33) is not a reliable source for this information, since IMU noise accumulation and much of the crosscoupled acceleration are below the threshold measurement of AVG G. Time required for buildup depends on how stable the orbiter is when attitude hold is initiated. The -Z buildup is significant during close-in stationkeeping and especially during gentle separations. The crew must closely monitor R-dot using all ranging devices (CCTV, radar, laser, COAS) to avoid undesirable closing rates.

portions of the flight provide are normally flown in AUTO. Manual flight common is the normal mode of operation from 56 black until the completion of cellour. (This portion of the flight profile is discussed in detail in Section 7.4.) Selfgenerated gathlance based on taxing the information will be discussed, but if gathlance is good, flying the error needles in CSS will result in the most consistent tracking of the planned entry insigniory.

Deprint Burn

Monitoring

Normally, the denield farm will be flown to AUTO using both OMS engines. The OMS engines are gratualled to control orbiter antisade in all three area. Capability exacts to concreate mean basis OMS engines to one OMS engine, to the all 4K RCS leta, or traine knoward X will be project for one OMS engine failure of TiG or at any time during the burn. A single OMS engine can control plica and yew, but noll usual be controlled for the RCS. It flight control does not recognize the OMS engine failure control does not recognize the OMS engine failure, control does not recognize the OMS engine failure, control does not economicated by the RCS. It flight control does not recognize the OMS engine failure, control does not adopty but merchanie. One of the control burns using the RCS center must be forem merculaby.

Orbit Rules of Thumb

- In propellant-limited situations, use the following guidelines:
- Stay in VERN as much as possible.
 - To conserve forward RCS, use TAIL ONLY control mode.
 - During prox ops, when controlling outof-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects.

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7.3 ENTRY

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Overview of Entry Flying Tasks

The entry phase of flight covers the transition from Earth orbit to the end of landing rollout. Guidance phases for portions of the entry phase are deorbit burn guidance, entry guidance, TAEM guidance, and approach/land guidance.

Monitoring

Crew monitoring of performance is required throughout entry. This subsection presents the information necessary to monitor and control the vehicle during the deorbit burn and entry phases of guidance. This task consists of monitoring vehicle displays to determine if guidance, navigation, and flight control are performing correctly and taking action, if required, to ensure a safe landing. An in-depth knowledge of how these systems work, along with an understanding of the reference trajectory and orbiter flight control system (FCS) will enable crewmembers to recognize offnominal situations and correct them before serious performance or control problems develop.

Takeover

Takeover rules and criteria are described in the Flight Rules. Interpretation of onboard information will aid the crew in their assessment of when to manually intervene. From the available information, the crew assesses the performance of the automatic guidance system and remains prepared to take over with manual guidance for off-nominal situations. Some of the conditions requiring crew takeover are:

- Navigation errors
- L/D dispersions
- Atmosphere variations
- Winds
- Deorbit execution errors
- GNC failures
- Degraded performance.

Any of these conditions, if left uncorrected, could lead to unrecoverable range problems or loss of vehicle control.

Guidance and flight control perform well. It is highly unlikely manual takeover will be required. MCC is also available to help with a ground controlled approach (GCA).

Manual Control

In some instances, the crew will be required to take manual control and fly the orbiter. The Deorbit Burn and Entry sections contain the basic principles for CSS flying, although these portions of the flight profile are normally flown in AUTO. Manual flight control is the normal mode of operation from .96 Mach until the completion of rollout. (This portion of the flight profile is discussed in detail in Section 7.4.) Selfgenerated guidance based on navigation information will be discussed, but if guidance is good, flying the error needles in CSS will result in the most consistent tracking of the planned entry trajectory.

Deorbit Burn

Monitoring

Normally, the deorbit burn will be flown in AUTO using both OMS engines. The OMS engines are gimballed to control orbiter attitude in all three axes. Capability exists to downmode from both OMS engines to one OMS engine, to the aft +X RCS jets, or to the forward -X RCS jets. The burn time of ignition (TIG) is selected to protect for one OMS engine failure at TIG or at any time during the burn. A single OMS engine can control pitch and yaw, but roll must be controlled by the RCS. If flight control does not recognize the OMS engine failure, control will be sloppy but acceptable. Deorbit burns using the RCS only must be flown manually.

The DEORBIT BURN, DEORBIT BURN MONITOR, and the DEORBIT BURN FLIGHT RULES cue cards are used to determine the required actions for malfunctions affecting the burn. The philosophy embodied in these cards is to either safely complete the burn or stop the burn above a safe altitude.

The ADI error needles are used to monitor guidance and control during deorbit burns. The body axis burn velocity components (VGO_x, VGO_y, and VGO_z), along with TGO and Δ VTOT, should also be cross checked.

3021/ DEOR OMS BOTH 1* L 2 R 3 RCS SEL 4 S TV ROLL 180 TRIM LOAD 6 P L+10_4 7 LVL-15.7 9 WT 217047 10 T16 <u>006/09:56:00.0</u> TGT PEG 4	B MNVR EXEC BURN ATT 24 R 083 25 P 195 26 Y 300 MNVR 27* REI 4366 GMBL P 40.4 + 5.8 P 40.4 + 5.8	1 006/09:40:23 000/00:15:37 XTOT 321.9 TGO 2:58 VGO X +303.40 Y + 14.42 Z +106.60 HA HP TGT 130 + 9 CUR 130 +129
14 C1 15339 15 C2 (-10.6124 16 HT 65.831 17 0T 113.720 18 PRPLT(-)_6824 TGT PEG 7 19 AVX[-]_208.7 20 AVY (+]_225.6 21 AVZ (-]_95.6 LOAD 22/ TIMER 23	PRI 28* 29* SEC 30 31 OFF 32 33 GMBL CK 34	35 ABORT TGT FWD RCS ARM 36 DUMP 37 OFF 38* SURF DRIVE ON 39 OFF 40*

10016.CNV

DEORB MNVR Display

Monitoring the VGOs in addition to the error needles provides insight into the status of guidance during the burn. Noting the VGOs prior to TIG will tell the crew whether guidance thinks the vehicle is in attitude for the burn and whether the OMS burn will ignite at all. Attitude must be within $\pm 90^{\circ}$ of required burn attitude for OMS ignition. If VGO_x is positive, the OMS will probably light and steer the vehicle to the burn attitude.

To monitor burn progress, the crew can watch VGOs, HA, and HP during the burn. The VGOs display how much ΔV is left to go in orbiter body axis coordinates. For any OMS or ±RCS burn, most of the burn should be in the appropriate X direction. HP will gradually increase or decrease, depending on whether the OMS burn is posigrade or retrograde. For deorbit burns, HP should always decrease.

WARNING

The RHC is "hot" during an OMS burn. The DAP will mode to manual if the RHC is bumped

An SM alert and "DAP DNMODE RHC" message will annunciate with OI-28 and subs software.

NOTE

Propellant-wasting, out-of-plane deorbit burns will have a PEG 7 delta V_{γ} (LVLH) component. If no propellant is wasted then the PEG 7 delta V_{γ} is typically zero.

OMS burn thrust vector control (TVC) is calculated independently from the ADI error needles.

- OMS TVC gimbals the OMS engines to null vehicle rates and point sensed thrust in the desired ΔVTOT direction.
- ADI error needles display vehicle attitude error from the attitude that would point the net thrust through the c.g., as defined by the trim angles, and in the desired Δ VTOT direction. If trim angles are incorrect or flight control does not recognize an engine failure, the ADI error needles will not display correct error information.

For a +X RCS burn, the ADI error needles are correct, as long as flight control recognizes that it is an RCS burn. Error needles are never correct for a -X RCS burn.

Approaching cutoff, the crew should monitor current HP approaching targeted HP, TGO approaching zero, and Δ VTOT approaching zero. If TGO goes to zero, and the OMS engines do not cut off (chamber pressure zero and engine valves closed), the OMS engine switches should be turned *OFF* to prevent an overburn.

7. TRAJECTORY MANAGEMENT AND FLIGHT CHARACTERISTICS 7.3 Entry

NOTE

OMS guidance will cut off, based on VGOX. If out of attitude, there will be large residuals in VGOY or VGOZ after the burn is complete. VGOZ residuals should be trimmed by the CDR using the THC, per the Deorbit Burn cue card procedure.

If an early cutoff occurs, the appropriate procedure from the Deorbit Burn cue card should be executed to achieve deorbit targets. OMS propellant, aft RCS, forward RCS, and prebank may be used to recover the underburn. If the underburn magnitude exceeds RCS and prebank capability, landing site redesignation may be required. For more detailed information on OMS burn downmoding, consult the appropriate Flight Procedures Handbook.

Takeover

Deorbit burns are normally flown in AUTO flight control and are started and stopped by GPC commands. Duration of the burn, as well as maintaining proper attitude during the burn, are the two most important criteria.

Deorbit burns that cut off at a perigee greater than Safe HP will generally be retargeted for another burn one orbit later or up to 24 hours later, since Safe HP orbital lifetime allows the delay. Deorbit burns that cut off at perigee less than Safe HP must be completed to attain acceptable Entry Interface (EI) conditions.

EI targets will be met within allowable tolerances if post burn residual DV is within 2 fps. Specifically, a 2 fps underburn equates to a 30 nautical mile (n. mi.) energy error at EI, which is well within guidance capability.

A 3° attitude deadband is used in the TRANS DAP. Attitude error or deviation greater than 3° prior to the burn indicates a flight control malfunction. The crew should check ITEM 27 on the MNVR display or downmode to MAN DAP and maneuver back to ignition attitude. The deorbit burn attitude is entered in a controlled, timely manner, and the burn can be postponed for an unacceptable attitude error. Deadband in the TVC DAP is very small. If ignition has occurred, a manual takeover should be performed for unexplained deviations greater than 5° .

NOTE

Engine out transients may cause a momentary attitude deviation greater than 10°. These transients are an excellent confirmation of an engine out. Manual takeover should not be required.

Manual Control

Fly the error needles or the ADI REF ball if available. Cross-check the VGO components. During OMS TVC DAP attitude maneuvers, keep rates reasonable (less than 2 deg/sec). Approximate VGO component fractions of DVTOT depend on the type of burn. If only one OMS engine is used, yaw the vehicle about 10° into the good engine. Normally, manual flight control during an OMS burn requires very few RHC inputs once the guidance needles are centered, and the TVC DAP begins attitude hold.

For an RCS-only burn, the attitude deadband is 3°, and the burn is flown manually using the RHC for attitude control and the THC for the burn with four +X aft RCS jets.

One technique for +X RCS burns is to fly the correct attitude as displayed on the MNVR EXEC display, check the VGOs, set a REF ball, pitch up 3° on the ADI, let go of the RHC, and start the burn with the THC. The vehicle will pitch down to the correct attitude, since aft RCS jets are above the c.g., and the 3° deadband will hold it there. Another technique is to start the burn in attitude with the THC, allow the vehicle to pitch down toward the 3° deadband limit, then pitch up 6° to the other side of the deadband. The vehicle will slowly pitch back down and hold the desired attitude. This technique is called the Patterson maneuver.

It is also acceptable to just keep the needles centered using small RHC inputs. This technique requires constant inputs in pitch and will use more propellant to hold attitude, but is easier to remember than the Patterson maneuver. For short RCS burns, the extra propellant usage is minimal The VGO ratio table below lists appropriate ratios of VGO_{xyz} to VTOT for different burn maneuvers.

	BOTH OMS	L (R) OMS	+X RCS	-X RCS
VGO.	1	1	1	-1
VGO	0	1/5 (-1/5)	0	0
VGO,	1/4	3/4	1/6	1/3

VGO Ratios

NOTE

A BFS OMS burn is targeted in the same manner as PASS, but must be flown manually.

Entry

Monitoring

During the entry phase, guidance provides steering commands for trajectory control from initial penetration of the atmosphere (about 400,000 ft) at a range of about 4100 n. mi. from the landing site, until TAEM (2500 fps, about 60 n. mi. from landing site at an altitude of about 80,000 ft). The primary objectives of entry guidance are:

- Guide the orbiter along a path that prevents exceeding structural, thermal, and stability design limits.
- Deliver the orbiter to a satisfactory energy state and vehicle attitude at initiation of TAEM guidance.

Entry guidance is based on drag control. The correct drag level is calculated, based on Mach (velocity) and range. Bank is then used to control lift until the desired drag is established. Entry trajectory constraints are shown in the following chart.



Entry navigation (NAV) computes the orbiter's position, velocity, and distance/direction to the landing site. NAV also computes Mach, q-bar, There are numerous interfaces and alpha. between NAV and flight control. The crew optimizes NAV performance by accepting or inhibiting four types of sensed data: drag-H, TACAN, air data, and MLS. Bad NAV information can cause flight control problems, since NAV information is used to tailor flight control for the varving flight regimes encountered. Mission Control monitors navigation performance during entry using tracking TACAN and air data should not be data. accepted to NAV, or air data accepted to G&C without a go from Mission Control, unless communication capability is lost.

WARNING

Large NAV errors can cause loss of vehicle control, because NAV data are used to select control effectors and set control gains.

Dedicated instruments, CRT displays, and cue cards are available to assist the crew in monitoring entry performance. The ADL alpha/Mach indicator (AMI), and the altitude/vertical velocity indicator (AVVI) are the primary dedicated instruments for monitoring entry performance. Five ENTRY TRAJ CRT displays are available for monitoring entry guidance. ENTRY cue cards are used as references to compare actual and predicted performance.

After the deorbit burn, the crew transitions to MM 303 and maneuvers to the EI-5 attitude that was uplinked with the deorbit targets and voiced up in the DEL PAD.

During the early part of entry, the RCS command lights are a good indication of DAP activity. If the crew transitions to MM 304 at EI-5, the vehicle will be very close to attitude, and only occasional jet firings will occur as attitude drifts back and forth between DAP deadbands. If the crew is late transitioning to MM 304, or if an attitude error has been allowed to develop while working system problems, a large number of jet firings can occur. Up to 250 lb of RCS propellant can be wasted. Crews should closely check that the orbiter is in the proper attitude prior to MM 304.

From q-bar = 0 to q-bar = 0.5, the RCS only is used for attitude control. From q-bar = 0.5 (12 KEAS) to q-bar = 8.0 (48 KEAS), the elevons will trim in response to pitch jet firings. At q-bar = 2.0 (24 KEAS), the elevons are used for control. At q-bar = 40 (109 KEAS), the pitch jets are turned off.

At q-bar = 10 (54 KEAS), the roll jets are deactivated. Yaw jets continue to fire for bank control until Mach is less than 1.0. Yaw jets should fire from both pods at a similar rate (symmetric firings).

At q-bar = 50 (122 KEAS), the RCS *PITCH* and *ROLL* activity lights are reconfigured. Illumination of the *PITCH* light indicates elevon or aileron rate saturation. Three or more yaw jet commands turn on the *ROLL* light. The yaw jets are terminated at Mach 1. The *PITCH* jet light will continue to indicate elevon and aileron rate saturation.

Orbiter performance during bank maneuvers is the pilot's cue to dynamic stability characteristics. The two most important factors the crew must monitor are YAW jet activity lights and roll rate. The first roll command is at 3 deg/sec; subsequent roll reversals are commanded at 5 deg/sec. The rate of roll maneuvers is important to minimize H-dot and drag excursions. Prompt execution of roll commands will minimize the bank angle required to establish the desired drag profile.

Using the ADI, AMI, and AVVI, in conjunction with the ENTRY ALPHA cue card, allows the crew to monitor vehicle performance relative to pre-mission planned trajectory. Comparing alpha, range, altitude, H-dot, and roll reference to actual values is a good crosscheck on guidance. The data on this card is flight (and planned entry) specific, but most of the data is useful on any entry. The only data that changes significantly is the direction of Rref (reference roll angle). The magnitude of Rref does not change much.

ENTRY ALPHA Cue Card

Five CRT displays are the primary displays for entry monitoring or manually flying entry. ENTRY TRAJ 1 appears at MM 304 (OPS 304 PRO). TRAJ 2 through 5 appear at predetermined velocity breakpoints. Each display is a continuation of the previous one.

In the center of the ENTRY TRAJ display there is a dynamic plot of velocity (Y-axis) vs. range (X-axis). An orbiter "bug" is placed on this display as a function of range and velocity. The dashed drag lines are used to determine the desired drag for the current range and velocity. Interpolation is required. For example, the orbiter bug on TRAJ 1 shows desired drag of 12. SFOC-FL0884 Rev. B



ENTRY TRAJ 1 Display (Mach 25-Mach 17)



ENTRY TRAJ 2 Display (Mach 17-Mach 14)



ENTRY TRAJ 3 Display (Mach 14-Mach 10)



ENTRY TRAJ 4 Display (Mach 10-Mach 5)



ENTRY TRAJ 5 Display (Mach 5-Mach 2.5)

NOTE

On TRAJ 4 and 5, the orbiter bug is placed by energy (E/W) vs. range. This difference does not change the operational use of the displays.

NOTE

Desired, reference, and commanded drag are interchangeable terms; they mean the same thing.

The entry guidance algorithm is also running real time to calculate desired drag. The output of this algorithm is indicated by the arrow on the drag scale (left side of the ENTRY TRAJ display). Remember, the arrow points to where you want to be. The current drag, as sensed by the IMUs, is displayed as a triangle on the TRAJ display.

Guidance commands a roll angle that will dump lift as required to achieve the desired drag. H-dot control is an essential part of this operation. Guidance will bank until it sees an acceptable H-dot, then bank to an H-double-dot that equals zero to maintain this H-dot.

The desired H-dot is a function of reference H-dot and drag error. Reference H-dot is the H-dot required to maintain desired drag. If current drag is less than reference drag, guidance will fly to a higher H-dot (more negative).

Guidance displays reference H-dot on the lower right corner of the TRAJ display. The crew can also look directly below the orbiter bug and read a rough estimate of reference H-dot at the bottom of the TRAJ display.

Entry guidance will also modulate alpha to remove drag errors. By changing alpha $\pm 3^{\circ}$, guidance can instantly change the drag by about 10 percent (3 degree modulation is the limit). Alpha modulation is much faster than roll control. If guidance is using alpha modulation to remove drag errors, it will roll to achieve an H-dot that will eventually put the orbiter in the correct air density. In a few minutes, the drag error will be removed without using alpha modulation.

As the orbiter bug proceeds down the trajectory lines, it leaves triangular trailers every 15 guidance cycles (28.8 sec) that are used for trend analysis. For ENTRY TRAJ 3, 4, and 5, the trailers are displayed every 8 guidance cycles (15.36 sec). Only six trailers can be displayed at one time.

A guidance box appears upon initiation of closed loop guidance and moves relative to the shuttle symbol to reflect drag errors (D-D_{REF}). The guidance box leaves trailer dots. Ideally, the nose of the shuttle symbol will be inside the box, and a dot will be located in every triangle. The first roll command will be visible on the TRAJ display shortly after the initiation of closed loop guidance. Timely execution of the first roll command will minimize the bank angle required to establish desired drag.

If the guidance box is to the left of the shuttle symbol, drag is too small (you will land long) and the guidance trend is toward high energy. The opposite condition indicates drag is too high.

Alpha is monitored on the AMI and ENTRY TRAJ displays. Measured alpha is displayed on the AMI and ENTRY TRAJ. These parameters should be compared with the values on the ENTRY ALPHA cue card. ENTRY TRAJ displays reference alpha (computed by guidance) via an arrow and nav-derived (actual) alpha by a triangle. Normally, these overlay each other. However, guidance will add small biases to alpha to remove drag errors. If the ADI pitch error needle is centered and the alpha triangle is offset from the arrow, it is an indication of alpha modulation. Alpha modulation is expected during and after a roll reversal.

Heading error is defined as delta azimuth (DEL AZ or ΔAZ on the ENTRY TRAJ displays) and is the angle between the velocity vector and the great circle direction to the runway. DEL AZ is displayed on the HSI as the difference between the primary bearing pointer and the lubber line. There is also a digital value of DEL AZ on the ENTRY TRAJ displays. Bank angle controls drag, and therefore energy, during entry. Because the bank angle causes the orbiter to continually turn, a crossrange capability of approximately 750 n. mi. can be obtained. This gives the orbiter the advantage of using landing sites that are not directly under the orbital groundtrack. Roll reversals are performed to keep DEL AZ within limits. The velocities at which the reversals occur are a function of crossrange.

Initiation of a roll reversal is indicated by a flashing orbiter bug and phugoid damper bar on the ENTRY TRAJ and a full scale deflection of the roll error needle on the ADI. The first roll reversal will occur at a DEL AZ of 10.5° . Subsequent roll reversals occur at a DEL AZ of 17.5° until Mach = 4 when DEL AZ limit ramps to 10.0 by Mach 2.8.

The ENTRY MANEUVERS cue card itemizes important events that the crew must monitor during entry. Off-nominal activities are indicated by asterisks (*). Crew action items are keyed to velocity. Items to be verified only are marked with a check ($\sqrt{$).



See section 5.4 for more detail on this card.

NOTE

V in Kft/sec is equal to Mach; e.g., V=10K=Mach 10.

Automatic program test inputs (PTIs) may be included as part of entry trajectories to obtain aero data postflight. These data are used to further define the aerodynamic characteristics of the shuttle, help expand the operational envelope, and reduce aero data base uncertainties. PTIs are executed automatically by the entry DAP and are input into the flight controls downstream of gains and filters so that a known control deflection or jet firing can be made. The crew enables PTIs on SPEC 50, and flight control must be in AUTO. Execution of PTIs is monitored on the SPI and GNC SYS SUMM 1 for control deflections, by the RCS activity lights for jet firings, and by data on the PTI Monitor Cue Card. Normal vehicle performance parameters also must be continuously monitored to ensure there is no trajectory degradation introduced by the PTIs.

Takeover

The entry trajectory is normally flown in AUTO until subsonic, when the crew modes to CSS. Upon moding the GPCs to MM 304, dedicated displays and ENTRY TRAJ displays become available. DAP controls for the AEROJET DAP are located on each eyebrow panel. Manual takeover can be executed using the pushbuttons or by moving the RHC more than 7° out of detent.

NOTE

During entry, moding to CSS is separate for the pitch axis and roll/yaw axes. It is possible to be in CSS pitch control and AUTO roll/yaw or vice versa.

Low Energy

A ROLL REF "down" arrow on the ENTRY TRAJ display indicates a low energy condition. In addition to the down arrow, a fault message will be generated. If DEL AZ is allowed to go out to 10.5, the small roll angles required to fly low energy may not be able to bring DEL AZ back in. The crew should select R/Y CSS and initiate the first roll reversal when DEL AZ = 5°.

AUTO flight control may be reengaged after completion of the first roll reversal.

Delta State Update

If the NAV state of the orbiter goes bad on entry, MCC can uplink a good state vector (position and velocity). This is normally done by using the command uplink. If the command uplink is not available, data from the GPS unit will be forced to update the orbiter state vector, the delta state will be read up on the voice uplink, and the crew will have to enter the values on SPEC 50.

The crew must also take manual control (CSS) before a velocity uplink is incorporated into the GPCs. MCC will remind the crew when to take CSS.

Undesirable Transients

Prior to any event capable of introducing an unwanted transient into the flight control system, such as a delta state update that includes a velocity component, the crew should select CSS to prevent undesirable transients. Automatic flight control may be reengaged upon completion of the event and reconvergence of the guidance needles. RCS Critical Entry (No Yaw Jet).

The ENTRY CONTROL Cue Card contains two procedures that cover possible DAP problems during entry.

ARCS QTY (L + R) <10%: This procedure contains propellant conservation actions if the ARCS quantity (L + R) drops below 10 percent during entry.

WARNING

Going NYJ with q-bar <10 may cause roll opposite to RHC command. Reverse aileron also gives reverse roll jets. Roll jets are turned off at q-bar = 10.

When q-bar is below 20 psf and any RCS propellant remains, stay in AUTO because the No Yaw Jet mode is not certified. If no RCS propellant remains, select No Yaw Jet and the FIXED elevon schedule to get the elevons deflected down to a more effective position.

When q-bar >20 (≈77 KEAS), select No Yaw Jet (certified mode) and the FIXED elevon schedule. If control problems arise, select AUTO and use the remaining RCS to save you.

At Mach 6, any gaugeable propellant should support the remainder of the flight (jet activity is terminated at Mach 1).

At Mach 5, trip ailerons to $\leq 1^{\circ}$. This allows the rudder to pick up the trim load.

AIL TRIM $\geq 3^{\circ}$: This procedure contains the appropriate actions to take when aileron trim reaches 3° during entry. The software limit for aileron trim is 3° for the baseline DAP (default for TAL) and 5° for wrap DAP (default EOM). Possible causes for large aileron trim include Y c.g., bent airframe, and asymmetric boundary layer trip (ABLT).

If TAL, activate wrap DAP to increase the software trim limit from 3° to 5°.

If aileron trim saturates at 5°, raise the body flap to get the elevons down into the airstream.

If aileron trim continues to saturate, the following additional actions are required. The combination of No Yaw Jet and saturated aileron trim requires low rate maneuvers to prevent loss of control. At Mach 13, begin to get as close to alpha 30° as allowed by entry alpha limits (3° below reference). At Mach <5, when rudder is active, trim ailerons back to <1°.

WARNING

Never trim the ailerons back until the rudder is active at Mach 5.

At Mach 2, return the body flap to AUTO for the transonic region and approach and land transition.

High Freq OSC or Surf/Jet Cycle

The DAP includes bending filters in all axes that protect the DAP from coupling with the orbiter structure in a resonant oscillation. If the bending filter constants were wrong, it could be possible to cause an oscillation.

Symptoms are a high frequency oscillation (4 Hz), accompanied by airframe vibration caused by oscillation of the aero surfaces. The crew may observe these oscillations on the SPI or the ADI rate needles. A yaw jet limit cycle may also occur.

The procedure ensures that the correct body bending filter is in use (SPEC 51) and then takes CSS. It may be a problem with AUTO.

If the condition persists, select Low Gain on the ENTRY MODE switch to cut the DAP gains in half. Return the ENTRY MODE switch and P, R/Y to AUTO when the oscillation or cycling stops.



ENTRY MODE Switch on Panel L2

Manual Control

WARNING

If possible, do not downmode to CSS without consulting MCC. Deviations from the desired entry drag profile can cause violation of thermal limits or failure to reach the planned landing site.

In MM 304, prior to closed-loop guidance, allow alpha to deadband $\pm 3^{\circ}$ and bank to drift $\pm 10^{\circ}$. This can save up to 200 lb of RCS propellant.

After closed loop guidance, the first bank command should be in the direction of the

landing site (primary bearing pointer on the HSI). This maneuver is usually done in AUTO. It should occur at an H-dot of -240.

If CSS is required, move the RHC to about half deflection, watch the roll rate needle on the ADI, and bank at about 3 deg/sec. Prompt execution of the first roll command will minimize the bank angle required to establish the entry profile.

To fly the most fuel-efficient entry, hawk the guidance needles, and always center the pitch needle first. Keep rates small and try not to start and stop the rate more often than necessary. Minimize the number of discrete RHC movements to reduce unnecessary RCS jet firings. Overly aggressive control during entry can cause depletion of available RCS propellant. The *MED* position of the *ADI ERROR* switch is recommended for entry.

Use 6 deg/sec bank rate to perform a roll reversal. A good cue to stop the roll reversal maneuver is H-double dot passing through zero. Returning the RHC to detent at this point will result in a smooth reduction in bank rate with final bank angle very close to roll command. A 6 deg/sec roll rate will minimize H-dot and drag excursions during the reversal. A gentle roll reversal at less than 6 deg/sec roll rate can require the use of large bank angles to recapture the desired drag profile.

CAUTION

Monitor DEL AZ carefully when flying R/Y CSS, especially at lower velocity. Azimuth errors can quickly make it impossible to reach the desired landing area.

A good instrument crosscheck of actual drag (D_{ACT}) , reference drag (D_{REF}) , bank angle, H-dot, and H-double dot is required when flying a CSS entry.

The following is a summary of tasks required during a CSS entry:

- Fly scheduled alpha per the cue card or ENTRY TRAJ.
- Bank as required to maintain H-dot \approx H-dot REF +20 (D_{ACT} D_{REF})

 Perform roll reversals based on DEL AZ (10.5° for first reversal, 17.5° for subsequent reversals) to Mach = 4. The DEL AZ limit then ramps down to 10° at Mach 2.8.

No Yaw Jet/RCS Critical Entry

The hypersonic handling characteristics of the orbiter are very different when in no yaw jet. The primary difference is the time required to start and stop roll rates. This difference is so great that the flight control system automatically downmodes to CSS and manual flying is required.

When in no yaw jet, the flight control system uses adverse yaw to start and stop a bank. The crew will see this by an initial roll opposite the commanded direction. This adverse yaw decreases with Mach. By Mach 5, the rudder becomes active and the orbiter flies much better. When performing roll reversals, it is important to use the recommended 5 deg/sec roll rate to minimize altitude descent rate and drag fluctuations. A gentle roll rate of less than 5 deg/sec may feel more comfortable, but the trajectory dispersions it will cause will make the ride uncomfortable later.

To initiate a roll reversal in no yaw jet, the RHC should be moved smoothly to establish a roll rate of 5 deg/sec. To stop a roll reversal, a large lead is required to prevent overshooting the desired bank angle. This lead varies with Mach. The following is a list of typical lead angles required to capture the desired bank from a 5 deg/sec roll. The roll is stopped by centering the RHC.

Mach	Lead Angle (deg)
>22	55
22-7	35
<7	15

After the roll reversal, the roll needle should be kept centered. Control will be sloppy, so the needle cannot be kept perfectly centered. It takes a lot of work. It helps to try and lead the roll needle by monitoring H-dot and predicting what guidance is going to do next. For example, if guidance is commanding to a large negative H-dot, you can expect that guidance will command a roll out of bank in the near future. Developing good skills in flying manual entries helps in predicting what guidance will do next.

NOTE

Do not compensate for the sloppy control by lagging behind the needles. Adding lag to the system will cause large, lowfrequency oscillations in H-dot and drag.

The most critical region of a no yaw jet entry is between Mach 12 and Mach 8, where control margins are smallest. This is empirically derived from 6 degree-of-freedom simulations. With the aero uncertainties present today, a control problem is not expected in the no yaw jet mode. If control problems are encountered at any velocity, and RCS control is still an option, reenable the yaw jets by returning the ENTRY MODE switch to AUTO. Once control is restored, and the orbiter is in a stable attitude, return to the no yaw jet mode.

Off Nominal Trajectory Control

Should the orbiter be outside the CRT-displayed nominal energy envelope, for whatever reason, corrections are necessary to recover. Both the high and low energy cases are discussed from a manual control point of view.

High Energy Recovery

If the orbiter is very high energy on entry, guidance will calculate a drag that is larger than the orbiter can withstand. This can be seen when the orbiter bug is to the left of the high energy line on the ENTRY TRAJ display. The high energy line is the solid line furthest to the left on the TRAJ display. In this case, the crew must take CSS and manually fly to the maximum drag that the orbiter can withstand.

The details of this procedure are beyond the scope of the SCOM, and are taught in the Entry Guidance Workbook, CBT, and classes.

WARNING

It is very easy to overshoot maximum drag while flying high energy entries. It is better to be high energy at TAEM interface than to be at TAEM interface without wings.

Low Energy Recovery

If the orbiter bug is to the right of the low energy line, guidance is calculating a drag that is smaller than the orbiter can sustain. In this case, the orbiter must fly into air that is so thin that there is not enough lift. The low energy line is the farthest right line on the ENTRY TRAJ display.

If on a TAL abort, the crew should enable LOW ENERGY logic on the TRAJ display. Low energy logic automatically lowers alpha to 31° (or low alpha, or max L/D), and flies a bank angle of approximately 2.2 times delta azimuth. Although this software will function on an end of mission (EOM) return, it is not certified. It is possible that lowering alpha to 31° at the higher Mach numbers found on an EOM will overtemp the leading edge of the wings.

If low energy on an EOM, the crew should take CSS. In pitch, fly alpha low (3° below the alpha arrow on the ENTRY TRAJ display), in roll fly 2.2 times DEL AZ.





Backup Flight System

The backup flight system (BFS) is capable of performing nearly all of the primary flight system functions (controlled by PASS software) during deorbit, entry, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the orbiter. A moderate control transient should be expected when BFS is engaged.

Deorbit

Automatic maneuvers are not available in BFS. The crew must manually fly to deorbit burn attitude using the error needles, MNVR EXEC display, and ADI attitude. The TRANS DAP supports both *DISC RATE* and *PULSE* modes, but all three axes are switched when *DISC RATE* or *PULSE* is selected.

During the burn, attitude must be maintained manually using the ADI error needles and REF ball. Upon completion of the burn, the maneuver to EI-5 attitude is a manual maneuver.

Entry

BFS does not support PTIs. Upon entering MM 304, flight control mode is CSS through landing/rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to GNC immediately upon engage. If air data has not been previously accepted in PASS, the crew should inhibit air data to GNC upon BFS engage.

There is no digital DEL AZ output in BFS. The crew must use the primary bearing pointer on the HSI.

Sensory Cues

During the night portion of an entry, the glowing plasma sheath around the vehicle can be observed through the orbiter windows. The pulsing light has not interfered with tasks inside the vehicle. The plasma glow is less visible during daylight portions of entry and may not be noticeable.

Returning from orbit, some crewmembers have reported increased sensitivity to g as it builds during entry. One crewmember observed that "when you hit a quarter g on entry, it seems like two g's in the T-38." Crewmembers should be aware that their ability to perform entry tasks may be degraded from that experienced in the SMS during training. Keep in mind that Gs stay around 1.3 until Mach 2.5. Roll reversals on entry will feel different than pure roll maneuvers in a conventional aircraft due to the orbiter's entry angle of attack. Pilots will probably notice the yaw rate required during the bank change as much as the roll rate. Some mission specialists have stated that they could barely feel the roll reversals.

At high Mach numbers, a slight vehicle buffet may be noticed as well as some light structural vibration as dynamic pressure increases during entry.

Ground Controlled Approach

Although GCA techniques are available, they are emergency alternatives only. Control should be quickly returned to autoguidance when conditions permit.

During entry, trajectory is monitored via the Tracking and Data Relay Satellite (TDRS) and ground radars. Should the trajectory diverge and approach energy limits, a GCA will be performed.

MCC, via the CAPCOM, will provide the crew with bank attitude, heading, airspeed, and speed brake information.

WARNING

On a high energy GCA, the crew should help monitor Gs. If the crew thinks that the current bank angle is leading to an over-g, the crew should call MCC and roll out of bank to not exceed Nz limit (2.0 to 2.5 g's, depending on orbiter weight.

Important—H-dot leads an over g. An H-dot of about -300 will maintain about 2.0 g's. If H-dot is bigger (more negative) than about -300, and Gs are headed up to the limit (~2.0 - 2.5 g's), roll angle should be decreased. MCC should be notified before roll angle is decreased.

GCAs are divided into three phases, based on energy: high velocity (Mach 10 - Mach 3), TAEM (Mach 3 - Mach 0.9), and final approach.

Criteria for electing to perform a GCA depend upon autoguidance capability to achieve a nominal trajectory by Mach 5. In the high velocity phase, MCC provides bank magnitude information to control drag and bank direction to control crossrange. To keep workload under control, fly roll/yaw CSS and pitch, speed brake, and body flap AUTO.

During TAEM, a more conventional technique of heading to control ground track and airspeed to control energy is used. Fly both pitch and roll/ yaw in CSS. Perform turns using 30° bank angle unless MCC requests a steeper bank. Control airspeed by modulating alpha and bank angle.

Final approach GCAs are similar to traditional airplane GCAs. Heading information controls alignment with the runway centerline, and position information references glide slope. Speed brake is used to control airspeed.

Off-nominal energy situations could be caused by incorporating erroneous navigation data into guidance or selecting an incorrect landing site. If this is the case, the GCA will be used to control the entry profile until NAV can be updated via a ground uplink or a manual state vector update. Once the NAV state is correct, MCC will terminate the GCA and call for a return to AUTO flight control.

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Entry Rules of Thumb

- 2 OMS: TGO ≈∆VTOT/2.
- 1 OMS: TGO ≈∆VTOT.
- RCS: TGO ≈1.7 x ΔVTOT.
- Adjust H-dot reference 20 ft/sec for every 1 fps² of drag error. [H-dot ~ H-dot_{REF} + 20 $(D_{ACT} D_{REF})$]
- As an approximation, 1° of bank change produces 0.7 ft/sec² H-double-dot change. However, there is no lag in the H-double-dot tape. You can roll until the H-double-dot tape reads the desired value.
- A 3° change in alpha produces a 10 percent drag change.
- First bank (H-dot capture) should occur at an H-dot approximately -240 ft/sec.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:

The shuttle bug superimposed on guidance box superimposed on nominal trajectory line

- Actual drag equal to reference drag
- Appropriate bank angle, H-dot, range and altitude.
- Attempt to contact MCC before taking CSS.
- If you must take CSS:
 - Control range by controlling drag.
 - Control drag by controlling H-dot.
 - Control H-dot by controlling H-doubledot.
 - Control H-double-dot by controlling roll angle.
 - Control everything slowly by small corrections.

7.4 TERMINAL AREA ENERGY MANAGEMENT AND APPROACH, LANDING, AND ROLLOUT (OPS 305)

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Definition and Overview

This section presents information required to pilot the orbiter from Mach 2.5 (3.2 for RTLS), where terminal area energy management (TAEM) begins, all the way through approach, landing, and rollout on the runway. TAEM guidance provides information to the pilot and guides the orbiter until the transition to approach/landing guidance at an altitude of 5000 to 10,000 feet. Derotation and rollout logic take over after the orbiter touches down on the runway. Procedural information for the TAEM and approach/landing guidance phases are contained in the Entry Checklist and cue cards. Pilots sometimes refer to the flight phase from .95 Mach to touchdown as the approach and landing phase of flight. This is the phase of flight in which the crew normally controls the vehicle manually (CSS) and in which the Shuttle Training Aircraft operates. By this definition, the approach and landing portion of the trajectory includes both subsonic TAEM guidance and the approach/landing guidance regions.

TAEM and approach/landing guidance trajectories allow the orbiter to handle a large variety of dispersions. Certain specified ground rules and constraints such as weight, c.g., aerodynamic limits, distance past runway threshold, velocity, altitude rates, lateral rates, and energy margin must be observed to ensure guidance is capable of directing the orbiter to a safe landing. Mission Control monitors these limits closely. Carefully following guidance commands (error needles) will generally provide the crew the best chance for coping with environmental dispersions.

TAEM is divided into four segments: S-turn, acquisition, heading alignment, and prefinal. Approach and landing trajectories are divided into five segments: trajectory capture, outer glideslope (OGS), preflare and inner glideslope (IGS), final flare, and touchdown. TAEM and approach and landing regions are jointly designed to allow the orbiter to land safely. This section presents information for monitoring and takeover during the early portions of TAEM and then details the manual flying tasks during each segment of the trajectory.

General information on handling qualities, flight control surfaces, priority rate limiting (PRL), winds, limits, BFS, sensory cues, and autoland is presented at the end of this section.

Terminal Area Energy Management

Monitoring

TAEM guidance is initiated automatically as the orbiter decelerates through Vrel = 2500 fps (=Mach 2.5, Mach 3.2 for RTLS). This normally occurs at about 82,000 ft altitude and about 60 n. mi. from the runway. The crew should note transition to MM 305 and appearance of the VERT SIT displays. Head-up display (HUD) symbology also appears at TAEM interface. TAEM guidance controls the orbiter by flying an altitude vs. range profile—glideslope. TAEM also has energy airspeed limiting features (and angle of attack for RTLS), which are rarely seen.

The outputs of TAEM guidance are functions of errors from these profiles. The validity of the output commands depends upon the accuracy of NAV and air data. Guidance is only as good as the NAV state.

TAEM Guidance

TAEM guidance operates by phases. S-turn, if required, dissipates energy by turning away from the HAC until energy conditions allow a nominal approach. Acquisition turns the orbiter until its ground track is pointed at the HAC.



Heading Alignment Cone (HAC) Profile

Heading alignment turns around the HAC until the orbiter is near the runway centerline. Prefinal transitions from the HAC to the runway centerline.

Outputs of TAEM guidance are:

- Pitch command (N,)
- Roll command
- Speed brake command

At TAEM interface, if vehicle energy is too high and the HAC turn angle is $<200^{\circ}$ (for OPS 3 entries), an S-turn will be commanded. During the S-turn, the orbiter will fly a constant bank angle of 30° for end-of-mission (45° for RTLS) until the total energy/weight decreases to nominal +10,000 ft. Acquisition phase is then resumed, and the orbiter turns back toward the HAC tangency point.

Between Mach 0.95 and 14,000 ft, the speed brake is controlling energy. Below 9000 ft, it is controlling airspeed to 300 KEAS. The logic is blended between 14,000 and 9000 ft.

CAUTION

Energy can be dissipated very rapidly. Ensure a high energy condition exists (MCC or visual) if an S-turn is triggered.

Tracking the HAC

Guidance uses an algorithm for roll command that is a function of error with respect to HAC radius (Δ R) and the rate of change of distance to the center of the HAC (Δ R-dot). Primary and secondary bearing pointers are referenced to the HAC tangency point and HAC center respectively as computed by Area Nav. Wind magnitude affects HAC tracking. Roll angle is larger when flying with a tailwind and smaller with a headwind. On average, the HAC roll angle is 45°.

Prefinal

When the orbiter is 8 miles away from the runway, guidance transitions to prefinal. At prefinal, the roll error needle may become very sensitive. The crew should either aggressively fly the roll needle or manually fly to the runway. Lagging the needles will only add to the oscillation of the roll error needles.

If the orbiter is flying into a headwind when prefinal starts, the roll needle may command a roll to wings level. This is more likely in the STA, which is not usually flying as fast as the orbiter does at this point. This rollout is due to a small Y-dot, where Y-dot is the closure rate to the runway center line.

At prefinal, the flight director marker changes from a square to a circle. It also points to the orbiter's velocity vector at this time.

Overshooting the runway centerline may cause the CDI and GSI on the HSI to disappear momentarily. Area Nav thinks the orbiter wants to go around another HAC. This will clear itself momentarily, but the crew can ensure having a glideslope indicator by placing the HSI SELECT MODE switch on panel F6 or F8 to APPROACH. This will force the glideslope indicator to display deviation from final approach glide path.

7.4-2

Pitch and Roll Commands

The output of TAEM pitch channel is Nz command. If AA feedback in the normal direction is lost, the crew must fly pitch CSS and ignore the pitch error needles. If the orbiter is down to two AAs, it is fail critical (i.e., one more failure will cause bad feedback). In this case, the crew will fly pitch CSS and closely monitor the pitch error needles by cross-checking the other data.

The crew has a great deal of data to monitor to make sure the pitch channel of TAEM is working correctly. There are five different sources of glideslope (altitude) information.

Glideslope data source	Type of glideslope	Type of HAC	Scaling
GSI on HUD	Reference	Cylinder	±5000 ft till about Prefinal, then ±1000 ft
Orbiter bug on VERT SIT	Nominal	Spiral	Scale: 30K to 100K
GSI on HUD	Reference	Spiral	±5000 ft till 10,000 ft then a linear ramp down of scaling to ±500 ft at 5000 ft altitude
Vertical scale on PASS SPEC 50 HORIZ SIT	Reference	Spiral	±5000 ft until Prefinal, then ±1000 ft
ADI pitch rate pointer	Reference	Spiral	±5000 ft until Prefinal, then ±1000 ft

Glideslope Parameters

In addition to glideslope information, the crew must monitor energy and airspeed. Both energy and airspeed are used in the pitch channel. In addition to the onboard displays, MCC is calling "energy" based on radar tracking data. This data must be incorporated by the crew. Before HAC intercept, MCC measures energy and calls energy. On the HAC, MCC measures glideslope (altitude) and will make calls based on the following:

- $< \pm 1000$ ft altitude error ON
- 1000 to 2000 ft altitude error slightly high or low
- >2000 ft altitude error high or low

The term "energy" is no longer used.

NOTE

It is essential not to confuse glideslope and energy. TAEM guidance does certain things based on energy (mainly move the speed brake) and certain things based on glideslope. There are also glideslope displays and energy displays. People often use these terms interchangeably.

WARNING

TAEM limits the supersonic roll limit to 30° to protect the ground from a large sonic boom. The HAC cannot be flown at 30°. If supersonic on the HAC, crew intervention is required to go over 30°.

Large HAC Turn Angles (270°)

Several unusual things happen with a large HAC turn angle.

First, the difference between the HSI and the other displays is greater. The primary bearing pointer can be 45° off at HAC intercept. The GSI is not very useful until 270° on the HAC.

Second, guidance will command an energy dump, a pull-up maneuver, and a pull-up recovery maneuver. The crew has very little insight into what is happening inside of guidance. In general, the vehicle will pitch down for the energy dump, pitch up to get subsonic, then pitch down to recover. The crew must faithfully fly the pitch error needles until 270° on the HAC. At this time, a normal instrument scan may be used.

WARNING

The pull-up maneuver is performed in TAEM by lowering maximum airspeed to about 200 KEAS. If TAEM does not have air data, it will command an uncontrollable pitch up at about Mach 1.3.

Third, the crew will have very little time flying before HAC intercept on an entry with a large HAC turn angle.

Displays

The primary glideslope/energy displays for TAEM are the vertical situation displays (VERT SIT 1 and VERT SIT 2). The VERT SIT plot is scaled with altitude on the Y-axis and range to the runway on the X-axis. Three trajectory guidelines represent maximum airspeed, nominal, and maximum lift-to-drag (L/D) ratio. Numerical values along the lines are EASs that should be flown to maintain that reference. An orbiter symbol shows current altitude versus range (glideslope). Pitch attitude of the orbiter symbol indicates H-dot. Use of theta limits is discussed later in this section.

The HSI is driven by Area Nav, which can be independent of shuttle guidance and navigation calculations. This gives the crew a source of navigation processed differently from the onboard state vector and based only on data taken from TACAN or MLS. The HSI and Area Nav are driven according to the *HSI SELECT SOURCE* switches on panels F6 and F8. There are three options available: *NAV* (NAV state vector to Area Nav), *TACAN* (raw TACAN data to Area Nav), and *MLS* (raw MLS data to Area Nav). An additional switch allows selection of the individual TACAN or MLS LRU (1, 2, or 3).



Instead of the HAC inverted cone geometry, Area Nav defines (and the HSI displays) the HACs as 15,500 ft radius cylinders. This causes the HSI and guidance ground track information to differ slightly. During TAEM, the HSI primary bearing pointer indicates the bearing toward the HAC intercept point called way point 1 (WP1), and the secondary bearing pointer indicates bearing to the center of the Range displayed in the HSI DME HAC. windows corresponds to range to the runway via the HAC (PRI MILES) and range to the HAC center (SEC MILES). Range to the runway can be varied by moving the HAC using ITEM 6 and 7 on SPEC 50. The HAC on SPEC 50 is an imaginary inverted cone tangent to the runway centerline at 12,000 ft altitude and nominally centered about a point 7 n. mi. from the runway threshold. For low energy situations, the crew can shift the HAC to a point 4 n. mi. from the threshold by executing ITEM 7. The point where the HAC is tangent to the runway centerline is called the entry point. For a nominal HAC configuration, the entry point is called the nominal entry point (NEP). Executing ITEM 7 repositions the HAC to a minimum entry point (MEP), which is tangent to the runway centerline at 6000 ft.

ITEM 6 allows selection of an overhead (OVHD) approach or a straight-in (STRT) approach. This allows the crew to position the HAC on either side of the runway centerline. OVHD/STRT and NEP/MEP can be combined to define four HACs that are available to the crew for energy management purposes. Guidance is always initialized to the OVHD NEP HAC.





HSI SELECT Switches on Panel F6 and F8

NOTE

Within 35 n. mi. of the runway, switching between OVHD/STRT is not recommended. The heading error generated by a downmode could nullify any energy gains.

The glideslope indicator on the HSI displays calculated altitude error computed by Area Navigation. Note that this is not a guidance computation. The scale is 2500 ft per dot until Area Nav transitions to Approach (usually within 2.5° of Course Deviation), then it becomes 500 ft per dot. Crewmembers can force this scale change by selecting *APPROACH* on the *HSI SELECT MODE* switch on panel F6 or F8. With the *HSI MODE* switch in *ENTRY*, HSI mode, auto switching from TAEM to Approach will occur under the following conditions:

 Orbiter altitude is less than 18,018 ft for NEP (12,000 ft for MEP), and the absolute value of the CDI is less than 2.5°. Orbiter altitude is less than 12,018 ft for NEP (6000 ft for MEP) irrespective of CDI value).

Data presented by the glideslope indicator are calculated assuming the orbiter will fly from its present position, over the proper ground track trajectory, to touchdown.

The glideslope indicator shows altitude error only, not energy error. Similarly, on the VERT SIT displays, the vertical scale is altitude, not energy.

The E/W scale (E/W = units in feet) on VERT SIT 1 and 2 is displayed above 20,000 ft AGL. A triangle shows the calculated energy of the vehicle relative to the design trajectory. Overbright lines above and below the center NOM indication show 8000 ft high and 4000 ft low on total specific energy. If the pointer is between the +8000 and -4000 ft marks, TAEM is controlling glideslope. If out of this band, TAEM is controlling energy.

These are energy status lines, not altitude. As is the case with the glideslope indicator, E/W assumes a proper ground track will be flown. A high E/W bug means high energy. A high HSI glideslope pointer indicates low altitude on the glideslope.



E/W Scale on VERT SIT 1

Above the nominal energy marks is a mark labeled STN (S-turn). When vehicle energy, represented by the triangle, is above the STN mark, guidance may command an S-turn to dissipate energy. Near the bottom of the scale is another mark labeled MEP. Energy below this mark will trigger an "SW TO MEP" message. An arrow on the bottom half of the scale marks the straight-in (STRT) energy level. Below this mark, an "OTT ST IN" message is triggered. The arrow disappears at 45 n. mi. range, signifying that a downmode to STRT will probably produce a longer range-to-go.

For low energy situations, it is best to try the STRT downmode first. This will avoid a short OGS prior to preflare. If energy is still below the MEP mark, try the MEP downmode. The best downmoding option is a function of the HAC turn angle. For example, downmoding from an OVHD to STRT-IN within 180° has little effect.

Unfortunately, the energy pointer is not very useful in deciding if the orbiter can make the runway. The orbiter bug combined with airspeed must be used. If the orbiter bug is on the low line on the VERT SIT and the orbiter is currently flying maximum L/D, then the runway will barely be reached on a no-wind day. It the orbiter bug is on the high line on the VERT SIT and the orbiter is currently flying maximum airspeed, then the runway will barely be reached on a no-wind day.

Both the high and low lines assume that no downmode is made. An S-turn, selecting straight-in, selecting MEP, or selecting a different runway will all have large changes to the range flown to the runway.

CAUTION

Take CSS before evaluating different downmodes. This way the displays can be assessed without committing a turn in the new direction. If the downmode is accepted, AUTO flight control can be resumed.

In summary, crew concerns during TAEM are:

- Remaining within critical flight control and structural limits (q-bar, N_z, beta, roll angle, angle of attack)
- Ensuring timely and accurate data are input to the NAV state

- Maintaining E/W within limits required to achieve A/L interface
- Monitoring critical systems
- Keeping pace with increasing workload

Takeover

In addition to the takeover conditions discussed in the Entry section, the crew must downmode to pitch CSS if air data has not been taken to G&C (ITEM 28 on GNC 50 HORIZ SIT) prior to Mach 2.5. Since TAEM guidance tries to set up an altitude/range profile, a transient is possible if NAV altitude is incorrect prior to air data being incorporated. A step change in FCS gains is also possible due to Mach, alpha, and q-bar errors. If air data is not incorporated into guidance and control by Mach 2, the crew must go CSS and fly theta limits. Flying theta limits is discussed later in this section.

Manual Control

During the supersonic portion of TAEM, the pilot's main goal is to guide the orbiter to the edge of the HAC on the glideslope with the correct amount of energy. As with the rest of entry, closely following guidance provides the best chance for coping with environmental dispersions—if guidance is working correctly. If guidance is bad, NAV information on the HSI and VERT SIT displays may still be usable for manual control of the trajectory.

With good NAV, put the primary bearing pointer on the nose (or the predictors will point at the HAC on SPEC 50).

The most precise pitch control indicator is the orbiter bug on the VERT SIT. Pitch up and down until an H-dot that drives the orbiter bug back to the nominal line is achieved. Make sure not to fly slower than max L/D or faster than maximum airspeed. Max L/D is best flown by using max L/D alpha. L/D alpha is not a function of weight and roll angle and responds much faster than airspeed.

The maximum airspeed of the orbiter is now 333 KEAS. TAEM and the displays still have the old limit of 305 KEAS supersonic built in. Because of worst case air data errors, it is recommended



not to go over 321 KEAS (actual indicated airspeed).

If very low, fly maximum range alpha (max L/D) and change the HAC or runway selection if required. Back up navigation with real world visual cues if weather permits.

In extreme cases where guidance and navigation are bad, a GCA, along with the view out the windows, can be used to arrive overhead the field for landing. GCA procedures are discussed in Section 7.3.

Manual control during the subsonic portion of TAEM is discussed later in this section.

Heading Alignment Cone

The HAC is intercepted at various altitudes, depending on HAC turn angle. The altitude varies between about 50,000 ft for a 360° HAC to 20,000 ft for a 90° HAC (straight in). The SPEC 50 HORIZ SIT horizontal scale, and the ADI roll rate pointer, provide a HAC turn time-to-go indication.

A proper lead is the easiest way to keep the roll guidance needle centered. Leading the HAC turn correctly will quickly establish the orbiter on the HAC without calling for more than 45° bank nominally or up to a maximum of 60° with a strong tailwind. As long as NAV and guidance are good, closely following guidance on the HAC will optimize the chances of staying within vehicle g limitations and countering wind effects.

HSI glideslope data (GSI) can also be used to maintain situational awareness while flying the HAC in order to anticipate guidance commands and minimize deviations from the reference altitude profile. The GSI calculations assume a heading alignment cylinder instead of a heading alignment cone, and computes errors assuming the orbiter is on the proper horizontal ground track. For reasonable deviations from the HAC, these errors are small and the GSI display is still useful. NOTE

The GSI has significant differences from TAEM guidance and the other glideslope displays until 270° on the HAC. The GSI should not be used to correlate with the pitch error needles until on the HAC with <270° of HAC turn to go.

The circle displayed on SPEC 50 is based on the instantaneous radius of the HAC at the orbiter's current position. For large HAC turn angles, the extended runway centerline will initially be projected inside, rather than tangent to, the SPEC 50 circle. As the orbiter continues around the HAC, the circle will become tangent to the runway extended centerline. Since the displayed circle is based on the instantaneous HAC radius, there will be a very slight trajectory error if the predictor dots are overlaid on the circle. For most situations, these errors are small and do not affect the usefulness of the SPEC 50 display. To fly precisely on the HAC requires that the guidance predictor dots be maintained slightly inside the SPEC 50 circle.

CAUTION

Any delay in following the guidance commanded roll on the HAC can result in going below glideslope, even if the guidance needles are flown perfectly after the delay.

The SPEC 50 HORIZ SIT and ADI rate pointer scales for crosstrack error and glideslope error may also be used to fly the HAC. Keeping the reference triangle or pointer centered on the scales ensures flying the reference trajectory.

HAC Options

Profile options are included in the guidance and navigation system to improve low energy situations. The options include:

- Straight-in approach
- HAC shrink (spiral adjust)
- MEP

Selecting the straight-in approach option on SPEC 50 will reduce the HAC turn angle to 180° or less. When guidance computes the orbiter to

be well below glideslope, the second option is invoked automatically by TAEM guidance. The HAC radius shrinks, allowing the orbiter to fly a shorter approach profile.

NOTE

A spiral adjust will occur only if the remaining HAC turn angle is greater than 90° and the orbiter is on the HAC.

The MEP option moves the HAC center point 3 n. mi. closer to the runway. MEP is selected by ITEM 7 on SPEC 50.

Range savings using these options vary as a function of HAC turn angle.

None of the options are nominal procedures. They are used only when the orbiter is in a low energy situation.



Range Saved vs. HAC Turn Angle

Default Air Data and Theta Limits

If air data has not been incorporated to G&C by Mach 1.5, default air data values will be used to set DAP parameters. Default air data should insure adequate flight control for a safe landing, although flying qualities may be slightly degraded.

Although default air data ensures that the flight control gains are set correctly, it essentially removes the airspeed limiting features on TAEM. Default air data will never tell TAEM it is flying too slow or too fast.

Theta limits are a set of pitch attitude limits that will keep the orbiter between minimum and maximum airspeeds. Vehicle pitch attitude, as well as the NOSE HI and NOSE LO limits, is displayed on the VERT SIT display. A 50° bank angle limit is imposed when flying theta limits. With no air data to G&C, theta limits apply from 1500 fps (2000 fps operational constraint) until rolling out on final.

WARNING

Operationally, do not exceed 50° angle of bank during theta limits. Bank angles greater than 57° will exceed maximum and/or minimum theta limits.

WARNING

No warning is provided when pitch up alpha limits are exceeded. Crewmembers should closely monitor theta limits and air speed to prevent loss of control. The pitch error needle will command past this limit if in a low energy situation or approaching a HAC greater than 300°. Mach 1.5 to 1.0 is the most critical phase.

CAUTION

Theta limits and a tailwind combination can rapidly cause a low energy situation, requiring aggressive corrections. This is one of the situations where the crew will take the last ADTA data, if available, rather than fly theta limits.

Outer Glideslope

The OGS is an equilibrium glide path that provides sufficient energy at preflare for a safe landing. Sufficient energy includes:

- · Having enough energy to compensate for deceleration between preflare and touchdown
- · Allowing a minimum of 5 seconds of stable flight time on the IGS for the pilot to make final corrections
To provide sufficient energy at preflare, the OGS design must handle both high and low energy dispersions over the entire weight span of the orbiter. The OGS is a sloped-line segment that intercepts the ground at the aim point.



Time to correct trajectory dispersions is provided by the altitude at which the OGS is acquired. Nominally, this occurs at 12,000 ft. Transition from TAEM to A/L guidance normally occurs at 10,000 ft, but if the transition criteria have not been satisfied by 5000 ft, A/L transition is forced. The criteria for transition from TAEM to A/L get tighter as altitude decreases.

TAE	TAEM TO APPROACH/LAND TRANSITION CRITERIA							
10,000 F	Т		50	00 FT				
< 4	DEG	FLIGHT PATH ANGLE ERROP	< 0.5	DEG				
< 1000	FT	CROSSRANGE ERROR	< 100	FT				
< 1000	FT	ALTITUDE ERROR	< 50	FT				
< 24	PSF	DYNAMIC PRESSURE ERROR	< 24	PSF				
(288-312	(KEAS)	and a new property and	288-312 K	(EAS)				

TAEM to A/L Transition Criteria

This allows A/L equations to cycle through initial transients and time for the rate terms to reach their damping values.

Reference velocity on the OGS is 300 KEAS for all vehicle weights. This velocity is required to compensate for the expected deceleration on the IGS. The design goal is to fly as fast as possible while remaining within maximum airspeed limits (333 KEAS)/q-bar (375 psf).

A 20° OGS is used for lightweight vehicles, and an 18° OGS is used for heavyweight vehicles. The design goal was to fly as shallowly as possible while maintaining sufficient speed brake reserve to cope with winds and trajectory dispersions. Since both high and low energy dispersions are possible, GSs were selected that resulted in a speed brake setting of 65 percent for midrange weights. One of the reasons for not forcing A/L guidance until 5000 ft is that TAEM has direct q-bar control limits that will keep the orbiter on the front side of the L/D curve.

Guidance and Control

Guidance attempts to maintain the referencealtitude-range profile by computing a normal acceleration command to guide the orbiter along the selected OGS trajectory. The N_z command is converted to a pitch command and displayed on the ADI and HUD. If the pitch command results in a velocity that is different than 300 KEAS, the speed brake responds to correct the velocity error.

Leaving the speed brake in AUTO allows guidance to reposition it, as required, to maintain the reference 300 KEAS velocity.

The body flap, if in AUTO, is commanded to retract to the trail position (34% on SPI) on the first A/L guidance pass.

Navigation

Upon receiving good data from the groundbased microwave landing system (MLS), preland navigation is begun. Unlike entry NAV, preland NAV maintains only one state vector, but executes twice as fast (every 1.92 sec vs 3.84 sec).

The MLS provides extremely accurate azimuth, range, and elevation, which correct the onboard NAV state. Typical errors are about 5 ft altitude, 21 ft downtrack, and 17 ft crosstrack when processing MLS data.

NOTE

Both range and azimuth data "good" flags are required to process MLS data. Without an elevation data "good" flag, azimuth and range will still be processed, but if either the azimuth or the range data "good" indicator is lost, all MLS processing will cease. If MLS data are lost for any reason (above 1500 ft) after processing has begun, TACAN and ADTA information will again become available to NAV until 1500 ft and 500 ft respectively. If MLS data are lost below 1500 ft, ADTA altitude processing is not possible.

NOTE

With TACAN data in FORCE mode, MLS data cannot be processed.

Smart Speed Brake Logic

To control orbiter touchdown energy, the speed brake is retracted at 3000 ft to a value calculated by onboard guidance that will target the remaining velocity profile to a fixed touchdown energy. The calculated speed brake position is a function of:

- Wind speed
- Vehicle weight
- Velocity error
- Density altitude
- Aim point (if applicable)
- Short field speed brake option (if applicable).

This position is maintained until 500 ft where the A/L guidance calculates an adjustment to the retract angle. This adjustment is based on any changes in winds and predicted density altitude since the 3000 ft calculation. No more adjustments are made until touchdown. The 500 ft adjustment altitude was selected because the time to fly from 3000 to 500 ft is approximately the same time it takes to fly from 500 ft to touchdown. This allows time for the adjustment to have an effect on the vehicle energy state.

When the close-in aim point is selected, 1000 ft are directly added to the downrange total. The idea is to keep the same touchdown energy target even though the geometry has been shifted in by 1000 ft. This lets the vehicle respond to atmospheric conditions that required the close-in aim point.

Selecting the short field option on SPEC 50 forces Autoland guidance to dissipate an additional 1000 ft of touchdown energy. The energy dissipation is achieved by carrying an

additional 12° to 13° of speed brake from 3000 ft altitude to touchdown. When this option is used, the pilot lands the orbiter 10 kt slower than the planned touchdown velocity and maintains the same nominal 2500 ft touchdown range. From an energy point of view, the additional 1000 ft of dissipated downrange can be converted to a velocity 10 kt slower than nominal touchdown velocity.

The short field speed brake retract option may also be used on all missions if the touchdown ground speed is predicted to be greater than the flight rule limit (214 knots). Using the short field option for this reason on a non-TAL landing will be decided by the flight director and will require an item 39 entry by the crew. The goal is to provide additional margin from the 225 KGS certified tire speed limit. It is for this safety concern and for common training procedures that when the short field option is used, the crew should land 10 knots slower rather than 1000 ft shorter. This option may be selected for TAL runways to ensure an adequate rollout margin or to prevent tire failure due to a high groundspeed touchdown.

The maximum allowable speed brake command at 500 ft is 50°, due to degradation of orbiter handling qualities near touchdown. This maximum limit is not invoked when short field option is selected.

After the speed brake setting is adjusted at 500 ft, the guidance command remains constant until the weight-on-wheels signal is sent to the GPCs. When this signal is latched, the speed brake is commanded to full open.

Visual Aids

Aim Points

The OGS aim point location was determined by energy requirements for landing and geometry constraints for transition between the two glideslopes. Distance from preflare to touchdown is proportional to orbiter deceleration time. This distance is directly related to aim point location.

The nominal aim point is located 7500 ft from the runway threshold. A close-in aim point is located 6500 ft from the runway threshold. Use of the close-in aim point provides an immediate energy increase by moving the OGS intercept point 1000 ft closer to the runway.

The nominal aim point is a rectangle, whereas the close-in aim point is a triangle. Colors are chosen to contrast with the local terrain. Aim points on lakebeds and light-color terrain are usually black. For tree- or vegetation-covered terrain, aim points are usually white. A dark background is preferred for the precision approach path indicator (PAPI) lights, which are placed on each aim point.

To enhance the flight crew's ability to acquire the aim points and PAPI lights, a strobe light system is installed at the close-in aim point. Six highintensity, directional strobe lights are located adjacent to the aim point. The lights flash at 90 cycles per minute (cpm) with an intensity of 1 million candlepower. For night operations, this intensity is reduced to 10,000 candlepower by means of a capacitor step and red filter.

PAPI Lights

The PAPI lights define the OGS. On a nominal approach, the crew should see two red and two white lights (20° GS). For heavyweight landings, an 18° GS is flown (three red and one white PAPI.

Three intensity settings are available for the PAPI lights: day, dusk, and night.

At fixed installations such as Kennedy Space Center and some Edwards and Northrup runways, intensity is controllable from the tower. Portable PAPIs must be adjusted at the aim point.



Aim Points

7.4-12



Techniques

When established on the OGS, the HUD runway should overlay the actual runway. Differences indicate the amount of NAV error. If the overlay is good, then NAV and guidance should be good, and declutter level one or two may be selected and the guidance symbol followed. If excessive NAV error exists, declutter but do not follow guidance. The HUD gamma reference marks should lie next to the aim point if the vehicle is on the proper trajectory.

Without a HUD, use the ADI error needles as long as the NAV state is good. With MLS data, the NAV state will generally be very good. Use of TACAN only will produce errors requiring the pilot to fly the OGS primarily using the HUD and external references.

Since the PAPI lights only show an instantaneous GS status, they must be continuously monitored for trends. If the onboard NAV state is reasonably good, and the crew tracked guidance around the HAC, energy should be close to nominal, and the HUD velocity vector should be positioned near the aim point after rolling wings level on final. If the PAPI lights are not operational, use the rectangle on the ground at the nominal aim point (or the triangle at the close aim point), and align the gamma reference marks on the HUD with the appropriate aim point on the ground.

Night approaches should be considered instrument approaches. Due to lack of outside references, bank control is more difficult. Sink rate is not apparent until after preflare.

When flying a manual speed brake approach, maintain 300 KEAS on the OGS, then close the speed brake at 2500 ft. If speed brake settings are known, the pilot not flying the approach should set the speed brake at 3000 ft and 500 ft.

High energy conditions are best corrected by deploying the speed brake to 100 percent. S-turns on final are not recommended because the turn dissipates an uncontrollable amount of energy leading to a low energy condition.

For low energy cases, close the speed brake and fly the wings level max L/D of 10.5° alpha. Push over no later than 5000 ft in order to have enough energy to preflare.

CAUTION

Entering preflare with less than 240 KEAS does not allow enough energy to rotate the nose to a safe touchdown attitude.

With speed brake stuck closed, lowering the landing gear early results in equivalent drag of 60 percent speed brake.



Stuck open speed brake can be compensated for by flying a steeper OGS with an adjusted aim point closer to the runway.

If a higher than nominal altitude condition exists at rollout (GSI full deflection), the CDR must make an immediate and aggressive pushover to reacquire the proper flightpath to ensure the transition to A/L occurs as early as possible. Manual speed brake should be selected, to 100 percent if required, to attempt to maintain the desired OGS airspeed of 300 KEAS and avoid exceeding the q-bar limit at 321 KEAS (350 psf). If the BFS is engaged, it is even more imperative that the CDR make an early attempt to correct to the proper glidepath, since the BFS has no A/L guidance mode.

CAUTION

When rolling onto the OGS with excess altitude, TAEM prefinal guidance gains may not be aggressive enough to command the orbiter back into the A/L envelope. If guidance is followed, the resulting flightpath will parallel the reference OGS with the aim point displaced down the runway. When A/L is forced (not later than 5000 ft AGL), guidance will give excessive pitch commands to attempt to reacquire the OGS. If followed, these commands could result in an excessive dive angle requiring as much as a 2.0 g pullout for the preflare maneuver. This can be avoided by the CDR closely monitoring the HSI glideslope indicator while flying the HAC and bearing in mind that the ADI pitch steering needle provides a much more noticeable indication of Nz command than the HUD.

Preflare

The preflare maneuver is used to transition from the OGS to the IGS. Flight path geometry is a sector of a circle tangent to the OGS and an exponential to the IGS. H-dot of about 190 fps must be reduced to less than 3 fps at touchdown. Preflare reduces H-dot to about 12 fps, with the remainder taken out in final flare. Pullup is about 1.35 g.



Preflare Geometry

Since the speed brake is retracted at 3000 ft and preflare nominally occurs at 2000 ft, the orbiter's velocity will increase about 10 KEAS. As flight path angle nears the minimum steady state value (-12°), velocity will begin to decrease.

Techniques

There is a strong tendency, especially with inexperienced pilots, to be too aggressive in the preflare or to anticipate the maneuver, ending up high and slow. This tendency is aggravated at night, when closure rate and depth perception cues are reduced.

CAUTION

The preflare is a gentle maneuver. Early and/or aggressive preflare may result in a high and slow inner glideslope from which a hard landing can occur.

Utilizing the HUD flare markers will generally result in good preflare maneuvers. Approaching 1000 ft to 800 ft, use the ball bar to intercept the IGS at about 300 ft. Without a HUD, the ball bar is the best reference during preflare.

For some low energy cases, delaying preflare to as late as 1000 ft may help to correct the situation. Perform a flare maneuver that results in a landing with a very minimal amount of IGS. Stuck open speed brake (greater than 60 percent) will require a more aggressive preflare with very little time on the IGS.

CAUTION

Failure to anticipate the rapid airspeed decay during preflare with stuck open speed brake (more than 60 percent) may result in high sink rate landings.

Use crab angle to control drift due to crosswind during the preflare. A significant change in crab angle during preflare should be expected due to the large change in airspeed and altitude during the maneuver.

Inner Glideslope

Transition to the IGS begins at 300 ft. Once the landing gear is deployed, and the orbiter is on the IGS, deceleration is fairly constant at 4 KEAS per sec. Each additional second the orbiter remains airborne results in a 4 knot slower touchdown velocity. The 1.5° IGS was designed to give the pilot at least 5 sec of stable flight before final flare.

Once stabilized on the inner glideslope, since the orbiter is decelerating, some pitch attitude changes will be required to maintain the desired trajectory.

Landing Gear

The landing gear creates a great deal of aero dynamic drag, which can significantly alter touchdown energy. The landing gear is deployed on an altitude cue by the pilot who is not flying the approach. Current flight procedures are to arm the gear at preflare (2000 ft) and lower the gear at 300 ± 100 ft. The design requirement is to have the gear down and locked at least 5 sec before touchdown. Gear deploy should not be delayed beyond 200 ft. A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. A nominal 300 ft deploy is assumed in landing energy predictions.

Final Flare

The final flare maneuver reduces H-dot on the IGS to an acceptable value at touchdown. Final flare should be a smooth increase in pitch attitude started at an altitude high enough to result in a timely decrease in H-dot before touchdown. Strive to touch down 2000-3000 feet down the runway at a safe rate of descent. Shoot for an airspeed within +5 to -15 of the target airspeed.

Maximum H-dot at touchdown was designed to protect the main gear struts from unacceptable loadings. Each strut can withstand up to 207,000 lb, although the actual H-dot limit varies from 6 to 9 fps as a function of vehicle weight.

A very important factor in reducing H-dot is the powerful aerodynamic ground effect of the orbiter. This effect grows as altitude decreases, increasing L/D by about 25 percent. Minimize RHC inputs prior to touchdown, and expect ground effect to cushion sink rate.

The 1.5° IGS used by guidance is a compromise. It does not require a large maneuver to land, yet maintains a reasonable ground clearance when coming out of preflare.

Techniques

A negative handling quality of the orbiter is that initial vehicle response to pitch control inputs is backwards from the desired performance. This is due to relative locations of the c.g., aerodynamic center, control surfaces, and the pilot's seat. For example, a pitchup command from the RHC causes an upward elevon deflection. The up elevon initially causes a decrease in lift (approximately 2000 lb per degree), and the wheels actually move closer to the ground at a faster rate. The expected positive lift increment will not occur until the orbiter has rotated to a higher angle of attack.

CAUTION

Attempting to reduce H-dot may actually increase the rate, and, if timed incorrectly, can result in an early touchdown.



Ball Bar Geometry

approaches.

Pilot eye height just prior to landing is nearly constant. Therefore, out-the-window cues are poor indicators of actual H or H-dot after control inputs.

The HUD should be used to monitor pitch attitude and make precise adjustments both on the IGS and for final flare. For no-HUD approaches, use the far end of the runway or the horizon, since pitch attitude changes are very difficult to see due to a lack of references.

A "bang-bang" technique of pitch attitude corrections on the IGS has proven to be effective for some pilots. Small pitch inputs are made, and the RHC is quickly returned to detent. After each input (or series of inputs for larger corrections), wait until the effect is apparent before making another correction. This technique is less effective as landing weight increases and c.g. moves forward.

Ball Bar

The ball bar defines a 1.5° GS. Overlaying the center of the ball across the center of the bar results in a threshold crossing height of 26 ft. Normal guidance profile changes due to winds will result in some difference in threshold crossing heights. Try to shoot for 20-30 feet threshold crossing height during training.

Touchdown rectangles on the runway surface may also be used. The leading edges of the marks are 2500 ft from the threshold, and the

attitude effective e made, detent. r larger pparent This

from the IGS to touchdown.

The same touchdown speeds are usually targeted by the pilot when flying CSS to provide a more consistent energy reserve and orbiter pitch attitude at touchdown. Energy reserve is the time (in sec) that the orbiter could have flown until pitch attitude reached tailscrape angle (15°). Energy reserve varies with weight, since heavier vehicles must fly faster than lighter vehicles in order to produce aerodynamic lift equal to weight. Consistent energy reserve and consistent pitch attitude are very important factors that help pilots land with sink rates within vehicle limits. CSS target touchdown speed is 195 KEAS for weights less than or equal to 220,000 lb and 205 KEAS for weights greater than 220,000 lb.

marks are 200 ft long and 40 ft wide. Aiming

the orbiter straight toward the marks from ball

bar intercept until final flare results in good IGS

control and safe threshold crossing heights. This technique is especially helpful for no-HUD

For the final flare, matching digital altitude and

digital airspeed on the HUD (40, 240 ... 30, 230.

. . 20, 220) will result in a smooth maneuver

GUIDANCE MODE	T/D Point	T/D velocity by vehicle weight (KEAS)					
boorded anthrophytomical and	(ft)	< 200 K	200 K - 220 K	> 220 K	> 245 K		
Nominal guidance - all aim points	in manual a	1 ion 9	abden Fans and	Marian	Le to regial		
Auto or CSS	2500	195*	195	205	205		
Short field speed brake		1110 TRO	minelly set at n	March Constant	And shows		
Auto or CSS	2500	185	185	195	195		

* 185 KEAS is acceptable for certain touchdown energy cases.

Ball Bar Geometry

Energy Reserve/Tailscrape

Starting with STS-50, the speed brake (in AUTO) targets 2500 ft at 195 KEAS touchdown energy for lightweight vehicles and 205 KEAS for heavyweight vehicles. A rough rule of thumb is 90 ft of touchdown distance corresponds to 1 knot of airspeed.



TAILSCRAPE — The maximum pitch attitude (deg) the vehicle can land at and not scrape the tail (body flap).

ENERGY RESERVE — The time (sec) the vehicle could have continued flying after touchdown until the tailscrape condition.

The most significant factors influencing touchdown energy are:

- Winds
- Density altitude
- Vehicle weight
- Velocity error at 3000 ft

Off-nominal factors such as landing gear deploy altitude, GNC air data SOP, tile damage, stuck speed brake, and NAV errors may also be significant.

Variations in touchdown energy of ± 500 feet due to the factors listed above are not unusual. Pilots should strive to touch down 2000-3000 feet down the runway at a safe rate of descent within $\pm 5/-15$ knots of the target airspeed, allowing touchdown airspeed to vary slightly with touchdown energy dispersions. Minimal RHC activity prior to touchdown is desired to preclude pilot induced oscillations.

For crosswind landings, use crab angle to control drift. Maintain the required crab angle all the way to touchdown.

Weight on Wheels Discretes and Flight Control Moding

At touchdown, the weight on wheels (WOW) discrete must be set to properly mode flight control for derotation and rollout. The crew can set the WOW/weight on nose gear (WONG) discrete manually by selecting the *SRB* or *ET SEPARATION MAN* mode and depressing the appropriate pushbutton. To avoid derotation transients, this action is deferred until after nose gear touchdown.



SRB SEPARATION and ET SEPARATION Switches and Pushbuttons on Panel C3

-

CAUTION

Failure to set the WOW discrete allows the DAP to remain in A/L mode. Gains are not optimized for derotation and rollout and may cause control problems.

Crews are trained to routinely set WOW/ WONG manually at nose gear touchdown to protect for a WOW and/or WONG discrete failure. If a manual *SEP* pushbutton is depressed at main gear touchdown, the rollout discrete will be set when pitch attitude decreases below 0°.

Flight software performs other checks to ensure the WOW discrete is not set while the orbiter is still airborne.

Once the WOW discrete is set, the speed brake opens to 100 percent to help slow down the vehicle. The WOW discrete also sets flat turn and HUD discretes, which cause mode changes in the aerojet DAP. Setting WOW also modes the pitch channel to AUTO for auto load relief. In the roll/yaw channel, when WOW is set, rudder trim freezes, aileron trim freezes, and auto load balancing becomes active. Auto load balancing uses aileron commands generated through the roll channel to balance loads on the main tires. These commands are computed as a function of true airspeed, lateral acceleration, and vehicle yaw rate. Also at main gear touchdown, lateral acceleration feedback and rudder trim loops are opened. In CSS, pitch axis information drives only the ADI error needles. WOW also sets the RHC to half the original gains for better derotation control.

Derotation

There are two phases of the derotation portion of orbiter landings, attitude hold and the derotation maneuver itself. Both are important and are discussed separately for clarity.

Attitude Hold

This phase is designed to reduce maximum loads on the main landing gear. Pitch attitude is held constant until EAS decreases to 185 KEAS, when beep trim is used to perform the

Derotation Maneuver

The manual backup derotation maneuver will be used if beep trim is inoperable or inhibited. The recommended pitch rate in CSS is 1 to 2 deg/sec. Input the derotation command smoothly over a period of 1 to 2 seconds.

Executing a manual derotation requires good crew coordination and must be practiced in the simulator. The pilot not flying the approach and landing should call out airspeeds, with a "derotate" statement at 185 KEAS. A positive nosedown command must be input and held with the RHC to generate the desired 1 to 2 deg/sec pitch rate. When pitch rate is established, callouts of "down at 1, down at 1-1/2," are very helpful in maintaining a constant rate until nose gear touchdown. The pitch rate needle on the ADI is the best source of this information. The onset rate of the derotation rate command is critical for minimizing main gear loading during and after derotation. Too quick an onset can result in main gear oscillations and load spikes that go over the max limit. Too slow an onset can result in high nose gear loads. Heavy gross weight landings on lakebeds (high rolling friction coefficient) are the most difficult to control.

CAUTION

Derotation is a critical maneuver. Do not delay derotation, especially on lakebeds at heavy gross weight. Loss of elevon effectiveness can cause hard nose gear slapdowns and possible structural damage. Derotation must also be initiated at the proper rate. If the derotation command is input too quickly, main gear loads may be exceeded at high landing weights due to strut oscillations. If the derotation is input too slowly or at the wrong rate, nose gear limit loads may be exceeded.

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Derotation must be commenced at the proper speed and the pitch rate maintained throughout the maneuver. Attempts to significantly slow or stop the pitchdown rate can cause a dangerous PIO. The beep trim switch ramps up to a commanded 1.5 deg/sec rate and gives a smooth derotation.

Rollout

Two phases of rollout are coast and braking. Rollout margin and brake energy limits are defined to ensure the orbiter can stop prior to the end of the runway. Generally, high-energy rollout margin is considered to be 2000 ft and is measured either from the end of the runway or the end of the usable overrun. Brake energy is limited to 42 M ft-lb for end of mission landings. If predicted brake energy exceeds these values, runway redesignation will be considered.

Shorter abort site runways will have a barrier to protect against brake failures. Note that crosswinds directly increase resulting brake energy when differential braking is used for lateral control during rollout.

Short field speed brake may be selected on SPEC 50 to achieve required rollout margin or brake energy limits. This software logic adjusts the speed brake retract function to target a touchdown velocity 10 KEAS slower at 2500 ft past the threshold for all weights.

Coast

Coast phase begins when the weight on nose gear (WONG) signal is set. Elevons are moved automatically from the position required to control derotation to 10° down in order to reduce loads on the main landing gear. The crew should monitor auto load relief on the SPI. If it does not occur, manual load relief should be initiated.

WARNING

Failure to perform load relief can cause unacceptably high loads on the main gear, resulting in potential tire failures and loss of control. Deceleration on the runway during coast is about the same 4 KEAS per sec as on the IGS.

Nose Wheel Steering

HUD rollout discrete and groundspeed enable are nominally set at nose gear touchdown. Nose wheel steering (NWS) is available once ground speed enable is set. Steering may be accomplished with differential braking, rudder inputs (above 100 KGS), or NWS. Two modes of NWS are available:

- NWS 1(2): Rudder pedal deflections incorporated as biases to N_y feedback.
- OFF: No steering commands; nose wheels caster.

Braking

The start of braking is normally determined by groundspeed, although distance remaining on the runway is also considered. Braking begins when groundspeed is less than 140 KGS and the orbiter has passed the midfield point, or if distance remaining is less than 5000 ft. Deceleration rate of 8 to 10 fps² should be maintained until below 40 KGS where the rate is decreased to about 6 fps². Maximum braking is applied if distance remaining is less than 5000 ft at more than 140 KGS.

Barrier

The barrier system is similar to systems used aboard aircraft carriers to recover damaged airplanes. It consists of a net, positioning system, and energy absorbers. The net is made of vertical nylon straps that are bundled together at the top and bottom. The orbiter nose passes through the vertical straps, which then catch on the wings, pulling the net down from the positioning stanchions. The straps spread out uniformly over the wings and provide a distributed retarding load.

On each side of the runway, two spools of nylon tape are attached to the side of the net. As the orbiter pulls the net, the spools unwind, paying out tape. The spools are mounted on water turbines that convert kinetic energy into heat. The system is capable of stopping a 260,000 lb orbiter that engages the net at 100 KGS. Barriers are placed about 800 ft from the end of the runway overruns on short abort runways (less than 12,000 ft).

Some damage will occur to gear doors, probes, and tiles during barrier engagement. The crew module and fluid systems will remain intact.

Barrier systems are portable and can be transported via C-130 aircraft and stored at landing sites. Setup time is about 6 hours, using an eight-person crew. The stanchions can be raised or lowered in about 10 sec.

To engage the barrier, try to be as slow as possible and as close to the runway centerline as possible. Nose wheel steering or differential braking may be required to keep the vehicle on the runway.

Techniques

NWS should be used for directional control and brakes used for stopping unless differential braking is required. NWS operations in *NWS* 1(2) are crisp and responsive with no tendency to overshoot or overcontrol.

The NOSE WHEEL STEERING switch on panel L2 has an extension device mounted on the shaft to make it easier to locate.

If NWS 1 fails during fallout, NWS 2 may be susceptible to the same failure and inoperative. NWS 2 may still be selected in extreme cases such as runway departure.

With NWS in *NWS* 1 (2), the orbiter will tend to turn into a crosswind during rollout. With NWS in caster (*OFF*), the orbiter will tend to turn away from a crosswind.

If a tire failure occurs during rollout, the orbiter will turn toward the failed tire. When the turning moments due to crosswind and tire failure are in the same direction, large control inputs will be required to maintain runway centerline. When the turning moments are in opposite directions, smaller control inputs will be required, and pilots must be careful not to overcontrol.

Rollout performance is best demonstrated in the vertical motion simulator (VMS) at NASA Ames Research Center. NWS and tire failures are

realistically modeled, allowing crewmembers to experience actual orbiter dynamics while making corrections. Crew coordination and skills are practiced in the Shuttle Mission Simulator (SMS). Crewmembers should ensure that different rolling friction coefficients and wind conditions are seen, as well as appropriate system failures that disable or downgrade the NWS system.



Switch on Panel L2

Handling Qualities

The space shuttle DAP is a rate command system. When the RHC is moved from detent, aerosurfaces are deflected to command a bank or pitch rate. Due to control requirements during high speed flight, the aerosurfaces are very large and can generate large rates, even with a heavyweight vehicle. Smooth control inputs will minimize transients and the initial tendency to overcontrol.

Control harmony is excellent in all axes, with crisp response and essentially deadbeat damping. Returning the RHC to detent reduces vehicle rates to zero (plus or minus rate deadbands). Control surfaces remain active and will attempt to maintain attitude.

The shuttle training aircraft (STA) is an extremely accurate simulator of orbiter flying qualities below 35,000 ft altitude. Training for

high and low energy cases in the STA will prepare crewmembers to handle the actual vehicle from about the 180° point on the HAC. The STA also has the capability to demonstrate navigation state errors up to 6500 ft short, 2000 ft long, and 1,200 ft laterally from the desired touchdown point.

Elevons

During subsonic flight, all four elevons are commanded up and down simultaneously for pitch control. For roll control, the elevons are commanded differentially, similar to ailerons on a conventional aircraft.

Body Flap

The body flap is used to trim the elevons during entry and TAEM. When guidance transitions to the A/L phase, the body flap is commanded to trail. Normally, the body flap is operated in AUTO. If the body flap is not in AUTO, the crew should return to AUTO or manually position the body flap to trail at A/L transition.

CAUTION

The body flap is a large control surface and exerts a powerful pitching moment on the vehicle. Proper positioning is required to ensure adequate control margins.

Speed Brake

Although energy is controlled primarily by bank angle and the resulting drag in hypersonic and supersonic flight, the speed brake is the primary energy control device in subsonic flight. A/L guidance modulates the speed brake to control airspeed, when operated in AUTO. Speed brake position is constrained to a lower limit of 15° to prevent physical binding of mechanical linkages when the rudder is deflected. Postlanding, the minimum speed brake retract angle is 25 percent, denoted by a fixed marker on the SPI.

It is important to take manual control of the speed brake if guidance or NAV is questionable. For example, erroneous air data could cause flight control to generate erroneous position commands, resulting in high or low energy or a flight control transient at a critical moment. At

3000 ft AGL, the speed brake is closed automatically to a computed value based on wind, weight, density altitude, velocity error, aim point, and short field option. At 500 ft AGL, guidance can command a final adjustment of the speed brake position based on density altitude and wind velocity.



Surface Position Indicator on Panel F7

The speed brake is normally operated in AUTO throughout approach and landing. Speed brake position and command are displayed on the SPI and the HUD.

WARNING

The speed brake is a very powerful drag device. Overlooking a stuck speed brake or neglecting to retract the speed brake when operating in MAN can result in dangerously low energy.

Rudder

Corrected body roll rate is used in the DAP yaw channel as a yawing rate error to generate rudder commands. This essentially provides turn coordination. Rudder pedal deflection serves only to bias the N, feedback. Since rudder deflection is largely a function of the automatic stability loops, crewmember rudder pedal input should not be required prior to touchdown.

Trim

Automatic trim loops in the shuttle flight control system work very well, and although manual capability is available, it is not usually required in the approach and landing flight phase. One

exception is after a BFS engage. In this case, the trim values initialize at zero, and the pilot can help the flight control system return to a trimmed condition more quickly by trimming manually.

Priority Rate Limiting

All aerosurfaces (except the body flap) are rate command limited by priority rate limiting (PRL) software. This allows full advantage of available hydraulic system power while not overloading the hydraulic systems. Rate command limits vary as a function of the number of hydraulic systems available. Simulations have shown that vehicle control is adequate with reduced rate limits, but pilots should be aware that control could be degraded in aggressive maneuvers. Beep trim derotation will be used to prevent elevon saturation and high nose gear slapdown loads.

HYD SYSTEMS	ELEVONS	AILERONS	SPEED BRAKE	RUDDER
1	13.9	13.9	3.8	7.0
2	20.0	20.0	D.86(closing)	12.0
3	20.0	20.0	76.1(openind (14.0

PRL Rate Limits in Degrees per Second

Automatic PRL normally requires little crew interaction. Hydraulic pressure from all three sensors in each system is sent to the GPCs via flight aft (FA) multiplexer/demultiplexers (MDMs). A hydraulic subsystem operating program (HYD SOP) provides redundancy management (RM) for fault detection and isolation of failed transducers. A selection filter generates one pressure from each system.

HYD SOP declares a hydraulic system failed if the selected system pressure drops below 1760 psi. Fail flags are provided to PRL software, which then rate-limits aerosurface commands based on number of good systems. PRL status and management are on SPEC 51.

Utilizing item numbers, the crew can place PRL in automatic systems management, deselect a system, or invoke manual systems management. A failed system is indicated by a down arrow in the system status column. Failed systems are not used by PRL. Loss of hydraulic pressure information can cause a PRL dilemma and a question mark (?) is displayed next to the affected system. When a dilemma is declared, PRL leaves the system status as it was prior to the dilemma. The crew can then either manually deselect or reselect the system after determining its real status using other cues.

3051/051/	'	OVERRI	DE	2	008/0	04:13	3:37
ABORT MODE	2		ENTR	Y FCS			
TAL	1	ELEVON	FILTE	R	ATMOS	PHER	RE
ATO	2 7	AUTO 17*	NOM 2	:0*	NOM	22	2*
ABORT	3 I	FIXED 18	ALT 2	1	N POI	E 23	3
MAX THROT	4	SSME RE	POS 19 E	NA	S POI	E 24	1
		IMU STA	T ATT DE	S	Con Car	PRL	11-11
PRPLT D	UMP	1	3 25		SYS	AUT	DES
		2	26		1	28*	31
INH IGNCT	5	3	27		2	29*	32
OMS DUMP					3	30*	33
ARM	6	ADTA	н	α	P	4	DES
START	7	L 1	20466	+ 7	0 0	58	34
STOP	8	- 3	20466	+ 7.	0 0	58	35
9 OLIAN/ST	DE 78	R 2	20892	+ 6	9 0	58	36
OMS DIMP T	TG 520	4	20892	+ 6	9 0	58	37
one bonn i	10 520	ET SEP	20032	ROLL	MODE	AIT	0
		AUTO	38	AUT	O SEL		42
AFT RCS 13	INH	SEP	39	WRA	P MOL	E 45	
14 TIME	0	ET UMB	DR	VENT	DOOF	CNT	PT.
		CLOSE	40	OPE	N	43	*
FWD RCS 15	INH	RCS RM I	MANE	CLO	SE	44	1000
16 TIME	0	CTOW	00 41	cho			

PRL STAT/MGMT ON OVERRIDE SPEC 51 Display

Wind Effects on Trajectory

Winds affect the orbiter's capability to fly the desired HAC trajectory and can result in high or low energy situations if not handled correctly. Since the onboard navigation and guidance systems cannot predict winds, the crew must be prepared to anticipate high wind conditions and compensate for them. Information on wind speed and direction is passed to the crew prior to the deorbit burn. This information is updated as required during entry. Data are provided for the following altitudes:

the second	and the second s
ALTITUDE	HAC POSITION
50K	THE PARTY AND
38K	270
28K	180
20K	90
12K	FINAL
7K	al of such
ЗК	antitica Il co
SURF	enter entrance

Wind Data Table

7.4-22

The current speedbrake energy-control logic in TAEM guidance compensates for wind conditions prior to and on the HAC to maintain a nominal energy profile. Manual flying techniques should not be required to counter wind conditions. Normal piloting techniques, flying the guidance needles, should be sufficient.

Wind data is obtained by the Flight Dynamics Officer (FDO) in the MCC from the NASA meteorologists. Wind data is forecast based on balloon data and later compared to winds observed by the STA weather aircraft. Since the wind conditions that can cause low energy have much more serious consequences, they are discussed in more detail here.

Constant Headwind

For a given reference airspeed, any headwind greater than zero will result in less kinetic energy (less ground speed) than the no wind or tailwind case.

Sudden Headwind Increase

For a given initial energy state, a headwind shear will cause more drag and greater energy loss, until the pilot compensates for the immediate drag increase.

Tailwind Below 50 Feet

Tailwinds, or reduction in headwinds, are normally favorable in a glider because of the reduction of drag. However, at less than about 50 ft, the beneficial effects of drag reduction, integrated over such a short period of time, are outweighed by the sudden loss of available energy caused by the instantaneous decrease in KEAS. Large sink rates and hard landings may result.

Crosswinds

Use crab angle to control lateral drift due to crosswind from outer glideslope intercept until touchdown. Expect a noticeable change in crab angle during preflare and on the inner glideslope due to the large changes in velocity and the change in wind speed as altitude decreases.

Post touchdown, align the fuselage with the runway to reduce nose gear side loads at nose gear touchdown. During rollout, the orbiter will tend to turn into a crosswind with NWS in NWS 1(2). With NWS inactive, the orbiter will tend to turn away from a crosswind.

Limits

Headwind, tailwind, and crosswind limits are listed in the Flight Rules and summarized in the Limits section of this manual. These limits are conservative and are based on simulator, wind tunnel, and actual flight data. End of mission runways are selected so that all parameters are within limits.

Backup Flight System

The BFS is capable of performing nearly all of the primary flight system functions during TAEM, approach, and landing. This section presents the major differences, from the flight crew viewpoint, between the two systems. Differences in handling qualities between the PASS and the BFS are very small in the training simulators, and no large differences are expected if BFS is engaged onboard the orbiter. A moderate control transient should be expected when BFS is engaged.

The BFS does not support PTIs. Flight control mode is CSS from engage through landing rollout.

The BFS maintains only one state vector during entry. Redundancy management is performed on most systems, but in a simpler manner than PASS. BFS is also set up to accept air data to GNC immediately upon engage. If air data has not been previously accepted in PFS, the crew should inhibit air data to GNC after BFS engage.

The HUD is not supported in BFS. MLS is not supported. Guidance terminates in BFS at 2000 ft, ADI error needles are stowed, and the speed brake is commanded closed at 2000 ft. On a BFS landing, the crew must remember at 3000 ft to set the speed brake to the DEL PAD setting.

Off-Nominal Approaches

This section briefly summarizes the procedures used to correct problems typically encountered during STA training. More detailed information is available in the Approach and Landing Flight Procedures Handbook.

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Navigation Errors

A bad navigation state can put the orbiter in a high or low energy condition. If the error is detected early in entry or TAEM, Mission Control will declare a GCA and provide guidance to the landing site until the navigation state can be corrected with a state vector uplink or manual state vector update. If errors are observed after the field is in sight, pilots can use visual cues in addition to MCC calls to fly to the runway.

Stuck Speed Brake

Procedures for stuck speed brake approaches vary with speed brake setting and are summarized in the following table. These procedures depend on detection of the stuck speed brake prior to the HAC, where energy can be adjusted more easily without using the speed brake.

SB Setting (Stuck)	TAEM	AII/	Aim Point
>60	FLY 1-2 dots high	< 220 K: 25° GS	* 4000 ft
	throughout TAEM	> 220 K: 21° GS	(Page 12)
40 - 60	AUTO P, R/Y	Fly needles	CLSE
30 - 40	Fly 1 - 2 dots low Mtn EAS < 300	15° GS	CLSE
< 30	AUTO P, R/Y At M < .95 deploy gear	Fly needles	CLSE

* Aim 1/2 way between 7500 aim point and threshold.

Stuck Speed Brake Procedures

Early Gear Deploy

If the gear is deployed early (on the HAC), pilots should manually close the speed brake and select the close-in aim point. The EAS should be monitored, and if it exceeds 300 knots, return the speed brake to AUTO to protect the 312-knot gear limit. Monitor vehicle conditions and reclose the speed brake, if required. At 3000-ft altitude, manually close the speed brake. In general, if the auto speed brake retract command is less then 30 percent, expect to land short/slow. If the auto retract command is greater than 40 percent, expect to land long.

Sensory Cues

Most crewmembers report a fairly smooth ride throughout TAEM to landing, with the exception of some buffet during the transonic region. On final, the orbiter responds very little to turbulence in comparison to the STA due to the orbiter's higher wing loading.

When returning from orbit, crewmembers should be aware of the potential for some change in vestibular sensations. Head movements will tend to make these changes more noticeable. Flight crewmembers should avoid exaggerated head movements during landing to reduce the possibility of disorientation.

Sun glare and residue on the windows from the SRB separation motors can reduce visibility during landing, especially at low Sun angles.

Gear deploy causes very little structural vibration and may be difficult to detect.

The orbiter landing gear absorbs touchdown loads very well, and for low sink rate landings, it may be difficult to feel touchdown. The first cue to the mission specialists that the orbiter has landed may be the beginning of derotation followed by nose gear touchdown. For some flights, depending on runway surface, vehicle weight, and center of gravity, derotation and nose gear touchdown could be quite dramatic.

After returning from orbit, crewmembers need to be aware that some degree of decreased balance and coordination, as well as dizziness, may be experienced when getting out of their seats. Studies are in progress to quantify these effects and improve current countermeasures. At present, crewmembers should exercise caution when leaving their seats and preparing for egress.

Autoland

Although the orbiter has been certified for hands-off automatic landings, this capability has not been verified. Simulations indicate that performance is acceptable under reasonable wind conditions for most weight and c.g. combinations.

Although the orbiter may be flown in AUTO for the entire approach and landing, CSS control until MLS acquisition is recommended. This is due to possible transients as the NAV state is updated by MLS data. A runway equipped with MLS is required for autoland. Based on SMS and STA data, the autoland system tightly controls azimuth and elevation tracking during the approach. Corrections may be abrupt if not close to the nominal trajectory when AUTO is selected.

As with any automatic control system, the crew's task is to monitor the approach and take over manually if performance is not acceptable or to recover from system failures. Since there is no onboard independent monitor, the crew's visual perception of the approach determines takeover criteria. This may differ somewhat among crewmembers and requires a significant number of automatic approaches in the SMS and STA to achieve a reasonable level of proficiency. Both the HUD and ADI should be monitored during the approach. Splitting crewmember duties between the pilots has proven to be an effective method of monitoring autoland performance.

CAUTION

Pilots must use extreme care when executing a manual takeover from automatic flight control after commencement of pre-flare. Very little time exists before touchdown to damp vehicle attitude transients which may be induced by the takeover.

Techniques

After OGS intercept, MLS acquisition, and A/L transition, engage AUTO PITCH and ROLL/YAW. Attempt to have ADI error needles centered or tracking toward the center position prior to engagement. Should a takeover be required, the CSS PITCH and ROLL/YAW pushbuttons should be used to downmode. This avoids undesirable transients caused by a "hot-stick" downmode. Takeover should be performed only during stable flight conditions, if possible. A manual takeover on the OGS or IGS is much less demanding than during a dynamic phase of the approach such as preflare.

With good autoland performance, the crew should only be required to lower the gear at 300 ft and apply brakes after nose wheel touchdown. Rollout guidance is provided by the MLS and lateral control by the NWS.

	- Andrews	PAPI 7500 FT	PAPI 6500 FT	MARKING 7500 FT	AIM PT. 6500 FT	BALL	TACAN	TACAN	stated of Sold -
RWY	MLS	(NOMINAL)	(CLOSE-IN)			BAR	(PRIMARY)	(BACKUP)	REMARKS
EDW 17L	√ JR CH 6	~	V	V	V	V	EDW 111 (SS)	PMD 92 (SS)	san ti squade del
EDW 23L	-			V	V	•			Threshold & TD MK
EDW 35B			•	V	V	•		125,000,000	Threshold & TD MK
EDW 05B	-		_	-	V		No. of Street, or other	Constant of	Threshold & TD MK
EDW 15	√ JR CH 6	V	V	1	7	~	a naga an	adenticitation	Threshold & TD MK XENON
EDW 33	_	11. 20 · 20 · 10 · 10 · 10 · 10 · 10 · 10 ·	V	V	Z	V	Cleanda	herman 10	Threshold & TD MK
EDW 22	√ SR CH 8	V	V	V	1	V	monitor	The Draw	XENON **
EDW 04	10 ma 12 (1)	Y	1		~	1	approxide ave differ	n militari n Militari	Underrun unusable/ displaced threshold XENON **
EDW 18L	on chatte don	majund	-actesidq or	Y	7		i entanas	tatic app	Threshold & TD MK XENON **
KSC 15	√ SR CH 8	Y	1	- Colera	(1)	7	TTS 59Y (DS)	COF 97 (DS)	XENON
KSC 33	√ SR CH 6	V	ν.	MAN ME	(1)	Y	SNG 121Y (SS)	HMN 92 (SS)	XENON
NOR 17	√ JR CH 6	1	V	\checkmark	√(1)	V	the second		XENON
NOR 23	-11-	V	V	~	V	~			
NOR 35	-	V	-	V	V	2	and and and		
NOR 05	—	-	-	V	V	Ι	10 10 10		A REAL PROPERTY OF
BEN 36	√ SR CH 6	V	V	V	√ (1)	~	BEN 118 (DS)	CBA 116 (DME)	XENON
BEN 18	-	\checkmark	V	V	√(1)	V		C. Property in the second	and report should be
MRN 20	√ SR CH 6	V	V	-	(1)	7	MRN 100 (SS)	AOG 23 (DS)	Barrier 800 ft from end of overrun, XENON **
ZZA 30	√ SR CH 6	V	V	-	(1)	V	ZZA 64 (DS)	MLA 58 (DME)	Barrier 800 ft from end of overrun, XENON **
BYD 32	√2JRS CH 6	V	V	-	(1)	1	BYD 121Y (DS)	BJ 76 (DME)	Barrier 800 ft from end of overrun, XENON **
HNL 08R	√ JR CH 6	-	-	-	(1)	~	HNL 95	CKH 86	Barrier 800 ft from end of Rwy, XENON **
GUA 06L	√ JR CH6	-	V	-	(1)	7	UAM 54	UNZ 100	Barrier 800 ft from end of overrun, XENON **

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NOTE

THIS CHART REFLECTS CAPABILITIES AND CONFIGURATIONS WHICH ARE DEPENDENT ON MISSION CHARACTERISTICS; i.e., INCLINATION, AND DAY VS NIGHT RTLS, TAL, AOA CASES. * SURVEYED POINTS WHERE PAPI LIGHTS/BALL BAR CAN BE INSTALLED. (1) AIM POINT IDENTIFICATION LIGHT SYSTEM (APILS) AVAILABLE. ** XENON lights can be installed at these locations for mission requirements. AIM POINT MARKING @ 6500 FT IS A TRIANGLE, 7500 FT MARKING IS A RECTANGLE. (2) SINGLE GENERATOR ONLY. (DS) REFERS TO DUAL STRING TACAN TRANSPONDERS, (SS) IS A SINGLE STRING UNIT.

Navaids/Landing Aids Hi/Low Inclination

Terminal Area Energy Management and Approach, Landing, and Rollout Rules of Thumb

- A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.
- 90 ft of touchdown distance corresponds to 1 knot of airspeed.
- TAEM guidance uses pitch to control glideslope, bank angle to control ground track, and speed brake to control energy above about 14,000 ft and airspeed below this altitude.
- Overhead HAC with NEP allows the most downmode options for energy.
- Fly theta limits at Mach 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50°.
- For an early gear deploy, immediately close the speed brake.
- OGS is 20° lightweight (< 220,000 lb) and 18° heavyweight (> 220,000 lb). Aim point is 7500 ft nominal and 6500 close in. Touchdown speed is 205 knots heavyweight and 195 knots lightweight. When short field speed brake is selected, touch down 10 knots slower than nominal.
- Deploy the drag chute just before starting the derotation. Start the derotation at 185 KEAS using beep trim. At nose gear touchdown, manually back up WOW/WONG by taking the SRB SEP switch to MAN and pushing the pushbutton.

- During training, pilots should strive for a threshold crossing height of 20 - 30 feet on nominal approaches. Touchdown goals are airspeed within +5/-15 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, ensuring ample margin before violating limits.
- With NWS in *NWS* 1(2), the orbiter will tend to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.
- If the orbiter is landing with a known failed tire, the second tire on that axle is expected to fail during derotation at the point of maximum loading.
- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect.
- If the turning moments due to tire failure and crosswind are in the same directions, large control inputs will probably be required.
- If the turning moments due to tire failure and crosswind are in opposite directions, the control inputs required to counteract tire failure will be reduced. In this situation, pilots must be careful not to overcontrol. A good rule of thumb is to be more cautious with the rudder pedal, matching the crosswind turning tendency.
- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

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8. INTEGRATED OPERATIONS

CON	ITENTS	
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The most successful teams are those that have learned to work together and know each other's responsibilities, strengths, and weaknesses. In a system as complex as the space shuttle, the Mission Control Center (MCC), the Launch Control Center (LCC), and the flight crew must work as an integrated team with each part supporting and contributing to the performance of the other.

Each team member must be completely aware of his or her responsibilities and realize that safety and mission success depend on proper

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Flight Crew Duties for Dynamic Flight Phases.

It is critical few the crew to lay our responsibiliness early during training and follow their plan. As malforschons, occur, the division of responsibilities may change. For example, the PLT may have to concentrate on the projectury coordination among team members. The duties and coordination functions discussed in this section are typical of the responsibilities assigned by the CDR and the Flight and Launch Directors. Specific assignments will vary from mission to mission.

Preplanned decisions that have been approved by the Space Shuttle Program are published in the Flight Rules and Launch Commit Criteria. These are designed to minimize the amount of real-time discussions when off-nominal situations occur. The Flight Rules also serve as the basis for real-time decisions. Rules are developed using system performance capabilities documented in the Shuttle Operational Data Book (SODB), along with program certified capability. Where circumstances do not allow staying within the operating base (SODB + certified capability), the Mission Management Team may choose to take any necessary action to ensure the safety of the crew and shuttle.

During prelaunch and flight operations, the Mission Management Team (MMT) chairman is responsible for near real-time policy decision. The launch team and the flight teams consult with the MMT chairman as soon as possible whenever operations outside the shuttle operating base are required.

other members of the cone on fact proposed This is concerned and there when the post-one body worked are intervelated. The CDA and PLT much enter ar other machines the velocity one members of the creat machines the velocity trajectory and statistical awareness of morated fractilities where their effection is denote to different problems.

Orbit Phase

On order tasks are usually less time critical and response indices are reconcriticat as occasion is is important that more than one creationer in trained for each field task to protect for the percention when the porters creating on the delete is or base with another task. Massive might be major payload associate, for boardelete field in a porter payload associate. For boardelete field is major payload associate, for boardelete field is senter payload associate, for boardelete field is payload Commander and charged of

8.1 FLIGHT CREW DUTIES AND COORDINATION

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Dynamic Flight Phases

CONTENTE

For a shuttle flight crew to work well together, each crewmember needs to have his or her job clearly defined. This definition includes the tasks assigned and when they are to be performed. Individual responsibilities will be assigned by the mission commander based on mission requirements. One way in which duties might be divided for dynamic flight phases is summarized in the following table.

POSITION	PRIMARY	SECONDARY
CDR	Trajectory/Nav Abort Boundaries * DPS ECLSS Nominal Timeline Navaids ** Mission Success Mission Safety Voice Transmissions to MCC	Communications Flight Control Channels OMS RCS Contingency Abort Boundaries *
PLT	MPS EPS APU/HYD OMS RCS Flight Control Channels	Trajectory/Nav Navaids ** Mission Success Mission Safety Voice Transmissions to MCC
MS2	Overhead Panels Overhead Gauges Communications	Abort Boundaries * Navaids ** Nominal Timeline Reference Data
MS1	Contingency Abort Boundaries ** Photography Reference Data	Nominal Timeline Overhead Panels Overhead Gauges
MS3	Stowage Middeck Panels/Actions	Photography

* Ascent only ** Entry only

Flight Crew Duties for Dynamic Flight Phases

It is critical for the crew to lay out responsibilities early during training and follow their plan. As malfunctions occur, the division of responsibilities may change. For example, the PLT may have to concentrate on the trajectory while the CDR deals with an ECLSS malfunction. To ensure the trajectory is being monitored, especially during the early portion of crew training, the CDR could verbally ask the pilot to watch the gauges. As training progresses, crews gain an understanding of when another crewmember requires assistance and usually provide backup without being asked.

Another way crews work together is to monitor keyboard entries and switch throws. By allowing someone else to check a keyboard entry before it is fed to the GPCs or check that the correct switch is being actuated before it is moved, crewmembers can greatly reduce the chance of errors. For crewmembers to provide a good crosscheck for each others' activities, they must remain together as they work nominal and malfunction procedures. Calling out page numbers, procedural titles, and step numbers will help everyone follow through the procedures.

During dynamic flight phases, or any time when dealing with several malfunctions, it may be best to divide into groups or detail individuals to separate tasks to successfully deal with all problems in a timely manner. The CDR usually takes the lead in assigning tasks. As the proficiency of crews increases, crewmembers often assume responsibility without being formally assigned by the CDR. Whenever groups/ individuals begin working separate problems, they should attempt to periodically update the other members of the crew on their progress. This is especially critical when the problems being worked are interrelated. The CDR and PLT must exercise care to ensure that at least one member of the crew monitors the vehicle trajectory and maintains awareness of the nominal timeline when their attention is drawn to different problems.

Orbit Phase

On orbit tasks are usually less time critical and responsibilities are redistributed as necessary. It is important that more than one crewmember is trained for each flight task to protect for the occasion when the prime crewmember might be ill or busy with another task. Mission specialists usually assume the prime responsibility for major payload activities. For Spacelab flights, the senior mission specialist will be assigned as the Payload Commander and charged with



successful payload operations. The following table lists a sample division of duties for the orbit phase.

POSITION	CDR	PLT	MS1	PS2	MS2	MS3	PS2
EVA		10.01			X	1000	1.8
EVA 2	C-CL		a server			X	THE R. M.
IVA	and the second	X					
MEDIC	2	A Star		Property in	1	and the	
IFM	all of	1	a second	abrest	2	uspath	ind 1
EARTH OBS		2	1.5	29.1	1	hige !	Sec.
PHOTO/TV	10.0	2	111		1	1010	eif i
Prime Payload	2	1	200	11	502	19135	132-
Secondary Payloads	112	SSX 3	X	X	1322	(Lacas)	are :
DTO XXX	1	and the	1999	Aret	Carles	2	12.1
DSO XXX	22362		10/3/3	1.1	Jacobs	1	2
1 Drimo		190.00	115,78	C.C.M. all	122	20000	17.00

2 Backup

On-Orbit Division of Responsibilities

Intercom Protocol

During ascent or entry most crews have a standard protocol of voice callouts to help them keep track of mission events. Typical callouts and associated displays for ascent and entry are listed in the following tables.

MET	EVENT	CALLOUT
00:00	SRB Ignition	DCR: Lift-off/102
00:30	Throttle Bucket	PLT: Throttle down
01:00	Throttle Up	PLT: Three at 104
02:12	SRB Sep	DCR: Pc < 50, Sep, 103, TMECOs converged
03:00	BSP 25. CL	MS2: EVAP OUT t coming down
08:00	MECO -30 sec	DCR: Coming up on MECO
08:32	MECO	DCR: MECO, MECO confirm, ET sep, 104, check targets
10:32	MECO +2:00	PLT Dump/start

Ascent Displays and Callouts

EVENT	CREWMEMBER	CALL		
MLS to state vector	MS	MLS		
A/L	MS	Approach & land, BF trail		
~5 K ft	PLT	Radar altimeter, 1 & 2 check good		
4K ft	PLT	4,000		
зк п	PLT	3000		
	MS	Boards%		
2K ft	PLT	2,000, Preflare next		
	DCR	Preflare, arm the gear		
	PLI	1 000 ft kte/PLT cell max EAS in preflare)		
IK IL	PLI			
500 ft	PLI	500		
400 ft	PLI	400		
300 ft	CDR	Gear down		
	MS	Boards%, gear is down		
300 200 70 70 ft -40 -30 -20 -5	PLT	ft,knots (steady rhythm)		
TD	PLT	Touchdown		
Shale of the second	DCR	Drag chute (if abort landing or high energy.)		
WOWLON	PLT	WOWLON (Call WOWLON when it occurs, HUD format changes.)		
185kts (Lakebed) 175KTS (Concrete	PLT	185/175 Derotate (Even without WOWLON)		
Drag chute deploy	CDR	Drag chute		
Derotation	PLT	Pitch rate(Report at a regular cadence during derotation. Target 1°-2° per sec concrete on 2°-3° per sec lakebed).		
Nosegear TD	PLT MS	WOW set (Manual by depressing ET SEP or SRB SEP PB) Load relief (or no load relief) NWS Fail - (if NWS light is on)		
Midfield	PLT	Midfield		
5K ft remaining	PLT	5,000 ft remaining		
140 130 120 110 100tt	PLT	ft, (Decel reading) (Target 6-8 ft/sec*)		
80 70 60 50 60 kts (±20)	CDR	Jettison (drag chute)		
40 kts	PLT	40 kts anso off		
Wheels Stopped	CDB	Wheels Stopped		
	ODA	miletis stopped		

Landing Comm Protocol

When a street

Flicht Crew Duties for Dynamic Englit 1048

It is critical for the cases to tay out resperation-tothes early during training and tolloar their plant. As mail-suctions accurs, the director plant componentialities may charage, for example, the ET may have to concernings on the inductory

8.2 WORKING WITH MISSION CONTROL

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To work well together, the flight crew and MCC must be aware of each other's capabilities. Integrated simulations, where members practice their roles on an actual mission, are one way in which the team members learn about each other. Another way is for members of the flight crew to observe in MCC during integrated simulations and for Flight Controllers to ride along and observe flight crews operating in the Shuttle Mission Simulator (SMS).

MCC Resources

While visiting MCC, crewmembers will notice that an immense amount of downlist data is available for Flight Controllers to analyze the performance of orbiter systems and follow mission activities. The downlist data is formatted on various displays with orbiter DPS keyboard entries, fault messages, and switch discretes available, as well as numerical parameters. Many of the parameters in the downlist data stream are not displayed onboard the orbiter. The flight control team also has access to inputs from the customer, direction from NASA management, weather observations and forecasts, engineering test data and analysis, systems performance histories, and radar tracking data.

To properly utilize this data, personnel are divided into groups concentrating on specific vehicle systems or operational functions, with each group led by a Flight Controller. The Flight Controllers pass information and recommendations over the intercom voice loops to the Flight Director. The Flight Director uses the information to make decisions on the proper conduct of the mission, and manages the flow of information to the crew via the CAPCOM or uplink commands.

Operations Monitoring and Control

Optimum MCC performance depends on successful receipt of telemetry and tracking data. Orbiter DPS or instrumentation failures, as well as communications failures, can quickly degrade the amount of assistance available from the ground. If possible, the CAPCOM will inform the crew whenever downlist data is lost or regained.

To track the crew's progress through the nominal timeline, Flight Controllers observe individual crew keyboard entries and switch throws via MCC displays. It is usually possible for the ground to follow the crew's progress without voice calls, but an occasional status call can be helpful. The crew can also help the ground by closely following the nominal timeline and by loading maneuvers with future start times well before they are required.

MCC will try to anticipate points in the timeline where an MCC GO is required for the crew to proceed, and call before the crew reaches that point. If the crew reaches a point where an MCC GO is required before MCC calls, they should ask for a GO.

When malfunctions occur, the controllers in MCC will usually see a trend develop in their data before the crew hears an onboard alarm. Whenever possible, and especially on orbit, MCC will attempt to warn the crew and advise a course of action before a fault message occurs. For failures that occur more rapidly, the crew will see a fault message first and the ground will see the problem a few seconds later in the telemetry data stream. After a few seconds to diagnose the problem, the responsible Flight Controller will advise the Flight Director on the proper course of action. On direction from the Flight Director, the CAPCOM will then relay the necessary information to the crew. Usually this transmission will include instructions to follow a procedure in the FDF, specific switch actions, or information on why a false alarm occurred. CAPCOMs will strive to use the precise FDF procedural titles and the same switch nomenclature listed on orbiter panels to minimize confusion. If the situation permits, the CAPCOM will also try to pass to the crew the rationale for the decisions that have been made, especially those involving resources not available to the crew.

Air-to-Ground Voice Communications

Flight crews should be aware that the monitoring of crew voice calls is given very high priority in MCC. Whenever the crew calls on air-to-ground, all discussions cease on the Flight Director's loop in order to concentrate on the crew's transmission. Crew calls to inform MCC of fault messages or advise the ground on progress through normal procedures can interrupt information flow in MCC. Advisory calls on progress through nominal procedures should be reserved for periods of reduced communications activity or for when the ground is having problems with downlist data. For confirmation of noncritical system problems, one plan that works well is to wait 15 to 20 seconds after the appearance of a noncritical fault message before calling the ground. This allows the ground time to digest the problem and call the crew, without interruption. Waiting for MCC to make the first call when noncritical fault messages occur should result in the quickest possible problem confirmation.

Of course, flight crew calls can be extremely helpful when MCC is experiencing data problems or when failures occur which require immediate attention. A crew call in these instances will focus MCC's attention on the problem brought up by the crew. Following are some appropriate calls to MCC that are not specifically required by procedure:

Acknowledging MCC transmissions.

- Reporting deviations from the timeline or from a procedure.
- Beginning/Ending postinsertion, deorbit prep, or major payload activities.
- Beginning/Ending malfunction procedures. (This call is generally not made for critical malfunctions or during periods of high workload.)
- Beginning major DPS reconfigurations or cockpit switch configurations.
- Shutting down a main engine, APU, or fuel cell, or taking electrical buses off line unless previously directed by MCC.

- Reporting engine failure, fire, DPS set splits, or flight control problems. (These problems may not be immediately apparent in downlist data.)
- Reporting any problem the crew desires
 MCC to give immediate attention.
- Calling MCC prior to MDM port mode/power cycle.
- Changing telemetry formats.
- Switching to alternate ACCU or PCMMU.
- Reporting headset, CCU, or ATU problems.

If practical, flight crews should obtain MCC confirmation of a malfunction before working a malfunction procedure. By the same token, crews should call MCC whenever beginning a malfunction procedure for deviating from the nominal timeline without MCC direction, if the pace of activities and communication status permits. During periods of high activity, MCC will assume that the flight crew is prioritizing problems and automatically working the necessary malfunction procedures as problems arise. In these cases, MCC will save voice confirmation and direction to work malfunction procedures for the most critical problems.

To minimize verbiage and confusion, standard phraseology is frequently used in calls between the orbiter and MCC. Some of these calls are summarized in the table on the next page. Standard abort mode boundary calls are presented in Section 6, Emergency Procedures.

Unplanned downmodes to manual flight control should be discussed with MCC if time and flight control performance permit.

Aborts or redesignation of landing site/runway should only be performed at the direction of MCC if air-to-ground communication is available. If air-to-ground communication is not available, or if mission safety is in question, the CDR assumes ultimate authority for mission decisions. In this case, the crew will use onboard procedures and flight rule summaries to take whatever action is required to safely conclude the mission.

CALL	MEANING
Roger	Your transmission has been received.
Wilco	Will comply with received instructions.
Say again/repeat	Repeat your last transmission.
Read back	Repeat the list of information just transmitted.
Good read-back	The information just repeated was correct.
Stand by	Wait, we will have an answer or be ready to listen shortly.
Stand by on the xx procedure	Wait, we will have a plan of procedure/action soon, do not execute the xx procedure.
Hold	Stop executing the mentioned procedure at the current step.
You are go for	You have permission to execute
The xx system is go	The xx system is working adequately.
Expect ratty comm due to	Expect degraded communication due to
in the blind	We can't hear you, but we're transmitting, hoping that you can hear us.
Lost data	MCC has lost vehicle downlink data, expect reduced MCC troubleshooting assistance.
Regained data	MCC has regained downlist data.
UHF only	MCC or orbiter transmitting or receiving on UHF only. May also mean loss of orbiter downlink data.
Comm check	Voice communication check, acknowledge and describe quality of transmission.
LOS	Loss of signal/without comm. Sometimes used to mean star/object no longer in view.
AOS	Acquisition of signal/good comm. Some- times used to mean star/object in view.
Abort	Execute theabort mode. MCC will also uplink an abort light.
Take TACAN	Accept TACAN for use by NAV software.
Take Air Data	Accept Air Data information for use by NAV and GNC software.
GoCSS	Take pitch and/or roll/yaw CSS as called.
GoAuto	Return to Auto Pitch and/or Roll/Yaw flight control. For Orbit Ops, select Auto DAP.
Check DAP	Ensure the DAP mode matches the mode mentioned in call.

Standard Air-to-Ground Voice Calls

Unless mission requirements dictate a cuttercent timetine, the crew will arrive at K9C 3 days, orior to launch. Circadian shifts are performed during this period, except for flights requiring large shifts and 34-hour operations. These preves start their circadian shift prior to departing Houston.

Cherk activities are conducted per a relaxed timeline centil the actual launch day, when the schedule is tightly controlled. Hasically, crew

Telemetry Uplink

In addition to voice communication, MCC has the capability to electronically uplink information to the orbiter. This capability is frequently used to reduce crew workload, uplink large amounts of information, or to uplink information where accuracy is critical. Crews may request that MCC uplink information rather than using a voice transmission if they feel it would be beneficial and if there is sufficient time for the ground to prepare the uplink. In extreme cases, the MCC also has the capability to uplink keyboard entries to the orbiter GPCs in the form of DEU equivalent uplinks. Common uplink information is shown below:

- Communication system configuration commands.
- State vector updates.
- Table maintenance block updates (TMBU) to alter software caution and warning limits.
- IMU compensation.
- OMS burn targets.
- Alternate landing site information.
- TIPS messages for daily execute packages. Contains flight plan and procedural changes, amplifying information, news from home, systems, and consumables status.
- Unscheduled TIPS messages containing information not conveniently passed using voice transmission.

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8.3 PRELAUNCH

0	0	AT	T	E	NI	T	C
C	U	IN	1	E	IN	1	5

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Mission Control Center	8.3-1
Launch Control Center	8.3-1

Prelaunch activities begin at KSC with the start of the launch countdown. For purposes of discussing responsibilities of the flight crew as they relate to the LCC and MCC teams, prelaunch is considered to start upon flight crew arrival at KSC.

Flight Crew

Crew activities at KSC are outlined in a letter promulgated by the Director of Flight Crew Operations Directorate (FCOD). All activities are coordinated by the FCOD Vehicle Integration Test Office. Each mission has different timelines, and activities vary among pilots, mission specialists, and payload specialists.

The flight crew is subject to Health Stabilization Plan restrictions. These limit direct contact to a small group of individuals who are especially badged as Primary Contacts. Thus, exposure of the crew to communicable diseases with short incubation periods is minimized.

Typical activities for the flight crew at KSC include:

- Shuttle systems briefing
- Countdown status briefing
- STA flights
- Weather briefing
- FDF review
- Preflight physical exam
- Equipment checks
- T-38 flights

Unless mission requirements dictate a different timeline, the crew will arrive at KSC 3 days prior to launch. Circadian shifts are performed during this period, except for flights requiring large shifts and 24-hour operations. Those crews start their circadian shift prior to departing Houston.

Crew activities are conducted per a relaxed timeline until the actual launch day, when the schedule is tightly controlled. Basically, crew members are responsible for their scheduled events.

Mission Control Center

The MCC is in a monitor mode during most of the launch countdown. Active participation is required for communication checks, weather coordination, and inputs to the MMT on shuttle systems anomalies.

Flight controllers and MCC support personnel are responsible for their own readiness for flight. This includes console and computer systems configuration and checks. All necessary materials required to support flight operations are positioned. The MCC shift teams usually begin their circadian shift during the countdown.

Launch Control Center

LCC personnel man consoles around the clock once the launch countdown commences. Each shuttle and ground system is monitored by one or more members of the launch team. The countdown is managed by an Orbiter Test Conductor responsibility for (OTC) who has accomplishment of all steps listed in the countdown Operations and Maintenance Instructions (OMI). Prelaunch OMIs implement checkout requirements designed to demonstrate operation of all testable subsystems within prescribed limits. The launch countdown OMI is performed under strict quality control. Any deviation is documented and must be accounted for, either by repair, replacement, or a waiver from the MMT. In certain areas, launch may be permitted with equipment losses, provided they are well understood to be isolated occurrences and not symptomatic of a generic problem.

LCC responsibilities include the conduct of the countdown OMI under the OTC's direction, systems monitoring, test and checkout, recording any deviations, making recommendations on system problems, and ensuring any violations of the Launch Commit Criteria are brought to the attention of the Launch Director.

The launch team is stationed in one of the firing rooms of the Launch Control Center building at KSC.

8.4	LAUNCH	
CON	TENTS	9 min 7 min 30 and
Fligh	t Crew	8.4-1
Missi	on Control Center	8.4-2
Laun	ch Control Center	8.4-2

Shuttle launches are complex interactive tasks, where each member of the LCC, MCC, and flight crew performs an integral part. For purposes of discussing responsibilities of each element, launch activities are considered to start at flight crew ingress into the shuttle.

Flight Crew

The flight crew enters the orbiter about 2 hours 45 minutes before launch. Prior to ingress, final weather and systems briefings are conducted and the crew dons their launch/entry suits (LESs).

Ingress is accomplished with the assistance of a suit technician and an astronaut support person (ASP). These individuals are part of the closeout crew who perform final shuttle checks on the launch pad.

Upon completion of ingress, activities are governed by the FDF Ascent Checklist, which summarizes crew tasks from the countdown OMI. These activities are presented in Section 5.

Crew responsibilities include responding to LCC and MCC requests per the checklist. Emergency procedures are discussed in Section 6.

As the launch countdown progresses, crewmembers will be asked to configure certain systems and make various keyboard entries. This direction will come from the OTC via airto-ground loops. The NASA Test Director (NTD) may also communicate with the crew via air-to-ground loops, especially if an off-nominal situation occurs. MCC inputs are voiced to the crew by the CAPCOM, who also utilizes the airto-ground loops. The crew normally uses air to ground to respond to LCC or MCC calls during the launch count. The LCC has the capability to transmit to the crew using $A/G \ 1$, $A/G \ 2$, or A/A loops. Normally, only one loop is used at a time. The MCC transmits simultaneously on all three loops. Occasionally, this causes an echo because of different time delays. The crew should report this phenomenon to MCC because the delays can be adjusted in real time to remove the echo. Normally the LCC OIS 212 loop, which is used for the direction of launch activities, will be patched into the A/G loop for the crew to monitor.

The LCC also has the capability to talk and listen on ICOM 1 and ICOM 2. Transmission on these loops is restricted to a small number of consoles in the Firing Room. If the LCC enables a patch, the entire launch team can receive ICOM conversation. This patch is normally disabled. ICOM is used only as an emergency backup to the A/G and A/A loops. The ICOM loops are routed through the T-0 umbilical. A/G and A/A loops are RF transmissions through the MILA ground station.

Weather aircraft observations may be patched directly into one of the RF loops if necessary. This will allow the shuttle crew to communicate directly with the weather aircraft crew.

Certain other consoles in the LCC have the capability to transmit directly to the crew. These include the Launch Director, Landing Recovery Director, and Shuttle Operations Director.

All voice loops are recorded continuously. This includes both ICOM loops, all three RF loops, and all LCC/MCC channels.

The maximum time the crew will remain in the shuttle in the event of a launch scrub is 5 hours 15 minutes, excluding safing and egress time. This allows 2-1/2 hours of hold time after the earliest planned launch time.

Prior to actuation of any shuttle switches or controls other than those called out in the checklist, the crew should inform the OTC. This will prevent the LCC team from recording an unplanned configuration change that could cause a launch hold. This is particularly important in the final minutes of the countdown.

Mission Control Center

The MCC Flight Director is responsible for calling a launch "hold" for all problems that jeopardize the ability to safely monitor and recover the shuttle and crew after launch. This includes problems in:

- MCC
- Spacecraft tracking and data network
- Landing area facilities
- Abort landing area weather

In addition, the Flight Director is responsible for overall control of the MCC command uplink capability.

Individual flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

The LCC Launch Director is responsible for giving the launch team the final go for launch. A formal poll of all elements is taken by the chairman of the MMT during a planned countdown hold at T-9 minutes. If all elements are go, the Launch Director is given permission to proceed with the launch countdown.

The Launch Director is also responsible for making a decision on weather acceptability at the launch pad for ascent trajectory.

When the countdown clock is restarted at T-9 minutes, all operations are under control of a computer system called the Ground Launch Sequencer (GLS). Shuttle systems are automatically configured and monitored by the GLS.

Preplanned hold points for troubleshooting are available in the final 9 minutes of the countdown. These hold points, called GLS milestones, allow the countdown clock to be restarted without recycling back to some previous time. GLS milestones are shown in the following table.

TIME TO LAUNCH	EVENT
9 min	GLS sequence start
7 min 30 sec	Access arm retract
5 min	APU start
4 min	Purge sequence 4
2 min 55 sec	LOX pressurization
1 min 57 sec	LH2 terminals replenish
31 sec	Go for RSLS auto sequence

If a hold command is issued between T-9 minutes and T-31 seconds, the countdown clock will be restarted upon successful resolution of the problem without a "GO" survey made of all elements. After T-31 seconds, only a cutoff is available. Cutoff will result in a recycle to T-20 minutes. Depending on launch window, another launch attempt may be possible.

At T-31 seconds, the GLS issues a command to the onboard GPC Redundant Set Launch Sequencer (RSLS) software. This command, GO FOR AUTO SEQUENCE START, enables the RSLS to reconfigure certain onboard systems such as the vent doors, start the main engines, and issue the SRB ignition commands. Throughout this period, the GLS continuously monitors various system parameters and will issue an automatic cutoff should the Launch Commit Criteria be violated.

If a cutoff command is issued, the RSLS will automatically shift control back to the GLS. A program is then automatically started, which safes the shuttle systems. If this GLS safing program does not run automatically, then LCC controllers safe the systems manually by issuing appropriate commands.

Throughout the countdown, individual LCC controllers are responsible for monitoring their systems and executing commands per the countdown OMI. Any deviations or anomalies are reported to the OTC.

8.5 ASCENT

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Mission Control Center	8.5-1

The ascent flight phase starts at SRB ignition and continues through OMS-2 cutoff. This is one of the most dynamic phases of a shuttle flight.

Flight Crew

The flight crew is responsible for monitoring vehicle performance and systems and executing procedures on the nominal timeline. Flight crew and MCC coordination is most critical in this phase of flight because of the time-critical nature of most activities. General crew and MCC coordination is discussed in Sections 8.1 and 8.2.

Mission Control Center

The Flight Director is responsible for overall direction of shuttle flights from SRB ignition until crew egress after landing. The Flight Director, after analysis of the flight condition, may choose to take any necessary real-time action required to ensure the safety of the crew and shuttle.

Deployment of a payload or experiment operations fail into this category. Other activities are not time critical. For example, crew exercise can be accomplished on a not-tointerfere basis.

Based on preflight assignments and training, each encommenter will have certain responsibilities. Most crows designate backup crowmenters for critical activities. These backup crewmenters society nantly all of the training that the prime crewmenter receiver. This policy provides the necessary schuidancy that might be required in the event of unforcesion circummunces, such as an injured crewmenter or an unploated contingency. A typical list of duty assignments is shown in performenter in an MCC has the prime responsibility for abort mode determination, since the abort region determinator (ARD) program can assess shuttle abort capabilities in real time. Data from independent ground radar tracking, along with telemetry of the current onboard state, is used in the ARD.

Each flight controller on the MCC team has specific responsibilities, based on discipline. For example, the Booster Officer monitors SRB, SSME, and MPS performance and informs the Flight Director of malfunctions and recommended actions.

Many voice loops are used within the MCC. All controllers have a responsibility to monitor the Flight Director loop and air-to-ground loops, in addition to their own internal and external communication loops. Because the workload can be quite high during off-nominal situations, the crew can help by minimizing air-to-ground calls when possible. Also, allowing time for the MCC to formulate an action, coordinate it among several disciplines, and transmit it back to the crew prior to making additional transmission will aid in MCC/crew teamwork.

In the ball, is the province of system. Shows of the communications, link, and the contained system is included in this restantiability. The fold? In the designated coulds point and approval of all types of commands, including these sent to payloads. With the exception of another communications systems commands uplieds directly effect the systems being and by the dight crew for control of the orthiter or payload. To ensure that the flight crew has communication is lost MCC has a responsibility to address are near sent directly each payload. To ensure that the flight crew has communication is lost MCC has a responsibility to address are many boyload systems that is and payload. To ensure that the flight crew has communication is lost MCC has a responsibility to address the flight crew when command payload commands are sent directly each minimum. The flight crew when command

8.6 ORBIT

CONTENTS	
Flight Crew	8.6-1
Mission Control Center	8.6-1

The orbit flight phase starts at OMS-2 cutoff and continues through deorbit burn ignition. Nearly all mission objectives are accomplished during the orbit phase.

Flight Crew

The crew is responsible for monitoring vehicle systems and executing the nominal timeline. Operating primary and secondary payloads is the major user of available time. This is the most benign portion of a shuttle mission in that time is usually available to perform in-depth troubleshooting of any malfunctions. Crews and MCC will take advantage of the available time to thoroughly troubleshoot malfunctions. General crew and MCC coordination is discussed in Sections 8.1 and 8.2.

Execution of on-orbit tasks, as called out in the Flight Plan and other FDF documents, is the responsibility of the crew. Some tasks must be accomplished on a very strict timeline. Deployment of a payload or experiment operations fall into this category. Other activities are not time critical. For example, crew exercise can be accomplished on a not-tointerfere basis.

Based on preflight assignments and training, certain each crewmember will have responsibilities. Most crews designate backup These crewmembers for critical activities. backup crewmembers receive nearly all of the training that the prime crewmember receives. This policy provides the necessary redundancy that might be required in the event of unforeseen circumstances, such as an injured crewmember or an unplanned contingency. A typical list of duty assignments is shown in Section 8.1.

Mission Control Center

The MCC is responsible for onboard navigation maintenance. Adequate navigation and maneuver definition will be maintained onboard to provide runway landing capability after loss of communication. The Flight Rules specify navigation state requirements.

Individual flight controllers monitor onboard systems and make recommendations to the Flight Director for any changes or reconfiguration. In some cases, uplink commands may be used to perform certain tasks such as antenna management or limit changes (to prevent nuisance alarms).

The Flight Activities Officer and the Payloads Officer are responsible for tracking the Flight Plan and payload activities, respectively. When there is a remote Payload Operations Control Center (POCC), responsibility for the major payload activity (such as Spacelab) resides with the POCC Director. Other payloads, such as middeck experiments, are still controlled by the MCC Payloads Officer. Changes to the Flight Plan, updates to the orbiter attitude and pointing, and replanning are the responsibility of the Flight Activities Officer.

The Integrated Communications Officer (INCO) in the MCC is responsible for operation of the MCC and shuttle command system. Status of the communications link and the command system is included in this responsibility. The INCO is the designated control point and representative of the Flight Director for approval of all types of commands, including those sent to payloads. With the exception of routine communications systems commands and nonhazardous commands, most command uplinks directly affect the systems being used by the flight crew for control of the orbiter or payload. To ensure that the flight crew has current shuttle and payload system status, if communication is lost, MCC has a responsibility to inform the flight crew when command Typically, several uplinks are transmitted. hundred commands are sent during each mission. The majority of these are transparent to the crew and do not require coordination.

8.7 ENTRY

CONTENTS	
Flight Crew	8.7-1
Mission Control Center	8.7-1

The second dynamic phase of a shuttle mission is entry. For purposes of discussing team responsibilities, entry activities are considered to start at deorbit burn ignition and continue through rollout.

Flight Crew

The crew is responsible for monitoring vehicle trajectory and systems and execution of the nominal timeline. The pace of activities during entry is generally not as severe as that experienced during ascent until the beginning of TAEM. Depending on inclination and altitude, communication with MCC may not be available for the deorbit burn and part of entry. Crews should be mentally prepared to carry out mission activities without MCC assistance during the deorbit burn and early portion of entry.

Crew duty assignments during entry are similar to those for ascent. General crew coordination and working with MCC are discussed in Sections 8.1 and 8.2.

Mission Control Center

MCC has the prime responsibility for deorbit burn targets. Factors in the selection include shuttle systems status, consumables, c.g. control, weather, and other landing site information. Although the crew has onboard capability to generate deorbit targets in an emergency, the MCC team, with their extensive capability, will normally calculate and uplink planned targets.

Upon completion of the deorbit burn, MCC is responsible for monitoring the entry trajectory and status of the onboard systems. Should a malfunction occur and be confirmed by the MCC, the crew is expected to work the appropriate cue card or pocket checklist procedure with no further direction. Activities outside the published procedures will be requested by the MCC.

If the trajectory diverges and approaches energy limits, the Flight Dynamics Officer will perform a GCA. Procedures are discussed in Section 7.

The communication workload during entry is similar to ascent with numerous loops in use. The crew can help to simplify the process by minimizing air-to-ground calls and allowing time for the MCC to develop a coordinated decision.

8.8 POSTLANDING

CONTENTS

Flight Crew	8.8-1
Mission Control Center	8.8-1
Launch Control Center	8.8-1

Postlanding activities start at completion of rollout and continue through crew egress. The LCC and convoy commander have certain responsibilities during this phase.

Flight Crew

After wheels stop, crew activities are controlled by the FDF Entry Checklist which summarizes crew procedures from the postlanding OMI. Normal activities include shuttle safing and systems reconfiguration for extended power up. These are described in Section 5, Normal Procedures.

The crew responds to MCC requests for activities outside the normal procedures. For example, certain reconfiguration procedures might be modified because of previous systems failures.

Communication with the convoy commander is established shortly after wheels stop. The convoy commander controls postlanding activities in the vicinity of the shuttle and can pass information about hazardous situations to the flight crew.

Mission Control Center

The MCC retains responsibility for orbiter systems until crew egress or ground support equipment (GSE) cooling activation, whichever occurs later. At this time the Flight Director hands over control to the Ground Operations Manager (GOM). Should MCC voice and telemetry be lost, or if an emergency crew egress is required, handover to the GOM will be accomplished ASAP.

While the MCC is controlling ground operations, flight controllers are responsible for monitoring their systems and interfacing in real time with their counterparts in the LCC.

Launch Control Center

Until handover, the LCC monitors the progress of shuttle safing and reconfiguration. LCC data monitoring is available to the GOM if loss of MCC system insight and communications capability occurs. In this case, handover will occur ASAP so that normal postlanding operations can continue. Should LCC monitoring capability be lost, the MCC will continue to support until LCC capability is regained or the shuttle is powered down.

Once handover is complete, the GOM and OTC have responsibility for all shuttle activities. The OTC coordinates completion of postlanding procedures and preparation for turnaround operations.

8.8-1

9. PERFORMANCE

CONTENTS

9.1	ASCENT	9.1-1
9.2	ORBIT	9.2-1
9.3	ENTRY (OPS 304)	9.3-1

This section contains information regarding the performance capability of the space shuttle during ascent, orbit, and entry (EI to wheels stop). Some performance related material is also included. The information presented is accurate but is usually derived from representative 28.5° and 57° missions. It is not intended for mission planning. The information is presented only for the purpose of broadening the crew's fundamental understanding of the vehicle's performance capabilities during each flight phase under the stated conditions. Mission-specific questions or requests for more detailed explanations should be referred to the appropriate Flight Design and Dynamics Division (DM) personnel.



Cargo Weight vs. Circular Orbital Astiguile St. Inclinatio

9.1 ASCENT

C	0	NI	T	EN	T	T	S
C	U	IN	1	EI	N	1.	9

Payload	9.1-1
Launch Window	9.1-2
Squatcheloids	9.1-4
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Altitude, Velocity, and Dynamic	
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Minimum Safe Orbit	9.1-10

Payload

The graphs below indicate the maximum weight payload that can be launched to a particular circular orbit with a 28.5° or 57° inclination. Also shown is the higher altitude capability of a direct insertion versus standard insertion mission profile, as well as the performance increase available using 109 percent versus 104 percent main engine power.



Cargo Weight vs. Circular Orbital Altitude 28.5° Inclination



Cargo Weight vs. Circular Orbital Altitude 57° Inclination

Launch Window

The launch window for a rendezvous mission must satisfy several constraints. A major factor determining the window is ensuring that the orbiter has sufficient performance capability (plus reserves) to achieve a coplanar orbit. The chart at the right (for a 28.5° mission) indicates the additional performance required if the launch occurs prior to the "in-plane" time. The window for a 57° mission is approximately 15 minutes (such a rendezvous has not been required).

The launch window developed for each shuttle mission delineates the period in which the orbiter can be launched without violating shuttle and/or payload constraints. Whenever possible, launch windows will protect daylight (sunset + 15 min) abort and end-of-mission (EOM) landings. The following three charts depict the launch windows for three shuttle missions. The launch windows for STS-50 and

STS-46 were constrained by lighting. The shape of the STS-53 launch window was dictated by the right ascension ascending node (RAAN) requirements of the mission payload.







STS-50 Engineering Launch Window Chart

9.1-2









Squatcheloids

Squatcheloids are curves that define the q-alpha (product of dynamic pressure (q)) and angle of attack (alpha) and q-beta (product of dynamic pressure) and sideslip angle (beta) limits of the orbiter first stage ascent. These q-alpha and q-beta limits are determined by the design limits of various orbiter structural components. The graphs show three representative squatcheloids for Mach 0.6, 1.25, and 2.20.



- Composite allowable flight contstraints (Greenlines), Nov 1989
- Constraint Envelope Limitations
- 0 Ascent Only
- 0 Estimated, based on V6.0 margins
- 0 Aero surfaces only
- 0 For IVBC-3 ground rules, constraints: Other nominal trajectory criteria may alter constraint envelope 0 Vertical tail loads ensure 1.4 safety factor
- 920.cvs

Mach = 0.60 Restricted Squatcheloid and **IVBC-3 Loads Squatcheloid**



- X Integrated vehicle baseline configuration -3 (IVBC -3) loads analysis
- Composite allowable flight contraints (Greenlines), Nov 1989
- Constraint Envelope Limitations
- 0 Ascent only 0 Estimated, based on V6.0 margins
- 0 Aero surfaces only
- 0 For IVBC-3 ground rules, constraints: Other nominal trajectory criteria may alter constraint envelope
- 0 Vertical tail loads ensure 1.4 safety factor 921.cvs
- Mach = 1.25 Restricted Squatcheloid and **IVBC-3 Loads Squatcheloid**


- 0 Aero surfaces only
- 0 For IVBC-3 ground rules, constraints: other nominal trajectory criteria may alter constraint envelope
- 0 Vertical tail loads ensure 1.4 safety factor 922.cvs

Mach = 2.20 Restricted Squatcheloid and IVBC Loads Squatcheloid

Main Engines

Prior to each mission, after day-of-launch winds and propellant loadings are known, the main engine propellant at MECO is calculated (including dispersions). The Space Shuttle Program Flight Performance Reserve (FPR) is the difference between propellant loaded and propellant required for the ascent profile. The FPR normally used for mission planning is 4652 lb. The FPR must be positive when recalculated on launch day using measured wind data.







One percent MPS propellant is approximately equal to 15,310 lb of LO2/LH2.

Altitude, Velocity, and Dynamic Pressure

The following three charts depict ascent altitude, velocity, and dynamic pressure as a function of MET for actual 28.5° and 57° missions.















MECO Targets

The direct insertion MECO target line charts depict the inertial velocity and inertial flight path angle required for various apogee altitudes for 28.5° and 57° missions.

ET Impact

The following map shows the projected ET impact areas for 28.5° and 57° (<190 and >190 n. mi.) standard and direct insertion missions given nominal performance and a nominal ET separation.



ET Impact Areas

Abort Mode Boundaries

Abort Mode Boundary charts are computed for each mission depicting the abort options available from launch until MECO. Two TAL site capability is required (three preferred), and no abort gaps are permitted for single engine out aborts. The MET/inertial velocity on the left of each abort bar gives the earliest time and velocity possible for the successful use of that abort mode. The MET/inertial velocity on the right of the bars indicates the last opportunity for that mode.



Abort Mode Boundaries - 28.5° Mission

Minimum Safe Orbit

If the orbiter is inserted into an off-nominal orbit, Mission Control will ensure that the vehicle has sufficient orbital lifetime. The lowest perigee that will guarantee the minimum orbital lifetime is a function of apogee and the delta time to the next prime deorbit opportunity. Reference Flight Rule 4-51 for more details. The following chart shows approximate time on orbit versus apogee and perigee for low inclination insertion.



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9.2 ORBIT

CONTENTS	
Drag	9.2-1
Period	9.2-1
Perturbations	9.2-1
OMS/RCS	9.2-2

Drag

Aerodynamic drag is a factor that must be considered when planning on-orbit performance capabilities. This is taken into account by Mission Control in evaluating orbital lifetime. The following chart indicates the incremental velocities required to maintain a specified orbit during a 24 hr period. Notice that the velocity requirement is approaching 0 at 160 n. mi. (nominal orbital altitude).



Aerodynamic Drag Effect On Orbital Velocity Chart

Period

As orbital altitude increases, the time it takes the shuttle to complete a full orbit also increases, independent of inclination. The following chart plots these approximate times (orbital periods) for various orbital altitudes.



Orbital Period vs. Altitude

Perturbations

While each orbital period takes approximately 87 - 96 minutes, the Earth has completed a fraction of its full 360° rotation per day. That fractional portion will cause subsequent groundtracks to be displaced westward an equivalent amount, based on this simple formula:

				Westward Displacement
360 deg ×	1	hr	× period min =	deg
24 hr	60	min	1 orbit	1 orbit

Given an 87- to 96-minute range of periods, each successive orbit will be displaced 21.75° to 24° west with about 22.5° nominal (160 n. mi. orbit).

INIS/RCS Estimated Performance

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If the orbiter's track were influenced only by the period of the orbit, at the end of the 16th orbit (90-minute period), the track would be expected to go directly over the launch site. This does not occur due to another force influencing the orbit. Nodal regression will shift the track approximately 7.5° west (for a 28.5° X 160 n. mi. orbit) each 24 hr. This force on the vehicle is caused by the gravitational impact of the equatorial bulge. The chart below depicts the nodal regression for various low-Earth orbits. It can be seen that higher orbital altitudes and inclinations diminish the amount of the perturbation.



Nodal Regression

OMS/RCS

On orbit, the vehicle's performance capability is dictated by the amount of usable OMS/RCS propellant minus the amount required for deorbit, entry, and reserve. This performance capability can be maximized by using the most efficient burns possible for mission accomplishment and attitude/altitude control. The charts on the next page provide a convenient "quick look" method for determining the performance penalty for OMS/RCS use.



Admidynia 12 ade

being

As termined allottade increases, the firme of bases of shourds to complete a null orbit also, ing page undependent of inclination. The following clasplots there approximate times (orbital period for vortices orbital altitudes.

Green an RP to Shamate range of periods millionecondre acht will bereingdared 21.75 to 24° metr with shoul 22.3° nominal (1ed a. miartell).

1%	OMS =	130 lbs	propellant
	01110		

1% RCS = 22 lbs propellant

		AV	SEC)								
					RCS					ON	IS
OBBITER + X			- X	±Υ	+ Z			- 7	z		
WEIGHT	HIGH	NORM	NORM	NORM	HIGH	NORM	LOW	HIGH	NORM	TWO	ONE
(1000 LB)	1	2	1,2	1,2	2	1,2	2	3	1,2	ENG	ENG
180	0.61	0.31	0.32	0.22	1.29	0.43	0.05	0.98	0.61	2.14	1.07
200	0.55	0.28	0.29	0.20	1.16	0.39	0.05	0.88	0.55	1.93	0.97
220	0.50	0.25	0.26	0.18	1.06	0.35	0.04	0.80	0.50	1.75	0.88
240	0.46	0.23	0.24	0.17	0.99	0.33	0.04	0.72	0.46	1.60	0.80
260	0.42	0.21	0.22	0.16	0.94	0.32	0.04	0.65	0.42	1.48	0.74

DAP CODE 1 = TRANSITION 2 = ON ORBIT 3 = ET SEP ONLY

		PROPELLANT USAGE TO START, MAINTAIN, AND STOP A 115 DEGREE ROTATION MANEUVER (LB)											
	ROTATION	RC	DLL	PIT	СН	YA	W	3-A	XIS				
JETS	RATE (DEG/SEC)	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT				
RCS	0.2	1.4	5.7	2.0	6.5	1.6	8.3	2.0	9.6				
RCS	0.2	10.3	23.9	13.1	28.3	9.0	20.3	8.8	20.2				
RCS	0.5	8.2	20.7	10.0	19.4	10.2	21.0	10.6	18.2				
RCS	1.0	6.8	23.7	12.9	22.4	13.2	24.1	16.5	26.9				
PRCS	2.0	6.4	34.2	22.0	32.7	21.0	36.6	30.2	45.5				

[AVERAGE ORBITER ACCELERATION (DEG/SEO ²)											
I	BOTATION	NORM	LOW	PRCS								
I	MANEUVER	PRCS	FWD	AFT	YRCS							
I	± Roll	0.923	\times	\times	0.021							
	+ Pitch	1.230	0.696	0.534	0.019							
1	- Pitch	0.851	0.478	0.373	0.008							
1	+ Yaw	0.703	0.449	0.242	0.014							

				ALU			PROPE	LLANT	USAGE	FORTE	RANSLA	TION M	ANEUV	ERS (LB	/FPS)		
	P. P. M.			A.R.		RCS											
BITER C.G. SHIFT		OBBITER	+ X		- X		±Υ		+Z		+ Z (LOW)		- Z				
ON	IS/RCS U	SAGE		WEIGHT (1000 LB)	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	OMS
	X _{c.g.}	Y c.g.		0.2	0.5	20.8 23.1	19.6 21.8	4.1 5.1	8.6 9.3	25.2 27.4	7.5 8.1	12.5 14.1	140.0 159.0	117.0 132.0	10.5 11.3	18.9 21.2	17.9 19.8
CS CS S	-0.36 +0.11 +0.13	0 0.04 0.04	25	0.5 1.0 2.0	0.5 0.5 0.5	25.4 27.7 30.0	24.0 26.2 28.4	6.1 7.1 8.1	10.0 10.7 11.4	29.6 31.8 34.0	8.7 9.3 9.9	15.7 17.3 18.9	178.0 197.0 216.0	147.0 162.0 177.0	12.1 12.9 13.7	23.5 25.8 28.1	21.8 23.8 25.8



OR FOF

FRO ARO

ENGINE	SPECIFIC IMPULSE (SEC)	THRUST PER ENGINE (LB)	PROP FLOW RATE (LB/SEC)	PROP MIXTURE RATIO (OX/FU)
OMS	313.2	6000	19.16	1.65
PRCS	280.0	870	3.11	1.60
VRCS	265.0	24	0.09	1.60

	PRIMARY RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 3.5 DEG/AXIS)												
an aller and a	100	NM	120 NM		150 NM		200 NM		300	NM			
ORBITER	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT			
(-nop inertial	10.5	20.2	10.2	19.8	9.8	19.3	9.3	18.6	8.8	18.0			
-pop inertial	11.0	24.0	10.2	19.9	9.4	17.7	8.4	15.7	7.6	14.6			
Z-pop inertial	8.6	21.0	8.6	20.2	8.6	19.3	8.6	18.5	8.6	18.0			
(-pop -Z-LV	9.8	21.2	9.3	20.8	8.4	20.4	7.3	19.8	6.0	19.0			
-pop -Z-LV	10.3	18.0	10.1	17.8	9.8	17.5	9.5	17.1	9.1	16.5			
X sol inertial	10.4	20.8	10.4	20.4	10.4	19.9	10.4	19.4	10.4	19.0			
Z sol inertial	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9	10.0	19.9			
K-PSL PTC	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0	9.3	19.0			

	1.4-5	VERNIER RCS THRUSTERS PROPELLANT USAGE (LB/HOUR) (ATTITUDE DEADBANDS = 1.0 DEG/AXIS)											
	100	NM	120	120 NM		150 NM		NM	300 NM				
ORBITER	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT			
X-pop inertial Y-pop inertial Z-pop inertial X-pop -Z-LV Y-pop -Z-LV -X sol inertial -Z sol inertial	3.0 1.9 2.9 4.1 0.5 2.9 3.6	11.6 6.3 11.5 13.3 1.0 10.6 8.8	1.5 1.6 2.0 1.6 0.5 2.2 2.6	5.7 4.7 8.1 5.1 0.8 7.7 5.5	0.9 1.5 1.6 0.7 0.5 1.8 2.3	3.8 4.5 6.8 1.3 0.7 6.7 4.8	0.7 1.4 1.5 0.4 0.5 1.8 2.2 3.8	3.0 4.3 6.5 0.6 6.5 4.7 3.4	0.6 1.3 1.4 0.4 0.5 1.8 2.2 4.3	2.8 3.9 5.9 0.4 0.5 6.1 4.5 3.6			

936.cvs

OMS/RCS Estimated Performance

APPENDIX A PANEL DIAGRAMS

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F6	A-4
F7	A-5
F8	.A-6
F9	.A-7
Overhead	
01	A-8
O2	A-9
03	.A-10
05	.A-11
06	.A-12
07	.A-13
08	A-14
09	A-15
013	A-16
014	A-17
015	A-18
015	Δ_10
017	A-20
017	A 20
019	A-20
<u>Left</u>	
L1	A-21
L2	A-22
L4	A-23
L5	A-24
L9	A-24
L11	A-25
L15	A-26
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C2	A-27
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R12U A-35	
R12L	
R13U A-36	
R13L	
R15A-38	
Δft	
A1U A-39	
A1I A-40	
AIR A-41	
A2 A-42	
A3 A-42	
A4 A-43	
A6U A-43	
A6I A-44	
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A8U	
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MO29J	A-58
MO30F	A-58
MO32M	A-58
MO39M	A-58
MO42F	A-59
MO51F	A-59
MO52J	A-60
MO58F	A-60
MO62M	A-61
MO69M	
WCS	
Thermal I	mpulse
Printer	
Airlock	
AW18A	A-63
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AW82D	A-65
AW82H	A-66

D.L. Iners







Panel F6



Panel F7

APPENDIX A: PANEL DIAGRAMS



Panel F8







Panel O1

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anel O3

APPENDIX A: PANEL DIAGRAMS

APPENDIX A: PANEL DIAGRAMS

A-10



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Panel O3



APPENDIX A: PANEL DIAGRAMS

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Panel O5

SFOC-FL0884 Rev. B



O'Taus'



APPENDIX A: PANEL DIAGRAMS







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Panel O15



Panel O16

A-19

APPENDIX A: PANEL DIAGRAMS





Panel O19

APPENDIX A: PANEL DIAGRAMS





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Panel L1





APPENDIX A: PANEL DIAGRAMS

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Panel L4





Panel L11



Panel L15





APPENDIX A: PANEL DIAGRAMS

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Panel C2




APPENDIX A: PANEL DIAGRAMS



Panel R1



Panel R2



Panel R4



Panel R6







Panel R11U



Panel R11L





Pile Veloro



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Panels RELLAND 6128. (Masion Dependen



Panel R13L

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Panel R15



Panel A1U

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Panel A1L



Panel A1R



Panel A3



Panel A6U



Panel A6L







Panel A8U



Panel A8L



Panel A11 (OV10 only)

Panel A11 (OO103 and OV104 only)

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Panel A12



Panel A13 (OV-102 only)

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Panel A13 (All vehicles except OV-102)



Panel A14



APPENDIX A: PANEL DIAGRAMS





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Panel ML31C



Panel M185E







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Panel MO10W



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APPENDIX A: PANEL DIAGRAMS







Panel MO51F







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A-64



Panel AW82D



A-66

APPENDIX B CRT DISPLAYS

This CRT Reference Summary is for information only. It provides the CRT displays documented in the Level C Functional Subsystem Software Requirements Display and Controls Specification, STS 83-0020J dated JUNE 16, 1994 effectivity OI-25 and subs. CRT SM mission reconfigurable displays documented in JSC-19590-XXX Level C Flight Software Requirements document (where XXX represents the number of the specific OPS Flight).

This document reflects the incorporation of approved CRs listed in the OCT 1995 CR Implementation Baselines through OI-25. For detailed information, reference the above documents. For information pertaining to distribution, contact Jim Cox or Jeff Knight at (310) 922-0769.

Display Location

To aid in locating a display, two tables of contents are provided. Contents A lists displays in alphabetical order. Contents B lists the displays according to subsystems and in descending order of hierarchy OPS, SPEC, and DISP. In addition, three IPL-related displays are listed separately under "Special Displays," and six HUD displays are listed under "Head-Up Displays."

CONTENTS A - ALPHABETICAL

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			GNC				SN		PL	L vest				
Display	PFS	BFS	0	1	2	3	6	8	9	0	2	4	9	Page
ACTUATOR CONTROL	X								X					B-14A
ANTENNA	X	1-16									X	X		B-7A
APU/ENVIRON THERMAL	X	18									X		1000	B-90
APU/HYDRAULIC	X	Store B									X			B-9A
BES MEMORY		X	x	x		x	X			X				B-15A
BES OVERRIDE	100	X		X		x	X						222	B-160
BUS/BTU STATUS	X	100							X				X	B-13F
COMWECDE	X	1.2									x		1000	B-8E
CONTROLLERS (BM)	X							X					100	B-12F
CONTROLS	X	5.0		x		x	x			12			200	B-68
CRYO SYSTEM	X	1.10									x		1000	B-80
DAP CONFIGURATION	X	1.8			x								100	B-4E
DELISTAND-ALONE S/T	1.11	1.18											1000	B-140
DOCKING STATUS	1	X											1000	B-10A
DPSUTUTY	X	X	x	x	X	x	X	X	X		X	x	x	B-11D
FLECTRIC	X										x			B-88
ENTRY TRAL 1	X	X				x								B-3D,15E
ENTRY TRAJ 2	X	X				x								B-3E,15F
ENTRY TRAJ 3	X	690				x								B-3F,15G
ENTRY TRAL4	X	X				×								B-3G,15H
ENTRY TRAIS	X	x				x								B-3H,16A
ENVIRONMENT	X										X			B-8A
EVA/MMU/ FSS	x										X	X		B-8F

CONTENTS A - ALPHABETICAL (continued)

and a land					(GN	С			Ι		SM		F	2		234
Display	PFS	BFS	0	1	2	3	6	8		9	0	2	4		9	1	Page
FAULT	X	X	X	×	•	X	×	1		•	X	•	•		•	B-	11F,16E
FCS/DED DIS C/O	×							2						L			B-12A
FUEL CELLS	X				1							X		L			B-8D
GNC SYS SUMM 1	X	×	X		I×	X								1		t	5-6C,16F
GNC SYS SUMM 2	×	×	×		ľ	X	1			_				1			B-6D
GND IMU CNTL/MONITOR	×	1								Č				1			B-13U
GPC/BTU INTERFACE	X	1											1		~		B-13H
GPC/BUS STATUS		4	L.	IĈ.	13	Ľ	Ľ.			2	~	IĴ,	Ľ		~		B-11C
GPC MEMORY	×	1	ľ	 ^	1	P	P	1	~	~	~	1	Ľ	1	~		B-110
GPS STATUS	X	29								~			ľ	1	~	-	D 124
GTS DISPLAY										^					^		RED
HORIZ STI (IN-HIGHT)	L Û			10			î۱	Ĵ									B-SE
HORIZ SIT (OUT-HIGHT)	I Û			10			Ĵ	Ĵ									B-5G
HOHIZ SIT (UUT-LEFT)	10			13			Î	Ĵ									B-16C
HORIZONTAL SIT	L Û	1 û		ľ	Ì		1					L			1		B-184-D
	1Ĵ	1^															B-9B
HTDHAULIG THERMAL	1¢							×				ľ					B-4F
IMU ALIGN	10					$^{}$		^		1.							B-148
MANUAL CONTHOLS										1^				×	×		B-128
MASS MEMORY HW	^													-			B-114
MENUNO. 1 XXXIPL																E	B-11P
MENU NU. 2, GPCIPL	-										L	1					B-12H
NWSCHECK	10					~			ſ		L						B-50
OHBIT TARGETING							×	×									B-64
OVERHIDE	10				$^{}$		^	î					×	×			B-70
PCMMU/PL COMM	10									1			x	x			B-75
PCS CONTROL	10												x	x			B-70
PDHS CONTHOL	10												x	x			B-71
PORS OVERHIDE	10												-				B-96
PURS FAULTS	1 û										I		x				B-100
PDHSSTATUS												x					B-78
PL BAY DOORS													x	x			B-96
PLHETENTION													x				B-90
PHPLITHERMAL					×	×	×	×									B-4H
HUS	10					^	î	Î	ľ	١,							B-130
HUS/HUAVADIA TEST (P/P	'l 🗘																B-120
ONORBIT									ľ								
REL NAV	X					x								6			B-58
RMORBIT	X					x											B-5/
RTLS TRAJ 2		×						X									B-168
SENSOR TEST (ON-ORBIT	x								×		1						B-120
SENSOR SELF-TEST (P/F	x								ŀ	1							B-138
SL MEMORY DUMP	X																B-130
SM CRYO PALLET	X	×								L		x	•	•			B-10B,17/
SM GROUND CHECKOUT	X	1				8							X	X			B-78
SM SYS SUMM 1	×	×										X	•	•			B-8G, 160
SM SYS SUMM2	X	×										x	•	•			B-8H,16h
SM TABLE MAINTENANCE	EX									I			×				B-70
STAR TRK/COAS CNTL	X					X	X										B-40
SWITCHES	X								X	1							B-120
SWITCH/SURF FDBK (RM	n x								X								B-126
TCS CONTROL	X									P	9						B-138
THERMAL	1	X										×					B-158
TIME	X			×		X			X	P	9		X	X	X		8-116
UNIV POINTING	X					X					1						B-30
VERT SIT 1	X	X					X	×			I						8-4A,40
VERT SIT 2	X	X					X	X			1	1					D-40,4L
XXXXXX MNVR YYYYY	X	X			X	•	X				1	1					D-St
XXXXXXXX TRAJ					X						1						P. IEF
XXXXXXXX TRAJ 1 (ASCENT)		X			X			×			I						P.150
XXXXXXX TRAJ 2 (ASCENT)		X			×				L	L	L	1				1	DETOL
- INDICATES PES ONLY	AVAI	LABILI	TY														_

CONTENTS B-OPS DISPLAYS

CONTENTS B-SPEC and DISP DISPLAYS

OPS No.	Display	PFS	BFS	GNC	SM	PL	Page
0001	GPC MEMORY	X	1	x			B-11C
0001	BFS MEMORY	1. 3	x	×		0038	B-15A
0001	THERMAL		×		x		B-15B
1011	XXXXXXX TRAJ	×	KR	x		1000	B-3A
1011	XXXXXXXX TRAJ 1	1.00	x	x		2498	B-15C
1021	XXXXXXXX TRAJ	x		x	P. T. C. S.	366	B-3A
1021	XXXXXXX TRAJ 1	1 6	x	x		11111	B-15C
1031	XXXXXXX TRAJ	x		x			B-3A
1031	XXXXXXX TRAJ 2		X	X			B-15D
1041	XXXXXX MNVR YYYYY	x	X	×	15.00	1	B-3B
1051	XXXXXX MINVR YYYYY	X	X	X	1994		B-3B
1061	XXXXXX MINVR YYYYY	x	X	x	1.00	C.	B-3B
2011	ANTENNA	X			x	in the	B-7A
2011	UNIV PTG	x		x	100	113	B-3C
2021	PL BAY DOORS	x	8.91	X	x	1000	B-7B
2021	XXXXXX MNVR YYYYY	x	x	x			B-38
3011	XXXXXX MINVR YYYYYY	x	x	x	30	1000	B-3B
3021	XXXXXX MINVR YYYYYY	x	x	x			B-3B
3031	XXXXXX MINVR YYYYYY	x	x	X		1000	B-3B
3041	ENTRY TRAJ 1	x		x	100	and a	B-3D
3041	ENTRY TRAJ 1		x	x		100	B-15E
3041	ENTRY TRAJ 2	x		×		- mark	B-3E
3041	ENTRY TRAJ 2		x	x			B-15F
3041	ENTRY TRAJ 3	x		x			B-3F
3041	ENTRY TRAJ 3		x	x			B-15G
3041	ENTRY TRAJ 4	x		x		100	B-3G
3041	ENTRY TRAJ 4		x	x			B-15H
3041	ENTRY TRAJ 5	x		x			B-3H
3041	ENTRY TRAJ 5		x	x			B-16A
3051	VERT SIT 1	x	x	x			B-4A
3051	VERT SIT 2	x	x	x			B-4B
4011	ANTENNA	x		x	x		B-7A
6011	XXXXXXX TRAJ	x		x	-		B-3A
6011	RTLS TRAJ2		x	x			B-16B
6021	VERT SIT 1	×	x	x			B-4A
6021	VERT SIT 1 (GRTLS)	x		x			BAC
6031	VERT SIT 1	x	×	×			BAA
6031	VERT SIT 2	x	x	×			BAR
6031	VERT SIT 2 (GRTLS)	x	1	x			P 40
8011	FCS/DED DIS C/O	x	1	Ŷ			B-40
9011	MASS MEMORY R/W	×		^	×	×	B-12A
9011	GPC MEMORY			×	^	^	B-128

SPECIAL DISPLAYS

Display	Page
XXXXIPL MENU NO, 1	B-11A
GPCIPL MENU NO. 2	B-11B
DEU STAND-ALONE SELF-TEST	B-14C

HEAD-UP DISPLAYS

Display	Page
FORMAT 1 PRE-WOW	B-18A
FORMAT 1 AFTER WOW	B-18B
OPSBLOW	B-18C
OF B BLOW	B-18D

SPEC No.	Display	PFS	BFS	GNC	SM	PL	Page
001	DPS UTILITY	X	-	X	X	X	B-18D
002	TIME	X	124 2	X	X	X	B-11E
006	GPC/BUS STATUS	X	-	X	X	X	B-11G
018	GNC SYS SUMM 1	X		X	1		B-6C
018	GNC SYS SUMM 1	~	X	X	1110	71.25	B-16F
019	GNC SYS SUMM 2	Ŷ	~	Ŷ	1	12 201	B-6D
020	IMU ALIGN	x		x		Sec. 1	B-4F
022	S TRK/COAS CNTL	x	1000	x	1	A. C. C.	B-4G
023	RCS	x	Ter!	x	Circl.	data	B-4H
025	RMORBIT	x	1.30	X	X	XYI	B-5A
033	RELNAV	X	1	X		1 Carlos	B-5B
034	OHBIT IGT	×	1	×	10.00	23	B-5C
040	RGA/ADTA/RCS	x	8.358	Ŷ	15 2	1 252	B-120
042	SWITCH/SURF	x		x			B-12E
043	CONTROLLERS	x	100	x	Lee 2	Land Co	B-12F
044	SWITCHES	X		X			B-12G
045	NWS CHECK	X	1854	X	2	202.00	B-12H
050	HORIZ SIT (IN-RIGHT)	X	1.7	X	1 State	at 10	B-5D
050	HORIZ SIT (IN-LEFT)	x		×	-	6	B-SE
050	HORIZ SIT (OUT-LEFT)	x	Constant-	x		110	B-5G
050	HORIZ SIT	1892	x	x	1 mail	CLUT ?	B-16C
051	OVERRIDE	×	See.	1000	Ster	31/2	B-6A
051	BFS OVERRIDE		X	1	mer		B-16D
053	CONTROLS	X			1992		B-6B
155	GPS STATUS	×	×	~	~		B-5H
162	PCMMI/PI COMM	Ŷ	100	~	×		B-/C
063	PL BAY DOORS	x	x		Ŷ		B-70
064	SM GROUND CHECKOUT	x			~		B-7E
066	ENVIRONMENT	x	1000	1000	x	103	B-8A
67	ELECTRIC	X	2423	barri	X	350	B-8B
068	CRYO SYSTEM	X	4	×	x		B-8C
076	FUEL CELLS	×	100	1000	X	1100	B-8D
77	EVA-MMU/ESS	Ŷ	1112	100	Ŷ	1342	B-BE
78	SM SYS SUMM 1	x	1. 10	Con-	x	Sec.	B-8G
079	SM SYS SUMM 2	x		Sec. 1	x		B-8H
079	SM SYS SUMM 2		X		x	1	B-16H
085	MASS MEMORY R/W	X	14	128	X	610	B-12B
185	APU/HYD	X	an po	Section	X	10.00	B-9A
88	APU/ENVIRON THERM	×	12		×	200	B-9B
089	PRPLT THERMAL	x			Ŷ	×	B-9C
090	PCS CONTROL	x			^	^	B-7F
)94	PDRS CONTROL	X		x	X	and the	B-7G
95	PDRS OVERRIDE	X		X	X	220	B-7H
96	PDRS FAULTS	X	-	×	X	×	B-9E
198	FALLT	X		X		×	B-9F
999	FAULT	^	x	x	×	×	B-11E
00	GTS DISPLAY	x		x	^	^	B-13A
01	SENSOR SELF-TEST	x	1	x	at all	-	B-13B
02	RCS/RGA/ADTA TEST	X	1	X			B-13C
104	TCS CONTROL	X		X		and a	B-13D
06	MANUAL CONTROLS	×	18-11	X		~	B-13E
10	BUS/BTU STATUS	x	1.00	×	-	×	B-14B
111	SL MEMORY DUMP	x	A STATE	^		^	B-13F
12	GPC/BTU I/F	X	2	X	204	Set al a	B-13H
113	ACTUATOR CONTROL	X	1 1-	1		23	B-14A
68	SMCRYO PALLET	X	1	1	×	ALLET	B-10A
168	SM CRYO PALLET	×	×	1	×		B-10B
169	PDRS STATUS	x	~		×		B-17A
	a la la la la la la la		1		~		8-100



B-3

APPENDIX B: CRT DISPLAYS













C









APPENDIX B: CRT DISPLAYS



APPENDIX B: CRT DISPLAYS





GPS STATUS XX X DDD/HH:MM:SS BFS DDD/HH:MM:SS





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STAT

GPS1

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This appendix contains a set of study according originally developed by Comparison in September 1999. They have been and which monitors and applicable by several of the second of the many of the base of these bases in the provide monitors with a set of contail applicable monitors are that, can be revised in these monitors are that, can be revised in these monitors are that, can be revised in these monitors are the station. The new contains are det in the PLT convergention, but should be useful for applies are presented as well.

The Study Notes are organized alphabetically by major system. Under each system heading notes on critical subsystems and malfunctions are presented. The test is written in Flight Data File shorthand using switch nonvenclature and CRT display terminology, which results in a annowinat cryptic former. Although directed primarily toward Generic and Flight Specific training, they should be readily understood by creating they should be readily understood by

Preparation for Shuttle Mission Sheulator (SMS) treining sessions is difficult due to the complexity of the Space Shuttle and the many flight phases that creatmembers are required to understand. A speck review of these Study Notes prior to SMS sessions sheuld help make training more productive. ture pump least P. H.O. Indo care le manualization dearen excelediumen, and indines and Min J. In the segment indines and Propriation APDs with personally in

keppt running except by tigh di umpenature. An APU dill be anu down for high off temperature if Mach > A gention dailure for high oil an angention tailure for high oil

Auto Shutdown

Controller will use an auto shadown command, if auto chuidean is enabled for RPM less that 80% on above 12% (auto shutdown is inhibited for the first 9.5 seconds after start to allow burbine spinsp).

- Auto shuidown classe secondary fuel centrol velve and fast tonk valves.
- An APU with in noderspeed doublewin is a candidate for cooldown and restart.
- APUs with overspeed shutdown will not be restarted.
- If anto shutdown inhibited and APU speed is confirmed above 129%, manuel shutdown is required as soon as possible.



APPENDIX C STUDY NOTES

CONTENTS

APU/HYD	C-1
Comm-Voice Data	C-3
Cryo	C-4
DPS	C-5
ECLSS	C-6
EPS	C-7
GNC	C-9
Instrumentation	C-12
Mechanical Systems	C-13
OMS	C-16
RCS	C-18

This appendix contains a set of study notes originally developed by Ron Grabe in September 1989. They have been extensively modified and updated by several crewmembers and reviewed for technical content by the Training Division.

The purpose of these notes is to provide crewmembers with a set of critical "need-toknow" items that can be reviewed in their entirety at one sitting. The notes are directed at the PLT crew position, but should be useful for other crewmembers as well.

The Study Notes are organized alphabetically by major system. Under each system heading, notes on critical subsystems and malfunctions are presented. The text is written in Flight Data File shorthand using switch nomenclature and CRT display terminology, which results in a somewhat cryptic format. Although directed primarily toward Generic and Flight-Specific training, they should be readily understood by crewmembers who have progressed through at least part of Pilot Pool training.

Preparation for Shuttle Mission Simulator (SMS) training sessions is difficult due to the complexity of the Space Shuttle and the many flight phases that crewmembers are required to understand. A quick review of these Study Notes prior to SMS sessions should help make training more productive.

APU/HYD

General

- Ascent: all APUs will be kept running through MECO if possible.
- Loss of one APU means hydraulic lock on one engine.
 - Loss of two APUs means 2 SSMEs in hydraulic lock plus loss of TVC for one SSME.
- Entry
- Pre-TAEM, a sick APU (high oil temperature, high hydraulic temperature, pump leak P, H₂O leak) may be manually shut down, cooled down, and restarted near Mach 1 to support landing.
 - Post-TAEM, APUs will generally be kept running except for high oil temperature. An APU will be shut down for high oil temperature if Mach > 1. A gearbox failure for high oil temperature is not catastrophic.

Auto Shutdown

- Controller will issue an auto shutdown command, if auto shutdown is enabled, for RPM less than 80% or above 129% (auto shutdown is inhibited for the first 9.5 seconds after start to allow turbine spinup).
- Auto shutdown closes secondary fuel control valve and fuel tank valves.
- An APU with an underspeed shutdown is a candidate for cooldown and restart.
- APUs with overspeed shutdown will not be restarted.
- If auto shutdown inhibited and APU speed is confirmed above 129%, manual shutdown is required as soon as possible.

Art PUMP LA P shows build-up o leading oil or fuel in catch bottles Bottl

Single APU Loss

- APU 1 means loss of nose wheel steering (OI-21 and subs, hydraulic system 2 can also be used for nose wheel steering).
- Single APU loss will not affect braking (loss of APU 3 plus either 1 or 2 means half brakes).

Switching Valves

- Supply either primary or one of two back-up hydraulic systems to the aerosurface actuators.
- Valve status only visible on SPEC 86 (SM OPS 2).
- During FCS checkout, check active hydraulic system selected.

Fuel Tank

- Supply supports about 110 minutes of operations (AOA).
- Nitrogen pre-charge required for start-up.
- Pressure displayed on panel F8 meter.
- Quantity (CRT and meter) is a PVT calculation.
- Isolation valves must be closed (de-powered) when APU is not running. No fuel cooling of solenoid valves.
 - Post APU shutdown, if fuel tank valve temperature high, pull circuit breakers.
 - Solenoid short may overtemp valves while APU is still running. Pull circuit breaker for second valve in parallel. Will keep APU running.

Fuel Pump

- Gear driven pump delivers fuel under pressure post start.
- "APU PUMP LK P" shows build-up of leaking oil or fuel in catch bottle. Bottle relieves overboard.

Cooling

- GG bed cooled by separate H₂O injection system for re-start. H₂O system not used during normal ops.
- Cooling required for 3.5 minutes in *INJECTOR COOL* prior to start. If no cooling of GG injector apparent, do not perform restart.
- If APU not started immediately following cool-down, injector temperature will rise again rapidly.
- Common tank for all APUs. Cooling capacity is 21 minutes.
- Fuel pump and fuel control valves are cooled passively by heat sinks and radiation shields.
- Water spray boiler cools hydraulic and lube oil.
 - Bypass valve isolates hydraulic cooling feature when not required.
 - Two controllers (A and B) use common water lines but have different spray logic.
 - Water quantity should not decrease during ascent. Pre-charge in H₂O boiler immerses oil lines. No spraying until MET about 11:00.

Hydraulic Accumulator

- Maintains pressure of about 2600 psi when APU not running (hydraulic pressure still about 65 psi).
- Prevents hydraulic pump cavitation.
- Low accumulator pressure on orbit indicates nitrogen leak or internal priority valve or unloader valve failure.

Circulation Pump

 Two-stage pump. First stage low pressure, high volume. Second stage high pressure, low volume. High pressure fluid can be diverted to repress accumulator. Otherwise, high pressure fluid mixes with low pressure fluid.

- On orbit, automatically turns on (when pressure < 1960 psi) to maintain accumulator pressure.
- Circ pumps keep hydraulic fluid moving for thermal conditioning on orbit. Automatically turn on for low hydraulic line temperatures.
- Only one circ pump operates at a time in GPC control for electrical loads considerations. The system with low accumulator pressure has higher priority than the system with low hydraulic line temperatures. For thermal reasons, two circ pumps at a time are OK if needed to recharge two accumulators.

Priority Rate Limiting

- Gets 3 hydraulic pressure inputs from each system.
- Crew can see 2 of the inputs on BFS SYS SUMM and F8 meter. MCC has access to all three inputs.
- Crew can also see hydraulic accumulator pressure which PRL doesn't see.
 - Use hydraulic accumulator pressure and RPM to resolve dilemma.
 - Accumulator pressure = 3000 means hydraulic system OK.
- PRL will show down arrow if declaring system down.
- SPEC 51 data:
 - AUT* means auto logic is active
 - DES* means manual deselection (toggle to reselect).
- For PRL ? and system good, leave auto logic selected.
 - Subsequent transducer fail may require deselect of auto logic and a manual deselect or reselect.
- For PRL down arrow and system good, deselect auto logic to reinstate hydraulic system into PRL.

Manual Shutdown

- Used to back up auto shutdown.
- Controller power off protects against uncommanded hot re-start.
- Must identify over or underspeed shutdown prior to controller power off (caution and warning light extinguished).

Ready-To-Start Talkback Gray

- · Low press selected.
- H,O spray boiler ready.
- APU fuel isolation valves open.
- GG bed temperature > 190 degrees.
- APU speed below 80%.
- Underspeed immediately after start is probably caused by 9.5 second timer failure. Auto shutdown is normally disabled during first 9.5 seconds of start. AUTO SHUT-DOWN to INHIBIT may allow start.

Comm-Voice Data

General

- *PANEL/CMD* on panel C3 switch passes Sband control to system selected on aft panel. One step total reconfiguration to alternate system.
- Normally, INCO manages system on LRU by LRU basis. All LRUs are system 1/system 2 redundant.

ACCU

- Routes all audio to ATUs.
- No voice (ICOM and A/G), switch ACCUs.
- CDR and PLT can talk to each other on same ATU without an ACCU.

Antenna Electronics Unit

- Switches antenna per GPC or RTC command.
- BFS commands for ascent and entry.
- SM GPC command on orbit with BFS in STBY or HALT.
- Commands routed to antenna electronics 1/2 over PL MDM 1/2. No cross-strapping capability.
- Manual selection available with loss of auto select.

Ascent/Entry Configuration

- S-band system 2 active in STDN mode.
 - STDN sites prime for comm.
 - On orbit, 1 to 2 hour call up.
- A/G1 and A/G2 selected simo.
- UHF T/R on A/A loop.
- TDRS available post-MECO on ascent and TAL.
 - On ascent, stored program command will mode to TDRS.
 - Active S-band system switches automatically if INCO does not clear command, or if BFS fails.
 - Manual reconfiguration of back panel to TDRS may be required post-MECO to restore comm if S-band failure, ground site failure, or BFS command failure occurs late in powered flight.

Encryptor, Transponder, and Power Amp

- In-line LRUs.
- Power amp and preamp not required if reconfigured to STDN low mode.
- Encryption is normally on uplink only.
 - Encryptor dedicated to one NSP. Not selectable separately.
 - Bypass selected for encryption failure.

NSP

- Processes uplink and downlink (voice, commands, and data), except UHF which bypasses NSP.
- Failure means no S-band voice, commands or data to/from ground.
 - "I/O ERROR NSP X" where X = active FF MDM (1 or 3). Could be just command failed. Check data/voice with MCC.
- Cryo

General

- Separate transducers for CRT digitals and overhead meters.
- CRT data goes off scale low for big leaks.

Heaters

- Each tank has A and B heaters.
- Separate controls/logic for O, and H, heaters.
- O₂ heaters have two elements with two current sensors per heater.
- Crew insight into sensor status in OPS2 only.
- If any current sensor trips (short), that heater is disabled.
- Heater logic (applies separately to O₂ and H₂)
 - Both tanks in a ganged pair must have low P before heaters in either tank are turned on.
 - Only one high P is needed to turn both heaters off.
 - During leak isolation, pressure in good tank may prevent heaters in leaking tank from coming on with both tanks' heaters enabled.
 - Control points for heaters:

 H_2 tank 1 and 2 pressure = 203 to 223

 O_2 tank 1 and 2 pressure = 811 to 84

- Tank 3, 4, and 5 set points slightly higher so tank 3, 4, and 5 will preferentially feed on orbit with all tanks in *AUTO*.

Leaks

- First step in ascent and entry cryo leak procedure is to determine number of tanks with pressure decreasing.
 - Only one tank leaking, leave configuration as is (manifold isolation valves open).
 Leak is a tank leak. Isolating tank will starve its fuel cell.
 - If all tanks decreasing, close manifold valves to isolate leak. Must react quickly for large multi-tank leaks.
 - If leak internal to fuel cell 3, need to reopen manifold valves ASAP. Manifold 3 does not have a relief valve.

DPS

General

- It is important to be able to identify GPC failures, for MCC often has little insight. Crew information affects MCC analysis and planning for subsequent failures (both DPS and non DPS).
- When using the GPC MODE switch, remove your hand between positions. On past missions, there have been problems with the switch being in two positions at the same time. This problem can occur on other orbiter switches also. It is good practice to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- Always clear fault message line as soon as messages have been seen. This will avoid missing annunciations of subsequent failures.
- Resume SPECs and DISPs from CRTs when not in use or prior to switching to another major function on that CRT.
- Hard assign CRTs (both PASS and BFS) via PASS CRT keyboard (BFS will DK listen). Dual CRT commanders can be caused by trying to assign a CRT to BFS that a PASS GPC is still driving.

• When moding PASS GPCs into the common set (i.e., STBY to RUN), always pause 10 seconds before making further switch throws or item entries to avoid possible fail-to-sync and ensure proper common set initialization.

BFS Engage

• Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or power it off) immediately to avoid I/O problems on the flight critical strings.

Restringing

- Deassign CRTs to avoid inadvertent entries.
- Before OPS transitions and restrings, verify the NBAT. Check proper MAJOR FUNC-TION and GPC switch configuration.
- Ensure the correct memory configuration is displayed prior to making NBAT changes.
- Dynamic flight
 - Use the Restring cue card.
 - Take the failed GPC to HALT (or STBY, HALT) prior to OPS MODE RECALL.
 - For an OPS 3 restring, perform the NAV DELTA ZERO update prior to IMU RESELECT.
 - Deselect surface feedbacks prior to OPS MODE RECALL. Reselect following OPS MODE RECALL.
 - Follow OPS MODE RECALL with BFS I/O RESET (or PRO to OPS 3 if TAL).
 - Avoid assignment of all three CRTs to the same GPC, especially on orbit.
 - Keep hands off of everything during OPS transitions, especially switches and CRT keyboards.

- Rules
 - Always restring to regain critical capability.
 - Powered flight. In general, you can recover stuck throttle if necessary for uphill performance.
 - Post MECO, pre ET SEP. Recover jets required for SEP.
 - Pre OMS-1. Recover single OMS ignition capability (delay burn). Regain critical system insight (if engagable BFS still available). Maintain single fault tolerance.
 - Entry. Regain vent door commands. Regain nose wheel steering for abort landing site or known directional control problems during rollout. Maintain ASA command and body flap command.
 - In general, port moding is preferred over restring to regain lost capability.
 - Prior to EI-5, restring for any failed GPC.

Set Split

- 2 on 2 or 2 on 1 on 1 split during ascent
 - Engage BFS.
 - If desired, the PASS set can be reconfigured pre-MECO if BFS is tracking and no additional complicating failures are present, rather than engaging the BFS.
 - Treat simplex machines or undesired set as failed GPCs. Work the GPC fail procedure twice sequentially.
 - BFS engage required on ascent for MPS commands if simplex machines or undesired set cannot be taken to HALT pre-MECO.
 - Restring may be performed with MCC coordination, in accordance with Flight Rules.
 - Be prepared for BFS engage if sets begin force fight or total set split.

- BFS engage decisions for set splits.
 - On seeing multiple GPC fault and CAM lights, call "SET SPLIT".
 - Check BFS and PASS GNC SYS SUMM.
 - If BFS tracking 2 PASS GPCs, check them for 1 IMU, 2 FCS channels, 1 RGA, and 1 AA. Minimum for good PASS set. BFS engage will be required for MPS commands on ascent if simplex computer is failed to sync and cannot be taken to *HALT*.
 - If BFS standalone, check PASS if time permits. Time available is based on NAV state without IMU data:

Powered flight - ≈10 seconds Entry - ≈45 seconds Orbit - plenty of time

• Distribute CRTs among different GPCs. On orbit, ensure all CRTs are not assigned to the SM GPC or a single GNC OPS GPC. Loss of the GPC with all CRTs loses PASS CRT interface.

ECLSS

General

- During ascent, only switch avionics bay fans and Freon pumps. Water pumps may be switched if avionics bay temps are increasing out of limits.
- NH₃ Boiler A/B control based on temperature in Freon loop 1/2.
 - If no flow in Freon loop, must use NH₃ boiler corresponding to good loop.
 - If slightly degraded flow in loop with NH₃ boiler selected, undertemp may result in degraded loop, if NH₃ boiler controlling based on temp in good loop. Select NH₃ boiler for loop with degraded flow.

Cabin Pressure

• First reaction to cabin leak is to close cabin relief isolation valves one at a time.

- Double check leak indications with MCC. May be due to cabin expansion or thermal effects.
- N₂/O₂ leak into cabin will cause rise in cabin pressure and for O₂ leak, PPO₂ will also rise (O₂ concentration available on orbit).
- dP/dT on meter and CRT come from dP/dT sensor.
- EQ dP/dT is calculated from cabin pressure sensor by BFS and standardized to a 14.7 cabin. EQ dP/dT is used when available to make ascent abort decisions for cabin leak. Backup dP/dT is also calculated from cabin pressure, but not standardized for a 14.7 cabin.

EPS

General

- Do not reset popped circuit protection device (RPC or circuit breaker) without consulting MCC.
- For critical actions, MCC may call for momentary reset of failed control or essential bus while crew holds switch for affected system in desired position (three finger trick).

AC Bus

- Surge on AC bus can cause main engine controller to trip off line. Avoid actuation or switching of AC powered equipment during powered flight unless called for in malfunction procedures.
 - Loads that can be switched in powered flight:

Avionics bay fans Freon pumps H₂O loops (only for an avionics bay temp high)

• AC bus sensors *OFF* on ascent to protect SSMEs for:

Loss of first engine

 Loss of SSME controller redundancy on any engine

- Loss of a single AC phase (takes down an SSME controller on two engines)
- When AC bus sensors are OFF, no hardware caution and warning lights will illuminate (no AC VOLTS or AC OVERLOAD light).
- AC voltage high
 - Ride until MECO unless volts exceed 130, or affected main engine controllers are lost.
 - Trip bus off line with AUTO TRIP selection on bus sensor.
- AC phase shift/phase-to-phase short (threephase motors stop)
 - Verified by multi-phase amps high.
 - Multiple three-phase motors fall off line, fuel cell pump, Freon pump, H₂O pump.
 - Take individual phases off line separately to find bad phase.
- If AC bus sensor in *AUTO TRIP*, AC phase will be automatically disconnected for either an AC overload or high AC volts.
- If AC bus sensor in MONITOR, will get hardware caution and warning, but will not get AUTO TRIP feature.
- AC bus sensor uses different transducer than one feeding F9 meter or CRT.
- AC bus sensor needs to see rapid rise or delta amps to issue an AC OVERLOAD indication.

Bus Tie Actions

- If re-establishing power to a main bus (main bus volts < 20), always unpower the AC inverters before tying to a good bus (prevents surges). Use long form bus tie procedure on cue card.
- If a tie results in a short, immediately untie.
- Never tie 3 main buses during powered flight. OK post-MECO, on orbit, and entry.

- Never tie into a short.
- Payload primary bus can be used to tie Main B to Main C (back door bus tie), or connect FC3 to Main C.
- Unless absolutely necessary, do not bus tie in first stage.

Fuel Cell

- Coolant pump and H₂ pump both driven by same AC bus and both pumps controlled by fuel cell ECU and *START/STOP* switch.
- Coolant pump draws 0.5 amps, H₂ pump draws 0.3 amps.
- Coolant pump delta P indication
 - Ground can see immediately if loss of fuel cell coolant pump is real (stop/start to check run current not required).
 - No comm, can stop fuel cell and check for 0.8 amp drop. This indicates both pumps were running (bad sensor). Restart gives full recovery (should see 0.8 amp increase).
- START switch sends pump start commands
 - Pressure should be sensed in 3 seconds.
 Delta P talkback goes gray.
 - READY FOR LOAD talkback requires 30 second timer and good heaters.
- Delta P relay failure may prevent fuel cell ECU from latching on fuel cell start command. DELTA P talkback won't stay gray. OK to hold START switch in START. After 30 seconds, second relay should latch command on (can release START switch).
- Coolant pump failure stagnates coolant loop
 - Stack T measured at outlet of stack. May actually decrease immediately after coolant pump failure.
- Exit T measured in H₂/H₂O loop.

- If H₂ pump running, exit T will progressively increase after coolant pump failure.
- Nine minutes of run time available after coolant pump failure, assuming normal fuel loading.
- O₂ is entirely consumed. H₂ is circulated continuously through power section and condenser.
 - H₂O is drawn out of stack by mixing with H₂.
 - H_2O is separated at the H_2/H_2O pump.
 - Dual gas regulator maintains proper pressure of reactants (about 60 psia). O₂ pressure feeds coolant loop accumulator.
 - Dual gas regulator problem indicated by COOL P HIGH/LOW. Tie buses and monitor fuel cell for degradation.
 - If O₂ reactant valve closes, coolant pressure will drop.
- Failure of the H₂/H₂O pump will lead to fuel cell flooding since water is not removed.
- Ascent and entry: PH status fail followed by slow degrade and exit temperature decreasing may be first signatures of flooding.
- Indicated on orbit by H₂ pump status fail.
- Crossover (uncontrolled O₂ and H₂O mixing)
 - Highly unlikely to happen rapidly without warning signs.
 - Fuel cell delta volts increasing is a warning.
 - PH high may occur, but not necessarily.
 - Fuel cell degradation will eventually occur.
- Separate PH sensor for each fuel cell and common sensor in H₂O manifold.
 - PH fail may indicate pending breakdown of Fuel Cell matrix (fuel cell crossover). Potential explosive mixing of H₂ and O₂.

- High fuel cell delta volts provides confirming cue.
- Assume matrix failure for PH fail and bus tie as soon as possible. Problem may be an H₂/H₂O pump failure.
- Common PH sensor can confirm individual fuel cell sensor. Will annunciate about 10 minutes after individual fuel cell PH (common PH only seen by crew on orbit).
- In normal configuration, redundantly powered loads are load shared.
 - Hot running fuel cell (real STACK T high) will grab more than its share of the load. Indication is high amps.
 - Flooding (real EXIT T low) will cause fuel cell to shed load.
- Water output of all fuel cells feeds common manifold.
 - Water expulsion for fuel cell is preferentially: Tank A (primary), Tank B (alternate), Dumped overboard (relief).
 - *FC H*₂*0 LINE HTR* controls heaters on each fuel cell primary and alternate path.
 - FC RELIEF LINE HTR controls heaters on each fuel cell relief line.
 - Each fuel cell relief line merges into one common manifold that vents H₂O overboard.
- Purge process pumps extra O₂ and H₂ through fuel cell.
 - Removes contaminants.
 - Excess O₂ and H₂ dumped overboard. All three fuel cell purge lines merge into one O, and one H, manifold.
- Purge only one fuel cell at a time.
- Nominal load is 7 kw per fuel cell. For powerdown operations, 13 kw OK on one fuel cell for 4 hours.

Main Bus Short

- Fuel cell will overheat in time. Amps high, fuel cell and main volts low.
 - Short before the fuel cell main bus switch will have high amps and will not drop when fuel cell is isolated from main bus.
 Fuel cell and main volts will remain low.
 Should be treated like a fuel cell short.
 - Fuel cell internal short. Amps low, fuel cell and main volts low.
 - Fuel cell inadvertent disconnect. Amps low (should be zero), fuel cell volts greater than 32, main volts near zero. OK to attempt reconnect.

GNC

BCE STRG X "D" Fail

- Will commfault feedback on affected FCS channel.
- Command path on that channel will remain good.
- Ports will not pop unless feedback goes bad under "D" failure.

Body Flap Commands

- Go out on FCS channels 1, 2, and 3 only.
- Each channel uses separate hydraulic system.
- FDIR is QMVS.

FCS Channels

- Each channel equally supplies every actuator (TVC and aerosurface).
- Each channel should get same command from GPCs.
- Never have more active channels on one GPC than another
- Position feedbacks on aerosurfaces for each channel.

- Feedbacks go to FDIR to determine surface position for GPC computations.
- Feedbacks also used individually in closed loop servo to position each FCS channel's input to actuator. Inputs are summed hydraulically.
- Port bypass, or port pop, is an electromechanical means to remove bad command/avoid force fights. Feedback deselection is a software means to avoid a bad input into the selection filter.
- A bad feedback will result in a bad actuator input for that FCS channel. Result will be a port pop (bypass), removing input.
- Single port pop with no other failures: no action.
- Two failures on any surface/TVC actuator. Take good channels to OVER-RIDE. Protects remaining two channels from port pop if a force fight develops (wrong channel might port pop). Take 2 seconds between switch throws to OVERRIDE.
- All port pop indications should be verified with MCC.
- If verified, single port pops may be bypassed in software on SPEC 53. Allows taking channel to OVERRIDE later if subsequent failures on other channels.
- Feedback deselection on SPEC 53 deselects all feedbacks on channel, and terminates FDIR on all aerosurfaces.
- If there are two failures on the same actuator, take the remaining FCS channels to OVERRIDE.
- Feedback RM for aerosurfaces.
 - PASS uses first 3 inputs (channels 1, 2, and 3).
 - RM will throw out a bad feedback and substitute channel 4.

- RM shuts down after first manual or auto deselect, including commfault.
 - PASS FDIR will never pass a commfaulted feedback.
 - PASS may lose control if 3 feedbacks erroneous due to combination of commfaults, channels off, or bad feedbacks on individual surface.
 - Any OFF channel should have feedbacks deselected. If channel is recovered, reselect feedback after channel is taken to ON.
 - Always maintain two good commands and one good feedback on each aerosurface.
- In OPS 6, only works in MM 602 and 603.
- BFS feedback RM.
 - Selection filter uses feedbacks on all four channels.
 - No redundancy management.
 - Only manual downmoding of selection filter.
 - Selection filter uses IMVS.
- ASA power fail.
 - Results in all ports bypassed and zero voltage feedback input to GPCs.
 - Deselect feedbacks on channel with an ASA power fail if failure is confirmed. On board signature is not conclusive.

FCS Channel Switches

- OFF bypasses ports on all actuator inputs for given FCS channel (turns off command). Also sends zero voltage feedback to FDIR.
- *AUTO* allows port popping to bypass bad FCS channel.
- OVERRIDE inhibits port pop on associated channel.

 Pause between all FCS channel switch position changes. Switches are break before make. Switch actuation can result in momentary loss of channel.

FDIR

 PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure, and crew management of the selection filter is required. However, PASS has an RGA SMRD FDIR that will continue to deselect any power failed RGAs. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.

GPC and MDM Failures

- Take associated FCS channel OFF.
- Removes what may be a command latched at the MDM.
- Also requires deselection of feedback (SPEC 53). Feedback to GPCs would be zero voltage if I/O restored.

IMU

- SPEC 21 shows IMU status.
 - OFF, BITE, blank in status field.
 - Mode designated by *: STBY (caged) or OPER (operate)
- GPC send operate command through FF MDMs.
- IMU returns status (operate discrete) over FF MDM card A.
 - IMU returns digital data over FF MDM serial I/O card
 - STBY and power off conditions available on SPEC 21 after "BCE STRG X IMU", but not after FF MDM lost.
- GPC or FF MDM port failure.
 - IMU will maintain operate command. Commands and output of MDMs are latched at last value.

- IMU will operate without pulse torquing compensation. Should maintain reasonable align for several hours.
- FF power cycle.
 - HAINS IMU can maintain OPER CMD LATCH for approximately 8 seconds.
- FF power fail.
 - IMU loses operate command and goes to STBY (upon recovery of I/O).
 - In STBY IMU spins down and cages.
 - FF 1,2,3 power failure signature (following "I/O ERROR FF X") is loss of SSME Pc tape (ascent). Deselect IMU PASS and BFS after FF power fail (IMU will come back caged when I/O regained). PASS will automatically deselect a commfaulted IMU in OPS 3.
- BCE STRG IMU.
 - Could be result of IMU losing power. SPEC 21 (orbit and entry only) shows IMU status OFF, mode STBY. An IMU BITE/T message annunciated at the same time is also a confirming cue for the IMU power fail.
 - Could be loss of IMU data to the FF MDM (serial I/O card down). Status and data blank on SPEC 21. Mode will still show operate, received over card A.
- Standby mode.
 - If IMU has moded to STBY, it will begin startup sequencing once the operate discrete is restored.
 - Transient power fail, causes startup sequence which cages IMU (approximately 90 seconds).
 - When IMU completes startup sequence (caged), it will mode to operate and be available to selection filter upon an I/O reset. Hence, any caged IMU should be deselected (PASS and BFS), if not already.



- PASS selection filter.
 - Any IMU not commfaulted (M) or deselected is a candidate.
 - An IMU in STBY is not a candidate.
 - Attitude selection is MVS at 3 level.
 - Downmode or upmode to 2 level. Maintain previously selected if available. Otherwise lowest numbered IMU.
 - Velocity is MVS at 3 level (component basis). Averaged at 2 level.
- PASS RM.
 - Either attitude or velocity fail removes IMU from selection filter.
 - PASS will not RM fail an IMU for a BITE (H/W or S/W) at 3 level.
 - IMU with BITE will fail RM if dilemma at 2 level.
 - If IMU miscompare at 2 level and PASS sees no BITE, IMU dilemma declared. Manual deselection required to break dilemma. Use MCC or deselect IMU. BFS is prime selecting to break tie.
- BFS RM and selection
 - Only commfaults, power loss, hardware BITE, and manual deselect will remove an IMU from candidacy.
 - Selection is MVS at 3 level.
- Once downmoded to 2 level, BFS will only upmode to 3 level if taken through OPS 0 and up to OPS 3.
 - Selection on downmode to 2 level is lowest numbered IMU.
 - At 2 level, BFS can be taken off lowest numbered IMU with deselect followed by reselect.
 - BFS uses first deselected, last reselected logic after MVS broken.
 - IMU deselected for H/W BITE will not be upmoded if other IMUs lost.

- IMU dilemma
 - If MCC comm available, ask MCC which IMU to deselect (PASS and BFS).
 - No comm, deselect lowest numbered IMU in PASS. BFS will use lowest numbered.
 - Let NAV run to determine which IMU is better.

Navaids

• For TACAN and ADTA management, talk to MCC before incorporating. Without communication, use the NO COMM TACAN MGMT and ADTA MGMT cue card.

SBTC/RHC

- During ascent, only the PLT SBTC is active. To get manual throttles, the PLT must depress the takeover button and then match the commanded throttle setting.
- During entry, both SBTCs are active. Manual speed brake control is selected by depressing the takeover button.
- For ascent, manual RHC control is available only in PASS and must be both PITCH and ROLL/YAW axes.
- For entry, manual RHC control is available in either PITCH or ROLL/YAW in PASS. BFS is always manual.

Instrumentation

General

- MDM loss results in parameters showing Ms.
- Signal conditioner loss shows data on respective parameters as L.
- Loss of OI MDM does not affect data to meters, but some digital data may be lost. DSC loss will affect most meters.
- OI DSC loss section of REF DATA is accurate only for DSC parameters, not MDMs.

Data

- Runs through signal conditioners and/or MDMs
 - Data from OI MDMs goes through PCMMU for most SM data.
 - PCMMU swap reads alternate ports on OI MDMs.
 - OR, OL, and OF DSCs (GNC data) go directly through MDMs to GPCs.

Mechanical Systems

General

- ET doors and latches, vent doors, star tracker doors, air data probes, payload bay doors and latches, RMS latching gear, and payload retention latches are powered by dual AC motors linked through a differential.
 - One motor fail results in double actuation time. Actuation times are listed in the FDF.
- Most actuators have dual microswitch pairs for open and close indications.
- Failed mid motor controllers or popped circuit breakers on MA73C are a frequent cause of payload bay door, ET door, or vent door single motor ops. Chart in post insertion book lists circuit breakers and motors affected.

Payload Bay Doors

- *PL BAY DOOR SYS ENABLE* switches only enable payload bay doors. Other systems in payload bay use *PAYLOAD BAY MECH POWER* switches to allow operation.
- "PAYLOAD BAY DOOR CONFIG" message means a microswitch is indicating differently than required by software for auto operations. Can occur any time during auto open/close sequence. May require manual door operation.
- "PAYLOAD BAY SEQUENCE FAIL" message caused by failure of proper microswitch

indications within single motor actuation time. Can occur during auto sequence.

ET Doors

- Close automatically in OPS 304 if TAL flag is set in software. Always double check doors closed before AOA OPS 3 transition or TAL flag set before late TAL OPS3 transition. No software backup to close doors in OPS 3 without TAL flag set. Only available in OPS 1.
- MPS

General

- Propellant (PRPLT) numbers on ASCENT TRAJ display calculated by guidance, not measured directly from tank.
- SSME will consume about 4% propellant per engine per minute at 104% throttles.
 - Total fuel consumption 1% every 5 seconds with 3 engines.
- Consumption is 2.5% per engine per minute at 65% throttles.
 - Total fuel consumption 1% every 8 seconds with 3 engines.
- Actual throttle setting in bucket will vary with SRB performance.
- Loss of an APU will cause hydraulic lockup. CMD PATH fail message post-MECO is possible. No action required.
- Selection of manual maximum throttles (109%) is not to be taken lightly. Estimated risk is increased by a factor of ten.

Command Path

- Command path failures require a manual shutdown with AC switches and MPS pushbuttons. This will create a data path fail.
- Engine with command path fail may not get guided shutdown command and will not shutdown with pushbutton only.

Data Path

- Must determine engine and command status.
 - Loss of acceleration indicates engine down.
 - Down arrows (¬) in GH₂ pressure and GO, temperature indicate engine is down.
 - Helium dP/dT > 40 for a few seconds, then zero indicating engine shutdown.
- If SSME down, use pushbutton to mode guidance, then AC bus sensor OFF.
- Assume bad command path until throttling is observed. No comm – assume command path.
- Engine shutdown auto *ENA/INH* logic inhibits shutdown for redline exceedance (limits) for a data path failure. *ENA/AUTO* resets limits to ENABLE. Crew has no indication of actual limit status. MCC does have status.
- Engine with data path fail will get a shutdown command if GPCs see other 2 SSMEs with Pc < 30%. Two Pc < 30 plus data path sets MECO confirm. MECO confirm will shut down engine if still running behind data path, even if before guided MECO.
- Engine with a data path fail will not display a red status light after engine shutdown (pre-BFS engage). Pc meter will also be inaccurate.

Engine Failure

- First priority is to ensure GPCs recognize it.
 - Check for "SSME FAIL L (C, R)" message. If no message, depress pushbutton.
- When time permits, AC BUS SENSORS OFF.
- If second SSME fail:
 - Check interconnect for single engine roll control.
 - Check SERC ON on ASCENT TRAJ.

Contingency abort actions if appropriate.

Entry

- If MPS caution and warning during entry, check BFS SYS SUMM 1 reg pressure and close appropriate regulator. Helium reg fail high and subsequent venting could be catastrophic.
- MPS caution and warning for low helium reg not expected for normal entry. Might occur on RTLS due to additional helium usage.

Helium Leaks

- Non-isolatable leak requires interconnect at 1150 psi.
 - Use previously failed SSME helium supply, if available.
 - Interconnect to pneumatics results from *IN-OPEN*.
 - Return all helium interconnect valves to GPC post-MECO.
- Non-isolatable leak may require SSME manual shutdown using pushbutton. Helium available may not support zero-g shutdown at MECO.
 - Shutdown must be with pushbutton (hydraulic cutoff) to conserve helium.
 - Helium interconnect may be called for to allow SSME to run to MECO. Interconnect may be well before 1150 psi cue.
 - Crew assumes shutdown is required at velocity on MPS cue card unless MCC advises that helium is adequate for zero-g shutdown.
- If MPS helium reg pressure starts to drop due to helium depletion, limits must be enabled to prevent catastrophic main engine shutdown (given the proper scenario).
- MPS pneumatic helium leak with leak in accumulator requires steps to repress accumulator at TMECO minus 30 seconds.



- Loss of ALC 1, 2, 3/APC 4, 5, 6 causes the A helium isolation valve to close for the C,L,R engines.
 - Helium leak isolation must not be attempted on the affected engine.
 - LH₂/LO₂ ullage pressure indications on BFS GNC SYS SUMM display will go to 12.0/0.0 for engine with ALC/APC failure.

Manual Shutdown

- Required for manual throttles, command path, and some stuck throttle cases.
- Low level cutoff will still work in manual throttle mode if command path is good.
- If any doubt about shutdown function, use AC switches and follow with pushbuttons to inform GPCs of shutdown.
- Shutdown with AC switches no-ops the MPS dump for affected SSME. Manual inerting may be required.
- When manual SSME shutdown is required, use the AC switches followed by the pushbutton except for:
 - Shutdown with pushbutton(s) only for manual MECO. Never shutdown with AC switches and pushbuttons at MECO.
 - Shutdown with pushbutton for helium leak.
- Use pushbutton to mode guidance when GPCs don't know SSME is already down.

Manual Throttle

- CSS requires manual throttle, which requires manual shutdown.
 - Manual MECO for uphill cases at target V_r.
 - Shutdown TAL and RTLS cases at BFS cutoff cue. This cue is based on NAV and indicates cutoff when on R-V line.
- Any manual MECO, depress 3 pushbuttons to ensure MECO confirmed.

 Secondary shutdown cue is PASS/BFS TMECO on TRAJ display.

MECO Confirmed Flag

- Set by any of the following:
 - Three shutdown commands with engine safing flags set (no data failures, 3 Pc's < 30%).
 - One data path plus 2 Pc's < 30%.
 - Manually depress 3 pushbuttons. PASS sets MECO confirm for three pushbuttons pushed separately or together. Can power cycle any FF MDM associated with bad control bus (printed near pushbutton).
 - OPS 104 PRO (OPS 602 PRO will not set MECO confirm).
 - Fast sep.

Net Positive Suction Pressure

- Requirement for engines down.
- If two engines are running, throttling at 3-g will bring good engines below 91% (OK for shutdown).
- Single engine press to TAL, ATO, or MECO
 - Manual throttle back to 67% at 2% propellant remaining.
 - Manual cutoff at guidance cue required.
 - If low level sensors uncovered, fuel depletion cutoff will be commanded.
 - NPSP requirements will be protected.

Pc Gauges

- Data for Pc gauges and status lights:
 - Left: FF2
 - Center: FF1
 - Right: FF3
- Pc on gauge goes to zero for MDM power fail. Freezes for port failure.
- Status lights go out for power failures and freeze for port failures.
Status Lights

- Amber = data path, electronic (fuel flow or Pc sensors) or hydraulic lockup.
- Red = engine in shutdown or redline exceedance.
- Second engine fail with limits inhibited may show amber plus "MPS ELEC" message in SMS. Likely cues "real world" are data path fail and loss of acceleration. Red light for limit exceedance also possible.

SSME Pushbuttons

- Control two functions, shutdown and GPC recognition.
- Pushbutton shutdown requires good command path and no pushbutton faults. Command path fail takes out pushbutton for shutdown.
- GPC recognition of SSME fail (to mode guidance) may be accomplished with pushbutton if no switch faults.
 - FF/pushbutton fault: must create data path fail with AC switches and depress pushbutton.
 - Control bus fault: AC switches (data path), power cycle associated FF MDM, depress pushbutton.
 - BFS requires good FF and control bus to mode guidance.

Stuck Throttles

- Command paths always require manual shutdown.
- With hydraulic and electric lockups, shutdown hydraulic.
- With two hydraulic lockups caused by hydraulic systems failures, shutdown highest priority from the cue card based on ATVC loss.
- One hydraulic or electric, only shutdown with three engines running, uphill, and performance low.

 Stuck throttle shutdown cues of 23K, 22.5K and 24.5K for three engine uphill, TAL, and two engine uphill correspond roughly to 30 seconds before MECO.

OMS

General

- Standard insertion OMS-1 burn at MECO+2 is critical.
 - Take status of OMS engines post-MECO following FA/GPC failures coupled with ALC/MN or CNTL bus failures.
 - If one engine not available, re-target for single engine burn.
 - Restring not allowed by flight rules to regain dual OMS engine capability if 4 +X jets still available for redundancy.
 - Underspeed at MECO, always burn OMS-1 at TTA = 2 for optimum efficiency.
 - For large underspeed at MECO (> 500 fps), supplement a single OMS engine with 4 RCS +X jets.
- Gauging active only with at least one OMS engine burning. Otherwise, overhead and aft quantity readings dormant.
- Overhead gauging ceases actual measurement between 45 and 30%.
 - Software routine decrements quantity with engine burning. Software assumes single engine flow rates.
 - Pick up accurate readings when aft probes active below 30% prop.
- If only one pod prop is available and 2 engines, feeding both engines from one pod is certified.
- OMS probes are historically inaccurate.

Burn Cues

• PASS MNVR display decrements TTG 2 seconds per display update.

- BFS MNVR display decrements TTG 1 second per display update.
- At ignition
 - Check Pc.
 - Check ball valves approach 100%.
 - Check fuel injector temperatures = about 220°.
 - Monitor engine inlet pressures.

Delta V Available

- 1% OMS prop (either side or total) = 6 fps delta V.
- 1% RCS (either side or total) = 1 fps delta V.
- 2 fps required for 1 nm HP change.

DPS Failures

- FA 3(4) failures commfault L(R) ARM/PRESS switches.
 - Guidance will not downmode to 1 OMS or RCS burns when switch turned off.
 - Guidance needles in error.
 - DAP remains in TVC DAP on downmode to RCS. This results in sluggish control.
- Set split or IMU dilemma, terminate burn if above safe HP. Determine bad IMU post burn by which IMU accel is not zero.

Thrust Loss

- At first indication of OMS thrust loss (usually Pc low), check for OMS engine down arrow. PASS requires Pc low and loss of acceleration for down arrow.
- BFS shows down arrow with loss of Pc only. Pc transducer fail will give false engine down cue.
- Check for ball valve fail. If not confirmed and ignition path is good, must assume prop fail. Cue card procedure will identify engine or prop fail.

- Orbiter will initially yaw into dead engine and then yaw into good engine.
- Know without doubt which engine is down before turning engine off.
- Ensure prop or engine fail identified.
- Simple OMS engine fail, crossfeed at 1/2 delta V.
 - Protect aft quantity. Crossfeed at minimum on PRPLT PAD.
 - Maintain good flow path to prop source.
 - For OMS-1 with large delta V, interconnect failed OMS to RCS and supplement with 4 +X RCS.
- For prop fail, consider engine lost. Use cue card to determine proper course of action.
- If both engines down, complete burn with RCS.
 - Interconnect good OMS prop to RCS, note OMS helium pressure, convert to burn time, and time RCS burn.
 - FA failures may cause only 2 +X jets available. Required burn time is almost doubled.
 - OMS gauging not active without an OMS engine burning.
 - Must protect RCS system from helium ingestion at OMS prop depletion.
 - For any prop failure, isolate bad prop from crossfeed lines.

Leaks

- Tank leaks must be confirmed with decreasing inlet pressure.
 - Tank leaks may be isolated by closing tank isolation valves.
 - If inlet pressures go to zero and tank stable, inlet line leak.

Gimbals

• Trim for 2 engine burns has parallel thrust vectors.

- Single engine burn trim is through CG.
- Gimbals move to trim position 15 seconds prior to TIG.

Nitrogen System

- Used to open ball valves and supply purge post burn.
- If N₂ tank fail, but good reg P available, save engine for deorbit.
- If reg P fails, ball valves will close and engine will fail.

OMS Dumps

• Time the dump. System failures can prevent automatic cutoff.

RCS

General

- Talkbacks get hardware fuel and oxidizer inputs (no MDMs involved).
 - Inputs must agree for open or close indication.
 - Miscompare results in barberpole.
 - RCS helium isolation valves are magnetically latched open. A and B valves are mounted next to each other at various helium tanks. Occasionally the vibration of operating a valve can jar the adjacent valve out of the open position. Crew procedures account for this. A momentary barberpole talkback may occur when an adjacent valve is operated.
- Quantity calculations are PVT determination based on helium in prop tank.
 - PASS calculation allows for substitution of inputs.
 - If any helium leakage, prop calculation will be erroneous.

Crossfeed

• Master crossfeed available in PASS OPS 1, 3, and 6.

- TANK ISOL and CROSSFEED switches must always be returned to GPC to protect master crossfeed sequence.
- Master crossfeed selection valves have simo jet firing limit, even if auto crossfeed not used (all OPS, both PASS and BFS).
- Auto crossfeed sequence in PASS OPS 1, 3, and 6.
 - Initiates crossfeed in response to low pressure in prop tank.
 - Protects against helium reg fail low (primarily for ET SEP).

Dumps

- OMS prop interconnected dumps
 - Smart interconnect handles FA MDM and EPS failures for intact dumps.
 - Dump time compensated for inactive manifolds.
 - Time the dump. System failures can prevent automatic OMS cutoff.

Heaters

- Pod heater, crossfeed line heaters, and jet thruster heaters (by manifold) on panel A14.
- Turned on post insertion. Some heaters redundant and switchable.

Interconnect

- RCS crossfeed requires check of left to right tank pressures.
- OMS to RCS interconnect requires low delta pressure and OMS tank pressure higher than RCS tank pressure.
- OMS PRES ENABLE must be toggled off when breaking interconnect. Software computation assumes OMS prop feeding when L or R OMS has *.

Jet Availability

Monitor on SPEC 23.

- Software considers a jet available (no DES*) unless:
 - Deselected by RM.
 - Manifold status in software = closed.
 - Manual DES item entry.
- RM will not deselect more than jet deselect limit.
 - Intialized at 2 per pod.
 - Limit does not apply to manual deselect or vernier jets.

Jet RM

- BFS RM is inactive (display and PASS monitor), unless engaged.
- Any detected RCS fault lights RCS JET caution and warning light.
- For jet fail ON, RM does not auto deselect.
- On the PASS, a jet fail OFF is auto deselected by RM. In the BFS, only the first jet fail OFF is auto deselected and only if it is not previously failed ON.
- Fail LEAK results in PASS auto deselect. Not available in BFS.

Leaks

- Isolation during ascent and entry
 - Always confirm decreasing helium pressure (CRT and meter) before isolating.
 - Confirm talkbacks reflect switch throws.
 - Reselect GPC position of TANK ISOL and XFEED switches.
 - Monitor prop remaining. Crossfeed before quantity reaches zero.
 - Helium leaks invalidate quantity computations.
 - Auto crossfeed may be used to open/ close valves if manual switch functions lost due to control bus failures.

- Confirmed jet fail LEAK, do not reselect jet since leaking prop will probably freeze in jet.
- RCS secure for leak isolation performed by first closing the manifold isols, then isolating from the bottom of the panel working up. When re-opening, must ensure prop supply before manifolds opened.

Manifold RM

- Software looks at open and close discretes.
- Any indeterminate combination results in "CL?".
- Crew can override manifold status on SPEC 23.
- SPEC 51, ITEM 7 overrides all manifolds in hardware "?" to open. No effect on manifold with commfaults.
- RCS RM loss occurs with "BCE STRG X B" (forward), or "BCE STRG X D" (aft). Manifold goes CL?.

Manual Reselection

- ITEM entry to remove * in DES column.
- Will not work if deselect due to manifold closure.
- Does not reset RM. Jet will not RM fail for same fault.
- DES INH item entry reprioritizes jets and disables RM auto deselect. Does not reselect jet.
- Double DES INH resets jet RM (toggling RM).
- ITEM 45 resets RM of all available jets at once. No effect on deselected jets.

On Orbit Burns

- Normally 2 jet burns.
- Will downmode to 1 jet burn if no jets available on one side.

OPS 1 and 3 Burns

• Aft RCS burns use 4 jets and downmode to 3, 2, and 1.

- Forward RCS burns use 3 jets and downmode to 2 and 1.
- Asymmetric +X burns require a lot of propellant for attitude control.

Tank Press High

- Indication of helium reg failure.
 - Close both helium regs to minimize helium loss.
 - Monitor low prop tank pressure and repress to protect manifold pressure. Jets will fail OFF if manifold pressure < 190.

Valves

- Prop valves are AC with control bus for switch power. Will operate on 2 phases if 1 phase lost.
- Helium valves are DC with control bus for switch power.

Vernier Jets

- Two side-firing forward jets.
- Two side-firing aft, two down-firing aft.
- Only aft side-firing jets can be lost and still have vernier mode (may still be lost for RMS loaded operations).

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APPENDIX D RULES OF THUMB

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This appendix is a compilation of the rules of thumb from the body of this manual. Topics are organized alphabetically keyed on commonly used acronyms and abbreviations.

APU/HYD

- APU fuel usage rates vary with loading, but average 1% per minute (3 to 3.5 lbs/minute). Usage rates are reduced by about half if the hydraulic main pump is taken to low pressure (*HYD MAIN PUMP PRESS* switch on panel R2 set to *LOW*), as is done during the abort once around deorbit coast period.
- The APU injector cooling tank shared by all three APUs contains enough water for 21 minutes of continuous flow. This is enough for six complete 3.5-minute hot restart injector cooling cycles.
- If all water spray boiler cooling is lost to the lube oil after an APU reaches full operating temperatures, only 4 to 5 minutes of operating time are available before bearing seizure occurs.

Ascent

- Monitor roll program on the ADI and BFS ASCENT TRAJ display.
- Before L/O +90 seconds, BFS engage is the crew's only option for loss of guidance and/or control. After 90 seconds, the crew can try CSS.
- Monitor the trajectory on the ASCENT ADI cue card and the PASS and BFS TRAJ displays. The Shuttle bug and predictors should follow the nominal trajectory line. Also monitor the HSI for the inertial velocity to be in the desired orbit insertion plane.
- Monitor guidance convergence by observing PASS and BFS TMECOs converging to expected time.
- If the crew takes CSS, they should take manual throttles. If the crew takes manual throttles, manual shutdown is required unless a low level shutdown occurs due to low performance. The cue for MECO is the BFS MECO cutoff bug or planned MECO V₁ minus 150 fps.
- Use OMS 1 TGTING cue card for system problems and OMS 1/2 TGTING cue card for performance problems to determine proper OMS 1 and 2 targets.

CCTV System

- When the VCU is powered on, the crew must wait 10 seconds before any CCTV commands can be accepted. This time is used to initialize the VCU.
- Always wait at least 4 seconds after powering off a camera before powering it back on. This gives the iris enough time to fully close.
- Always wait at least 4 seconds after switching from the RMS wrist camera to the RMS elbow camera before switching back to wrist, and vice versa. This gives the iris enough time to fully close.
- When ejecting OAST VTR tapes, always wait at least 10 seconds after selecting *STOP* before you attempt to eject the tape. Never unpower the OAST VTR while it is in a mode other than *STOP*. Either of these will result in tape breaking or fouling.

- Never leave a payload bay camera in a manual mode (either semi- or full) while in direct sunlight or any bright light. Damage to the camera will result.
- If neither you nor Mission Control is using a camera for extended periods, power it off to conserve energy and to keep it cool.

Communications System

- When the TDRS has an elevation of greater than +70 degrees or less than -60 degrees relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- Power amplifiers are specified to have a minimum power output of 100 watts. Flight experience has shown that a good downlink can be sustained with a power output of 65 watts.
- Payload interrogator output power, when in low power mode, will read zero. This measurement is meaningless as the output power is too small to be output by the instrumentation system.

C/W System

- The SENSOR RESET switch on panel L1 should be pressed when smoke concentration goes below 1.8. This prevents masking of alarms.
- When panel R13U is not in use, the *PARAMETER SELECT* thumbwheels should be set to a value greater than 119.
- Crewmembers should reset fault messages as quickly as possible after review to avoid covering other messages.
- The fault summary should be reviewed regularly to avoid missed fault messages.

DPS

 Always deassign CRTs from fail to sync GPCs and reassign to good GPCs to avoid inadvertent entries (NBATs/restrings, burn targets, etc.).

- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration. Post OPS transitions and restrings, check good configuration with SPEC 6.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and item entries.
- Always clear the Fault Message line as soon as you have seen the message; otherwise, you may miss subsequent annunciations from other failures.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both MODE and OUTPUT talkbacks are barberpole). If not, take the offending GPC to HALT (or if this doesn't work, power it OFF) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECs and DISPs from CRTs when not using them or before going to another major function on that CRT.
- When moding PASS GPCs into the common set (i.e., STBY-RUN), always pause 10 seconds before making further switch throws or item entries to avoid a possible fail-to-sync and to ensure proper common set initialization.
- It is important to be able to identify GPC failures, for Mission Control often has little insight. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non DPS).
- Always hard assign CRTs (both PASS and BFS) via PASS CRTs (BFS will DK listen). You can cause dual CRT commanders if you try to assign BFS to a CRT that a PASS GPC is still driving via a BFS CRT keyboard.



- Always distribute your CRTs among different GPCs. On orbit, always be sure SM is not on all CRTs at the same time; if you lose SM, you also lose PASS CRT interface. The same applies for single GPC GNC OPS configuration.
- When using the *GPC MODE* switch, always take your hand off between positions. On past missions, there have been problems with the switch being in two positions at the same time. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The *CRT SEL* switch should always be checked before making a keyboard entry, and data should always be checked on the CRT scratch line before it is entered.
- When moving GPC mode switches from RUN to STBY or STBY to RUN, refrain from moving any other GPC monitored switches or making keyboard entries for 10 seconds.

ECLSS

NOTE

Numbers presented here are for typical orbit power and heat loads and may vary significantly depending on attitude and power loading.

- Supply water tanks fill at about 1.5 percent per hour depending on fuel cell load (.8 lb/kW hr ÷ 16 lb over 1%; 14 kW typical orbit power load).
- Water tanks empty at about 100 percent per hour for a water dump, about 50 percent per hour when using the FES high load evaporator for cooling with payload bay doors closed, and about 16 percent per hour when using the FES topping evaporator for supply water dumps on orbit with the doors open.
- On-orbit cold soak is good for 20 to 30 minutes of cooling. Prelaunch Freon conditioning is good for 2 to 3 minutes of cooling.

- NH₃ boiler supply is good for 25 minutes of ground cooling.
- A single cryo O₂ tank is good for about 2 to 3 days of orbit usage depending on crew size and power level. H₂ tanks are sized to match O₂ usage.
- A single LiOH canister is usable for about 48 man-hours.

Entry

- 2 OMS: TGO $\approx \Delta VTOT/2$.
- 1 OMS: TGO $\approx \Delta VTOT$.
- RCS: TGO $\approx 1.7 \times \Delta VTOT$.
- As an approximation, 1 degree of bank change produces 0.7 ft/sec² H-dot change. Large bank errors cause corresponding errors in H-dot, allowing a phugoid to develop more quickly.
- A 1 degree change in alpha produces a 1.7 ft/sec² drag change, which is equal to an 8 degree roll change.
- Prior to the first bank, monitor vehicle attitude at 0 degrees bank and 40 degrees alpha.
- First bank (flight path angle capture) should occur at a drag acceleration of approximately 3 fps² and/or q-bar of approximately 8 psf.
- Monitor the trajectory on the ENTRY ALPHA cue card, and the PASS and BFS TRAJ displays:
- The Shuttle bug superimposed on guidance box superimposed on nominal trajectory line.
 - Actual drag equal to reference drag.
 - Appropriate bank angle, H-dot, range and altitude.
- For an off-nominal trajectory, check that guidance is working to put the guidance box back on the Shuttle bug (zero range error) within the trajectory envelope.
- Attempt to contact MCC before taking CSS.

- If you must take CSS:
 - Control range by controlling drag.
 - Control drag by controlling H-dot.
 - Control H-dot by controlling H-double dot.
 - Control H-double dot by controlling bank angle.
 - Control everything slowly by small corrections.

EPS

- *Never* close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.
- Any interruption of continuous ac power during ascent may result in the loss of main engine controller redundancy. Reconfiguration of ac powered equipment prior to MECO should be avoided.
- Never connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Fuel cell run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time varies inversely with fuel cell load.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Duration varies with crew complement and power load.
- A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

EVA

- Always use "make before break" tether protocol.
- Don't use the glove as a hammer.
- EVA crewmember must remain tethered at all times.
- Slow and deliberate motion provides much greater stability than quick, jerky motions.
- Body positioning is 90 percent of the task.
- Each EVA crewmember should check out his or her own EMU.

GNC

- The PASS FDIR for the RGAs, AAs, and aerosurfaces terminates after the first failure. After the first failure, crew management of the selection filter is required. For the BFS selection filter, crew management is always required. Proper selection filter management is required for proper control.
- For FCS channel management:
 - Never have more active channels on one GPC than another.
 - If there are two failures on the same actuator, take the remaining FCS channels to *OVERRIDE*.
 - Always maintain two good commands and one good feedback on each aerosurface.
 - Delay 2 seconds between switch throws when moving FCS CHANNEL switches to OVERRIDE.
 - Port bypass, or port pop, is a mechanical means to avoid force fights; feedback deselection is a software means to avoid a bad input into the selection filter.
- For ascent, only the pilot's SBTC is active. To get manual throttles, the pilot must depress the *TAKEOVER* button and then match the commanded throttle setting. Manual rotational control is available only in PASS and must be both pitch and roll/yaw.

- For entry, both SBTCs are active. To get manual speed brake, the CDR or pilot must depress the *TAKEOVER* button. Manual rotational control is available in either pitch or bank in PASS, and required in both axes in BFS.
- For TACAN and ADTA management, talk to MCC before incorporating.
- Without communication, the crew will use the NO-COMM TACAN MGMT and ADTA MGMT cue card.

Landing/Deceleration System

- Landing gear should not be deployed at equivalent airspeeds greater than 297 knots.
- ± 1 knot of touchdown speed corresponds to ± 100 feet of distance.

Lighting System

- Power consumption of cockpit lighting can be as much as 1 to 2 kW with all lights on.
- When payload bay floodlights are turned off, they should remain unpowered for 10 to 16 minutes prior to repowering.

Mechanical Systems

• Always use a timer when operating mechanical systems, noting either dual or single motor time. Do not continue driving if greater than the single motor time has elapsed without the mechanism reaching the desired state.

MPS

- Direct insertion MECO is usually close to 8 minutes 30 seconds.
- For three engines at 104 percent, fuel consumption is about 1 percent propellant/5 seconds. For three engines at 65 percent, fuel consumption is about 1 percent/8 seconds.
- An SSME will consume approximately 4 percent propellant per engine per minute at 104 percent. Propellant remaining is displayed on the ASCENT TRAJ display and is a guidance-calculated number.

- When an engine fails, the helium dP/dT is greater than 40 for several seconds, due to engine shutdown, and then it goes to zero. This is a good crosscheck to confirm engine shutdown.
- The selection of max throttle is not to be taken lightly. It increases the risk of catastrophic failure of an SSME by 10 times.
- Five ways to set MECO confirmed are: three Pc's less than 30, two Pc's less than 30 plus one data path failure, three SSME PBs, OPS 104 PRO, and FAST SEP.
- PASS will downmode a commfaulted MAIN ENGINE SHUT DOWN pushbutton and allow the pushbutton to safe an engine under a data path failure. BFS does not allow this. If a MAIN ENGINE SHUT DOWN pushbutton is commfaulted in BFS, it is inoperative.
- An OPS 602 PRO does not set MECO confirmed.
- BFS requires all three *MAIN ENGINE SHUT DOWN* pushbuttons SIMO to set MECO confirmed; PASS only requires to see the PBs once.
- To shut an engine down, both contacts on the *MAIN ENGINE SHUT DOWN* pushbutton must be good. If one contact is commfaulted, the button can be used to set the safing flag on an engine that failed under a data path failure. If a contact is power-failed, the button is inoperative unless it is commfaulted.
- An SSME command path failure must always be shut down manually with the A/C switches and PBs.
- An SSME FAIL C (L, R) message indicates that the GNC software has recognized an engine shut down. Two of these messages will enable single engine roll control mode.
- An engine in data path failure will never display a red *MAIN ENGINE STATUS* light, pre-engage.

- There are no direct indications to the crew of limit shutdown enable/inhibit status. The status is available to Mission Control, or it can be deduced by the crew.
- Limits <u>must</u> be enabled on an engine when the helium regulator pressure begins to decay due to a helium leak. An SSME will almost certainly fail catastrophically if there is insufficient helium, and limit shutdown is inhibited.
- Manual shutdown of hydraulically or electrically locked SSME is dependent on which issues the performance call, due to low-level C/O sensor timing.
- Actual throttle levels on the first stage throttle bucket can vary due to SRB thrust level dispersions. This is an artifact of "first stage adaptive guidance."
- Loss of an APU means hydraulic lockup. SSME CMD C (L, R) messages are possible post-MECO. No action is necessary.
- 23 k, 22.5 k, and 24.5 k V₁ are about 30 seconds before MECO on the three-engine uphill, TAL, and two-engine uphill cases respectively. Note that V₁ indication is lost to the crew post-engage.
- MPS ENGINE POWER switches look very similar to *He ISOLATION* switches and are located close together on panel R2. Use caution.
- Shutdown with A/C switches will always cause a data path failure.
- Loss of ALC 1, 2, 3 (APC 4, 5, 6) will cause SSME helium isolation A to close on the C, L, R SSME with no direct indication to the pilot. Do not attempt subsequent helium leak isolations.

OMS

- 1 percent of OMS propellant
 - = 6 fps ΔV
 - = 3 n.m. ΔHp
 - = 130 lbs (80 lbs oxidizer, 50 lbs fuel) uses 40 psi of helium for long burns.

- One OMS engine causes approximately 1 fps² acceleration.
- For OMS ignition, there must be power and command to at least one coil on both control valves.
- OMS TVC requires an enable discrete from the FF MDM, and commands from the FA MDM.
- FUEL INJECTOR TEMP message may be a signature of a bad temperature transducer or a fuel blockage.
- CHAMBER PRESSURE message may be a signature of a bad pressure transducer or an oxidizer blockage.
- There are several failures that inop OMS FDI (FA MDM commfault or Pc transducer failed high).
- Always check redundant sources to confirm any malfunction.
- An OMS engine failure post-MECO should be signified by a down arrow on the MNVR display.
- Max blowdown on the OMS is approximately 39 percent.
- 1,000 lbs of OMS (approximately 8 percent) moves the X c.g. 1.5 inches aft and the Y c.g. 0.5 inches left or right.
- Max OMS quantity for landing = 21 percent.
- Orbit
- In propellant-limited situations, use the following guidelines:
 - Stay in VERN as much as possible.
 - To conserve forward RCS, use TAIL ONLY control mode.
 - During prox ops, when controlling outof-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects.

TRAJECTORY:

- NC: Sets up 1-rev transfer to Ti
- NCC: 1st onboard targeted burn targets the Ti point
- Ti: Burn (usually posigrade) that sends the orbiter into proximity with the target, uses RADAR data
 - MC1-4: Midcourse correction burns
 - Out-of-Plane Null (OOPN): Usually between MC1 and MC2, places target and orbiter co-planar (Y = 0)
 - Ti Delay: Places orbiter in a footballshaped holding pattern, posigrade (Ti DVX +3 fps)

SOURCE OF ERRORS: Trajectory

Attitude maneuvers and jet cross coupling

Burn trims

Orbiter vents (APU, FES, etc.)

Drag uncertainties

• STAR TRACKER PASS:

- Deselect an IMU during ST pass to reach 2-level (RM will prime select an IMU for attitude)
- Monitor RESIDS < 0.05 (BREAK TRACK if locked onto star or debris)
- Assumes on PROP vector, FDF provides criteria to select FLTR vector

SOURCE OF ERRORS: Star Tracker Pass

Prime selected IMU attitude problem

Either IMU accelerometer problems

Star tracker bias

Maneuvers and length of time since last state vector update

Marking on a star instead of the target

- RADAR PASS:
 - Use radar if range <135 k (range eclipsing at greater ranges)
 - Radar data verifies data from ST pass
 - Procedure handles either FLTR or PROP vector selected
 - Procedure provides criteria to select FLTR vector or to do FLTR to PROP vector transfer
 - INH angles data and mode radar to ATRK during maneuvers to burn attitude

SOURCE OF ERRORS: RADAR Pass

Range eclipsing

EL/AZ greater than 30 deg

Ku biases (range)

• TARGETING:

- Onboard targeting done on SPEC 34
- Load BASE TIME (Ti TIG) to TGT SET #1
- Load and verify TGT SETs with ITEM 1 +
- Compute burn solutions with ITEM 28
- MC2 TIG based on elevation angle constraint (rather than a particular time), so MC2 TIG can change

-3 and +7 minute TIG slip limits

MC2 TIG becomes the new BASE TIME

- NAV MANAGEMENT:
 - Always have a FLTR vector
 - Upon RNDZ NAV enable, PROP vector is created and TGT vector begins propagating
 - Perform FLTR to PROP vector transfer after new sensor acquisition
 - If commfault or suspect bad data, then troubleshoot and ask questions
- BURNS:
 - ∆V <4 fps multi-axis RCS burn (DAP:LVLH)
 - $\Delta V >4$ fps +X RCS burn (maneuver to attitude, then DAP:INTL)
 - ΔV >6 fps OMS burn (maneuver to attitude, DAP:AUTO)
 - Posigrade burns: Thrust Vector Roll (TVR) = 0
 - Retrograde burns: TVR = 180
 - For RCS burns, DAP TRANS: NORM until VGO <1 fps then PULSE
 - If VGO Z is positive: burn X, Y, Z
 - If VGO Z is negative: burn Z, X, Y
- PTG/DAP MANAGEMENT:
 - Z target track until reaching the R-bar, then +ZLV
 - A7/VERN used for attitude hold (1 deg attitude deadband, 0.016 deg/sec rotation rate)
 - B7/PRI used for maneuvers (2 deg attitude deadband, 0.5 deg/sec rotation rate)
 - TRANS pulse size = 0.1 fps during RNDZ, .05 fps during prox ops
- SYSTEMS CONCERNS (single point):
 - GNC GPC FAIL:

2 GNC GPCs are required for Ti and PROX OPS

RNDZ NAV is disabled when going through OPS 0 (such as during redundant set expansion or contraction). Only the FLTR vector is saved when RNDZ NAV is disabled. Restrings do not affect RNDZ NAV

CNCL pointing option (TGT ID = 1) before RNDZ NAV disabled

- MDM FF3:

Loss of VERN jets

Loss of RADAR data to NAV (display on Panel A2 is unaffected)

Loss of -Y star tracker

MDM FA1 or FA2:

Loss of VERN jets

– MDM FF1:

Loss of -Z star tracker

– PL 1:

Loss of automatic Ku pointing (Ku modes: GPC and GDSG lost)

IMU 2 - Restring 1221 for IMU redundancy

- MISCELLANEOUS:
 - 1 fps posigrade or retrograde =:

16 kft downtrack/rev

3.5 kft radial/0.5 rev

0.5 nm altitude change (HA or HP)

– 1 fps radial =:

3.5 kft downtrack/0.5 rev

900 ft radial/0.25 and 0.75 rev (decoupled from the other axis)

1 fps Out of Plane = 900 ft/0.5 rev (decoupled from the other axis) LVLH rate = 0.06 deg/sec; 4 deg/min; 360 deg/90 min

Expending about 35-40 lb of RCS propellant to maintain attitude results in a cross-coupling of 1 fps in -Z direction

In propellant-limited situations, use the following guidelines:

Stay in VERN as much as possible

To conserve forward RCS, use TAIL ONLY control mode

During prox ops, when controlling out-of-plane errors, start as early as possible, wait for the node to make inputs to null rates, watch the deadbands, and do not fight orbital mechanics effects

PDRS

- Whenever there are both talkbacks and CRT displays that reflect microswitch status, they should ALWAYS both be checked during any operation affecting them.
- Whenever troubleshooting RMS malfunctions in the long-form MAL book, always READ AHEAD. The MALs have a knack for having page breaks in extremely bad locations, and if you don't know what you're supposed to look for <u>before</u> you turn the page, you could be in trouble.
- The hand controllers are rate-proportional and are extremely sensitive. They should be held in such a way that you can control the full range of inputs without ever stopping to rearrange your hand. Care must be taken to not overcontrol the inputs. A good practice is to slowly and steadily input a desired command, wait patiently until you see the reactions of that command on the arm, and as the desired motion is achieved, slowly back off the input. Ideally, you should reach the axis detent at the same time the arm achieves the desired position and attitude.
- MPM motion may cease during deployment or stowage before the expected micro-

switches are made. This is due to the fact that the last part of travel in either direction is when the overcenter lock is locking. Therefore, don't turn off the *PORT RMS* switch when visible motion stops. Wait for the microswitches.

- Practice safety habits, the most important of which are brakes on, then power off (if required) for abnormal joint response and use EE CC for abnormal EE ops during the specified conditions.
- During arm cradling, periodically check all joint angles to make sure that joints that you have already aligned to zero have not moved.
 During soft stop, position hold does not work; therefore, external forces can move joints out of desired alignment.
- CCTV cameras have a tendency to malfunction at the most inconvenient times. Expect this and know how to perform all operations without cameras.
- Develop a scan pattern that encompasses window, CCTV, and panel status.
- Never rotate the *MODE* switch through *DIRECT* while the brakes are on. This actually puts the arm in mode, and sets you up for a possible runaway if a *SINGLE/ DIRECT DRIVE* switch failure occurs or is present.
- Verify the *RATE* switch setting by feel <u>and</u> talkback status. This should be done EVERY TIME prior to moving the arm, regardless of mode.
- Make sure you know the proper definitions of "cradling," "stowing," and "berthing."
- Rates for berthing/unberthing: Usually maintain rates at about 0.4 to 0.5 ft/sec between Z = 414 and -438. For Z < -438 (away from the bay), rates can be increased somewhat.
- For berthing or unberthing of payloads with keel trunnions: the keel pin enters/exits the AKA when the longeron trunnions are at the top of the built-in 8-inch PRLA guides.

D-9

RCS

- 1% RCS prop = 1 fps ΔV .
- 1% RCS prop = 22 lbs.
- 1,000 lbs of ARCS prop moves X c.g. 1.2 in, X c.g. ± 0.4 in.
- 1,000 lbs of FRCS prop moves X c.g. -3.5 in.
- ARCS max blowdown qty 24%.
- FRCS max blowdown qty 22%.
- Loss of a single downfiring vernier jet is loss of vernier mode.
- If fuel tank pressure is 20 psi higher than the oxidizer tank pressure, then verniers are no-go.
- Always secure the RCS from the manifolds to the helium tanks.
- Always open the RCS from the helium tanks to the manifolds.

TAEM

- A 100 ft difference in gear deploy altitude equals about 250 ft of touchdown energy. Gear deploy should not be delayed past 200 feet altitude.
- 90 ft of touchdown distance corresponds to 1 knot of airspeed.
- TAEM guidance uses pitch to control range, bank angle to control ground track, and speed brake to control q-bar.
- Overhead HAC with NEP allows the most downmode options for energy.
- Fly theta limits at Mach 2 (NLT Mach 1.5) if air data is not incorporated to G&C. Maximum bank angle is 50 degrees. Speed brake should be controlled manually when flying theta limits.
- Manual HAC techniques are only used when requested by Mission Control. To execute the manual HAC procedure, fly 220 to 230 KEAS and follow roll commands. At 120 degrees turn to go, resume flying pitch and roll guidance.

- For an early gear deploy, immediately close the speed brake.
- OGS is 19 degrees lightweight (< 220,000 lbs) and 17 degrees heavyweight (> 220,000 lbs). Aimpoint is 7,500 ft nominal and 6,500 closein. Touchdown speed is 205 knots heavyweight and 195 knots lightweight and short field speed brake.
- At main gear touchdown, manually deploy the speed brake. Start derotation at 185 KEAS at approximately 2 degrees per sec. At nose gear touchdown, manually back up WOW.
- During training, pilots should strive for a threshold crossing height of 15 to 20 feet on nominal approaches. Touchdown goals are airspeed within 5 knots of the target value, sink rate within structural limits, negligible lateral drift, and minimal RHC activity. A good target value for sink rate is 3 fps or less, insuring ample margin before violating limits.
- With NWS in *GPC* or *DIRECT*, the orbiter will tend to turn into a crosswind. With NWS *OFF*, the orbiter will tend to turn away from a crosswind.
- If the orbiter is landing with a known failed tire, the second tire on that axle is expected to fail during derotation at the point of maximum loading.
- If both main gear tires fail on one side, the orbiter will tend to turn toward that side. The turning moment due to crosswind can either reinforce or reduce this effect.
- If the turning moments due to tire failure and crosswind are in the same directions, large control inputs will probably be required.
- If the turning moments due to tire failure and crosswind are in opposite directions, the control inputs required to counteract tire failure will be reduced. In this situation, pilots must be careful not to overcontrol. A good rule of thumb is to be more cautious with the rudder pedals, matching the crosswind turning tendency.
- Flight Rules call for landing with an existing crosswind on the same side as a known or expected bad tire.

ASCENT	DESCENT	PROPELLANT
Ascent Performance Margin	Xco Limits	1 deg of plane change = 440 ft/s
Management Beserve Beg. (Ibs)	FWD = 1076.7 in (BTLS = 1079.0 in)	
Pre Flight Design Requirements	AFT = 1109.0 in	OMS philosophy
Document = 3500	CONTACT - 11100.	1 ft/s = 21 8 lbs OMS @ 000 L lbs
Elicht Design Requirements	CON1 AFT = 1119.0 in	1 79 the _ 1 am
Decument = 2500		1./ 01US = 1 nm
Document = 2500	D/O Delta V's	
Cargo Integration Review = 1500	Descending approach is worst case ΔV	Maximum OMS load
Flight Planning Stowage	90 deg prebank will decrease $\Delta V \sim 10$ ft/s	OV102 = 25156 lbs
Review = 1500	(function of altitude)	OV103/4 = 25064 lbs
FPR = 4652	ES LA VUTIN	Min = 10800 lbs
ORBIT	If Xcg > 1091.5: 1 in Xcg = 2.2 miles	Max OMS ballast = 4000 lbs
	If Xcg < 1091.5: 1 in Xcg = 1.1 miles	1 % OMS = 130 lbs/side
1 hrlaunch delay = change in	As Xco increases (more aft) XR decreases	and the second s
orbital noon by 4 minutes	1 pm XB = 5780 lbs El weight	Hard Ballast
	1 cm XP = 4.28 cm D/O altitude	OV102 - can be installed in the aft
A scending node	1 nm XH = 4.38 nm D/O antitude	compartment
	As alblude and weight increase, XR increases	OV102/104 Box 12
20.5 deg - 1st ascending node	As inclination increases, XR increases (non-linear)	0 1 103/104 - Day 13
is @ Long = 173.38 East	As temp increases, XR increases (non-linear)	
57 deg = 121.55 West	IDaddd Lines	BCS philosophy
	Touchdown speeds	1 ft/s = 25 lbs (+ X) or 35 - 40 lbs
MISCELLANEOUS	185 kts if TD weight < 200 k lbs	(multi axis) @ 220 k lbs
	195 kts if 200 K lbs < TD weight < 220 k lbs	Max burn = 250 sec = 55 fps
O rbiters	205 kts if TD weight > 220 k lbs	Full FRCS = 2446 lbs
OV101 - Enterprise		ET blowdown offload = 2225 lbs
OV102 - Columbia	10 kts clower if short field secondhise to	Min FRCS - 1862 lbs
OV103 - Discover	nuide see mede is used if 000 h h . The sist	Full ABCS = 4970 lbs (over 100%)
OV104 Atlantic	guidance mode is used if 200 k lb < 10 weight	1% ABCS = 22 lbs/side
OVI04 - Atlantis	5 245 k lbs	1
Ovius - Endeavor		
OV102 weighs 7000 lbs more	Derotation 185 KGS with beep trim	INTERCONNECTION
than O V103/104	175 with RHC (manual)derotation	ITOMS < 14,000 lbs, VC off
	HPETALE OF THEW	If O MS > 17,000 lbs, VC on
Min planned flt duration = 96 hours	Mass Moment	If 14 k < OMS < 17 k, analysis req.
Charles and have a marked through	MM = TD Weight * (1172.3 - Xcg)/12	
Max/Min Beta Angle	for medium lake bed runways	ECS - N2
Max = 23.5 + orbital inclination	H MM > 1.47 M ft-lbs Concrete desire	Assertant Paul Tolerancy In
Min = 23.5 - orbital in clin ation	If MM > 1.54 M ft-lbs Concrete required	<u>0V102</u>
in a 20.0 - Oronarin cintation		6.28 lbs/day for 4 person crew @ 14.7 ps
Time	Note: IT ID X cg not known, use	add 114 lbs/day for additional crewment
	Xcg @ M = 3.5 + 1.5 in	4 35 lbs/day for 4 person crew @ 10.2 ps
CDT = GMT - 5hr	tomatic repoose in and	and 0.70 lbs/day for additional scow man
CST = GMT - 6 hr	Landing Weight Limits	add .079 lbs/day for additional crew memb
Daylight savings time from	EOM 233 k lbs	
1st Sunday in April to	RTLS 242 - 248 k lbs *	0 103/4
last Sunday in October	TAL 241 - 248 k lbs *	5.28 lbs/day for 4 person crew @ 14.7 ps
	AOA 233 - 240 k lbs *	add .114 lbs/day for additional crewmemb
	(Abort limits a function of Inclination)	3.66 lbs/day for 4 person crew @ 10.2 ps
	A COLORISON	add .079 lbs/day for additional crewmemt
	Nextilueant Clouds	and along the star postal bars
	Nochlucent Clouds	Dry wt Fully loaded wt
	It inc > 50, do not enter on descending opportunity	N2 83 lbm 143 lbm
	June through August.	
	the second secon	EPS
	RENDEZVOUS	PERM SWIICH PORPLASS SURVEY
	and the second	an the Underson A built
	1 deg of phasing/hour = 10 nm of A height	.09 Ibm Hydrogen = 1 kwh
	1 deg of phasing = 60 nm	.7 lbm Oxygen = 1 kwh
	17.5 ft/s burn changes other side of orbit 10 nm	.07 lbm Oxygen/hour = cabin leak rate
	140 ft/c burn will change plane by 1 dep of wedge	spapersky (TADADD)
	1 dee of A BAAN occurs for each relative lan	Dry wt Fully loaded wt
	I deg of a HAAN occurs for each relative tap	H2 227 lbm 319 lbm
	A PROPERTY OF THE PARTY OF THE	0.2 215 lbm 996 lbm
		LUE LIUIN

APPENDIX E OI UPDATES

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OI-28 SUMMARY

Unlike OI-27 FSW, the OI-28 FSW is not dedicated to one specific upgrade or new capability. OI-28 adds many new capabilities as well as corrections to existing capabilities. Some of the new capabilities include: ECAL automation, single engine RTLS rolloff elimination, variable intact abort throttle limits, and GPS corrections and automatic reboost. In addition, many other CRs and DRs were included to clean up the FSW. A brief summary of the CRs that might be of interest to the flight crew is listed below.

Change Requests

CR 90704F: DAP Hot Stick Downmode (PASS Only)

Generates an SM alert light, tone, and CRT message if the RHC is moved out of detent while the DAP is in AUTO in MM103-106, OPS 2, 8 and 3.

CR 90724D: ECAL Automation (PASS Only)

This modifies the RTLS TAEM guidance to use entry ECAL pitch and roll logic during an ECAL or Bermuda abort. It also modifies displays and controls to allow crew to enable/disable ECAL logic and display ECAL logic status on VERT SIT 1. The main benefit of this CR is that it allows the CDR/PLT to work other "cockpit fires" while monitoring the ECAL entry. It also eliminates (except for pull-up after ET SEP) the possibility of crew error or lag behind guidance due to distractions associated with working the major emergencies that initiated the ECAL scenario.

CR 90914C: Delay MOV MPS Dump/FRCS Dump @ MM602 (PASS/BFS)

Part of the forward c.g. expansion package. Beginning with OI-23, GRTLS forward c.g. relief was obtained by delaying the LO2 8-inch fill/drain dump from q-bar 20 to q-bar 20 + an Iloaded timer and by utilizing a forward RCS dump. Additional c.g. relief can be obtained by delaying initiation of the LO2 dump through the MOVs from MM 602 + an I-loaded timer. These changes provide flexibility to adjust the MPS LO2 and FRCS propellant dump initiation times with respect to MM 602. This will expand the payload manifesting capability and help manage the vehicle weight and Xcg position during RTLS entry.

CR 91050C: Improved Fault Tolerance for Beep Trim (PASS ONLY):

The beep trim switch is a two-contact switch that is processed per the normal RM scheme. Prior to this CR, a single switch contact failed "OFF" would have disabled the function of the beep trim switch. This CR modifies the beep trim processing after WOW to output a negative pitch trim derotation rate command if either beep trim contact is set when EAS is less than or equal to an I-loaded value. This effectively makes the beep trim switch two-fault tolerant.

CR91062D: Multiple TDRS State Vector Capability (PASS/BFS)

This modifies the current 2 TDRS satellite system in both SM and BFS to be able to use either 3 BFS or 4 SM TDRS state vectors for antenna management. It also modifies uplink to allow single TDRS SV to be uplinked in each command load. PASS SM will have four state vector slots that can be selected to either an A or B target for display and priority usage. PASS SM SV management will be crew controllable via the OPS 2 SPEC and ground controllable via both real-time U/L and time execute commands.

CR92100B: BFS Communications Reconfiguration Capability (BFS Only)

This change adds the capability for a crewmember to perform S-band PM communications system reconfiguration via item entry on the BFS Override display. This is needed because the Bermuda S-band station is being phased out and requires a mode handover to TDRSS at 6:00 minutes MET. This change will restore the single fault fail OPS capability to the S-band PM communications system.

CR 92175D: Uplinking Second-Stage I-loads (PASS/BFS)

Uplinking the RTLS and TAL dump timers allows for c.g. adjustments without offloading payload, and uplinking mass and trim I-loads allows for manifest changes late in the flow.

CR 92186A: Single-Engine RTLS Rolloff Elimination (PASS/BFS)

This adjusts the vehicle roll during RTLS flyback to improve single-engine roll control. It limits change in the vehicle yaw command for engine out (EO) during RTLS flyback. Essentially, it eliminates the Red Region Rolloff for RTLS.

CR 92187F: Automatic Reboost (PASS Only)

This adds the capability to automatically perform translation firings for reboost of a directly mated payload while monitoring rate and attitude errors. The reboost firings are interrupted when the DAP has a requirement for a rate or attitude correction and they are resumed when the DAP's rotational requirements are satisfied. The reboost firings can be defined for selection of jets, firing times, and frequency to meet the load constraints imposed by the payload and propellant distribution constraints.

CR 92188B: Modification of OMS/TVC No-Back Software (PASS/BFS)

This modifies the No-Back Fail logic to ensure that the OMS actuators are not erroneously powered should the active actuator feedback fail or experience a bias during powered flight. The active and standby position measurements are compensated and compared with a threshold to determine if an actuator should be powered. Currently the logic may erroneously power an actuator if the active actuator feedback measurement fails.

CR 92194A: RMS Direct Drive Bite Masking Correction (PASS Only)

During normal operations, the circuitry will detect a false direct drive failure on all undriven joints. The direct drive BITE is designed to detect failures of the direct drive circuit. There is a mask to prevent annunciation of the false alarm, however, the mask is incorrectly applied to all joints. This change will correct the direct drive BITE annunciation logic to mask annunciation on all but the driven joint.

CR 92198A: SERC OMS/RCS Interconnect Delay (PASS Only)

This inserts a delay into the SERC processing in the Abort Control sequence to delay the configuration of the OMS/RCS interconnect. By delaying this configuration, the orbiter will have access to the RCS jets for single-engine roll control maneuvers at the front end of twoengine-out scenarios.

CR 92208C: GPS Issues for Correction on OI-28 (PASS Only)

This CR fixes six requirements issues remaining from the PASS OI-26B single-string GPS and OI-27 three-string GPS implementation. It includes:

DR 109124	GPS Dilemma Display
	rioblem
DR 109120	GPS QA2 Tolerance
tions and such by rea	Reset
DR 109123	T_GPS_LAST_UPDATE
	Initialized Early
DR 109121	GPS Downlist Comps
alion ACASS One	Integer Overflow
DR 110439	Self Test PASS/FAIL
	Status on Spec 55
DR 109122	SATS_TRACKED Values
	Stale in Init/Test Modes

In addition, this CR corrects misleading GAX messages for GPS QA failures and removes

restrictions on QA2 limits that are best handled via I-loads. This CR eliminates six user notes that would otherwise become permanent for this OI release and subs. The GPS processing and displays of GPS status data is more consistent, improving the ability of crew and ground personnel to monitor and understand GPS performance.

CR 92209D: Runway and Navaid Location Data Uplink Capability in OPS 1/6/3 (PASS/BFS)

Adds the capability to uplink runway and TACAN location data in OPS 1/6 and MSBLS data in OPS 1/6/3. Currently, if runway or TACAN location data change after the I-load change window, new data must be uplinked in OPS 3. The PASS and BFS software does not accommodate uplink of runway or TACAN location data in OPS 1/6 or MSBLS location data in OPS 1/6/3. This new capability will expand intact abort landing capability.

CR 92210: Allow for Vent Door Single-Motor Operations (PASS Only)

Changes the vent door 8/9 position status check time from 5 seconds to 6.4 seconds, preventing a launch scrub for a single-motor failure during the RSLS checks. This hard-coded value controls the amount of time that is allowed between the issue of vent door operation commands and checking the vent door position that is used to build the status word. This would assist the vent door system in meeting the RSLS requirements if a vent door motor failed during launch countdown.

CR 92228B: Addition of SRB Sep Cues to the Downlist (PASS Only)

During STS-71, Range Safety personnel received a false indication of early SRB sep. Investigation revealed that they were using the SRB Sep Sequencer discrete that indicates Sep commanded, not actual physical sep. This CR would add four discretes to downlist, which indicate power loss at several connectors during SRB sep. This is in response to a Range Safety Panel action. However, several breakup cues are used: visual via TV or airborne/ground observers (PRIME CUE), tracking via SRB Cband beacon tracking system, and the downlisted SRB sep indication. BREAKUP MUST BE CONFIRMED for action to be taken – telemetry alone is NOT sufficient.

CR 92232B: Variable Intact Abort Throttle Limits (PASS/BFS)

With this change, use of higher I-loaded SSME intact abort throttle limits can be used for TAL and ATO (106 percent), while limiting the throttle limit at a lower I-loaded maximum for intact RTLS and late uphill aborts (104.5 percent). The benefit of this CR is expansion of TAL/ATO windows, while limiting unnecessary engine stress for RTLS. Also, in the event of systems and/or contingency aborts, crew flexibility is maintained by placing nominal and abort maximum throttle limit selection item entries on the PASS and BFS Override displays.

CR 92235B: Fix AOA Propellant Wasting Calculation (BFS Only)

For an AOA declared in MM 105 (PASS) or declared in MM 104(BFS), the OMS propellant wasting calculation for the OMS-2 burn (deorbit burn) is too large by the amount of the OMS assist burn. If the burn were performed without crew update of the prop wasting value (via Item 18), the burn would cut off early because all the usable OMS propellant would be consumed, precluding successful de-orbit. This CR adjusts the MM 104 guidance mass for pre-MECO OMS dumps (OMS assist burn).

CR 92252: Switchable NNY Filter (PASS/BFS)

By converting non-switchable NNY (yaw axis) bending filter in ascent DAP to a bilevel switchable filter (based on Vrel), one can reduce commit-to-flight (CTF) payload screening effort for SLWT missions in the high q-bar flight regime. This regime is very restrictive (15 K payload only) for the yaw axis "payload flex envelopes" developed for the SLWT configuration.

CR 92259A: Z Translation Mode Change Reinitialization (PASS Only)

This causes the translational pulse module to be reinitialized for a change in the Z translation mode. The current mode of operation can result in a much larger Z translation impulse than what was commanded or intended. This CR will eliminate that erroneous command.

CR 92260B: Six Jet VFAIL(PASS Only)

This allows for automatic VRCS downmode to RCS whenever any of the six vernier jets fail, rather than just for the four down-firing jets.

Other CRs Included in the Baseline

CR92152: BFS HAL/S Compiler Baseline Upgrade to REL 11V1 (BFS Only)

CR92157: IDD Clarification to Remove Blanks from FSSR Names (PASS Only)

CR92177A: Eliminate Erroneous CMD Path FAIL Annunciation (DR 109686) (BFS Only)

CR92189B: Deletion of MM SSME Controller Load Capability (PASS Only)

CR 92193A: RMS Tachometer Failure Override Calculation Update (PASS Only)

CR 92201C: Uplink V_MSSN_CNTN I-load (PASS/BFS)

CR 92207B: Correction to BFS Throttle CHG Logic (BFS Only)

CR 92221C: PSP Port Mode Processing Changes (PASS ONLY)

CR 92222C: RMS Software Updates for Full Fleet SPA (PASS Only)

CR 92230: Display FSSR Documentation Cleanup (PASS/BFS)

CR 92231: Fix BFS Scaling of SIG-V-COV-OUT (DR 109701) (BFS Only)

CR 92234: Calibration of MPS Helium Bottle Pressure Tranducers (BFS Only)

CR 92237: IDD Documentation cleanup of Uplink Data (PASS Only)

CR 92238B: FSW CR 91062D - Multi TDRS Cleanup (PASS/BFS)

CR 92239A: OI-28 BFS Flight Control PRD Cleanup (BFS Only)

CR 92240: OI-28 BSS PRD Cleanup (BFS Only)

CR 92245A: OI-28 BFS GN&C HIP PRD Cleanup (BFS Only)

CR 92251A: Correction for CR 92188 – OMS TVC No Back Failure Logic (PASS Only)

CR 92253: Rescind Implementation of CR 92206B in OI-28 (PASS/BFS)

CR 92256B: MPS Dump Sequence Doc Changes (PASS/BFS)

CR 92258A: BFS OI-28 Documentation Cleanup for Sequencing PRD (BFS Only)

CR 92261C: Add PPS Erase Key MSID's to Three String GPS Downlist (PASS Only)

CR 92263A: Correct Inconsistent Dolilu and BFS Oneshot Contiguous Memory (PASS/BFS)

CR 92264B: Correction CR for CR 90724D – OPS 6 Entry ECAL Automation (PASS Only)

CR 92267: Add Illegal Entry Requirements for HSD Items 10-15 (BFS Only)

CR 92268B: O2 Quantity Computation Deletion (PASS ONLY)

CR 92270A: Freon Coolant Loop Bypass Noise Filter Eval Change(DR 109136) (PASS ONLY)

CR 92271A: Downlist Cleanup of CR's 91062D & 92238B (PASS ONLY)

CR 92272: Step Up to the OI-28 DFG(PASS ONLY)

CR 92273: Delete Downlist Requirement for DECP (PASS Only)

CR 92275C: Preclude BFS Nav Nuisance Alarms (DR109712) (BFS Only)

CR 92278A: Automatic Reboost Cleanup (PASS Only)

CR 92284A: Add Explicit Rejection of MM SSME Controller Load Requests (PASS Only)

CR 92286B: KU-Band RF Protection Boxes added to an Antenna Management (PASS Only) CR 92287B: New Categories for OPS1 & OPS3 Drag Constants (PASS/BFS)

CR 92291: Downlist Time Consistency for RA Altitude & Nav Comp Altitude (PASS Only)

CR 92292B: GPS Related Category Modifications for OI-28 (PASS/BFS)

CR 92293: OMS-TVC No Back Failure Logic Enhancements (BFS Only)

CR 92295D: PSP Port Mode Reject Added to Spec 62 (PASS Only)

CR 92300: Downlist Corrections to CR 92261C (PASS Only)

CR 92303 : Automatic Reboost Cleanup II (PASS Only)

CR 92305: Correction for Nz Limiting of Roll Command for CR 90724D (PASS Only)

Discrepancy Reports (DRs) Fixed On OI-28

DR 108073A: Incorrect S/W Clock Initialization

DR 108694A: Pitch Paralleling After MECO in 3EO case

DR 108852E: Transient Spike in Horiz Sit Indicator Heading

DR 109179: Disable Block in GLJRCV Violates SAM 2 Timing Exceptions

DR 109182: DT_GPS_OFF_MIN not Assigned Homogeneously

DR 109183: Speedbrake Deflection Command not Updated on Transition to AUTO

DR 109189: Violation of BFS ICD MTU Listen (WIX 12) Timing Requirement

DR 109200: Fix Underscores on Item * of UNIV Ptg Display – AIDS

DR 109700B: Scratch Pad Line Not Cleared When BFS Takes CRT

DR 109706: MEDS HSI Course Pointer Fluctuates 90 Degrees During Approach/Landing DR 110263: TCS Error Response Incorrect for Operator 5 (GMEM READ) I/O

DR 110277A: LDB "Duplicate Transaction ID" Indicator Incorrectly Set

DR 110284C: FC Channel Failure Caused By Incorrect Speedbrake Command Init.

DR 110382A: Possible Pitch Paralleling in 3EO Case

DR 110456: SPEC 2011 Item Entry Disables Antenna Handover Capability

DR 110500A: Bogus Bits Brought into Buffer

OI-27 SUMMARY

GPS Updates

OI-27 increases the capability of the flight software to incorporate a three-string global positioning system (GPS) into the PASS and BFS when the TACANs are removed. However, until triple-string hardware is installed on all vehicles (over approximately 2 years), a mixed fleet operation of either single-string GPS (with TACANs) or triple-string GPS will continue. The driver behind mixed fleet operations is the orbiter maintenance down period (OMDP) schedule. The OI-27 FSW will support both single- and triple-string GPS operations. Removal of excess code from the general purpose computer (GPC) software, as a result of mixed fleet GPS/TACAN operations, is targeted for OI-29. STS-96 will be the first OI-27 flight, which will be a single-string GPS flight. STS-92 is the first three-string GPS flight.

Miscellaneous Change Requests (CRs) Not Associated With GPS

In addition to the changes associated with GPS, OI-27 includes several SM-related CRs. Significant, non-GPS related changes are summarized below.

CR 92088B: Add Uplink Reset of PSP to SM GPC Capability

Implements the capability for MCC to perform PSP I/O resets via ground command. This eliminates the last communications related activity that, until now, has been controllable only by the crew (via SPEC 62).

CR 92154A: Control of Ku-Band EVA Protect Mode via TEC

CR90850C added a Ku-band EVA protect capability, which allowed the ground to define a protection "box" for Ku-band operations during EVA. If the Ku-band antenna points into this box, the flight software turns off the Ku's traveling wave tube, preventing the antenna from radiating within the box. CR92154A allows for ground enabling or disabling of the Ku-band protection mode via a time executed command (TEC).

CR 92169C: Automation of Communications Forward Link Management

This CR allows the SM GPC to automatically select Ku-band for the uplink source to the NSP. The SM GPC will automatically switch back to S-band if the Ku-band is configured to Standby or Radar mode, or if the Ku-band DATA GOOD flag is invalid for more than 5 seconds. The intent is to use the Ku-system whenever possible because of its superior forward link margin over the S-band system (improved directionality and signal-to-noise ratio).

CR 92184A: Freon Radiator Isolation Valve Automation

This change automates control of the Freon radiator isolation valves in the event of a puncture of the Freon cooling loop located within the payload bay doors while on orbit. If Freon accumulator quantity drops below 12 percent for 5 seconds, the SM GPC will issue commands via the payload MDM to close the isolation valves. Resetting the isolation valves back to the "flow" position is via manual switch only. In the event of a false accumulator low annunciation and subsequent manual reset, the SM GPC will resume its monitor/autocommand function when the auto/manual switch is returned to auto. A reconfigurable I-load is used to disable the auto-isolation feature for vehicles that do not have the isolation valve hardware installed.

Significant DRs Fixed On OI-27

The following DRs will be source-fixed for STS-98 and subsequent flights. These discrepancies were discovered too late in the OI-27 development flow to allow for a source fix for the first two OI-27 flights (STS-92 and 97), and it was determined that the risks associated with a software patch were not warranted.

DR 108075: Item Entries Rejected on the OPS Mode Page

If a new SPEC is requested within approximately 1 second after a major mode transition is initiated, item entries and the single EXEC key on the OPS page will be rejected with "ILLEGAL ENTRY" for the duration of the major mode. A transition, when possible, to another major mode (forward or backward) will clear the item entry lockout. If the problem occurs during a MM102-to-MM103 transition, the crew will not be able to select a contingency abort should one be required. If the problem occurs during the MM103-to-MM104 transition and if OMS 1 is required, OMS 1 retargeting will be necessary because of the loss of the single EXEC key. The crew will have to mode to MM105 for the OMS 1 targeting/burn.

DR 110610 (PASS): OMS Assist Impact to AOA Prop Wasting Calculation

If an OMS assist burn is executed pre-MECO during a nominal ascent (no ATO) and an AOA is selected in MM105, the guidance estimate of the remaining OMS propellant for the deorbit burn targeting will be too high by the amount of propellant burned in the OMS assist. This could result in excessive out-of-plane OMS propellant wasting (ITEM 18 too large) and premature deorbit burn termination. The crew must verify proper ITEM 18 value when checking targets for a MM105 AOA.

DR 110609 (BFS): OMS Assist Impact to AOA Propellant Wasting Calculation

If an orbital maneuvering system (OMS) assist burn is executed pre-MECO and an abort to orbit (ATO) or AOA is required, but not executed until MM104, the guidance estimate of the remaining OMS propellant will be too high by the amount of propellant burned in the OMS



Yaw Steering Performance

assist. This could cause excessive out-of-plane OMS propellant wasting (ITEM 18 too large) and premature burn termination. Note that this DR is the same as DR 110610 for PASS, except that with BFS this condition begins with the transition to MM104 (vice MM105 for PASS).

OI-26A SUMMARY

Ascent Performance Enhancement CRs

CR 90958: Onboard Delta Psi Computation (PASS/BFS)

Also referred to as automated first-stage yaw steering, this CR allows delta psi to be calculated onboard, based on the Greenwich mean time (GMT) of lift-off for rendezvous in-plane, launched thus missions not minimizing performance loss. Delta psi defines the amount of first-stage yaw steering to be performed. Prior to OI-26, it was a fixed value that was uplinked as part of the launch targeting load. While the purpose of this CR is a performance gain, it can be used to expand the launch window. It has been stated that for a 51.6° inclination mission with a 5-minute launch window, this CR would either gain 500 lb of performance or expand the launch window to The figure on the next page 7.5 min. demonstrates that although the ascent performance margin is increased by 500 lb at the opening and closing of the launch window, the

best performance is actua

window. The Apollo program incorporated an onboard delta psi computation, but the Space Shuttle Program did not because there were no plans for high inclination rendezvous missions. With this CR, the launch azimuth will be computed onboard just prior to solid rocket booster (SRB) ignition if the I-load Earth-Fixed Plane Constraint Switch is set to OFF. The I-loads DELTA PSI LIM and DELTA_PSI_FAC are used to limit and then scale the delta psi value computed onboard. For PE certification, the I-load values chosen for DELTA_PSI_LIM and DELTA_PSI_FAC limited the onboard delta psi to within ±4.6°. Also, second-stage guidance was changed with CR 90958. If the launch time is greater than the value of T_GMTLO_PHASE, which is uplinked as part of the launch targeting load, a node adjustment is automatically made to the orbit plane to account for switching to the second planar window.

CR 91014: OMS Assist Performance Enhancement Burn (PASS/BFS)

By loading excess OMS above orbital requirements, and burning the excess in major mode (MM)103 post-SRB sep, between 350 and 600 lb of performance is gained for 4000 lb of excess OMS. The OMS assist burns are reserved for performance-critical missions and require the I-load OMS_ASSIST to be set to ON. The Abort Control Sequencer, which was designed

solely to support intact and contingency abort dumps, was modified by this CR to support the "nominal" OMS assist burn. The burn will begin at SRB sep + expiration of an I-loaded OMS assist delay timer. The value of this timer in analysis and testing has been either 10 or 15 seconds. The software protects against the OMS assist burn occurring below 70,000 ft. To provide the capability to update the OMS assist and ATO dump timer parameters to reflect the actual OMS propellant loaded and to enable or disable the OMS assist feature, the uplink OMS Dump Timer Load was created. This load is valid only in G9, and the data is transferred to BFS via the one-shot transfer.

The OMS dump time to go (TTG) on the OVERRIDE display is initialized with the contingency dump timer. Upon initiation of the OMS assist burn, the OMS dump TTG will reflect the OMS assist burn timer and the interconnect will indicate INH (the OMS assist burn will always be non-interconnected). To ensure that the interconnect is maintained if single engine roll control (SERC) is enabled, a test is made for SERC prior to initiation of the OMS assist burn. This is to protect in case two engines are out in MM102 and in the 15 seconds that it is estimated it would take the crew to arm and start the 2 EO on the TRAJ display, an OMS assist burn is initiated, terminating the interconnect needed to support SERC.

For an OMS assist burn downmode to an abort, the burn will continue until the dump timers have expired. If return to launch site (RTLS) or transoceanic abort landing (TAL) are selected during the OMS assist burn, the burn will continue until the dump timers have expired. If the RTLS or TAL are selected immediately after completion of the OMS assist burn, the RTLS or TAL dump and interconnect (if selected) are delayed until expiration of the required minimum OMS off-time (30 sec). The minimum engine off-time between firings is 240 sec for normal operation. However, the engine can be restarted after 30 sec, if required, for crew safety. This incurs some risks if the first burn was less than 15 sec. When the abort selection is made within this 30-sec window, PASS and BFS will show different values for the OMS TTG because PASS calculates the abort value for display, while the BFS does not. However, when the OMS engines are restarted, the OMS TTG values will be in sync.

For contingency abort cases initiated within the 30-sec window, the minimum OMS off-time is overridden. If a contingency abort is selected after the OMS assist burn completes, the interconnect begins as soon as the second engine failure is recognized. The crew must manually initiate the contingency dumps for two EO cases, which results in an adequate delay to ensure safe operation of the OMS engines.

If an ATO is declared, the OMS DELTA T COMPUTED is set equal to the quantity of the ATO dump timer plus the OMS assist timer; if the ATO dump is to be interconnected, the interconnect is enabled. The ATO dump calculation is intended to protect against a violation of the Shuttle Operational Data Book (SODB) constraint, which restricts the orbiter main engines (OMEs) from firing for less than 2 seconds. Engine firings of less than 2 sec are prohibited. If an engine shuts off less than 2 sec after starting, it must not be restarted for at least 30 min.

How the dump timers are affected by the OMS assist is best illustrated by the following three LM test cases. All of the PEs were enabled in these test cases; therefore, to understand each test case summary, a review of the appropriate PE CR may be required.

In all cases, the OMS dump parameters on the OVERRIDE display were initialized with the contingency dump values, and were updated with the OMS assist values upon initiation of the burn. LM test case no. 1 was a nominal ascent with first-stage trim, pitch steering during SRB tailoff, and the extended space shuttle main engine (SSME) parallel pitch phase active. The roll to heads up occurred when Vrel exceeded 12,500 fps. Pitch gimbal relief was not activated because SSME no. 1 was not failed. Second stage throttle-up to 106% occurred on the first pass of second-stage guidance because manual throttling was not active and there were no SSME failures. LM test case no. 2 was identical to test case no. 1, except that the right OMS engine was failed approximately halfway through the OMS assist burn. Because the failure of the OMS engine had very little affect other than a loss of thrust, and the decision has

been made not to compensate for OMS engine failures operationally, test case no. 2 will not be discussed any further.

LM test case no. 3 had an SSME fail 15 sec after the start of the OMS assist burn with RTLS selected 15 sec later. The OVERRIDE display was initialized with the contingency dump, and then updated to reflect the OMS assist configuration at the start of the burn. Selection of the RTLS resulted in the automatic selection of the interconnected RTLS dump, which was reflected on the OVERRIDE display. The OMS TTG is automatically adjusted to account for the amount already burned in the OMS assist burn. The OMS EQUIVALENT_ON_TIME is subtracted from the I-loaded RTLS dump timer and the result is displayed as OMS TTG on the OVERRIDE display. The OMS assist and RTLS dumps consumed a total of 21,081 lb of The second-stage throttle-up to propellant. 106% did occur on the first pass of second-stage guidance since the SSME failure had not yet occurred. However, SSME no. 1 was failed prior to ME_RETRIM, which meant that the SSME pitch parallel phase was not extended to main engine cutoff (MECO). Because this was an RTLS, there was no second-stage roll to heads up nor was pitch gimbal relief activated.

In LM test case no. 4, SSME no. 2 was failed 15 sec prior to completion of the OMS assist, with ATO selected 5 sec following completion of the burn, and a downmode to TAL 5 sec later. The OMS assist burn was initiated at SRB sep +10 sec, and was not affected by the failure of SSME no. 2. Five seconds after completion of the burn, ATO was selected, and the dump was changed to a non-interconnected/45%/200-sec dump. The onboard calculated 200-sec dump duration represents 30% of the OMS loading, but 15% was already dumped through the OMS assist, so the targeted total dump percentage is 45%. ATO dumps are treated differently from other abort dumps in that in an RTLS or TAL, the total amount to be dumped is known prelaunch and the I-loaded dump timers are preset with the total targeted dump time. The amount to be dumped during ATO is computed onboard and is a tradeoff between ascent performance and conserving OMS propellant for orbit operations. For all aborts, the total targeted dump times represent a dump of some portion of the "operational" OMS load plus a dump of all of

the OMS assist (if any). The ATO dump was not initiated because at least 30 sec must elapse between the end of the OMS assist and the start of any other dump. Five seconds later, the ATO was downmoded to a TAL, and the OVERRIDE display was updated to reflect a non-interconnected/80%/435-sec dump. The I-loaded TAL dump duration of 537 sec was reduced by the 102 sec of dump already accomplished by the OMS assist. The TAL dump was delayed until expiration of the 30-sec minimum OMS off time. The second-stage roll to heads up did not occur when the relative velocity exceeded 12,500 fps because TAL was selected prior to this velocity. Instead, the roll to heads up occurred at 14,000 fps.

To address OMS failures during an OMS assist, various options were assessed. Doubling the burn time was disregarded as an option as that would result in a full dump coming out of one OMS pod, resulting in a large Ycg offset. A crossfeed was deemed impossible because the switches on the overhead panel are too difficult to reach, and a flight software change to automate this would be very complex. The concensus was to do nothing. The AFSIG concurred with this recommendation, based on the rationale that although an OMS engine failure could result in a technical violation of the OMS tank landing constraints, downweight constraints, and/or the Ycg constraints, there was sufficient conservatism in all of these constraints such that when combined with the low probability of an OMS engine failure, this was not a safety of flight issue.

Test case no. 1: Nominal ascent		
Event	MET	OVERRIDE Display
Lift-off	0:00:00	ICNCT = ENA
thing againing	a bridges	QUAN/SIDE = 84
		OMS DUMP TTG = 563
SRB sep	2:04:37	
MM103	2:04:45	
OMS dump ON	2:14:51	ICNCT = INH
(SRB sep +10	the pite	QUAN/SIDE = 15
sec)	IN A PARA	OMS DUMP TTG = 100
OMS dump OFF	3:56:57	ICNCT = INH
	day wat	QUAN/SIDE = 15
nt abcorga UK	LS TANK	OMS DUMP TTG = 0
Roll to heads up	5:51:00	al a harmon as
3g throttling	7:15:48	de la companya de la
MECO	8:19:58	and the second second
ET sep	8:38:97	and the second second

Test case no. 3: Intact RTLS with SSME no. 1 failed 15 sec after the start of OMS assist. RTLS was selected 15 sec later

Test case no. 3: Intact RTLS with SSME no. 1 failed 15 sec after the start of OMS assist. RTLS was selected 15 sec later		
Event	MET	OVERRIDE Display
Lift-off	0:00:00	ICNCT = ENA QUAN/SIDE = 84 OMS DUMP TTG = 563
SRB sep	2:04:37	and the second second
MM103	2:04:45	
OMS dump ON (SRB sep +10 sec)	2:14:51	ICNCT = INH QUAN/SIDE = 15 OMS DUMP TTG = 100
SSME no. 1 failed	2:29:49	and a set and and and and
RTLS selected	2:44:48	
OMS/RCS interconnected	2:44:78	
MM601	2:44:78	ICNCT = ENA QUAN/SIDE = 86 OMS DUMP TTG = 540
Start flyback	4:40:15	
PPA complete	4:53:41	The Construction Construction of the
OMS/RCS RTN	6:04:91	
OMS dump OFF	6:05:05	ICNCT = INH QUAN/SIDE = 86 OMS DUMP TTG = 0
PPD	10:43:47	and a state of the state of the
MECO	11:02:18	The state of the second states
ET sep	11:16:09	Sugal man de la contra

CR 91015: Pitch Steering During SRB Tailoff (PASS/BFS)

In the software, the first-stage pitch command is computed in the boost guidance task from an Iloaded attitude table that specifies the pitch, roll, and yaw for a given Vrel. Linear interpolation is performed between each point in the table to smooth the attitude commands over the trajectory. Because the commanded pitch rate follows the slope of the pitch attitude vs. Vrel profile, the pitch rate command will trend toward zero in the SRB tailoff region. This results in the vehicle essentially being at an attitude hold for several seconds prior to the software commanding an attitude hold at SRB Second-stage guidance then has to sep. compensate for the "extended" attitude hold.

This CR snapshots the current pitch steering angle at a mission elapsed time (MET) of 100 sec, then propagates the pitch profile at a constant pitch rate of $0.44^{\circ}/s$ ($0.5^{\circ}/s$ for an EO prior to 100 sec) until SRB sep is approached. In other words, when MET ≥ 100 seconds, the pitch command is decreased at a constant rate so that the pitch rate command stays at a constant $0.44^{\circ}/s$ for an I-loaded number of seconds (NYSEP_DELAY) past the event

of OMS assist. Select ATO 5 sec after completion of OMS assist. Downmode to TAL 5 sec after ATO selection		
Event	MET	OVERRIDE Display
Lift-off	0:00:00	ICNCT = INH QUAN/SIDE = 84 OMS DUMP TTG = 563
SRB sep	2:04:33	
MM103	2:04:42	112 121 12236 259/13 11
OMS dump ON (SRB sep +10 sec)	2:14:47	ICNCT = INH QUAN/SIDE = 15 OMS DUMP TTG = 102
SSME no. 2 failed	3:41:49	
OMS dump OFF	3:56:54	ANTI ANTI ANTI ANTI ANTI
ATO selected	4:01:45	ICNCT = INH QUAN/SIDE = 45 OMS DUMP TTG = 200
TAL selected	4:06:64	ICNCT = INH QUAN/SIDE = 80 OMS DUMP TTG = 435
OMS dump ON	4:26:51	
Roll to heads up	7:55:77	Vrel = 14,000 fps
OMS dump OFF	10:01:03	ICNCT = INH QUAN/SIDE = 80 OMS DUMP TTG = 101
MECO	10:10:07	
ET sep	10:29:49	and the state of the state

NYSEP_DISABLE. The event NYSEP_DISABLE is set by Ascent Flight Control and is the point at which the Ny feedback is faded out. Once MET becomes greater than NYSEP_DISABLE plus the I-loaded delay (NYSEP_DELAY), the software holds the pitch command constant, allowing the pitch rate command to gradually bleed off to zero. This provides approximately 50 lb of performance as well as a more benign transient at second-stage guidance initiation. In a nominal ascent performance test case, with the CR both enabled and disabled, the primary difference between the two cases was the angle of attack at SRB separation, which was approximately 3.5° more positive in the enabled case.

CR 91016: Extend Pitch Parallel to MECO (PASS/BFS)

Today, pitch parallel biases are added to the SSME commands, beginning at AUTOTRIM_ENABLE (about 12 sec into second-stage) and removed at ME_RETRIM (approximately 60 sec prior to MECO) to avoid thrust vector control (TVC) saturation. With this CR, instead of setting the biases to zero at ME_RETRIM, a limiting function is applied to the pitch bias for SSME no. 1, enabling the parallel pitch bias to be gradually reduced in a linear fashion without sacrificing adequate gimbal authority. The bias plus the trim on the center engine is constrained by an I-loaded value, and the biases for the lower engines are constrained in a proportional manner to maintain moment balance. When limiting the sum of the bias plus the trim on the center engine to 7° in the test cases, the limit was encountered about 25 sec prior to MECO for a performance gain of approximately 140 lb. The biases are removed for any SSME or hydraulic failures.

CR 91018: Ascent DAP Trim for Performance (PASS/BFS)

This CR adds the capability to reduce the included angle between the SSME and SRB thrust vectors during first stage. The SSME thrust vector is moved by adding a pitch trim increment to the main engines; i.e., PBIAS_E1 for the top and PBIAS_E23 for the side SSMEs. To compensate for the resulting moment imbalance, an increment will be added to the SRB trim in the opposite direction. The trim will be faded out before SRB separation or immediately following an SSME or hydraulic failure.

CR 91045: 106% Throttle in Second Stage (PASS/BFS)

This CR allows first-stage and second-stage guidance to use two different nominal throttle settings for Space Station missions that are performance critical. At the time this CR was presented, the engineering community believed that the 106% throttle with the expendable SRB would add unacceptable loading in first stage. On the first pass of second-stage guidance, the throttle command will be set to the I-load K_CMD_STG2 if manual throttling is not engaged and an engine failure has not occurred. This provides the flexibility to recover approximately 1500 lb.

CR 91056: LO2 Step Pressurization (PASS/BFS)

This CR would reduce the LO2 tank pressure prior to MECO to provide more usable LO2 to the SSMEs for impulse propellant. Reducing the tank pressure requirement at MECO from 21 psia to 17.7 psia would provide an additional 320 lb of GO2 pressurant mass for the SSMEs, which would result in net performance gain of 292 lb. The lower ullage pressure is achieved by "stepping down" the GO2 flow control valves to the low flow position in flight. This logic will be inhibited via Iload because the active GO2 flow control valves and related electrical power distribution and control (EPDC) modifications were canceled, per PRCBD S052333CE on May 31, 1996.

Significant GN&C CRs

CR 90711: Auto Body Flap Performance Enhancement (PASS/BFS)

This CR addresses three separate functions. The first two functions apply to both PASS and BFS. The third function is a contingency abort item and, as such, applies only to PASS. First, the pitch and body flap channels were modified so that the elevator and body flap become active at the same time. By standardizing aerosurface activation to occur at q-bar greater than or equal to 2 psf, body flap excursions that occur prior to elevator activation will be eliminated. Currently, the body flap becomes active in MM304, and attempts to trim with the elevator frozen. This does not affect OPS 6 because the MM602 transition for an intact abort occurs at q-bar greater than 2 psf.

Secondly, this CR modifies the body flap output hysteresis to have different negative and positive inner deadbands. The "smart body flap" elevator/body flap profile was modified to keep the aerosurfaces away from the SSME nozzle "bluing" region. However, this change introduced a potential for body flap limit cycling, which was observed on STS-48. The limit cycling occurs because there is too much lag in the feedback signal. The body flap passes its intended position before the drive commands cease being issued. The limit cycling is not a safety of flight issue and the hardware community does not have an issue with the extra body flap usage. However, the flight design community believes the limit cycling is a deficiency in the design and recommends eliminating it.

Thirdly, this CR automates the manual body flap procedures used during a contingency abort (PASS only). With the current body flap logic, the body flap is driven to keep the elevator on a predefined Mach schedule. This increases the likelihood of stalling or losing the aerosurface when the body flap actuators become overloaded because of high q-bar

pullouts in contingency abort situations. The saturation of the body flap actuators can result in a loss of control even though plenty of margin exists with the elevons. Engineering developed a manual body flap schedule for each flight, which balanced the aerodynamic forces between the body flap and elevon; the crew then trimmed the body flap using this schedule. However, due to funding cutbacks, the generation of these flight-unique schedules was eliminated. With this CR, the hinge moment between the elevator and the body flap is balanced by driving the body flap with the elevator. This will increase safety by properly balancing the actuator loads for all contingency aborts and will react to a real situation better than the limited cases that are analyzed preflight.

CR 90974: Orbit Targeting Lambert Iteration Loop Exit Logic Correction (PASS Only)

On flight day 6 of STS-49 (OI-21), 5 of 10 attempts to perform targeting resulted in a TGT ITER alarm, indicating failure to converge within the specified number of cycles. The failure to converge was isolated to the use of mixed precision parameters (double and single) in the Lambert targeting convergence algorithm. Contributing to this occurrence was a tighter value for the I-load EPS_U, which is used in the convergence criteria. A mode team was convened, which determined that in addition to the mixed precision problem, an additional exit criterion was required in the Lambert task. This additon was to ensure that the Lambert iteration loop would be exited as soon as a value of U was found that was "close enough" to be considered the correct solution (reference DR 106633). The lack of this exit criterion was explained as the reason why the problem occurred repeatedly during the Ti maneuver on rendezvous no. 3 and why it was not observed at any other time. Apparently, the desired transfer orbit was nearly circular, which resulted in a U_STEP size that was small, but not small enough to terminate iterating. CR 90701, Orbit Targeting Iteration Loop Correction, was then approved for OI-22 to correct the mixed precision problem and to exit the criterion to exit the Lambert task if U_STEP < EPS_U. Subsequently, a TGT ITER occurred during a Ti computation in an STS-51 (OI-22)

integrated sim (DR 106677). The problem was traced to an incomplete set of calculations when the Lambert routine was exited on the step size criterion, which was implemented in OI-22. The result is an inconsistent set of variables, which are then passed from the Lambert task to the precision velocity required task. Since the occurrence of this problem is highly sensitive to the initial conditions, and therefore rare, and the signature of the error is unique, a crew procedure was adopted as a workaround. The crew procedure depends upon the value of PRED MATCH. The step size criterion is now known through analysis and study to be unnecessary to meet shuttle program requirements, and is deleted in OI-26 with this CR

CR 90991: Continuous Issuing of Shutdown Enable/Shutdown Command (PASS/BFS)

This CR modifies the SSME OPS to continue toggling the Shutdown Enable and Shutdown commands after receipt of the Shutdown Phase until verification of post-shutdown phase. This closes Unsatisfactory Condition Report (UCR) A031485, the only known open UCR to date. which documents an extremely low probability. catastrophic shutdown scenario that closes the prevalves on a running engine. This condition can only occur if multiple power interruptions take place within a 2 sec window, and the probability of a required failure scenario was determined to be 1 in 185,000,000 flights. However, because of the severity of the consequences and the simplicity of the software change, the decision was made to fix the condition. This CR will allow a sole surviving digital computer unit (DCU), which is recovering from a power interruption, to recognize that an engine shutdown sequence is in progress and proceed with the shutdown that the other halted DCU had begun.

CR 90996: ADI and HUD Display Integrator Mods (PASS Only)

Originally, this CR was planned for PASS and BFS implementation, but because of the resources required, it was only approved for PASS implementation. This CR adds logic to attitude direction indicator (ADI) processing to integrate the Nz (pitch) and roll errors while in control stick steering (CSS) during MM305 and MM603 terminal area energy management (TAEM) guidance (not approach and landing (A&L) guidance). It also integrates the Nz (pitch) error while in CSS during the RTLS Nz hold phase (MM602, IPHASE=5). The pitch and roll errors are integrated for display on the ADI error needles and the head up display (HUD). The purpose of the integrator is to increase the "sensitivity" of the displayed error as a function of the accumulated error (i.e., the longer the error exists, the larger the displayed error).

The input to the integrators is grounded an I-loaded period of time whenever large guidance commands are expected as well as when CSS mode is entered, which avoids saturating the integrator. The pitch and roll error integrators are set to zero upon transition to MM 305 or MM 603, at guidance phase transitions, for runway redesignation, for OVHD/STRT IN HAC change, for main entry point/normal entry point (MEP/NEP) heading alignment cone (HAC) change, upon transition from AUTO to CSS, and upon transition to the glide return to launch site (GRTLS) Nz hold phase (no roll error integration during the GRTLS Nz hold phase). The I-loaded period of time is determined by the I-loads TIDELAY, TIDELAYC (AUTO to CSS), and TIDELAY5 (GRTLS IPHASE=5), all of which are set to 19 cycles. Because the ADI processing runs every 160 ms, 19 cycles correlates to a 3.04 sec delay.

If the pitch error is greater than the I-loaded pitch error deadband, the error is "gained up," otherwise it is "gained down" (likewise for roll errors). For the GRTLS Nz hold phase, the pitch error deadband PERR_DB5 = 0.025 g, the pitch error gain up GP_INTUP5 = 0.15, the pitch error gain down GP_INTDN5 = 3.0, and the pitch error integration limit PINT_LIM5 = 1.0 g. For MM305 and MM603 TAEM guidance, the pitch error deadband PERR_DB = 0.2 g, the pitch error gain up GP_INTUP = 0.15, the pitch error gain down GP_INTDN = 1.5, and the pitch error integration limit PINT_LIM = 1.0 g. Also for MM305 and MM603 TAEM guidance, the roll error deadband RERR_DB = 10.0°, the roll error gain up GR_INTUP = 0.15, the roll error gain down GR_INTDN = 1.5, and the roll error integration limit RINT_LIM = 20.0° .

All I-load values were determined from testing with various crewmembers in Shuttle Engineering Simulator (SES) and Ames Vertical Motion Simulator (VMS) testing and were set via DCR 3660A.

CR 91003: Addition of ±X Jets for On-Orbit Rotational Control (PASS Only)

This CR adds the capability for the Alt primary reaction control system (PRCS) to use the ±X jets for rotational pitch control if selected by the crew via the DAP CONFIG display. The DAP CONFIG display was modified, deleting the inertia item entries 7, 8, and 9, and adding a new item 7 (XJETS ROT ENA) to allow the crew to turn the $\pm X$ jets on or off. The $\pm X$ jets provide improved pitch control authority for those configurations in which the Z component of the center of gravity (c.g.) is significantly different from the orbiter only position due to the Z moment arm. Prior to this CR, the ±X jet groups (groups 1, 7, and 8) were considered translation only groups, and not considered for attitude control firings. When Alt PRCS is active, the ±X jets can be included to supplement the 11 rotational jet groups for a total of 14 jet groups. The jet options are :

BOTH \Rightarrow 14 jets (all 14 PRCS jet groups)

LOW Z \Rightarrow 11 jets (8 low +Z rotational PRCS jets and ±X jets)

TAIL \Rightarrow 8 jets (6 tail only rotational PRCS jets and +X jets only)

LM executed four test cases using the minimum angle jet select algorithm with and without the $\pm X$ jets and the maximum dot product jet select algorithm with and without the $\pm X$ jets. Each test case consisted of a 50-minute inertia hold in an inertial attitude, which is perturbed by a gravity gradient torque in the pitch axis. The mass properties were similar to the expected 6A configuration and represented a very massive system (about 510,000 lb) with a high Zcg. The jet firing comparisons are as follows:

APPENDIX E: OI UPDATES

Case	Total Firings	Total Fwd Firings	Total Aft Firings	Total ±X Jet Firings	Prop Used (in lb)
Min. angle with ±X	71	38	33	66	17.7
Min. angle	96	45	51	0	23.9
Max. dot with ±X	70	24	46	44	17.4
Max. dot	124	58	66	0	30.8

CR 91013: Convert Second Stage Trim K-loads to I-loads (PASS/BFS)

This CR converts the second-stage trim table parameters from K-loads, which require a CR in order to be changed to I-loads, which are mission reconfigurable. This is to support mixed fleet usage of the lightweight tank (LWT) and SLWT. The second-stage trim table is used to provide c.g. tracking from SRB sep to software zero thrust. The mated coast deadbands as well as the nominal and TAL translation delta Vz parameters and the open loop drift time following external tank (ET) sep were also converted to I-loads with this CR. This was done in anticipation that these values may need to be changed in the future as a result of PEs and mission profile changes (i.e., roll to heads up and 52 n. mi. MECO). Converting the RTLS ET sep inhibits was also included in this CR for the purpose of "no-opting" the RTLS ET sep inhibits. Removal of the SRB and RTLS ET sep inhibits arose back in 1992 during the RTLS heavyweight certification process. The SRB sep inhibits were no-opted beginning with STS-73, per PRCBD S052891; however, since the RTLS ET sep inhibits were K-loads, the decision was made to wait until OI-26 to convert these K-loads to I-loads, and then to redefine the inhibit limits. Note that protection for the angle of attack remains. The table below summarizes the difference between the current RTLS inhibit limits. and the values contained in DCR 3655 for OI-26.

Current Inhibit Inhibit Limits in Parameter DCR 3655 Limits -5.0°/s to -20.0°/s to **BTLS** pitch rate limits +0.25°/s +0.25°/s -20.0°/s to -5.0°/s to +5.0°/s **RTLS roll rate limits** +20.0°/s RTLS vaw rate limits -0.5°/s to +0.5°/s -20.0°/s to +20.0°/s -89.0° to -89.0° to -1.5° RTLS angle of attack -2.0° limits **RTLS sideslip limits** -2.0° to +2.0° -20.0° to +20.0°

RTLS ET Sep Inhibit Limits

CR 91019: Guidance K-load to I-loads for Second Stage Roll to Heads Up (PASS/BFS)

This CR converts the three guidance parameters PHI_2STG, VRHO_PHI, and TVR_ROLL to I-loads. This will allow a roll to heads up in second-stage. PHI_2STG is the desired secondstage roll angle, VRHO_PHI controls the timing of the roll to heads up, and TVR_ROLL is the roll angle of the vehicle during orbit insertion and deorbit. No software logic changes are made by this CR. This CR is often confused as a PE; while it is not, it was included in the PE certification. The orbiter/ET roll to heads up maneuver at approximately T +6 min is required to allow an early handover to tracking and data relay satellite east (TDRS E). MILA will be used for tracking until the roll maneuver is performed because the Bermuda tracking station is being closed as a cost reduction.

CR 91042: Second-Stage Pitch Gimbal Relief (PASS/BFS)

This CR is not a PE; it is required to maintain control under specific conditions as a result of performance enhancements. The SLWT is approximately 8000 lb lighter than the currently used ET and causes the vehicle c.g. to move about 6 to 8 inches further up into the Z-axis at MECO. This higher c.g. makes controlling the vehicle difficult on press to MECO cases with SSME no. 1 failed when the orbiter Zcg is near the top of the entry c.g. box. The result is that the SSME no. 3 pitch gimbal will hit the hard stop due to thrust deformation before MECO. The control impact is an uncommanded pitch rate on the vehicle, the magnitude of which depends on the Zcg, the thrust structure deformation, and the thrust vector misalignment.

The thrust structure deformation that this CR alleviates is a function of pitch and yaw SSME gimbal deflections, SSME thrust, and normal and longitudinal vehicle accelerations. It results in different effective pitch (and yaw) gimbal angles for engines, even though they are sent the same command. This deformation becomes important when the engines are no longer capable of pointing through the vehicle c.g. in pitch or yaw. The yaw c.g. is always within reach, but the pitch c.g. for heavy, high Zcg payloads may be unreachable when the top SSME has failed. The thrust deformation is asymmetrical; i.e., the structure of SSME no. 2 is more rigid than that of SSME no. 3; thus, SSME no. 3 deflects more than SSME no. 2 for a given pitch command. These asymmetrical deflections produce a roll moment through "de facto" scissoring of the engines. As a result, even though SSME no. 2 still has pitch gimbal authority when SSME no. 3 has hit its pitch stop, it cannot help SSME no. 3 in pitch without inducing a roll moment on the vehicle; instead, it must back off to prevent the roll moment. A throttle down to minimum power level reduces the deformation magnitude, providing about 0.5 to 0.7° of pitch gimbal relief. This CR provides for an automatic throttle down to 67%, instead of 91%, if a pitch gimbal command exceeds an I-loaded value during the last 15 sec of powered flight with SSME no. 1 failed. The throttle down would only be commanded if all of the following are true:

- Manual throttling is not active
- SSME no. 1 has failed
- A pitch gimbal command exceeds an I-loaded threshold (10°)
- Vehicle mass is less than an I-loaded mass (i.e., near MECO)

For early EO cases that result in a low level cutoff, the throttle down to 67% causes an underspeed that is approximately 15 fps greater than for the 91% throttle case. This results in a 5 to 7 n. mi. reduction in apogee altitude. The larger underspeed occurs because 300 additional lb of LO2 is in the propellant line when the LO2 low level cutoff is commanded at 67% vs. 91%.

CR 91044: Star Catalog Uplink Capability (PASS Only)

This CR adds the capability to uplink changes to the vector components of the last 10 stars in the star catalog. It also replaces five stars with near neighbors and updates vector components of all stars in the catalog to Epoch 2005. At the March 24, 1995 SASCB, it was stated that the planned shuttle/station docking flights put the orbiter in a configuration where the orbiter -Z star tracker is blocked and the -Y star tracker is pointed to a region with minimal stars. Flight rules require that inertial measurement unit (IMU) alignment be maintained to within 0.5° to support an emergency deorbit. This would require maneuvering of the combined stack once a day to perform the required IMU alignments.

CR 91054: SRB Sep Yaw Gain Enhancement (PASS/BFS)

The integrated performance of the shuttle was found not to meet the Volume X requirements for SRB separation for certain worst-on-worst combinations of maximum body rates. The Volume X violation was not the result of any flight software problem; rather, an error was found in the RI/D simulator used for generic certification. As a result, a smaller SRB staging envelope was defined and verified, which is roughly half the size of the previous envelope (reference PRCBD S052829). This CR increases the separation clearances between the SRBs and the ET, providing more margin for the SLWT and "hedging" against any possible violations of the new sep box with heavyweight missions and performance enhancements. This is accomplished by reducing the SSME yaw moments and lateral forces immediately following SRB sep by setting the yaw gain to zero at SRB sep command and fading it back to full value over an I-loaded time period.

Other Significant CRs

CR 90961: Expansion of Orbiter SPC Buffer for BFS and SM (PASS/BFS)

This CR expands the existing stored program command (SPC) buffer from 10 slots to 25 slots in both the systems management (SM) GPC and in the BFS. The driver for this change was the increasingly complex command scenarios that

required multiple SPC loads to be built, stored in the MCC, and sent as SPC buffer space became available. Payloads are now requiring more Ku-band mode changes to accommodate science data return, and these are best performed by SPC sequences to keep the onboard and ground systems in sync. Furthermore, at certain latitudes, radio frequency interference (RFI) is heavy and can continue for extended periods of time. This can occur before and after the zone of exclusion (ZOE). BFS was included due to MOD's desire to incorporate the command loads for the TDRS and Diego Garcia handovers onboard. The TDRS handover alone requires eight SPCs.

CR 90962: Payload Throughput Buffer Addition (PASS Only)

This CR adds a new command buffer to the SM major function for exclusive use of payload and Payload Operations Control Center (POCC) commands. Currently, all payload and orbiter SM command loads (such as TDRS handover, and table maintenance block updates (TMBUs)) must share the same SM two-stage buffer. This often results in contention over buffer usage and requires frequent voice coordination between various MCC console disciplines. Instances have occurred when simultaneous POCC and orbiter command requirements have resulted in a delay of the desired POCC command sequences. Since payload commanding is done primarily in a throughput mode and does not require buffering and downlisting of the twostage buffer before execution, the payload throughput commands (PTCs) will now be buffered in a dedicated PTC buffer. Once they are completely received, immediately they will be made available for processing without a buffer execute command. The SM GPC will not downlist the buffer contents, nor will it continue to buffer the data if it is received while the link to the specified payload is busy. A PTC buffer clear op code is added to purge the contents of the PTC buffer.

CR 91081: Clearing the GPC Soft Error Counter (PASS Only)

Currently, the only way to clear the soft error counter (SEC) is by moding the GPC to STBY or HALT. Each GPC has an SEC for upper and lower memory. The SEC can record up to 127

counts per page. The maximum number of counts recorded on the lower page was 109 on STS-60. With future Space Station missions, engineering believes that the SEC will reach its maximum capability, and will no longer be useful unless it can be cleared. MOD has expressed the need to clear the SEC while keeping the GPC in RUN mode during Space Station operations. This CR adds the SEC as an additional item to be cleared/reset with the execution of Item 48 on SPEC 0. Currently, ITEM 48 EXEC restarts the sync trace log, resets GPC fail votes, clears the input/output (I/O) error log, GPC error log, and display electronics unit (DEU) initial program load (IPL) log. KSC will need to modify their Launch Control Center (LCC) monitoring software to account for the clearing of the SEC when an ITEM 48 is performed.

CR 92014: Space Vision System Auto-Control of Closed Circuit TV Cameras (PASS Only)

This CR implements a mission-dependent process in the SM GPC to allow the space vision system (SVS) to control the closed- circuit television (CCTV) cameras. The SM GPC will acquire the SVS camera commands via the PF1 multiplexer/demultiplexer (MDM) and translate them for output to the CCTV system via the PF2 MDM. The SM GPC will use a look-up table to convert the SVS camera commands into CCTV commands, such as pan, tilt, zoom, and focus. The output to the CCTV is indistinguishable from an uplink command; therefore, ground commanding of SVS-controlled cameras must be managed procedurally. The crew will initiate this new process with an item entry to a reconfigurable SPEC.

CR 92026: RMS PL ID Initialization Correction (PASS Only)

DR 107968 identified a deficiency in the position and orientation hold submode (POHS) logic implemented on OI-23, where changing payload identifications (PL IDs) could cause POHS to generate uncommanded motion or cause a trajectory tracking alarm. This condition occurs if the PL ID is changed without a payload attached while in orbiter loaded or payload mode with POHS active. This will also occur if the end effector (EE) ID is changed while in any manual augmented mode, loaded or unloaded, with POHS active. Since crew procedures call for the application of brakes when changing the PL ID, and the EE ID is only changed in unique situations, the SASCB community agreed not to patch the flight software. This CR corrects the deficiency by

- Ensuring that POHS resets any time the payload ID is changed.
- Correcting the auto mode logic to ensure operator commanded auto sequence (OCAS) is executed with the proper EE ID.
- Inhibiting EE ID changes while in auto mode, manual augmented mode, or test mode.

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