

Entry Digital Autopilot

ENTRY DAP 2202



Mission Operations Directorate Space Flight Training Division

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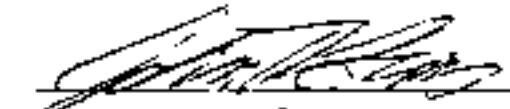
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Entry Digital Autopilot

August 1992

Approved by

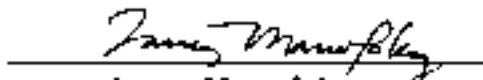


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Preface

This book is organized in sections. Begin each section by reading the objectives and learning material. If you are already familiar with the subject matter, skip to the practice exercises. If the material is new to you, be sure to read all the text carefully before doing the exercises. If you are using this workbook for recertification, answer the questions at the end of each section.

Before progressing to another section you should understand the correct answers to each of the practice items. The feedback gives the correct response to each item.

All the acronyms and abbreviations used in this workbook are defined when first used and listed in Appendix A.

This workbook is provided for your use. You may take notes or write comments anywhere you like.

Section 1: Digital Autopilot System

Objectives

At the end of this section, the student will be able to do the following.

- State the two control systems that the entry digital autopilot (DAP) commands
- State the two ways entry DAP is provided with command rates
- State the input data necessary for the determination of control requirements

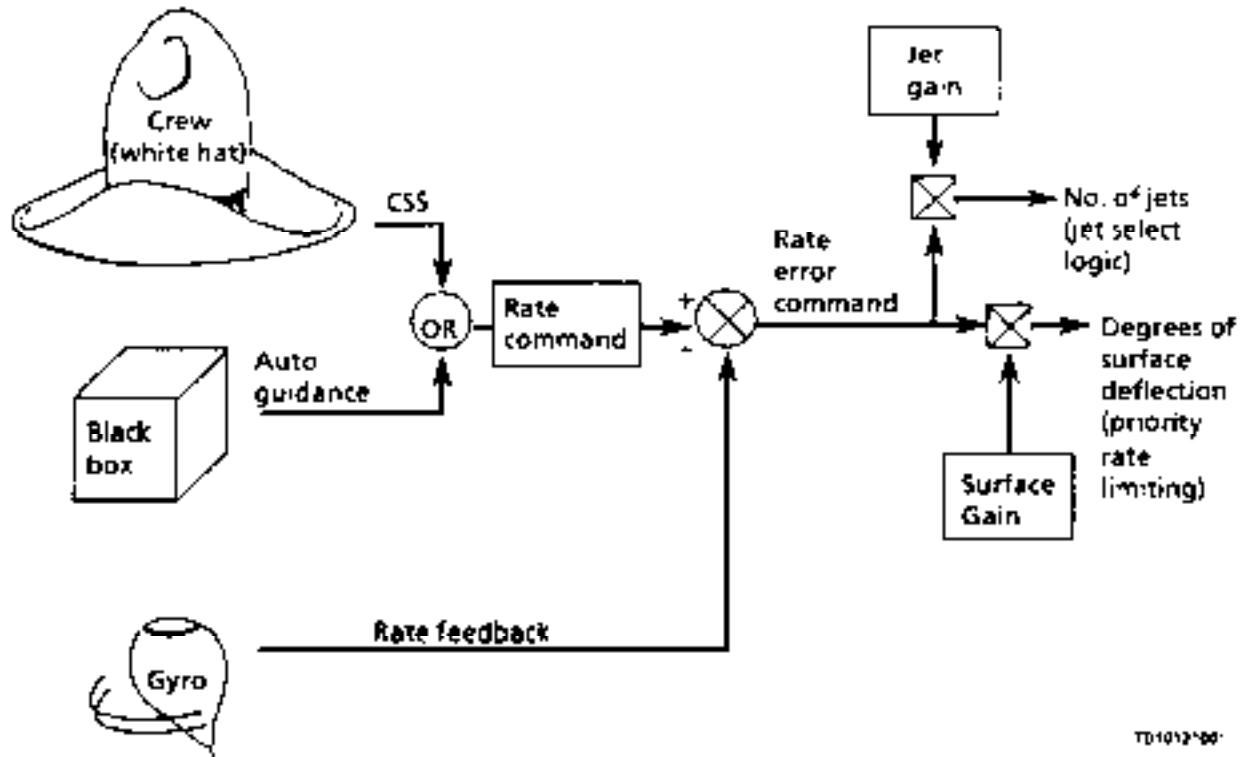
General Introduction

The entry or aerojet DAP, hereafter referred to as the entry DAP, commands the aerodynamic control surfaces and the reaction control system (RCS) jets to provide vehicle trim, coordinated flight maneuvers, energy modulation, and steering on the runway. The entry DAP is a rate command system, with the command rate provided by either the pilot through control stick steering (CSS) or by automatic guidance. The commanded rate is then compared to the actual rate (rate feedback), resulting in a rate error that is multiplied by the appropriate gains to produce RCS jet and/or aerodynamic surface commands. Figure 1-1 shows a very basic schematic of the entry DAP. Regardless of how complicated succeeding schematics become, they functionally reduce to the schematic shown by figure 1-1.

The shuttle entry DAP has some features that aid it in doing its unique flying. Turn coordination is provided so that bank maneuvers are coordinated automatically from entry to touchdown without rudder pedal inputs being required. Alpha modulation (angle of attack modulation) during bank maneuvers keeps the actual drag acceleration (DRAG ACTUAL) from diverging from the reference drag (DRAG REF) when rolling through the wings level attitude. The entry DAP drives the aerodynamic control surfaces to trim the vehicle during flight. The body flap is driven by the entry DAP to trim the vehicle in pitch. This offloads the trim provided by the elevons, allowing elevons to be used for vehicle control. The speedbrake (SPBK) is used as a pitch trim device at Mach numbers above 0.95 and provides energy modulation at Mach numbers below 0.95.

Command control surfaces and RCS jets for trim and coordinated bank maneuvers, energy modulation, and steering on the runway

Basic command loop



TD-1012-00

Figure 1-1.—Entry DAP job description.

The rotational hand controller (RHC) rate trim (pitch and roll "coolie hat") and the panel trim switches (roll, pitch, and yaw) provide manual trimming functions. The RHC trim switch can bias the commanded rates by 1.5 deg/sec in pitch (up or down) or 2.5 deg/sec in roll (left or right). At present, there is no operational use for this "coolie hat" on the RHC. The roll and pitch panel trim switches command aileron and elevator integrated surface positions. The roll panel trim switch can be used effectively to manually speed up the trimming process in the roll channel. The yaw panel trim switch can be used to bias the lateral acceleration (N_y) feedback by as much as $\pm 0.1g$.

Automatic programmed test inputs (PTIs), another feature of the entry DAP, are direct commands to the control surfaces or jets (downstream of any gains, biases, or filters) that provide perturbations from which aerodynamic coefficients can be extracted. These are used to expand the orbiter flight envelope and to reduce some variations and uncertainties in the aerodynamic data base.

As with any stability augmented control system, certain data are necessary for determination of the control requirements. These input data include navigation-derived parameters, rate gyro and accelerometer outputs, control surface position feedback, guidance commands, and past values of surface and jet commands. Figure 1-2 illustrates the required inputs for the entry DAP, as well as the destination of the output parameters.

The cockpit displays for the commander and pilot include entry DAP performance information on the attitude director indicators (ADIs), the three computer-driven cathode ray tubes (CRTs), the RCS jet activity lights, and the surface position indicator (SPI).

On the commander's and the pilot's ADIs, the vehicle rates are displayed on the rate pointers as shown in figure 1-2. The roll and yaw rates are in the stability axes, while the pitch rate is in the body axis. The ADI rate switch controls the magnitude of the rates displayed. The three switch positions provide low, medium, and high rates with corresponding values of 1, 5, and 10 deg/sec in each axis. The yaw error needle on each ADI displays the sideslip angle (beta, β) in the low dynamic pressure phase (low \dot{q}), and when \dot{q} is greater than 20 psf, it displays "scaled A_y ." This scaled A_y is the lateral acceleration after compensation for surface deflections, accelerometer location, jet firings, Mach number, angle of attack, and \dot{q} . Its accuracy is thus dependent on the modeling accuracy of the aerodynamics and sensors. This parameter is correlated to the control authority available from the yaw jets. A full-scale deflection of the yaw needle is equivalent to the lateral acceleration caused by a sideslip angle that would be balanced by the torque due to 2.5 yaw jets.

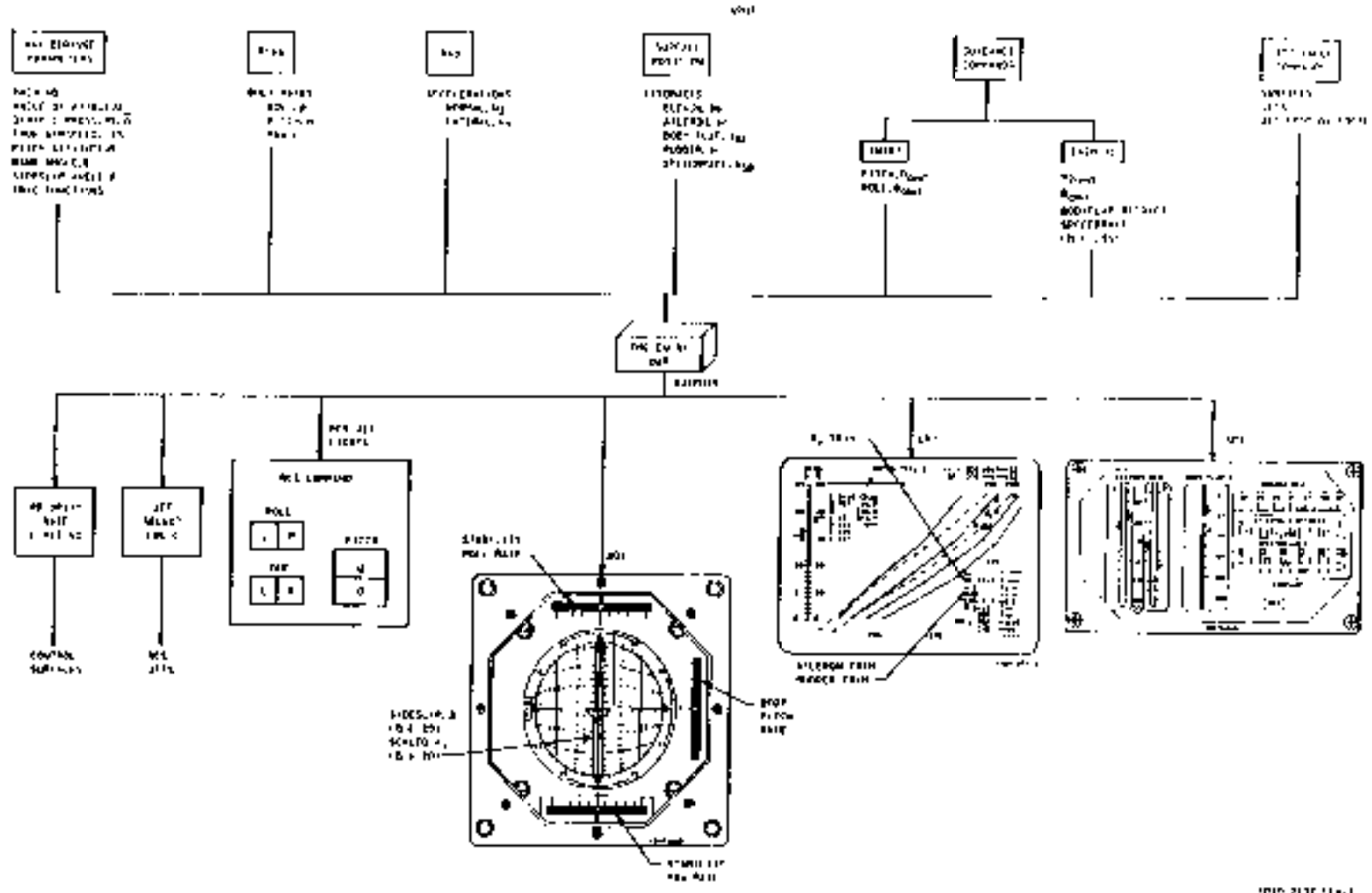


Figure 1-2.- Entry DAP.

Table 1-1.— Entry DAP features.

Rate trim RHC rate trim biases RHC command.

± 1.5 deg/sec pitch

± 2.5 deg/sec roll

Surface trim: Pitch and roll panel trim switches command elevator and aileron surface integrated positions.

$\pm 3^\circ \delta_a$ -33° to

$\pm 6^\circ \delta_r$ $+18^\circ \delta_e$

Yaw panel trim switch biases N_y feedback, $\pm 0.1g$ limit

Panel trim switches maximum trim rate commands:

(Pitch) δ_e : 2 deg/sec

(Roll) δ_a : 0.5 deg/sec

- Turn coordination is provided in auto and CSS through entry to flatturn/rollout (no rudder pedal commands normally).
- Turn compensation; i.e., pitch rate commanded in bank maneuvers, provided in terminal area energy management (TAEM) and approach and landing (A/L) phases.
- Automatic surface trim commands are from forward loop trim integrators.
- Body flap drives to trim vehicle such that elevons and SPBK may follow programmed schedules.
- Above Mach 0.95, SPBKs are used as a trim device rather than for energy modulation.
- Surface and jet automatic PTIs are for aero coefficient data reduction.

Questions

1. What two control systems does the entry DAP command?
2. What are the two ways entry DAP is provided with command rates?
3. What input data are necessary for the determination of control requirements?

Answers

1. Entry DAP commands the
 - a. Aerodynamic control surface system
 - b. Reaction control system

2. Entry DAP is provided with command rates
 - a. By the pilot through CCS
 - b. By automatic guidance

3. Input data include
 - Navigation derived parameters
 - Rate gyro and accelerometer outputs
 - Control surface position feedback
 - Guidance commands
 - Past values of surface and jet commands

Section 2: Pitch Axis

Objectives

At the end of this section, the student will be able to list the three separate aerodynamic control surfaces that control the pitch attitude of the shuttle.

Pitch Axis

Figure 2-1 is an overview of the major entry DAP events in the pitch channel from major mode (MM) 304 at entry interface (EI) minus 5 minutes through touchdown and rollout. These events are described in greater detail in subsequent sections.

Three separate aerodynamic control surfaces, as well as the pitch RCS jets, are active in controlling the pitch attitude of the vehicle. The surfaces are the elevons, the body flap, and the SPBK. The body flap and SPBK, which are involved with pitch trimming, are described first.

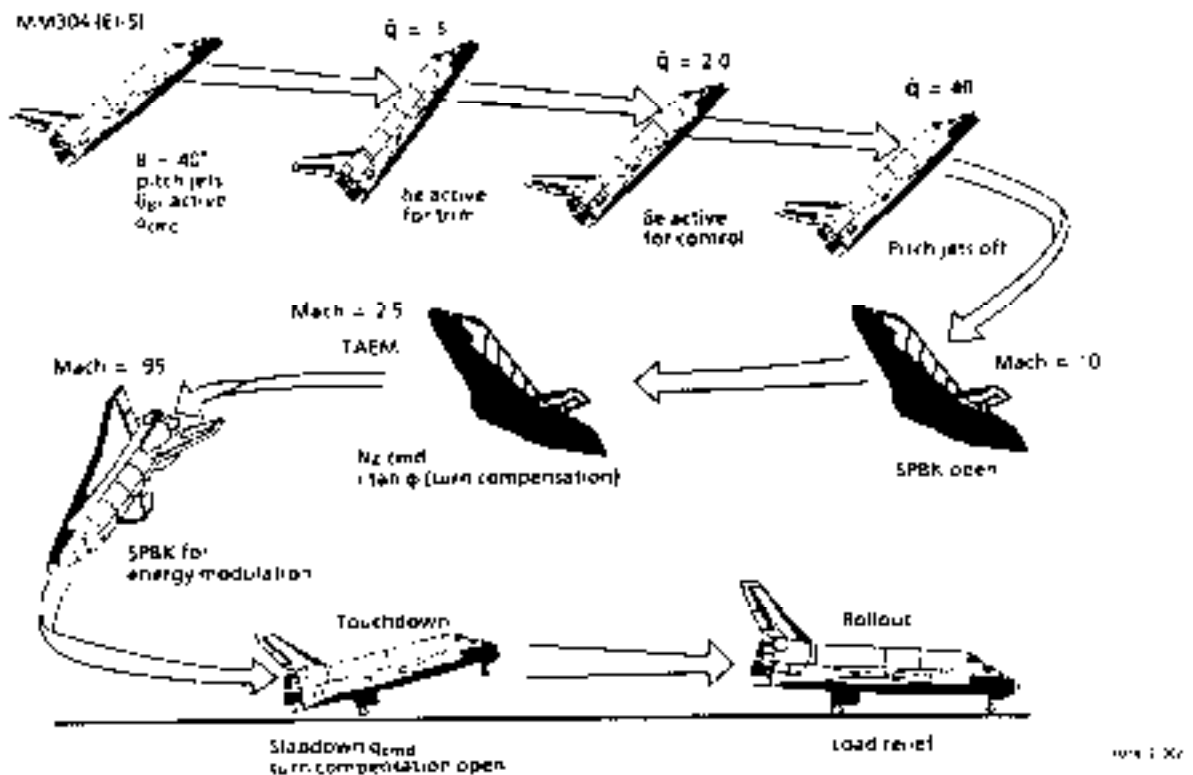


Figure 2-1.- The pitch channel.

Questions

1. What three separate aerodynamic control surfaces control the pitch attitude of the shuttle?

Answers

1. Three control surfaces that control pitch attitude are
 - Elevators
 - Body flap
 - SPBK

Section 3: Body Flap

Objectives

At the end of this section, the student will be able to do the following.

- Describe the primary purpose for the body flap
- Describe how the crew can manually position the body flap

Body Flap

The body flap, as previously stated, is a pitch trim device that is used to keep the elevons near or on a predetermined schedule. Whether the elevons are kept just near or on the predetermined schedule depends on whether the crew has the AUTO or FIXED elevon schedule selected and, for the AUTO schedule, the position of the body flap. The AUTO elevon schedule and body flap combination is designed to keep the elevons positioned where they can be the most effective without exposing the body flap or elevons to excessive heating or high hinge moments. Figure 3-1 shows that the elevon trim command is fed into the body flap channel, where it is differenced with the body flap position and the elevon schedule. The body flap moves so as to drive the elevon trim command toward the elevon schedule. The change in OI-20 adds the body flap position feedback to the body flap channel. This means that as the body flap moves toward the full up or down position, a Mach and position-dependent bias is added to the elevon trim to bias the elevon position. This causes the elevon position to shift up to 6° up or down, preventing the body flap from saturating for extreme off-nominal center of gravity (c.g.). This ability to handle the full c.g. range without body flap saturation is the primary advantage of the AUTO schedule. The difference between body flap, elevon position, and elevon schedule is compared to a deadband. The deadband determines if the error is greater than 1°. If the error is greater than 1°, the signal is conditioned by a gain function, fed through an integrator, and then differenced with the body flap position. This difference goes into the body flap hysteresis loop to determine if the body flap is within 1° of the required position. If it exceeds the 1° deadband, a command is sent to the priority rate limiting (PRL) to drive the body flap up or down until the elevon trim loop is satisfied.

The FIXED elevon schedule/body flap is similar to the AUTO elevon/body flap except the body flap position is not added to the elevon trim and elevon schedule. The body flap moves as described above to keep the elevons on schedule, even if the body flap must drive full up or down, and the elevon position is not biased to prevent body flap saturation. This is the primary disadvantage of the FIXED schedule; it can handle only approximately one-third of the total c.g. range

without body flap saturation. This could result in high hinge moments or thermal problems for the body flap. For flights without forward c.g. PTIs, we use the FIXED elevon schedule, which places the elevons in their furthest down position. We would also see this selection during no-yaw-jet operations.

An example of an elevon schedule, along with the body flap schematic, is shown in figure 3-1. The elevon schedule is a function of Mach. The AUTO elevon schedule is automatically selected upon transition to OPS 3, whether the transition is from OPS 1 or OPS 2. The FIXED schedule must be manually selected in all cases. A third elevon schedule, the gliding return to launch site (GRTL5) schedule, is automatically selected upon return to launch site (RTL5) abort select. No crew input is required or allowed. The GRTL5 elevon schedule is presently configured to be essentially the same as the AUTO sequence.

The crew can also operate the body flap manually. By pushing the body flap push-button indicator (PBI), the crew can select the manual body flap switch (spring loaded to off). This allows the crew the option of taking control of the body flap and manually positioning the elevons where desired. If the body flap is manually moved up(down), the elevons are commanded down(up) to maintain control and trim. Body flap rate during manual operations is faster than the rate during AUTO operations. Manual body flap is used during contingency aborts where control/trim requirements build up too fast for the AUTO system to keep up and for some off-nominal aerodynamics cases where the body flap is raised to lower the elevons, increasing elevon effectiveness.

The integrator loop in the body flap channel holds the body flap position. Without this loop, when the body flap command is removed, the body flap would sense a zero-position command, driving the body flap to zero or to within the hysteresis deadbands.

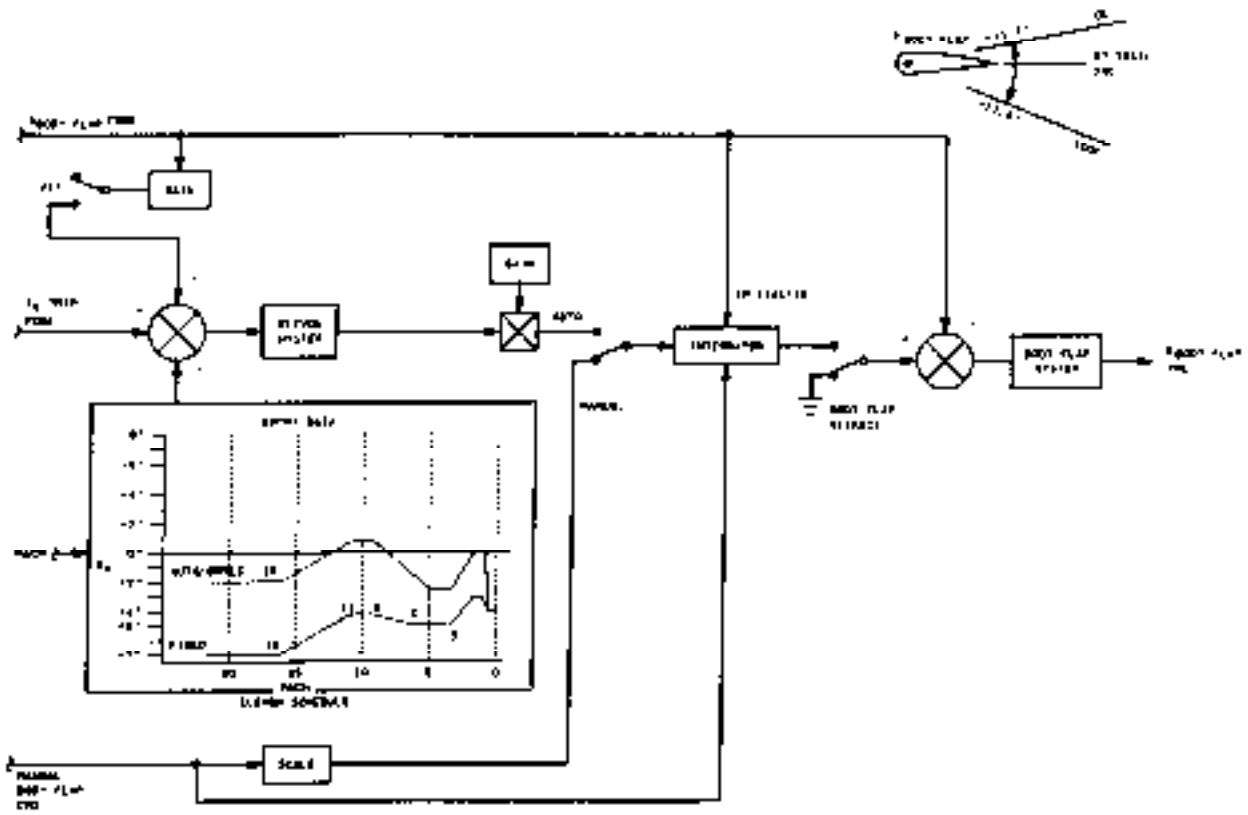


Figure 3-1.— The body flap channel.

Questions

1. What is the purpose of the body flap?
2. How can the crew manually position the body flap?

Answers

1. The body flap is a pitch trim device. The **FIXED** elevon schedule is used to keep the elevons on a predetermined schedule. The **AUTO** elevon schedule is selected to place the elevons where they are most effective without exposing the body flap or elevons to excessive heating or high hinge moments.
2. By pushing the body flap PBI, the crew can select manual body flap and then drive the body flap with the manual body flap switch (spring loaded to OFF). "MAN" illuminates on both PBIs.

Section 4: Speedbrake

Objectives

At the end of this section, the student will be able to do the following

- List the two purposes of the SPBK
- Describe the use of the SPBK in the 3000 feet of descent before touchdown

Speedbrake

The SPBK is used to aid in trimming the vehicle in pitch at Mach numbers above 0.95 and is used to modulate energy below that Mach number. Some of the aerodynamic characteristics of the SPBK are shown in figure 4-1. The figure shows the pitching moment contribution for various SPBK angles and Mach numbers, and the lift to drag (L/D) contribution for the same parameters. These data show that while there is a change in pitching moment with SPBK angle starting with Mach numbers as high as 8.0, there is little change in L/D until the Mach number is subsonic.

The SPBK, like the FIXED function of the elevons, has a programmed schedule for entry. An example of this schedule is shown in figure 4-1. The schedule shows the SPBK closed until Mach 10, at which point it is commanded to an open position (81 percent in this example). During ascent and the first part of entry, the closed command is -9° to ensure a tightly closed condition, preventing any heat damage.

At Mach 3.2, the SPBK is closed to 65 percent. The schedule holds this position until the Mach number reaches 0.95; the SPBK is then used by guidance to modulate energy.

A simple schematic of the SPBK channel is shown in figure 4-1. In the automatic mode, the SPBK command is driven by the SPBK schedule at Mach numbers beyond 0.95 and by guidance below 0.95. From $M = 0.95$ until 3000 feet above ground level (AGL), guidance uses the SPBK to control \dot{q} ; if above the reference \dot{q} , the SPBK extends; if below the reference \dot{q} , the SPBK retracts. In the 3000 feet before touchdown, guidance will adjust the SPBK twice, once at 3000 feet AGL and again at 500 feet AGL to ensure that the shuttle reaches the desired touchdown point at the desired airspeed. At 3000 feet AGL, guidance uses velocity error (from a reference velocity), vehicle weight, wind, density altitude, runway option (nominal versus short field), and aimpoint selection (nominal versus close-in) to adjust the SPBK. At 500 feet AGL, guidance uses wind and density altitude for SPBK adjustment. These commands are summed with a limit bias to prevent contact with the

hard stops and go through a SPBK limit logic out to the priority rate limiting. The manual operation of the SPBK is essentially the same, with the command coming from the crew via the SPBK controller.

Questions

1. What are the two purposes of the speedbrake?
2. How does the speedbrake function in the 3000 feet of descent before touchdown?

Answers

1. The speedbrake is used to aid in
 - a. Trimming the vehicle in pitch at Mach numbers above 0.95.
 - b. Modulating energy below Mach 0.95.

2. In the 3000 feet before touchdown, guidance will adjust the speedbrake twice, once at 3000 feet AGL and again at 500 feet AGL, to ensure that the shuttle reaches the desired touchdown point at the desired airspeed.

Section 5: Elevators

Objectives

At the end of this section, the student will be able to do the following.

- State when the pitch jets are deactivated
- State when the elevators are active for control
- Describe turn compensation
- Describe load relief bias

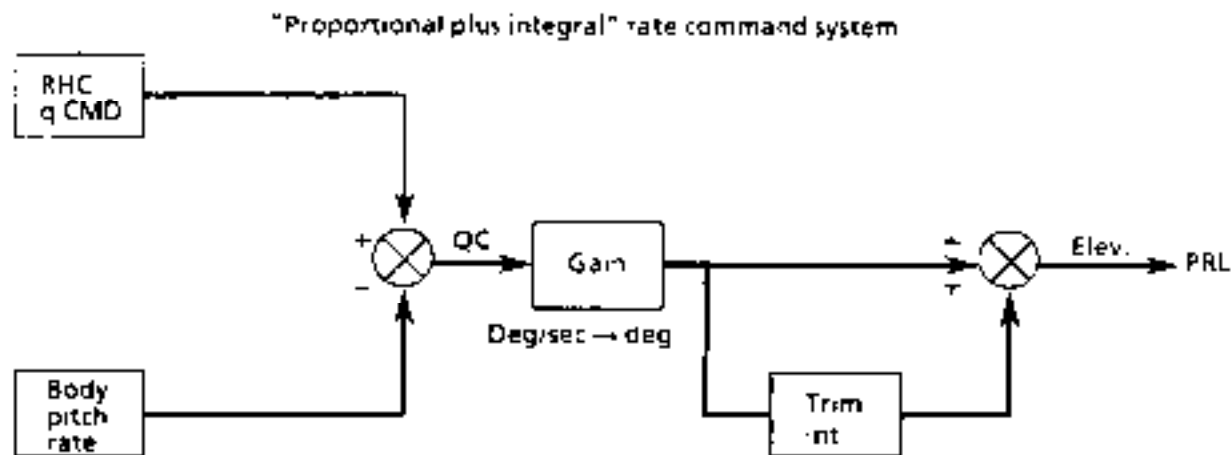
Elevators*

The pitch axis control is provided by the elevators (aerodynamically) and the pitch RCS jets (low \dot{q}). The control system is a proportional-plus-integral rate command system (fig. 5-1). This means that the elevator surface command is proportional (through the gain shown) to the RHC commanded rate. This elevator command is summed with the output of an elevator trim integrator in the forward loop, resulting in an elevator command to the priority rate limiting software.

The forward loop trim integrator accrues an incremental elevator deflection for pitch trim and prevents a standoff rate error. In other words, as the commanded rate is being satisfied (command equals feedback), the rate error would go to zero at the summation point, and without the trim integrator to hold the elevator at the last commanded position, the desired commanded rate could not be sustained.

Figures 5-2 through 5-6 show buildup of the flight control system (FCS) pitch channel of the entry DAP. These figures are slightly more detailed, but are still in a simplified form for ease of understanding and logical step-by-step additions of the various functions of the pitch channel. A complete schematic of the pitch channel, as well as those of the SPBK and the BF, is contained in the Functional Subsystem Software Requirements.

*Elevons are the actual aerosurfaces. Elevators refer to the use of the elevons symmetrically for pitch control; ailerons refer to the use of the elevons asymmetrically for roll control.



- Surface command is proportional to RHC rate command
- Forward loop trim integrator
 - Accures an incremental elevator deflection for trim
 - Prevents a standoff rate error

Integrator holds the δ_p trim command in the forward loop when $RHC\ q_{CMD} = \text{feedback}$ (Otherwise, the rate error would go to zero as soon as the command is satisfied, and the surface would try to return to the null position. You would never sustain the desired commanded rate.)

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Figure 5-1. – Pitch axis.

Figure 5-2 shows the CSS command path in the pitch channel. The CSS commands are input through the RHC. From there the input, which is commanded rate (q_{cmd}), takes two paths. Path 1 goes through various filters into the pitch RCS jet hysteresis logic, which determines whether or not the criteria for a jet command has been met. Assuming a jet command is issued, it goes out to the jet select logic (JSL) to fire the pitch jets. The \dot{q} greater than 40 pounds per square foot (psf) switch is opened when the dynamic pressure becomes greater than 40, negating further use of the pitch jets during entry.

Path 2 of the commanded pitch rate goes through a lead (or lag) filter and a fourth-order body bending filter. It is multiplied by a gain that converts a pitch rate error into an elevator command. This command is compared to surface position limits and sent to priority rate limiting, where the surface commands are issued. This elevator path is activated when the q becomes greater than 2 psf.

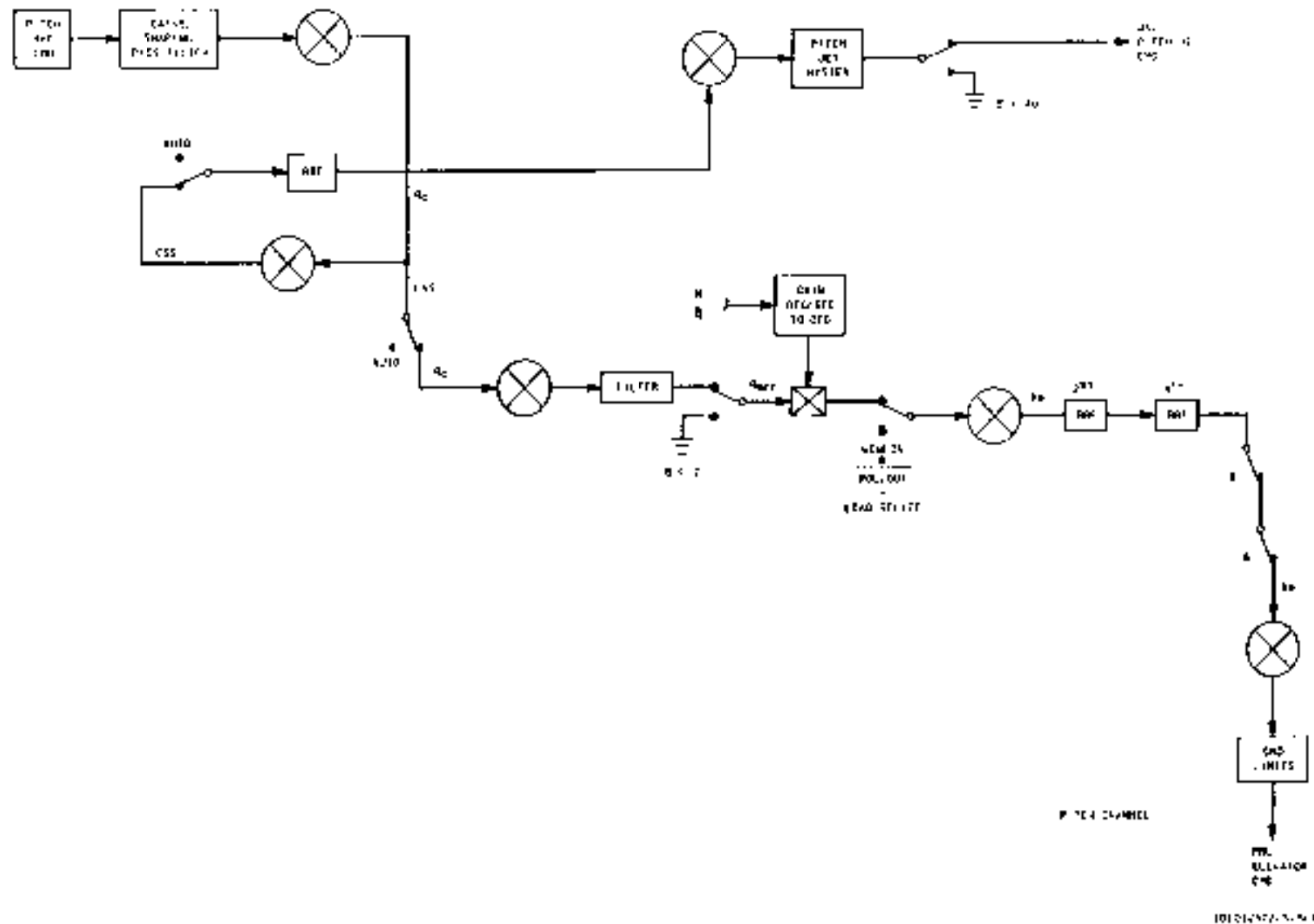


Figure 5-2. - FCS pitch channel buildup - CSS commands.

A turn compensation term becomes active at the beginning of the terminal area energy management (TAEM) phase and is used until touchdown. Turn compensation, which is calculated using measured parameters, is the amount of pitch rate needed to keep the nose of the vehicle up during a turn. A more complete understanding can be obtained from figure 5-3. Figure 5-3 shows a free body diagram of the orbiter in a steady state turn. The basic equation for a steady state turn is

$$\omega = \psi = \frac{g}{V} \frac{\sin \phi}{\cos \phi} \quad (1)$$

The body rates for the turn are

$$p = -\psi \sin \theta = -\frac{g}{V} \frac{\sin \phi}{\cos \phi} (\sin \theta) \quad (2)$$

$$q = \psi \sin \phi \quad (3)$$

$$r = \psi \cos \theta \cos \phi = \frac{g}{V} \frac{\sin \phi}{\cos \phi} \cos \theta \cos \phi \quad (4)$$

Consider a free body diagram of an aircraft in a level turn as seen from the rear.

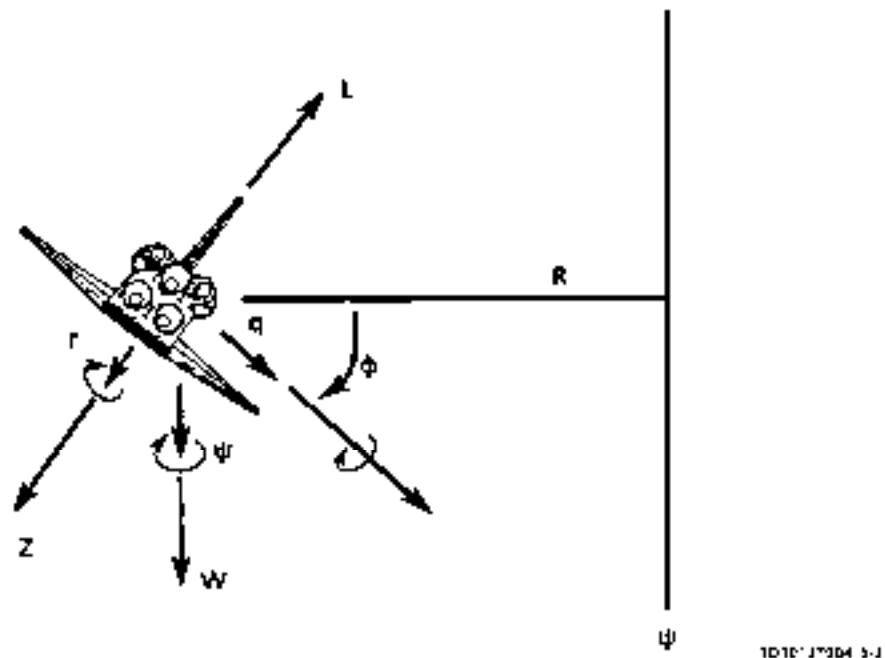


Figure 5-3.—FCS pitch channel buildup – Nose-up turn compensation.

Substituting for ψ in equations 3 and 4 yields

$$q = r \frac{\tan \phi}{\cos \theta} \quad (5)$$

If we assume that this is to be for a basically level turn, then θ is approximately zero and $\cos \theta$ goes to 1.0 resulting in

$$q = r \tan \phi \quad (6)$$

This pitch rate contribution is shown in the lower left corner of figure 5-4, and can be observed on the ADI pitch rate pointer during turns in TAEM if no CSS pitch commands are input during the bank maneuver.

The body yawing rate, r , which is taken to be the steady state rate, is found by substituting for ψ from equation 1

$$r = \frac{g \sin \phi}{V \cos \phi} \cos \theta \cos \phi \quad (7)$$

resulting in

$$r = \frac{g}{V} \sin \phi \cos \theta \quad (8)$$

The values of the yawing rate are calculated in the yaw channel of the entry DAP and used in all three axes from EI through touchdown.

Figure 5-4 shows the addition of rate feedback and trim loops. The body pitch rate, q , is the feedback value with which the RHC or automatic commanded pitch rate, q_{cmd} , is differenced to give pitch rate error, q_{err} . The pitch rate error, while going on to command the elevators and the pitch jets, also goes into the pitch trim integrator loop for low \dot{q} trim ($\dot{q} < 20$ psf). The pitch trim integrator becomes active at a \dot{q} of 0.5 psf. The elevators then begin to respond to the pitch jet firings. At a \dot{q} of 2 psf, when the elevators become active for control, the trim integrator also receives the preliminary elevator command. The trim integrator no longer receives pitch jet firing commands after \dot{q} passes 8.0 psf and is switched out in favor of elevator position feedback trim at \dot{q} equal to 20 psf.

At the point where the trim integration of q_{err} ceases, the elevator position feedback takes over for trim. The elevator position feedback holds the last value of elevator angle (δe) as the trim value. This technique, as opposed to integrating a continuing rate error, was designed because of concern about the possibility of surface actuator stall. Should the actuator stall, the rate trim integrator would continue calculating an increasing elevator trim position, but the elevator would

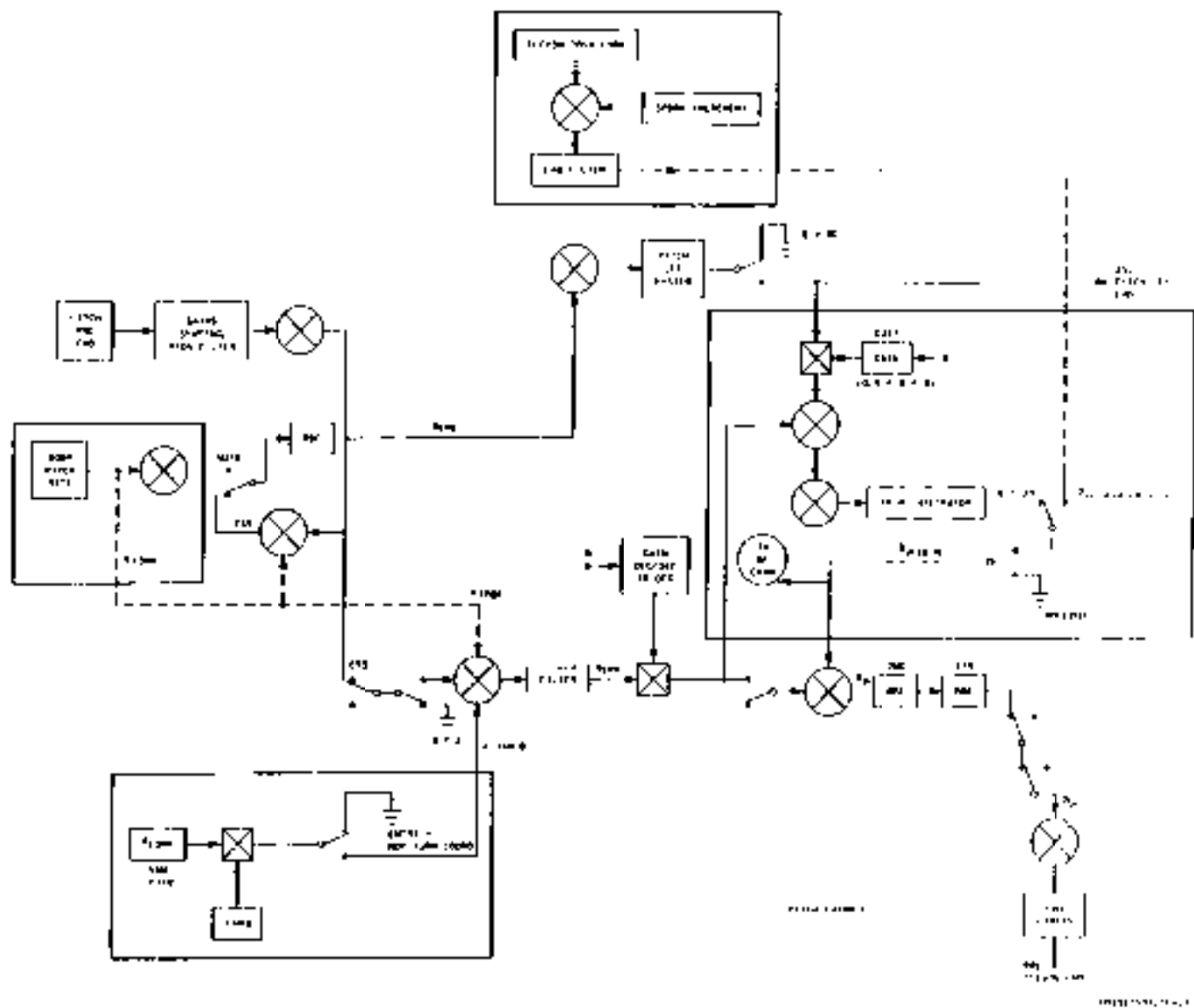


Figure 5-4.- FCS pitch channel buildup - Rate feedback and trim.

not be moving to that new trim position. If a sizable difference develops, and the actuator then becomes unstalled, the elevator would be driven to the trim position immediately, possibly overshooting the command and causing a large pitching moment transient. An increment to account for the pitching moment of the SPBK is added to the elevator feedback position and is also shown in figure 5-4.

Figure 5-5 shows the addition of the pitch panel trim switch, the RHC rate trim switch, the normal acceleration (N_z) command, and the PTJ modifications. The pitch panel trim switch feeds directly into the elevator trim loops. When this switch is activated, the elevators are driven to a new position. In actual practice, the results of using the pitch panel trim switch vary with control system configuration. There are four possible configurations, which are combinations of pitch and BF control in either automatic control mode (AUTO) or CSS. In pitch control in automatic mode (AUTO P), activation of the pitch panel trim switch to pitch up will initially move the elevators up, generating a nose up pitch rate. The pitch rate causes a pitch attitude error to develop. When the trim switch is released, thereby removing the pitch up command, the control system will automatically begin to remove any pitch attitude error and return the vehicle to its original attitude. The BF, if in AUTO, will deflect in such a way as to attempt to drive the elevators back onto schedule when the BF control logic senses it is outside its prescribed deadband. In the manual position, there would be no BF movement. After the control system had returned the vehicle to its original attitude, the elevators and BF would be at or very near the premaneuver deflections. The same pitch panel trim input while the vehicle is in pitch control in control stick steering mode (CSS P) creates a slightly different result. The same pitch rate and attitude error will develop, but once the input is ended, the DAP will only damp out its rate, leaving its vehicle at some new pitch attitude. Again, the BF function is determined by whether it is in AUTO or manual and the elevator position required to damp the rate and hold the new pitch attitude is also affected by the BF mode. The auto BF will be worked by the entry DAP to keep the elevator on its schedule. In the manual mode, any BF movement is restricted to crew action. Historically, the switch had a procedural use during the approach and landing test phase of the shuttle program when a manual direct mode was available in the entry DAP, while currently there is no planned operational use of the pitch panel trim switch.

Similarly, the RHC rate trim switch ("coolie hat") is a functional switch that has no planned operational use. The trim switch biases the rate signal coming from the RHC with a constant rate. The bias limit is ± 1.5 deg/sec. If control is in CSS, once the rate bias is commanded, it will remain there until it is removed by activating the switch again. Going from CSS to the automatic mode reinitializes the integrator of the rate trim switch and immediately removes any rate bias that has been commanded.

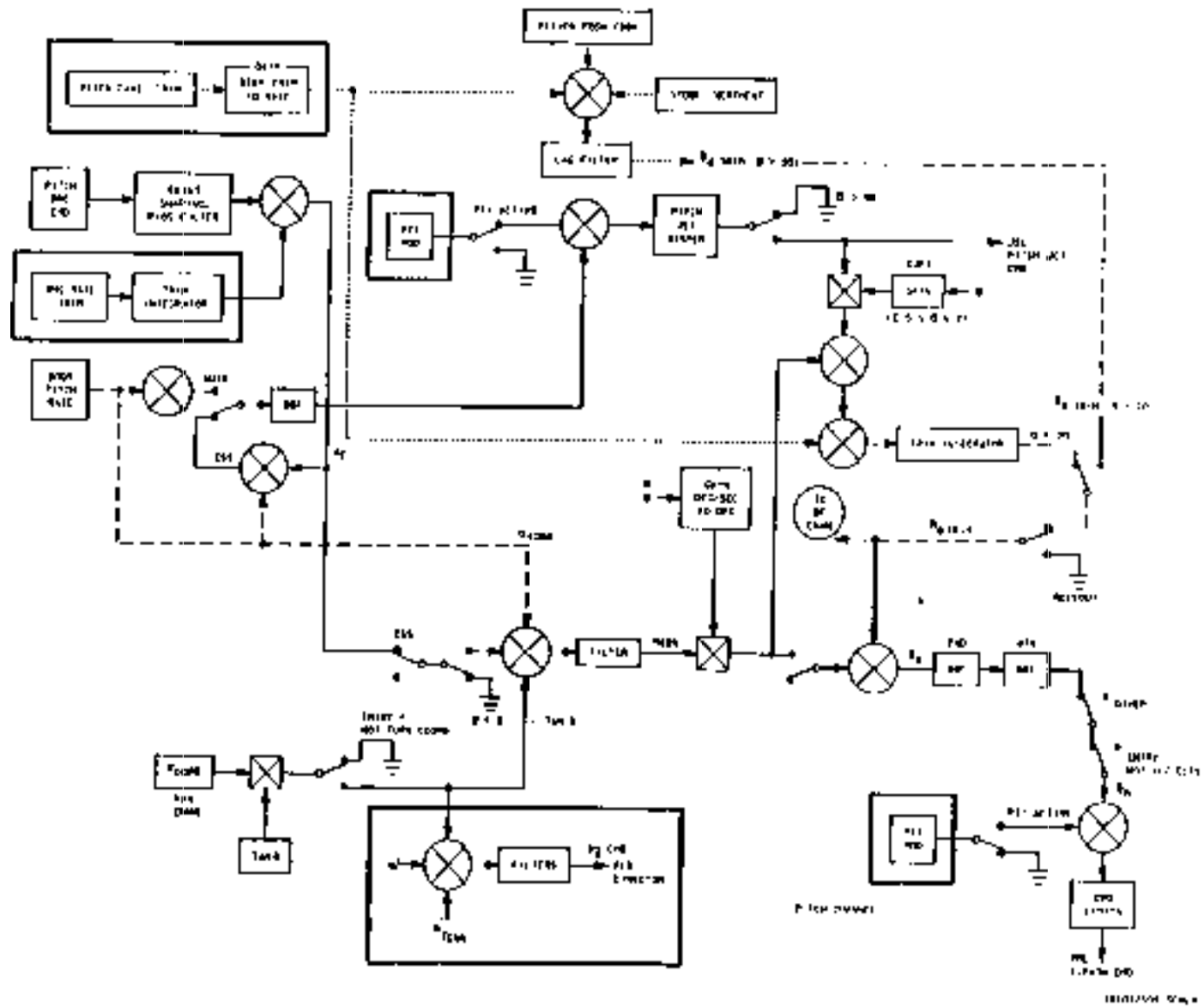


Figure 5-5.- FCS pitch channel buildup - Panel trim, FD CMDs, and PTIs.

There is a situation where the pitch rate trim switch might be used. An example of this would be a combination of failures such that a rate bias exists in the rate gyro assemblies (RGAs) signal in the pitch axis only. This rate error goes into the entry DAP as q_{dbk} (see figure 5-5), and if differenced with a null input, it then becomes a command to the elevators. Following the command to the surface, a real rate begins to build up. If the vehicle is being flown in AUTO P, a difference between alpha and alpha command (or N_z and N_z command) will result in corrective action to bring the vehicle back to the commanded attitude with a zero rate. When this is satisfied, the rate being commanded goes to zero, but the feedback rate is still biased and the process starts all over. As a consequence of this inability of the auto system to adequately control a pitch rate bias, the vehicle would have to be flown in CSS P. The pilot could compensate for the bias either by holding a constant rate with the RHC or by using the rate trim switch to cancel the rate. Once the decision is made to use the rate trim switch, it must be remembered that going back into AUTO P erases the corrective rate bias.

The PTI modification to the pitch channel is also identified in figure 5-5. There is one PTI in the jet command loop and one in the elevator command loop. As can be seen, these go directly to the jets or the elevators, bypassing any gains or filters. This is done to obtain the correct control input for the investigation of the aerodynamics or response characteristics of the shuttle. Figure 5-6, which concludes the pitch channel schematics, shows the automatic control loop, the low gain option, the GRTLS or alternate entry gain changes, the load relief bias, and the automatic slatdown commands.

The automatic commands are divided into two distinct parts. For early entry, the auto commands are based on angle of attack (alpha command). The alpha command comes from guidance, is differenced with the angle of attack feedback, and (after going through filters and gains) goes to the pitch jet loop and the elevator loop. The unfiltered, ungained difference is also sent to the pitch error needle of the ADI.

The auto pitch system changes from alpha command to N_z command at the TAEM interface. Here the N_z command is differenced with the feedback to generate the proper pitch command. Also, when the pitch control changes from α_{cmd} to $N_{z_{\text{cmd}}}$, the $N_{z_{\text{err}}}$ is taken from the pitch channel, conditioned, and sent to the ADI pitch error needle, as shown in the figure.

The two methods of pitch control are used, depending on the methods of trajectory control in early entry as compared to the late entry phase. In early entry, the longitudinal axis (pitch) is not the primary method of controlling the energy state. This is being done by the bank angle while the high angle of attack being flown is providing heating protection. It is easy, therefore, to fly a known alpha profile and base the pitch control on alpha command.

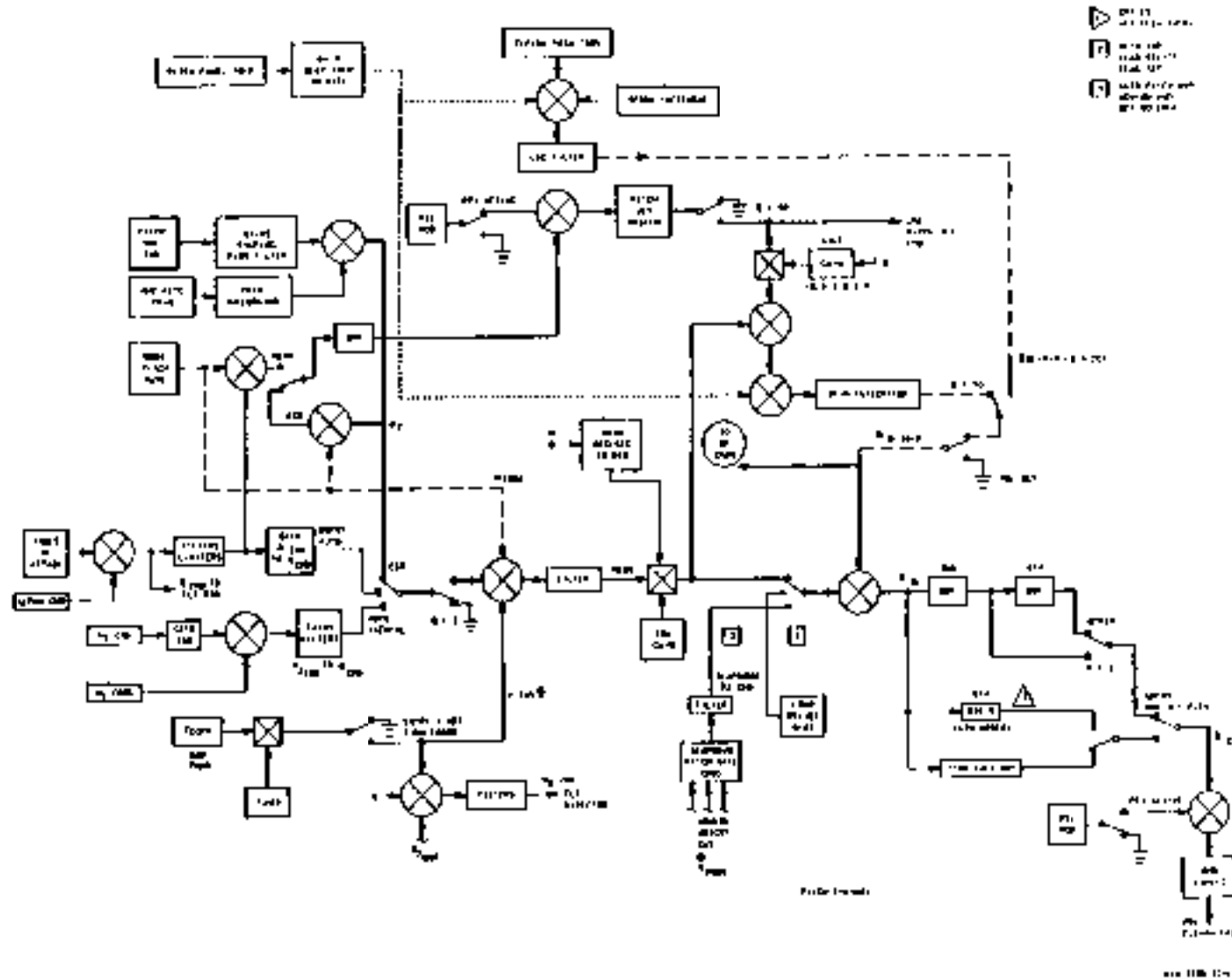


Figure 5-6.- FCS pitch channel buildup - Auto entry and TAEM guide CMDs.

In the late entry or TAEM phase, the bank angle is being used for controlling direction and is basically a function of the azimuth to the heading alignment cone (HAC). The longitudinal axis is now controlling the energy state. Thus, the guidance is controlling the energy state with altitude, altitude rate, \dot{q} , and the normal acceleration. If the vehicle is near nominal energy, the N_z command is primarily a function of getting to the proper altitude versus range profile. This is limited by high and low energy protection. The command for the altitude correction is then compared to the \dot{q} boundaries to ensure that it will keep \dot{q} within limits. Finally, the command delta is limited to 0.5g. This N_z command then goes to the FCS. The low gain option, a function of the entry mode switch, provides a gain reduction in all three axes should the need arise. In the low gain position, the gains to the control surfaces are halved to protect against a high frequency oscillation on the surfaces.

Another path to be taken in the event of a GRTLS abort or selection of the FIXED elevon schedule is also shown. This GRTLS schedule is automatically selected during a launch abort (MM 601), and the FIXED schedule is selected when going from OPS 1 to OPS 3, as during a transoceanic abort landing (TAL), or can be selected manually on SPEC 51, OVERRIDE. The AUTO elevon schedule and nominal body bending filter are automatically selected during a nominal entry. The AUTO and FIXED elevon schedules can be selected by item numbers 17 and 18, respectively. The nominal and alternate (or payload) body bending filters can be similarly selected by items 20 and 21. The payload filters would be for heavier than normal payloads, or the payload mounting may exhibit structural damping characteristics for which the nominal body bending filters were not designed. In the backup flight system (BFS) the same schedule and filter selection can be done on SPEC 51, OVERRIDE, with the same item numbers. Procedures specify that selection in the primary avionics software system (PASS) should be followed by the same selection of elevon or filter in the BFS.

The load relief bias assists in offloading the main landing gear during rollout. It is designed so that in AUTO the elevators are driven down, which reduces the load on the main tires and gear. If flown in CSS, the DAP will mode to AUTO once the load relief flag is set (the flag is set after an I-loaded delay since the rollout discrete has been set). The elevator position will be based on a schedule which is a function of ground speed. Should the crew need to intervene in pitch, the pitch control can quickly and effectively be taken by moving the RHC 12° out of detent or by moding to CSS. This logic works in the BFS also.

The last item shown on the pitch channel is the slapdown pitch rate command. At main gear touchdown, pitch rate commands for lowering the nosewheel are generated as a function of vehicle weight and are sent to the ADI flight director. The commands are converted into elevator commands when the vehicle is being flown in pitch AUTO.

Questions

1. When are pitch jets deactivated?
2. When are elevators active for control?
3. Describe turn compensation.
4. Describe load relief bias.

Answers

1. Pitch jets are deactivated when \dot{q} is greater than 40 psf.
2. Elevators are active for control when \dot{q} becomes greater than 2 psf.
3. Turn compensation is the amount of pitch rate needed to keep the nose of the shuttle up during a turn.
4. Load relief bias assists in offloading the main landing gear during rollout. The elevators are driven down, reducing the load on main gear and tires.

Section 6: Lateral-Directional Control

Objectives

At the end of this section, the student will be able to do the following.

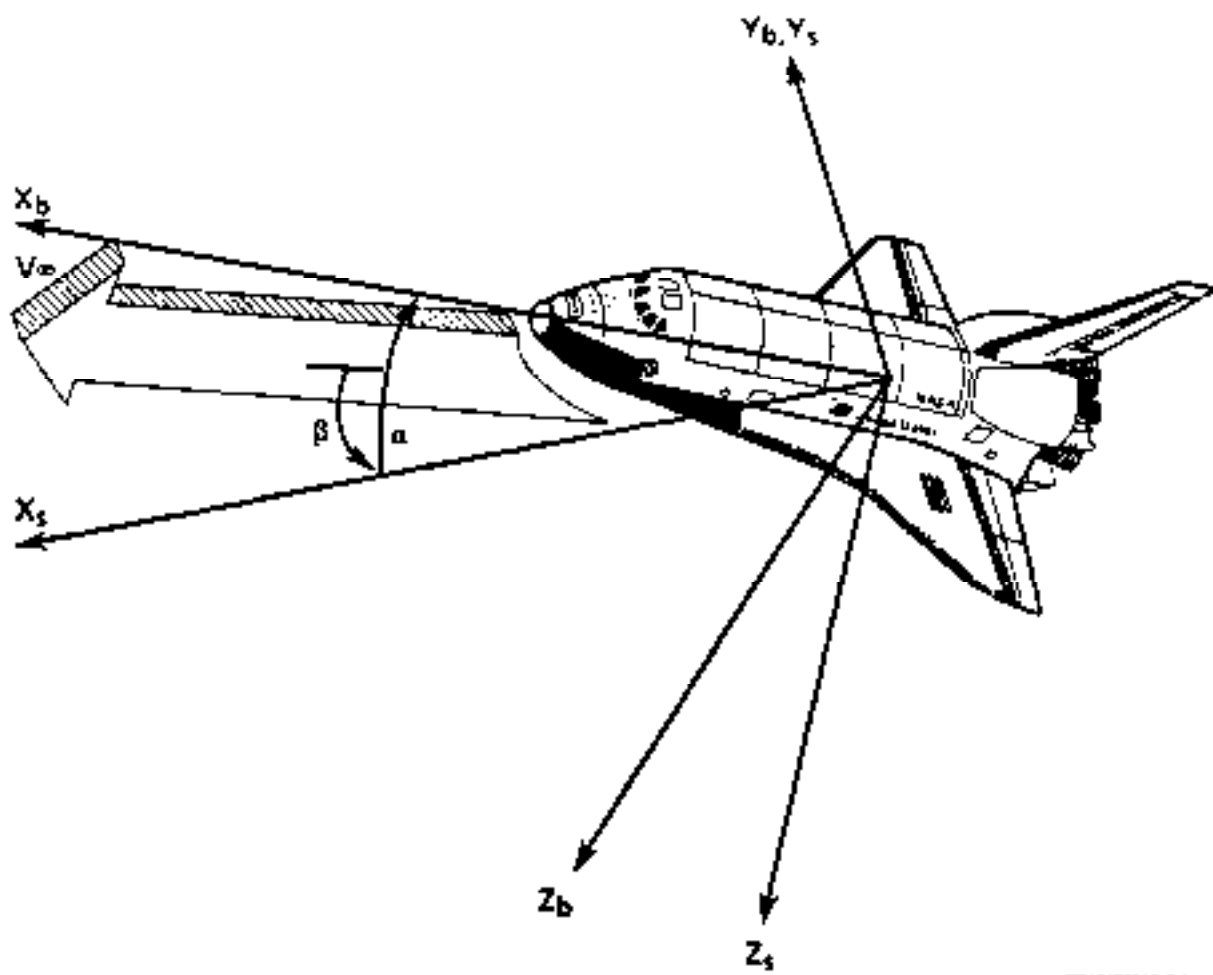
- Describe the stability axis system
- Describe the process in which lateral-directional control is maintained by first generating then controlling sideslip
- Describe the differences between the early and late regions of lateral-directional control
- Describe the significance of gain in roll channel (GALR)

Lateral-Directional Control

The roll and yaw channels need to be introduced together since the lateral-directional control of the orbiter is coupled (as in any aircraft) so that motion in one axis has an effect in the other axis, and with the shuttle it can at times be profound. After firmly establishing this relationship, the schematic of each axis is discussed individually.

At Mach numbers greater than 5.0, the high angle of attack being flown blanks the vertical tail to such an extent that the rudder is virtually useless. This makes the use of yaw jets and ailerons necessary to keep sideslip angle within controllable limit at higher Mach numbers. The use of yaw jets (yaw axis) and ailerons (roll axis) provides lateral-directional control, with the rudder coming into play much later.

To assist in understanding the roll/yaw control interaction, the stability axis system is introduced here. The stability axis system is shown in figure 6-1, along with its relationship to the body axis system. The stability axes differ from the body axes by the displacement of the X- and Z-axes following a rotation about the Y-axis through the angle of attack, α . By definition, the sideslip angle, β , is the result of a rotation about the stability yaw axis. The sideslip angle is then the angle between the stability X-axis and the projection on the body X-Z plane of the velocity vector of the orbiter.



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Figure 6-1.- The stability axis system.

The rate of change of the sideslip angle is a negative stability yaw rate ($\dot{\beta} = -r_s$)
 The following equations can be determined from figure 6-2.

$$p_s = p_b \cos \alpha + r_b \sin \alpha \quad (9)$$

$$r_s = r_b \cos \alpha - p_b \sin \alpha \quad (10)$$

$$\dot{\beta} = p_b \sin \alpha - r_b \cos \alpha \quad (11)$$

Lateral-directional control of the orbiter is maintained by the combined use of yaw jets, ailerons, sideslip angle, and rudder (when active) to produce bank maneuvers during entry. Although sideslip is intentionally generated during a maneuver, it must be kept within limits to prevent loss of control. The DAP does this by damping $\dot{\beta}$ to zero, using yaw rate feedback to the ailerons as derived from equation 11.

$$p_b \sin \alpha - r_b \cos \alpha = \dot{\beta} = 0 \quad (12)$$

$$p_b = r_b \cot \alpha \quad (13)$$

The bank maneuver is initiated by a bank* rate command sent to the yaw channel, resulting in a yaw rate command. If we command a pure stability axis bank rate ($r_s = 0$), then the body rates would be

$$p_b = p_s \cos \alpha \quad (14)$$

$$r_b = p_s \sin \alpha \quad (15)$$

$$p_{cmd} = p_s \quad (16)$$

If p_{cmd} is the commanded bank rate

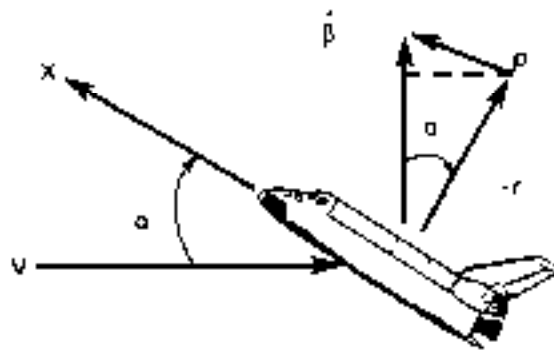
$$p_b = p_{cmd} \cos \alpha \quad (17)$$

$$r_b = p_{cmd} \sin \alpha \quad (18)$$

which are the required body roll and yaw rates for the stability roll maneuver.

*Bank refers to a rotation about the velocity vector, or a stability axis rotation. Roll refers to a rotation about the X axis, or a body axis rotation.

The equation of motion for $\dot{\beta}$ as a function of body roll and yaw rates can be determined from the free body diagram below.



$$\dot{\beta} = p \sin \alpha + (r - p) \cos \alpha$$

$$\dot{\beta} = p \sin \alpha - r \cos \alpha$$

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If we desire to have $\dot{\beta} = 0$ we can set the above equation equal to zero and solve for the desired roll rate

$$p \sin \alpha - r \cos \alpha = 0$$

$$p = \frac{r \cos \alpha}{\sin \alpha} = r \cot \alpha$$

where r is the effective yaw rate calculated in yaw channel.

Figure 6-2.—How the orbiter rolls.

To tie all this information together into a coordinated bank maneuver, the lateral-directional control is divided into two regimes, early and late, as was the longitudinal control. The difference between the two regimes for lateral-directional and longitudinal control is the absence of a sharp dividing point separating the early and late lateral control characteristics, as was present in the pitch axis. This can be demonstrated by the equation for aileron trim required to trim a $Y_c g$ offset.

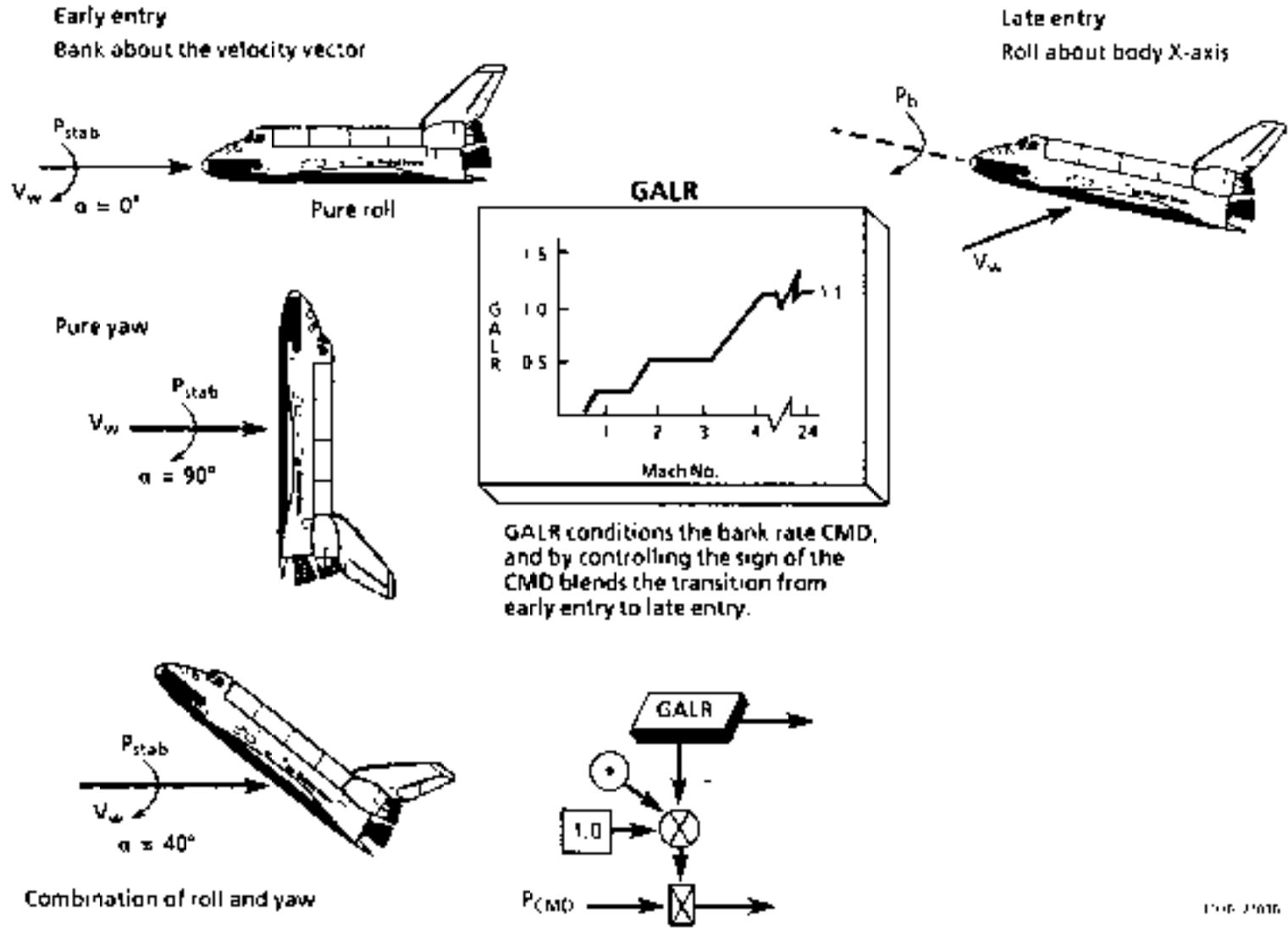
$$\delta_a \text{ trim} = \frac{\Delta y (C_N C_{n_\beta} + C_A C_{t_\beta})}{b (C_{l_\beta} C_{n_{\delta_a}} - C_{n_\beta} C_{l_{\delta_a}})} \quad (19)$$

At Mach numbers above 3.5, the entry DAP logic assumes that the denominator of the trim equation will be positive ($C_{n_{\delta_a}}$ and C_{n_β} are both negative). Bank maneuvers are initiated in the yaw channel, and the roll axis provides coordination and damping. At Mach numbers between 4.0 and 0.9, there is a gradual change from yaw channel bank maneuver initiation to roll channel initiation, with coordination

coming from the yaw channel). This happens as the aerodynamics are changing ($C_{n\dot{\delta}_o}$ and $C_{n\dot{\beta}}$ become positive), making the denominator of the trim equation negative

How is this accomplished? Figure 6-3 shows how the orbiter does bank maneuvers and how this transition is made. In early entry, the orbiter banks about the velocity vector. The figure shows that for zero alpha, a stability axis bank is pure body roll, and at 90° alpha it is a pure body yaw, while for nominal flight alphas the stability bank is a combination of body roll and yaw. The orbiter rolls about the body X-axis during the late entry. The roll channel gain, named GALR, is the mechanism by which the transition from early to late entry is made. The GALR gain conditions the bank rate command and, by controlling the sign of the command, blends this transition.

An example of a bank maneuver during early entry is shown in figures 6-4 and 6-5. Figure 6-4 shows a simplified schematic of the roll and yaw channels and actual STS-7 flight data for the first bank maneuver. Figure 6-5 is a depiction of the sequence of events during this maneuver.



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Figure 6-3.- GALR effects on the orbiter bank.

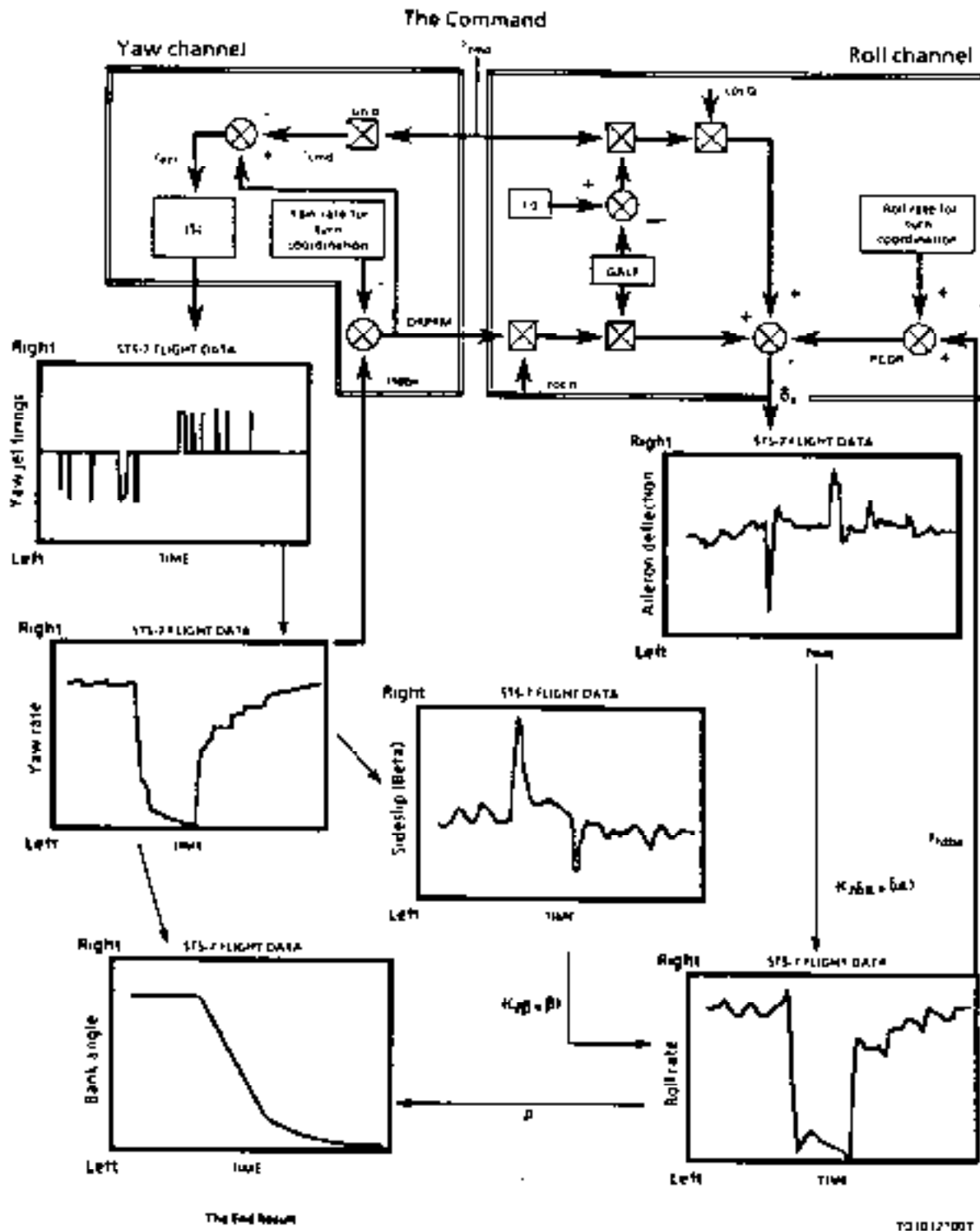


Figure 6-4.- Early entry orbiter rolls.

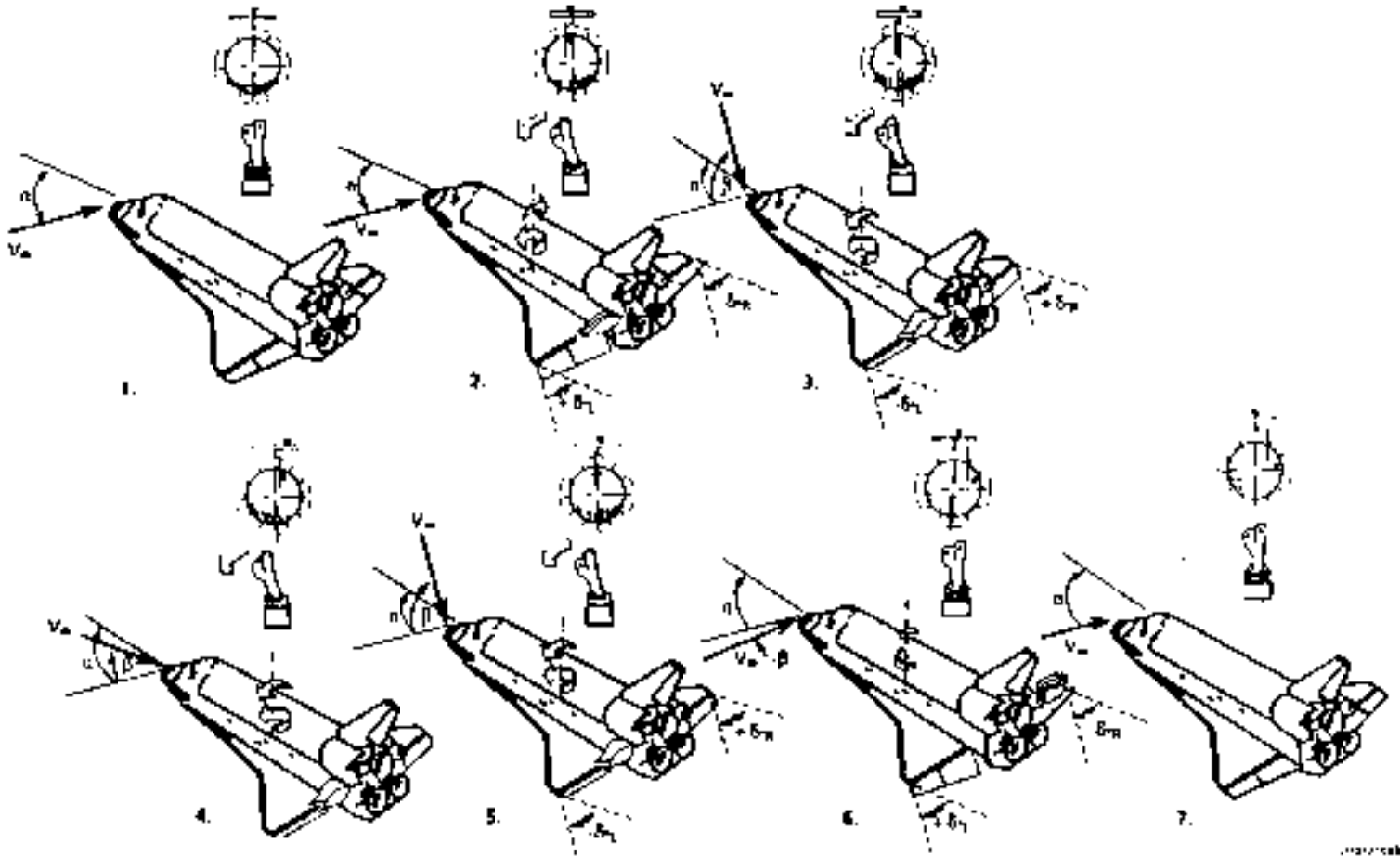


Figure 6-5.- Pilot's view of the orbiter roll.

The following is an explanation of the sequence of events during this maneuver.

1. From a steady state condition,
2. a left bank maneuver is commanded (AUTO or CSS). The command (p_{cmd}) feeds into the roll and yaw channels where it is turned into rate error signals using the relations shown in equations 17 and 18. The yaw error signal (r_{err}) goes to the JSL, and a yaw jet command is issued that initiates the maneuver. The roll command is multiplied by 1-GALR (which results in -0.1) in the roll channel; that assists in initiating the maneuver by creating a slight reverse aileron command. This small reverse aileron is virtually unnoticeable in normal operations and will be subsequently overridden by a proverse aileron (left roll, left aileron) command.
3. The body yaw rate created by the jet firing will cause the sideslip to build and is fed to the roll channel for turn coordination. It comes from the yaw channel corrected for steady state rates (equation 23) and is converted into a roll rate command by equation 13. This is multiplied by GALR (1.1) and summed with p_{cmd} , giving the normal, overriding left aileron for coordinating the left bank command. The combination of roll due to aileron ($C\ell_{\delta_a} * \delta_a$) and roll due to sideslip angle ($C\ell_{\beta} * \beta$) produces the body roll rate.
4. As the stability roll rate becomes established, its feedback term is differenced with the other roll rate terms to effectively produce a zero roll rate error once the proper body roll and yaw rates have been established.
- 5,6. When the RHC is released (assuming CSS), the reverse process occurs,
7. stopping the bank maneuver at the new desired bank angle.

Figure 6-5.—Concluded.

Questions

1. Describe the stability axis system.
2. Describe the process of controlling lateral direction when sideslip is generated.
3. Describe the difference between early and late regions of lateral-direction control.
4. Describe the significance of GALR.

Answers

1. The stability axes differ from the body axes by the displacement of the X- and Z-axes following a rotation about the Y-axis through the angle of attack, α .
2. Lateral-directional control of the orbiter is maintained by the combined use of yaw jets, ailerons, sideslip angle, and the rudder (when it is active) to produce bank maneuvers during entry. The sideslip is then damped by yaw rate feedback to the ailerons.
3. At Mach numbers above 3.5, bank maneuvers are initiated in the yaw channel, and the roll channel provides coordination and damping. At Mach numbers between 0.9 and 4.0, there is a gradual change from yaw channel bank maneuver initiation to roll channel initiation, with coordination coming from the yaw channel.
4. GALR is the mechanism that makes the transition from early to late entry possible. GALR gain conditions the roll rate command and, by controlling the sign of the command, blends the transition.

Section 7: Lateral-Directional Trim

Objectives

At the end of this section, the student will be able to do the following.

- Describe the condition that must be satisfied for the shuttle to be trimmed
- List the lateral-directional control effectors for trim
- State when the rudder becomes active for trim
- State the proper action if aileron trim is greater than 1° with rudder and aileron active

Lateral-Directional Trim

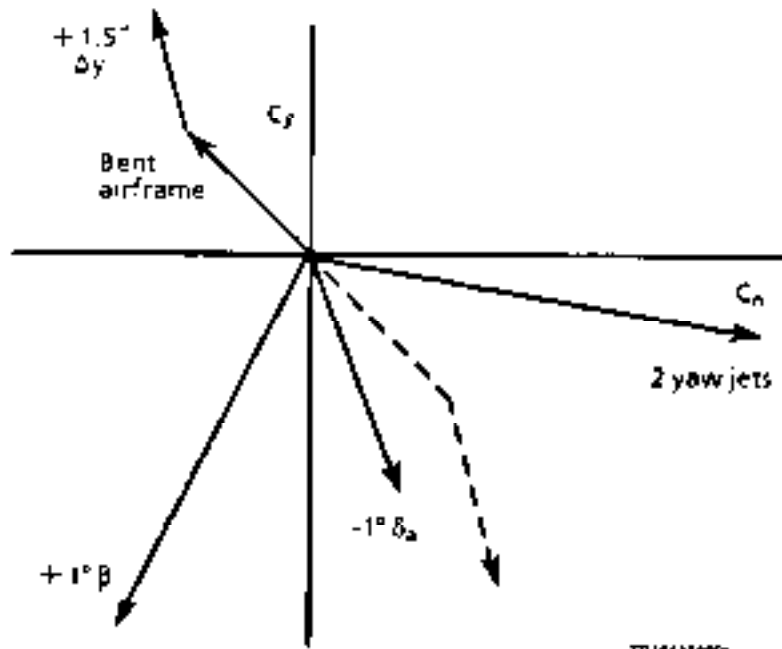
To be trimmed, the aerodynamic moments about an axis or set of axes must be zero. To assist in understanding lateral-directional trim for the orbiter, roll-yaw vector diagrams will be used. The initial diagrams shown in figure 7-1 depict, in terms of rolling moment coefficient (C_ℓ) and yawing moment coefficient (C_n), the steady state disturbing force vectors and the controlling force vectors. The disturbing forces are a c.g. offset along the Y-axis and a bent airframe (rolling and yawing moment at zero sideslip). The task of trimming the orbiter is to generate a set of control vectors that will balance the vectors of the c.g. offset and bent airframe. The dashed line in each diagram represents a mirror image of the untrimmed moments which the control effectors must balance.

One diagram is for early entry (Mach number greater than 5) and the other is for late entry where the rudder is active. The control effectors for trim are aileron deflection, sideslip angle, yaw jets, and rudder deflection (after Mach equal 5). The sign convention for the diagrams is as follows: positive C_n produces right yaw, positive C_ℓ produces right roll, negative aileron is left aileron (roll left), negative rudder is right rudder (nose right), and positive beta is right sideslip angle (nose left). It is very important to remember that each diagram (the direction and magnitude of each vector) is a function of angle of attack, elevon position, Mach number, and dynamic pressure.

Lateral-directional trim

The ability to trim out effects of c.g. offsets, bent airframe asymmetries

- Early entry at Mach > 5
 - Aileron
 - Sideslip angle
 - Yaw jets



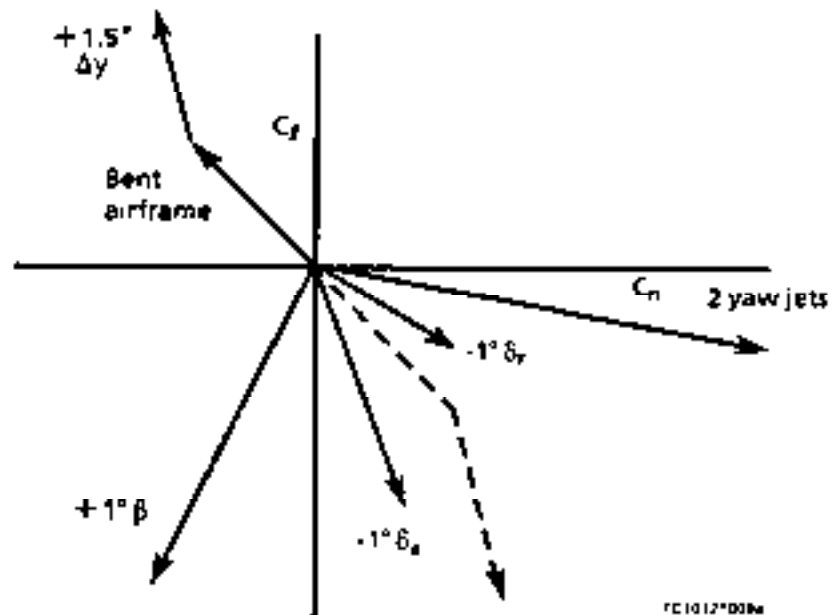
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- Late entry at Mach < 5

- Aileron
- Rudder
- Sideslip angle
- Yaw jets

- Late entry at Mach < 1.0

- Aileron
- Rudder
- Sideslip angle



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* Broken line represents mirror image of bent airframe roll and yaw moments that must be nulled.

Figure 7-1.- Lateral-directional trim.

In figure 7-2, examples of trim solutions are shown for the early entry. When the ailerons are not being used or are ineffective due to variations or elevator trim deflection, the trim is left to the RCS jet and side slip angle. In the case shown, the orbiter is trimmed with 0.6° of beta and the equivalent of 1.6 jets firing continuously. When the ailerons are active, they will be driven to trim the vehicle and tend to cause the cessation of jet firings. The crew can speed up the trimming and possibly save fuel by manually assisting with the roll panel trim switch. The technique is to watch the indications of yaw jet firing commands on the RCS activity lights and to trim away from the lights. For example, if right yaw jet lights are commanded on, the pilot can trim with the left aileron, in short activations of the roll panel trim switch, until the activity lights indicate no or few jet firings. One possible, better trim solution is shown that uses -1.8° of aileron and -0.12° of beta.

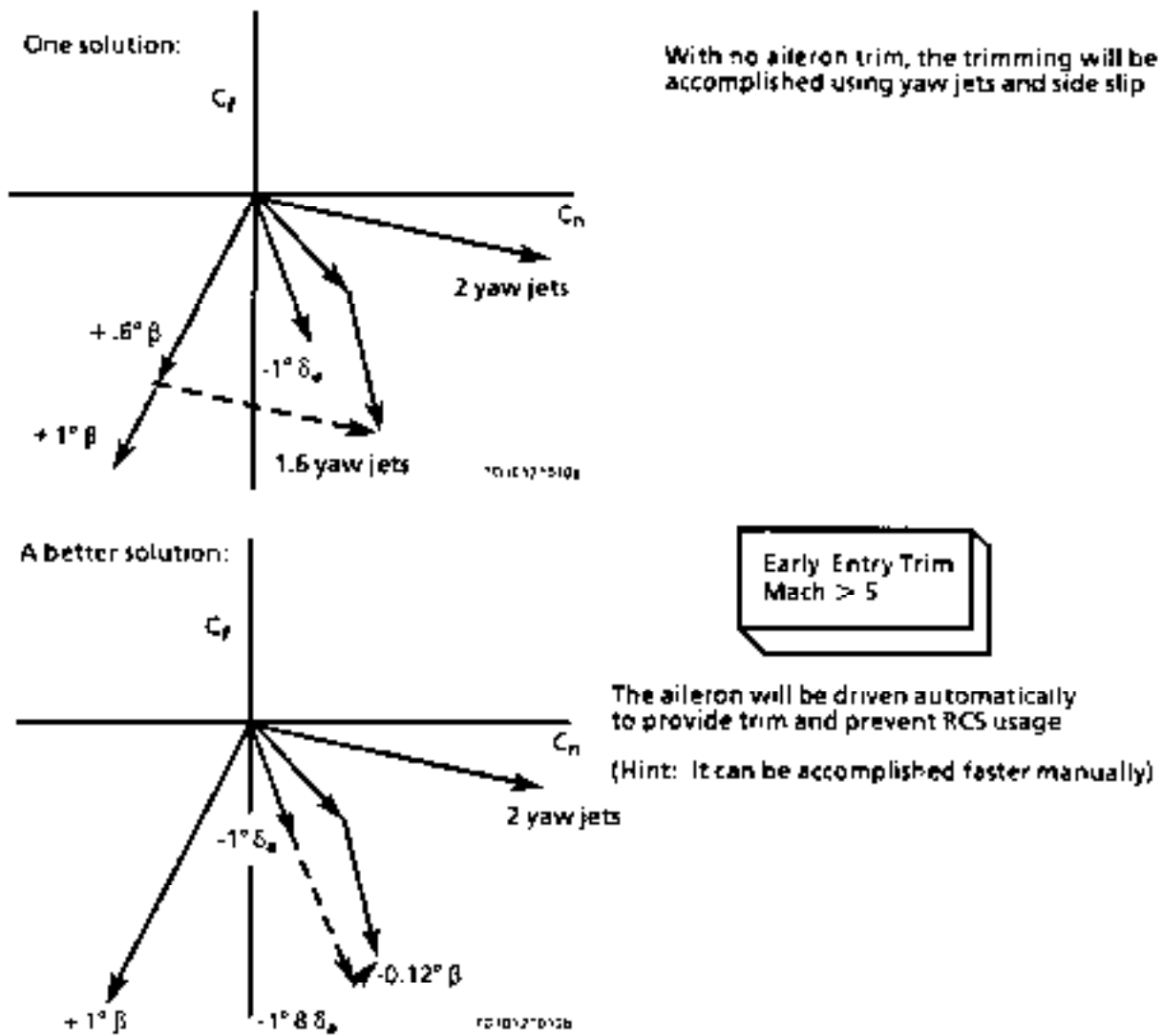


Figure 7-2.— Early entry trim Mach > 5.

The rudder becomes active at Mach 5 and under normal circumstances will assume a large portion of the trim function. In the case shown in figure 7-3, it can be seen that the trim solution can go from aileron and beta to rudder and beta or to a combination of aileron, rudder, and beta. Normally, the N_y feedback in the yaw channel will drive the rudder trim to remove sideslip angle, resulting in a trim solution of aileron and rudder. Until Mach number reaches 1.0, the jets are still available on a part-time basis. These figures hint at the fact that there is no unique trim solution, and any combination of control effectors within their individual limits is possible.

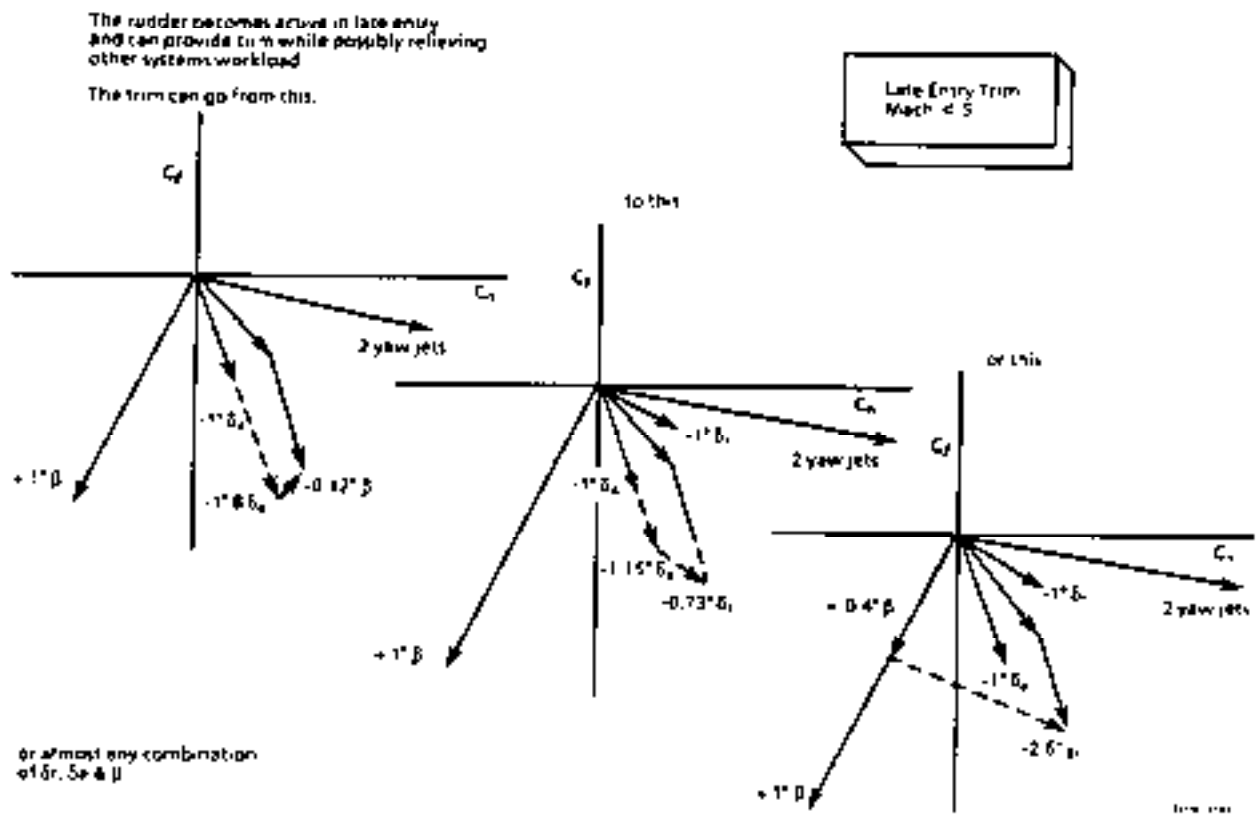


Figure 7-3.- Late entry trim Mach < 5.

From all the possible trim solutions available when the rudder becomes active, there are a few unlikely solutions which can be troublesome if they occur.

A particularly bad combination results from a coalignment of the aileron and rudder vectors. This is referred to as an aileron-rudder force fight and is shown in figure 7-4. As the ailerons and rudder move to trim the vehicle, their combined effects can be partially or totally offsetting. If each one fights the other, they will be driven to their respective limits, making it necessary for jets and the sideslip angle to complete the trim solution. Possible results are an excessive use of RCS propellant, a reduction in maneuvering capability (especially in the event of yaw jet failures), and in some cases a loss of control of the vehicle.

Should a force fight develop, and if the crew is monitoring their displays, the crew can intervene. A force fight can be detected on the ENTRY TRAJ and VERT SIT displays. Both display aileron and rudder trim. The numbers are the actual content of the trim integrators in the software. It must be remembered that it is best not to try to infer trim from the SPI. The SPI shows the combined value for trim and command deflection. Look to the CRT displays when the rudder becomes active. It is safe to allow some small amount of trim, but if aileron trim exceeds 1.0° with aileron and rudder active, trim the ailerons to zero and allow the rudder and sideslip angle to provide the trim. Monitoring is necessary because once trimmed out, the force fight can creep back in under certain conditions.

Questions

1. What condition(s) must be satisfied for the shuttle to be trimmed?
2. List the lateral-direction control effectors for trim.
3. State when the rudder becomes active for trim.
4. What is the proper action if the aileron trim is greater than 1° with the rudder and aileron active?

Answers

1. For the shuttle to be trimmed, the aerodynamic moments about an axis or set of axes must be ZERO.
2. Ailerons, yaw jets, sideslip angle, and the rudder are lateral-direction control effectors.
3. The rudder becomes active for trim at Mach numbers equal to 5 (late entry).
4. With the rudder and aileron active and aileron trim greater than 1° , trim the aileron to 0° and allow the rudder and sideslip angle to provide trim.

Section 8: Roll Channel

Objectives

At the end of this section, the student will be able to do the following.

- State when the roll jets are deactivated
- State when the ailerons are active for control
- State the consequences of GALR decreasing from 1.1 to 0.0
- State the basic purpose of NO Y JET
- State the reason why the commander may become aware of holding a constant roll command on the final approach and how it should be corrected
- Describe auto load balancing

Roll Channel

Figure 8-1 shows the major events of the roll channel in a manner similar to that of the pitch channel in figure 2-1. Beginning at EI-5, each event peculiar to the roll channel is shown in relation to the other events. These are discussed in detail in the following sections.

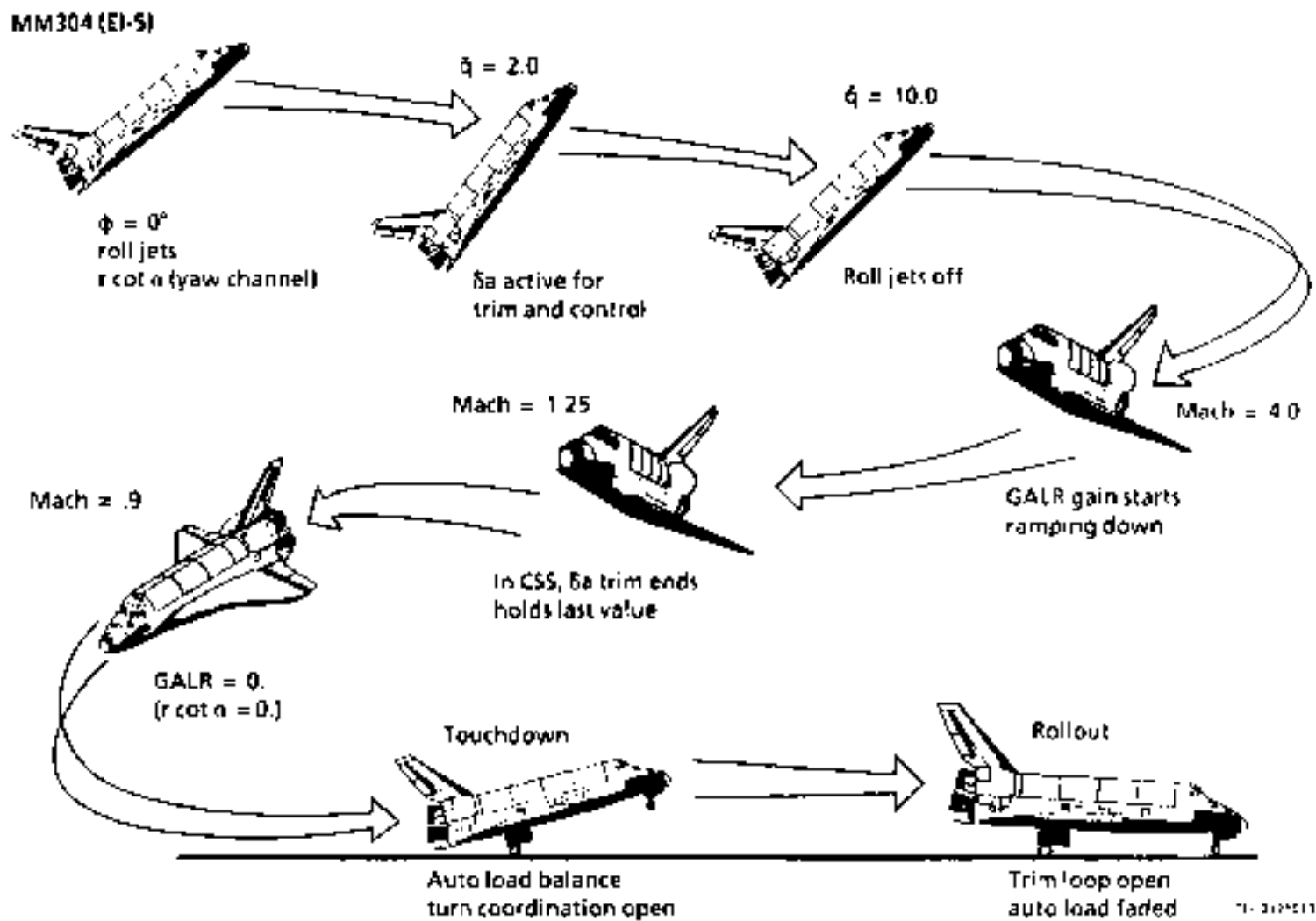
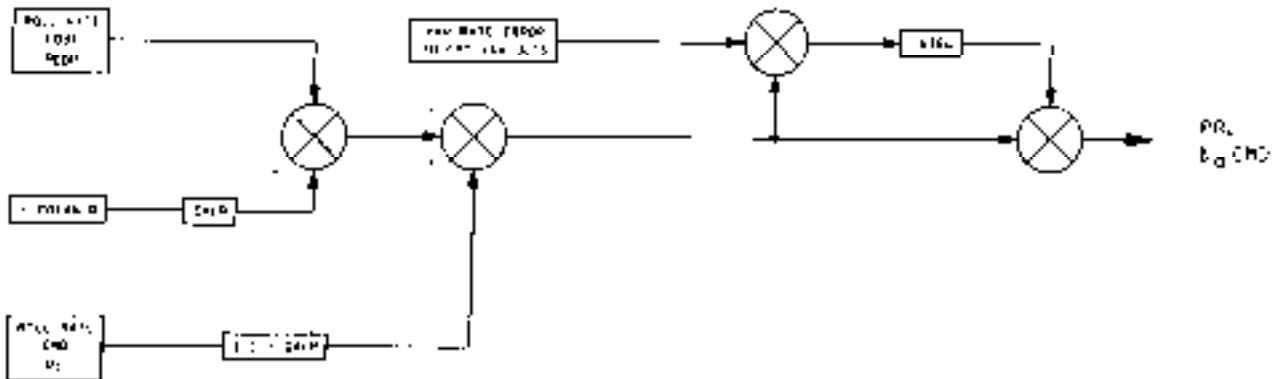


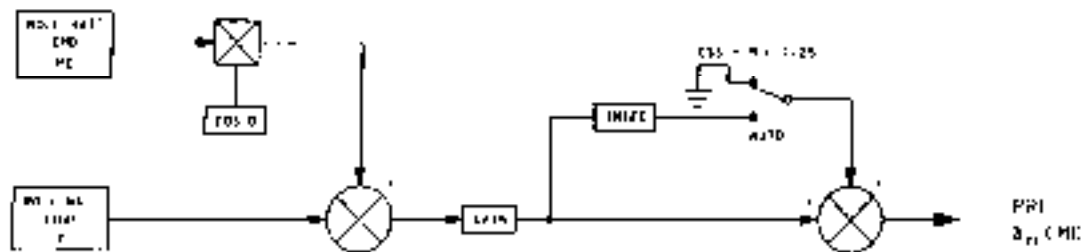
Figure 8-1.— The major events of the roll channel.

Figure 8-2 shows the basic schematic of the early and late entry roll channels. Early control is basic turn coordination with rate feedback and proportional command plus a forward loop trim integrator. The late entry control is a proportional rate command with feedback loop similar to the pitch channel.

For early entry, roll axis is basic turn coordination (β damping) into a proportional plus integral roll rate command system.



For late entry to subsonic flight, roll axis is roll rate command system with turn coordination (proportional for CSS).



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Figure 8-2.- Basic schematic of early and late entry roll channels.

The paths of the RHC bank command are shown in figures 8-3 through 8-7. The command, after being shaped, goes first to the yaw channel and then through various gains (remember GALR!) out to the roll jets (until $\bar{q} = 10$ psf) and the ailerons, which become active at $\bar{q} = 2$ psf.

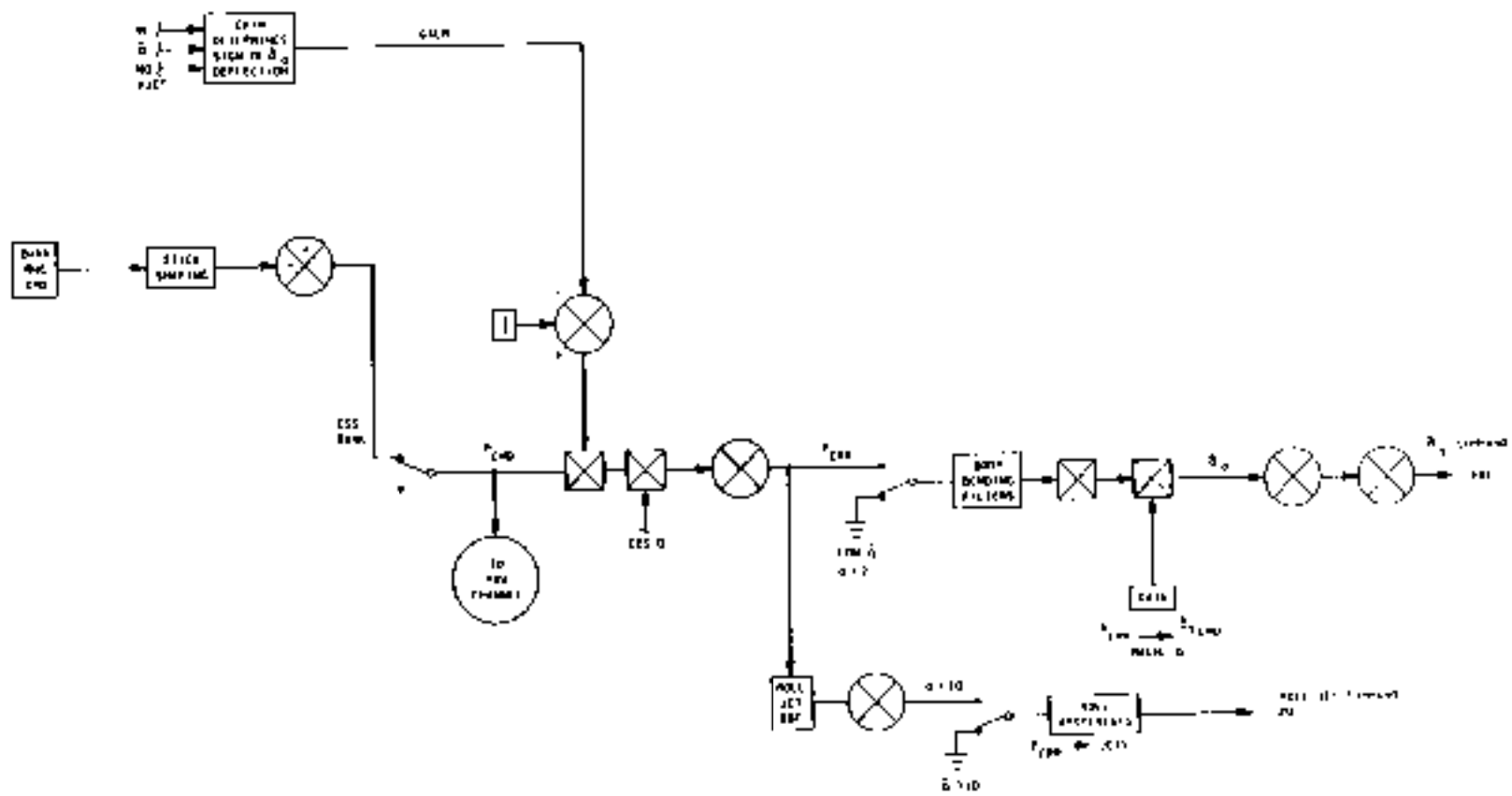


Figure 8-3.- The roll channel.

Figure 5-3 and equations 1, 2, and 4 aid in understanding the turn coordination. Substituting equation 1 into 2 and 4 yields:

$$p_{ss} = -\frac{g}{V} \frac{\sin \phi}{\cos \phi} \sin \theta \quad (20)$$

and

$$r_{ss} = \frac{g}{V} \sin \phi \cos \theta \quad (21)$$

which represent the steady state body rates for a turn, or the roll and yaw rates for turn coordination. These rates when differenced with the body rate feedbacks give the perturbation or compensated rates to be damped in the turn coordination and feedback loops in the entry DAP.

$$PCOR = p_b - p_{ss} \quad (22)$$

$$DRPRM = r_b - r_{ss} \quad (23)$$

Figure 8-4 introduces the terms in equations 22 and 23. The roll rate for turn coordination is calculated and added to the body roll rate, giving corrected roll rate feedback term in roll channel (PCOR). Yaw rate feedback term in yaw channel (DRPRM) comes from the yaw channel, then is multiplied by $\cot \alpha$ (refer back to equation 13) and by GALR, and then it is differenced with PCOR. PCOR and DRPRM make up the primary drives of the roll rate feedback.

Two additional terms contribute to the roll rate feedback to fine tune the system and to limit the growth of the sideslip angle. They are both sideslip-dependent terms and operate in a mutually exclusive manner. At \dot{q} less than 2 psf, this feedback is inertial β ; between a \dot{q} of 2 to 20 psf it is filtered inertial β , and at \dot{q} greater than 20 psf is the lateral acceleration, N_y . Both β and N_y terms come from the yaw channel.

The GALR gain is also shown in figure 8-4. It goes directly to multiply the DRPRM term and is subtracted from the quantity 1 before multiplying the commanded roll rate. In early entry this difference creates a small, negative value which acts upon the commanded roll rate to produce the initial, slight reverse aileron. The value of the gain begins decreasing at Mach 4.0 (see figure 6-3), and at about Mach 3.8, it will equal 1.0. A roll rate command is for an instant multiplied by zero, but as Mach number further decreases, so does the value of GALR. Therefore, the roll rate command is becoming increasingly proverse and dominant in determining the aileron response. Through GALR gain reductions, the aileron response is transitioning from the early entry system of primary β damping about the stability axis to performing conventional roll maneuvers about the body axis in the late entry system.

Two things are happening with the reduction of the GALR gain. The magnitude of the gain applied to the commanded roll rate gets larger in a positive sense until it reaches 1.0. This gives the conventional initial aileron response with respect to an input command for late entry (right roll command = right aileron). Secondly, as GALR approaches zero, the effect of the yaw channel input (DRPRM) is being removed from the roll channel.

One input item shown on the GALR gain loop is NO Y JET. This is a downmoding condition which is selected by the entry mode switch. Selection of this position grounds the command to the yaw jets and changes the value of the GALR gain. The functional use of NO Y JET is beyond the scope of this paper; therefore, while there will be mention of it elsewhere, no attempt will be made to describe its full operational use. Individuals should consult other materials such as the Flight Procedures Handbook (ref. 2) or the Entry Auto Monitoring Briefing. (Note: The value of GALR before $\dot{q} = 10$ psf is 1.0. Nominally, its value is then 1.1 until Mach = 4.0, where it begins its ramp down to zero. If in NO Y JET, the value of GALR will be 1.7 until Mach = 7, where it ramps down to zero by Mach = 0.9.)

Figure 8-4 also shows the aileron trim integrator loop. Aileron trim of the orbiter is accomplished by bringing the yaw rate commands being sent to the yaw jet hysteresis loop into the aileron trim loop. These are summed with the roll panel trim command and integrated. The ailerons take over the trimming being done by the yaw jets at a \dot{q} of 2 psf. This loop is active in the automatic mode until rollout, but when flying in CSS in the roll/yaw axis, the loop opens at Mach 1.25 and holds the last computed value of aileron trim fixed. This is important to remember when flying manually. The pilot may become aware of having to hold a constant roll command when flying around the HAC or down the final approach path. If the roll bias is encountered, simply trim the aileron with the roll panel trim switch.

As in the pitch channel, there is a low-gain multiplier available. Whenever the low gain position of the entry mode switch is selected, the gain being applied to the rate error aileron command is cut in half.

Information for crew displays comes from two locations in the roll channel. The body roll and yaw rates are combined (equation 9) to give the stability roll rate, which is sent to the bank rate needle of the ADI. The output of the aileron trim integrator is sent to the ENTRY TRAJ and VERT SIT displays and provides the crew with a direct readout of aileron trim.

The roll panel trim switch is introduced in figure 8-5. This trim switch, when activated, sends a signal to be summed with the yaw jet rate commands in the aileron trim integrator loop and can drive the aileron directly for trim purposes. The limits on aileron trim are $\pm 3^\circ$. The roll panel trim switch can be used to trim the vehicle in roll and is much faster than the auto trim function.

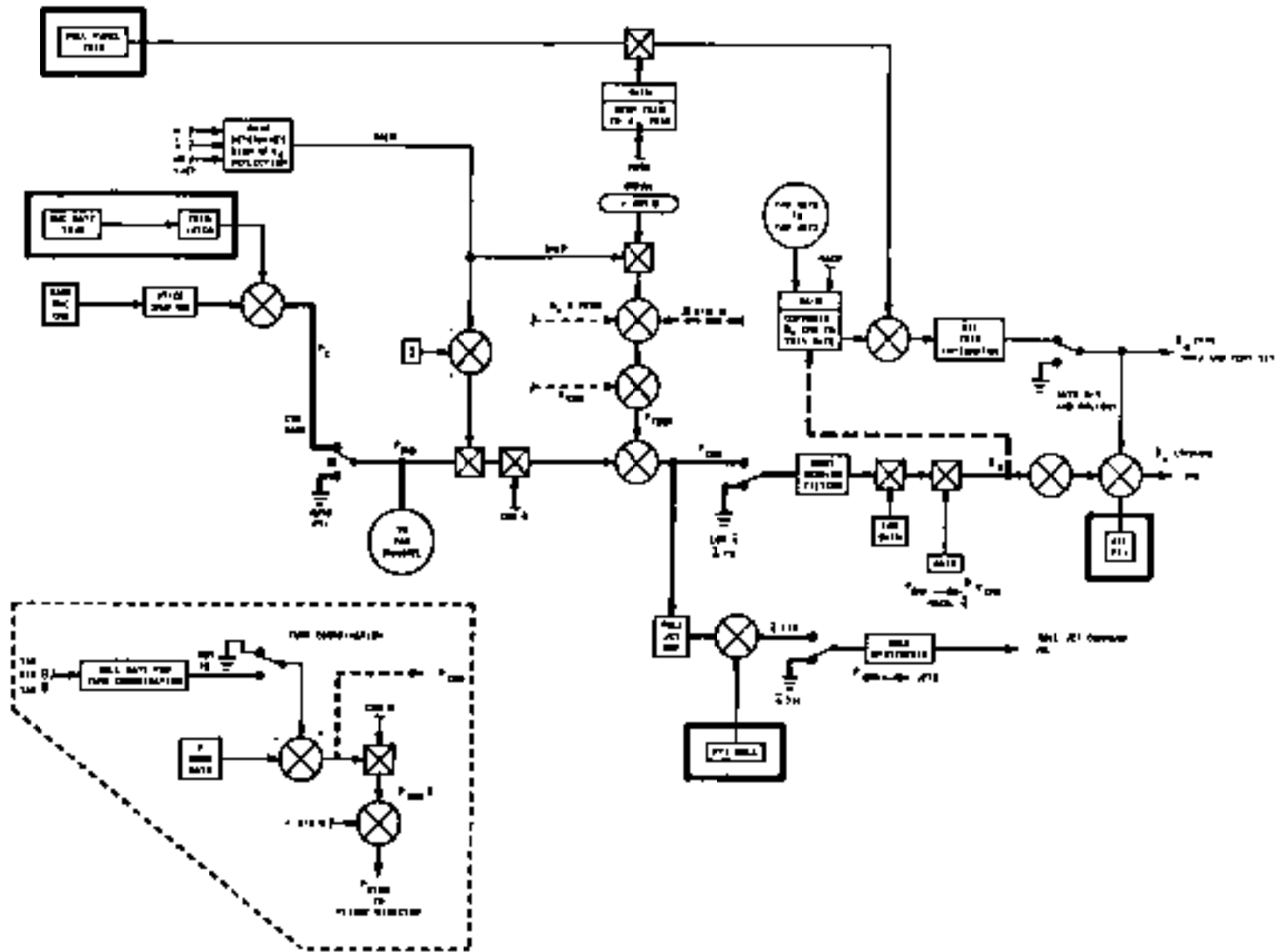


Figure 8-5.- The roll channel - Panel trim switch.

Should there be a lateral trim problem, such as a large offset in the Y c.g., the indications and procedure would be as follows: As the vehicle starts picking up effects of the atmosphere during entry with a Δy offset, a noticeable increase in yaw jet firings on one side would begin. The offset is causing the vehicle to fly with a sideslip angle for trim, and the jets are firing to control the magnitude of the sideslip and maintain trim. The RCS jet activity lights would be pulsing, showing commands to fire. At a \dot{q} of 2 psf when the aileron becomes active, these jet firing commands from the yaw channel cause the aileron to trim out the offset by trimming out the yaw rate error.

The auto system can generally be allowed to trim the vehicle, but in some cases can use an excessive amount of RCS fuel. The crew, by using the roll panel trim switch, can speed up the process manually. The procedure requires switching to CSS in the roll/yaw axes and, without maneuvering, using the roll panel trim switch to trim "away from the jet firings." In other words, if the right yaw jets are firing, the crew would trim to the left with the switch. Once the yaw jets have been canceled, the trim has been accomplished, and the amount of aileron required can be seen on the Trajectory display, as shown in figure 8-6.

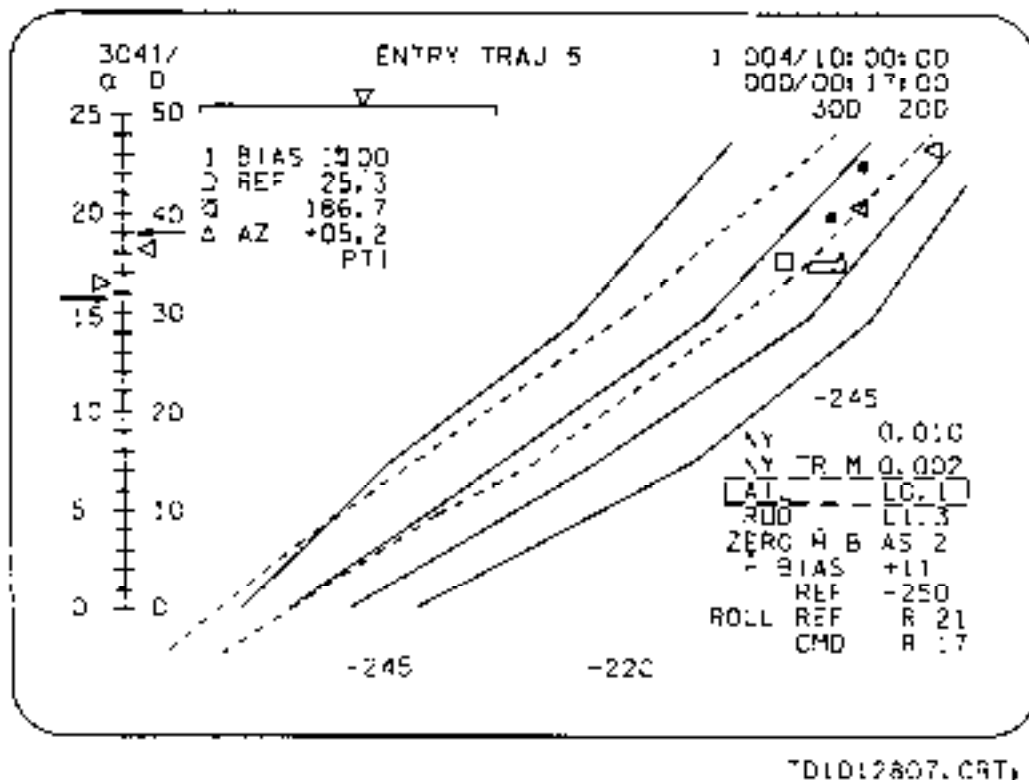


Figure 8-6.- The roll channel - ENTRY TRAJ 5 display.

As pointed out above, the aileron trim function stops at Mach 1.25 when in roll/yaw control stick steering mode (CSS R/Y) and holds the last value of trim. A cross check of the VERT SIT display will reveal any aileron being carried for earlier trim and, if a heavy stick is being sensed in roll due to a residual trim, the roll panel trim switch can be used to remove it. The switch behaves like a conventional airplane trim switch in this mode. If the RHC must be held left of detent, the commander should trim left or with the stick to trim the vehicle in roll.

The RHC rate trim switch provides a bias on the roll rate command coming from the RHC; a roll rate of ± 2.5 deg/sec can be input through this switch. This switch functions only in CSS R/Y; it is removed immediately and most effectively by going back to roll/yaw automatic mode (AUTO R/Y) and has no operational or procedural use.

The PTI modifications to the roll channel are shown in figure 8-6 and provide direct commands to the control effectors as was described in the pitch channel.

The automatic control loop is shown in figure 8-7. In the automatic mode, the bank angle is being commanded by guidance. This command is compared to the actual bank angle of the vehicle; from the resulting difference, a bank command is derived.

Following touchdown, the ailerons begin to receive commands attempting to balance the loads between the main tires. This command is based on true airspeed, N_y , and the yaw rate; it is designed to prevent an imbalance in the main tire load that might be present due to a crosswind during rollout. The lateral acceleration and the yaw rate are a function of the sideslip angle resulting from the crosswind, and they create an aileron command to roll into the wind in an attempt to reduce the sideslip angle. In CSS R/Y, the crew has enough roll authority to mask any auto load balancing by the entry DAP. At nosewheel slapdown, the last aileron command out of the auto load balancing is faded to zero over a 100-second time period.

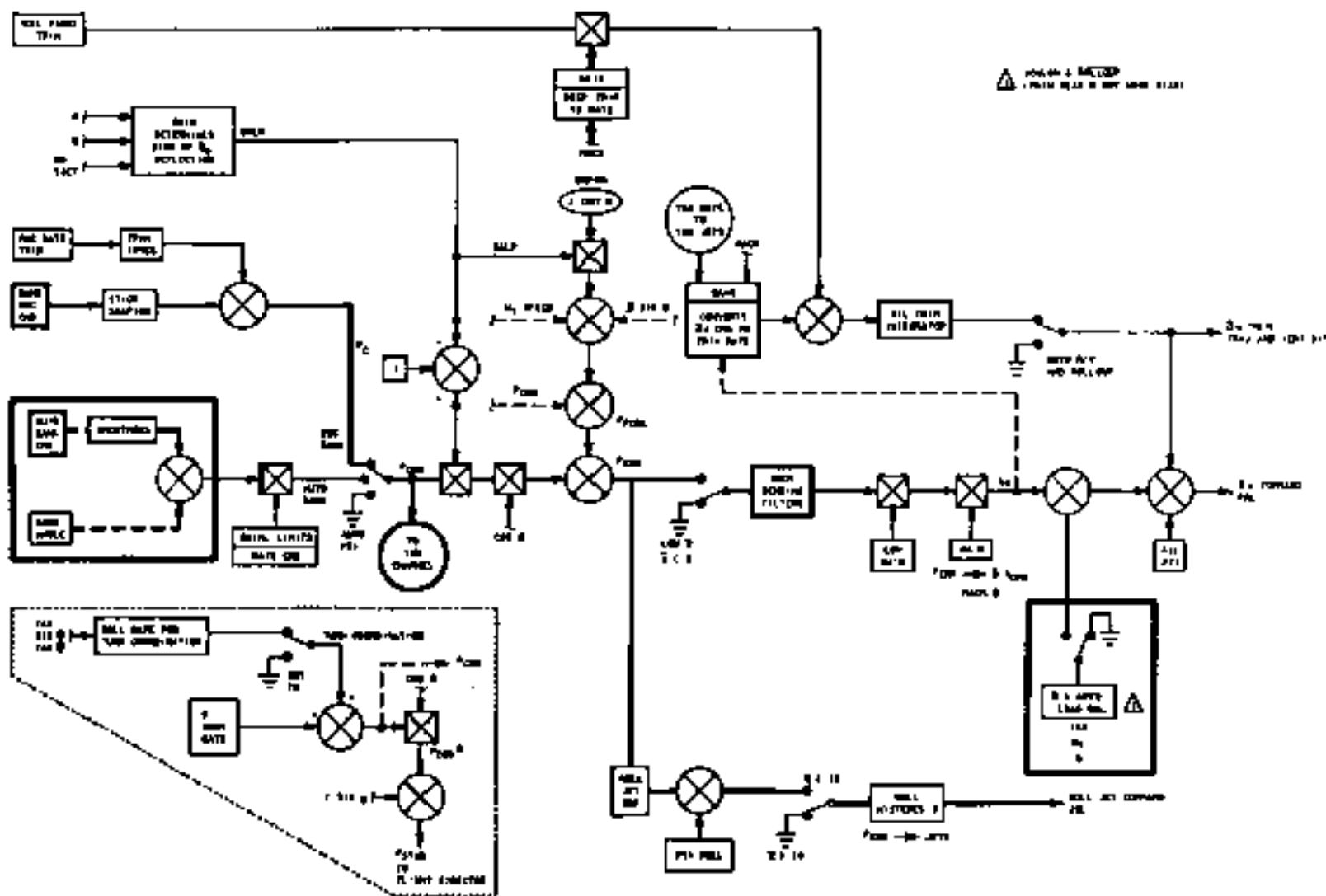


Figure 8-7.- The roll channel - Automatic control loop.

Roll Axis Functions

Feature	Function	Use
GALR	Determines the amount and sign of aileron that is commanded in response to a roll command input	<p>Allows blending of early phase into late phase. For $\dot{q} < 10$, GALR is 1.0; that gives only turn coordination in the roll axis and no direct command function. The bank command goes to the yaw axis and generates a yaw rate, which feeds the roll axis turn coordination. This function commands the proper roll rate to coordinate the stability axis bank. From $\dot{q} = 10$ to M 4.0, GALR = 1.1. This causes a small reverse aileron input in response to bank commands, which improves response (aids in achieving initial β). From M 4.0 to M 0.9 GALR goes to zero through a series of ramps and plateaus. This takes the roll channel configuration into the pure late system, where roll commands go to the aileron only.</p> <p>With downmoding NO Y JET option, GALR = 1.7, initially giving a large reverse aileron command in response to bank command inputs.</p>
PCQR	Corrects roll rate for vehicle turning	Allows proper turn coordination by removing roll sensed due to vehicle turning
$\beta \sin \alpha$	Inertial sideslip angle	Active $q < 2$. Inertial sideslip angle is used to command roll rate in a direction to reduce sideslip
N_y crossfeed to roll channel	Lateral acceleration crossfeed	Active when $p > 0.5$ deg/sec. Used to augment lateral acceleration during roll maneuvers to improve damping
RHC beep trim	Biases RHC roll rate command	Active CSS. To trim in roll rate, to compensate for RGA bias
Roll panel trim	Changes aileron position	Active in MM 304, 305. Inputs directly to forward loop trim integrator in auto and CSS ($M > 1.25$). In CSS, $M < 1.25$, the integrator acts as a pure trim device in response to the panel trim switch only.
Aileron trim logic	Provides auto trim function	Active MM 304, 305. Integrates roll and yaw rate error signals to provide proper aileron trim

Questions

1. When are roll jets deactivated?
2. When are the ailerons active for control?
3. What is the consequence of GALR decreasing from 1.1 to 0.0?
4. What is the purpose of NO Y JET?
5. Why would a commander become aware of holding a constant roll command on final approach? How should it be corrected?
6. Describe auto load balancing.

Answers

1. Roll jets are deactivated when $\dot{q} = 10.0$.
2. Ailerons are active for control when $\dot{q} = 2.0$.
3. The roll rate command is becoming increasingly proverse and dominant in determining the aileron response. Through GALR gain reductions, the aileron response is transitioning from β damping to performing conventional roll maneuvers.
4. This (NO Y JET) is a downmoding condition selected by the entry mode switch. Selecting this position grounds the command to the yaw jets and changes the value of GALR gain.
5. When flying CSS at Mach < 1.25 , the aileron trim loop opens and holds the last computed value of aileron trim fixed. The commander can trim the ailerons with the roll panel trim switch.
6. Following touchdown, the ailerons begin to receive commands to attempt to balance the loads between the main tires.

Section 9: Yaw Channel

Objectives

At the end of this section, the student will be able to do the following.

- State the driving parameter in the yaw channel for most of the entry
- State when the rudder becomes active

Yaw Channel

The major yaw channel events are shown in figure 9-1. This figure is similar to those of the pitch (figure 2-1) and roll (figure 8-1) channels. The detailed discussion of the yaw channel that follows expands and clarifies each of the events.

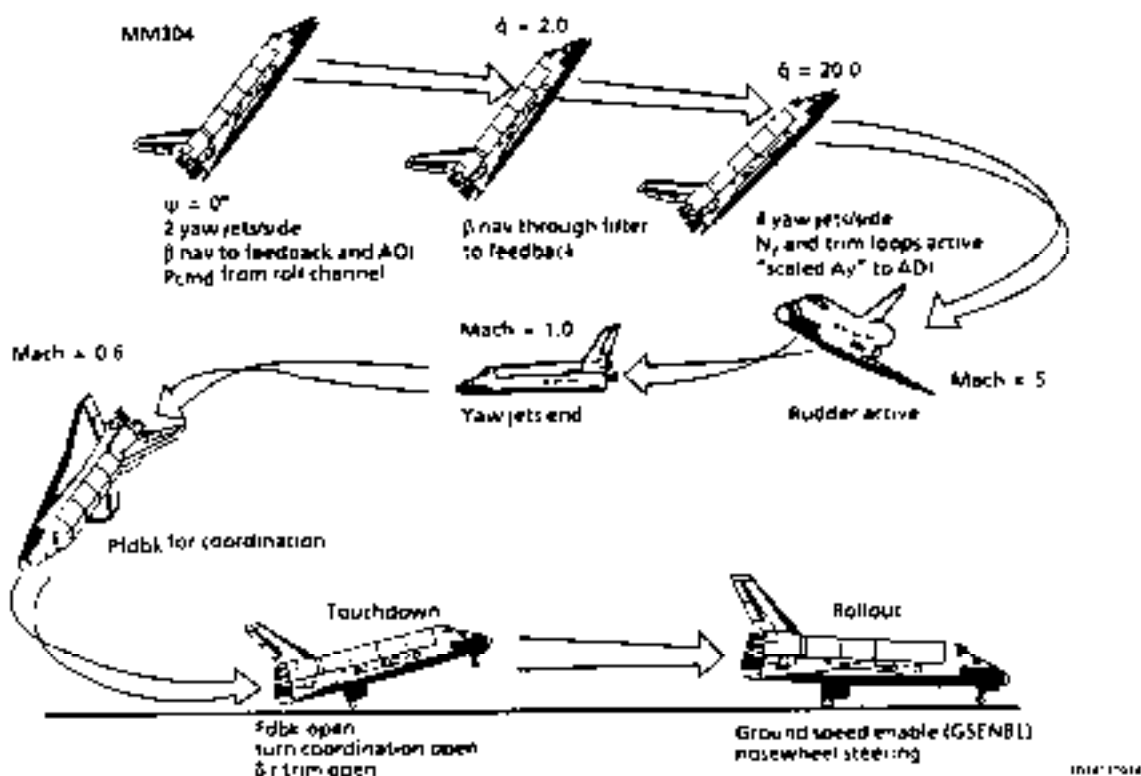


Figure 9-1.— Major yaw channel events.

Figure 9-4 shows how the inertial sideslip angle feedback is used for sideslip control during flight in the low \dot{q} regime (less than 2 psf). This sideslip angle is used in the roll channel for β control, as previously described, and is also sent to the yaw error needle on the ADI as an indication of sideslip angle to the crew (until \dot{q} is greater than 20 psf). After \dot{q} is more than 2 psf and less than 20 psf, the inertial sideslip angle is in the yaw channel to keep a large transient in β from developing, which might counter the rolling action during the first bank maneuver. This is accomplished by sending inertial beta through a washout filter that effectively removes the steady state value and allows only the transients in the sideslip angle to go through for control purposes. Sideslip angle, filtered or unfiltered, is sent to the roll channel until a \dot{q} of 20 psf is reached.

The yaw rate for turn coordination is shown in figure 9-4. This term, as calculated in equation 21, goes to the pitch channel (post-TAEM) for turn compensation. In the yaw channel it is differenced with the body yaw rate (feedback) to produce the compensated yaw rate (DRPRM, equation 23), which is used in the yaw channel as the corrected yaw rate feedback and is also used in the roll channel. The yaw channel also computes an estimated β or "scaled A_y ," which is sent to the yaw error needle on the ADI, replacing inertial sideslip angle at \dot{q} equal to 20 psf. The estimated β is computed using side acceleration (N_y) in combination with approximate aerodynamic coefficients.

The lateral acceleration loop (N_y) becomes active at a \dot{q} of 20 psf. N_y replaces inertial β as the sideslip control term. It is a yaw rate error based upon sensed lateral accelerations and is summed with the corrected yaw rate command to become a command to the jets and rudder. The lateral acceleration is sent to the roll channel to replace the β term at a \dot{q} of 20 psf.

The rudder, rudder pedals, and forward loop trim integrator become active at Mach 5, as shown in figure 9-5. The trim integrator should start taking over some of the lateral directional trim requirements and partially relieve the ailerons of that function. The crew can check this activity on the Trajectory displays or VERT SIT displays (figure 8-7).

The rudder pedals function strictly as a bias to the lateral acceleration feedback. The crew can make inputs through the pedals and can expect to see an initial rudder movement in the direction of the automatic stability loops. In practice, the orbiter usually is flown with the feet on the floor until touchdown, when braking and steering come into play.

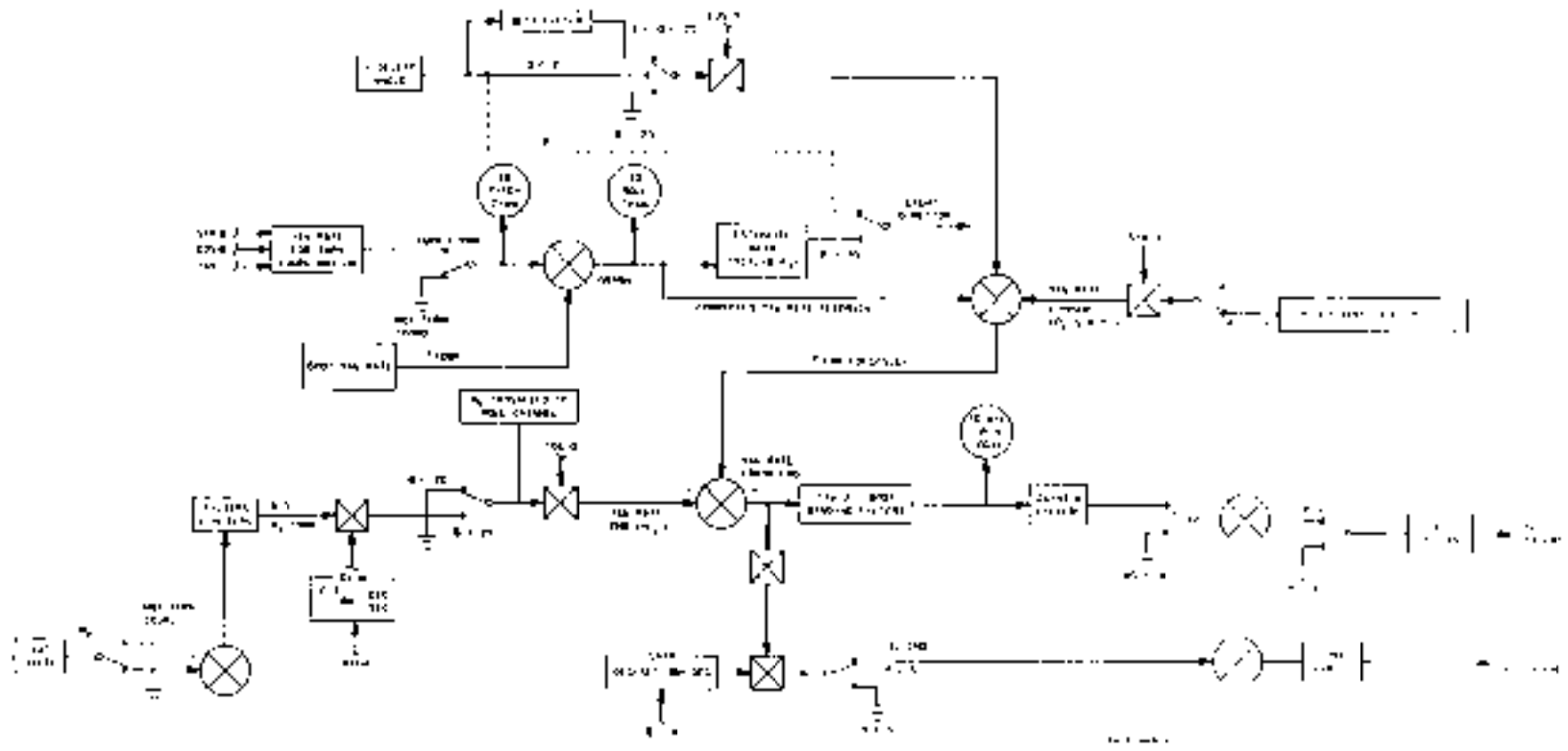


Figure 9-4.- Inertial sideslip angle feedback.

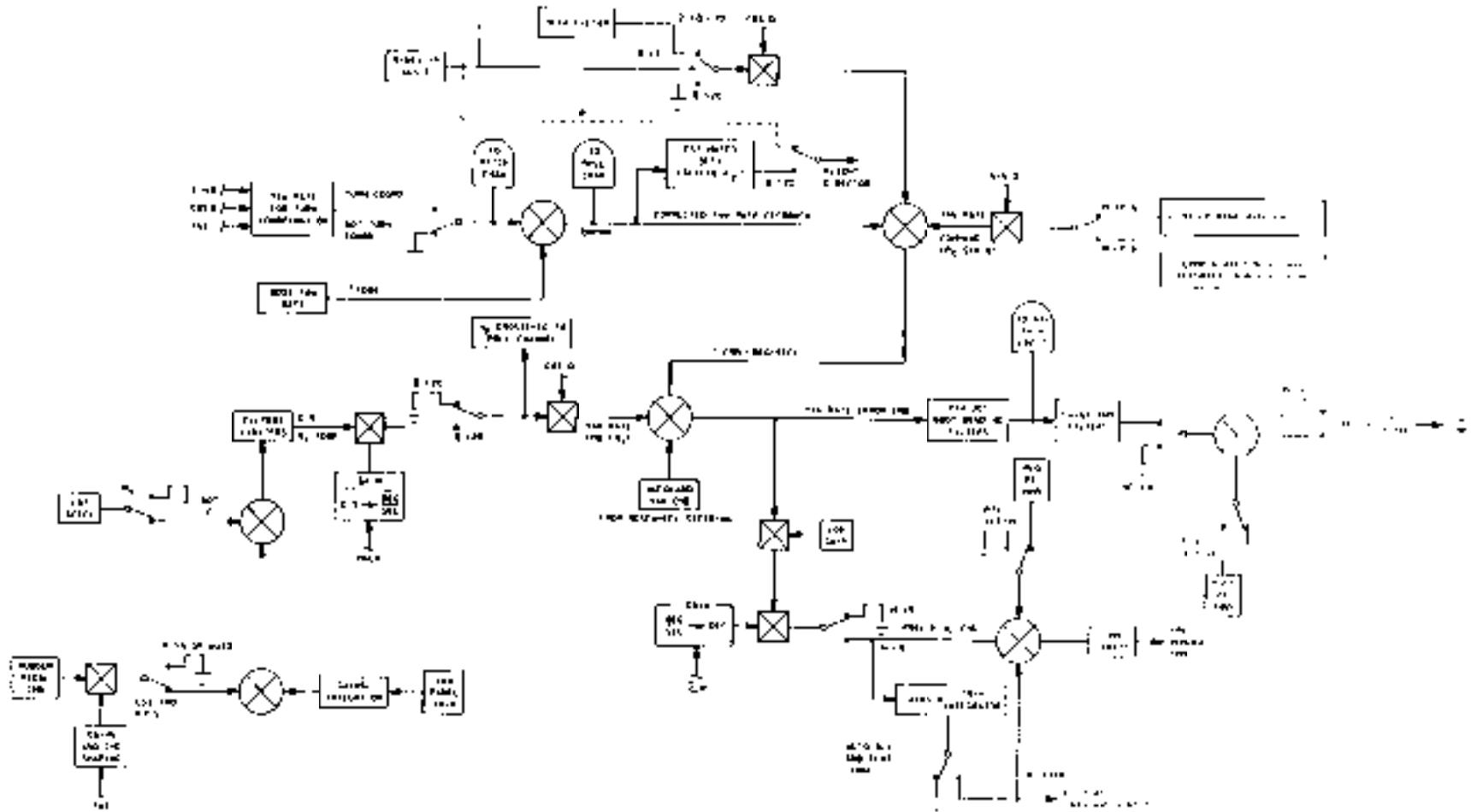


Figure 9-5. - Complete yaw channel.

At Mach numbers less than 0.6, the input changes from the bank rate command to a roll rate feedback term which is used to coordinate turns.

The autoland yaw commands are sent to the yaw channel when automatic nose-wheel steering is incorporated at nosewheel slapdown. This is an automatic mode that requires AUTO R/Y and a ground speed enable (GSENBLE) flag to be set.

The low gain and PTI modifications in the yaw channel are similar to those previously described in the pitch and roll channels.

Yaw Axis Functions

Feature	Function	Use
Limited bank rate command	To command jets and rudder in response to RHC inputs	Active $M > 0.6$. Multiplied by $\sin \alpha$ to construct yaw rate command for coordinated stability roll
Inertial sideslip angle	Limit sideslip in low \dot{q} regime	Active $q < 2$. To maintain sideslip within allowable limits, the body yaw component of nav derived sideslip is fed back and converted to a body yaw rate command
DRPRM	To correct yaw rate for vehicle turning	Allows properly coordinated turn by removing yaw rate sensed due to vehicle turning
Ny crossfeed to roll channel	Aids in coordinating roll maneuvers	Active when $p > 0.5$ deg/sec. Used to augment lateral acceleration during roll maneuvers to improve damping
Compensated roll rate feedback from roll channel	Used to scale yaw rate command	Active in $M < 0.6$. Roll rate shipped to the yaw channel is multiplied by $\sin \alpha$, which converts it to a body yaw rate command to damp β

Questions

1. What is the driving parameter in the yaw channel for most of the entry?
2. When does the rudder become active?

Answers

1. For most of entry, the driving parameter in the yaw channel is the bank rate command.
2. The rudder becomes active at Mach 5.

Section 10: Nosewheel Steering

Objectives

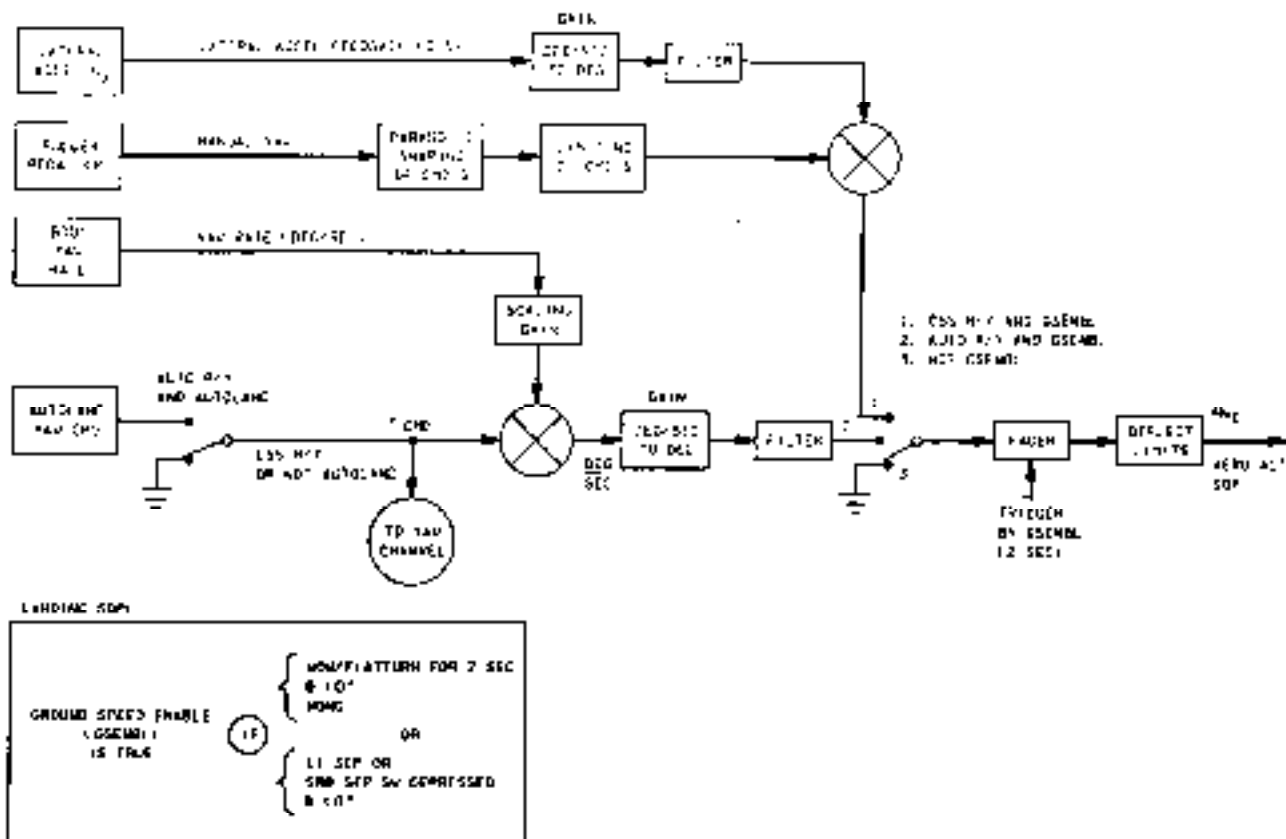
At the end of this section, the student will be able to do the following.

- State what the requirements are to set the GSENBFL flag and activate nosewheel steering (NWS)
- State the preferred CSS R/Y nosewheel steering mode and explain why it is preferred

Nosewheel Steering

The NWS schematic is shown in figure 10-1. NWS is available in both the manual (CSS) and automatic modes. It becomes active when the GSENBFL flag is set. This flag requires 2 seconds of having the weight on wheels (WOW) flag set, the pitch angle (θ) less than zero, and the weight on the nose gear (WONG) set. GSENBFL can also be triggered if the external tank (ET) separation (SEP) switch or solid rocket booster (SRB) SEP switch is enabled and the PBI is pushed and θ is less than zero. It is possible, but undesirable, to manually set WOW/WONG while airborne.

In the auto mode, the yaw rate command is sent to the yaw channel for rudder commands, is differenced with the body yaw rate feedback, and becomes an NWS command after passing through the proper gains. The nosewheel command is a result of the rudder inputs when the orbiter is being operated in CSS R/Y. In NWS 1 or 2, rudder pedal movement is read by the RPTA and from there fed into subsystem operating programs (SOPs) in the general purpose computers (GPCs). These SOPs bias the commands based on lateral acceleration feedback in order to prevent overcontrol. This also aids initial steering commands in response to tire failures. This provides the best control and handling qualities and is the most favored mode of control.



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Figure 10-1. - Nosewheel channel.

Questions

1. What are the requirements to set the GSENBK flag and activate nosewheel steering?

Answers

1. The GSENBK flag is set when there are 2 seconds of WOW, pitch angle is less than zero, and WONG is set. GSENBK can also be set if the ET SEP or SRB SEP switch is enabled and the PBI is pushed, and θ is less than zero.

Section 11: Event Chronology

Objectives

At the end of this section, the student will be able to do the following.

- State when the aerojet DAP is initialized
- State when the RCS activity lights reconfigure
- State what the RCS activity lights mean
- State when the yaw jets are deactivated

Event Chronology

EI-5

The chronology of significant entry events is shown in section 11. In table 11-1, the first event is EI-5, where the aerojet DAP is initialized at the beginning of MM 304. Generally, the control mode is AUTO in all axes, the control surfaces are neutral (flight dependent), command capability for four roll, four pitch, and two yaw jets is available per side, and there is a roll-pitch-yaw attitude of 0° - 40° - 0° . The maximum rates that can be commanded are ± 5 deg/sec in AUTO R/Y and ± 0.5 deg/sec in AUTO P. In CSS, the crew can command ± 6 deg/sec and ± 2.88 deg/sec in roll and pitch, respectively.

$\dot{q} = 0.5$

At a \dot{q} of 0.5 psf, the elevators become active for trim in response to the pitch jet firings. In this region the yaw jets are used to start the bank maneuvers, with the roll jets being used for coordination and to damp β during the maneuver.

$\dot{q} = 2.0$

The elevators become active for control. They respond immediately to pitch commands.

The ailerons become active for trim and control. They respond directly for trim, which is being driven by the yaw jet firings, and indirectly to roll command. It is in this region that bank control is being affected by the yaw plus roll jets.

At this juncture, the inertial sideslip angle is removed as a direct feedback in the yaw channel. It is, however, sent through a washout filter that allows the DAP to correct for transients in the sideslip angle and is displayed on the yaw error needle of the ADI.

$\dot{q} = 8.0$

The elevators no longer respond to pitch jet firings for trim

$\dot{q} = 10.0$

The roll jets are terminated. The ailerons are now responding directly to roll rate commands. From this point until $\dot{q} = 50$, the RCS roll activity lights are not active.

$\dot{q} = 20$

The number of yaw jets per side available increases to four. The elevator position feedback trim replaces the forward loop trim integrator loop. "Scaled A_y " replaces inertial sideslip angle on the yaw error needle of the ADI, and the lateral acceleration and lateral acceleration trim loops begin while the inertial sideslip angle is removed from the yaw and roll channel.

$\dot{q} = 40$

The pitch jets are terminated. From this point until $\dot{q} = 50$, the RCS roll activity lights are not active.

$\dot{q} = 50$

The RCS jet activity lights are reconfigured. The pitch jet lights indicate when the elevon rate limit has been saturated. The roll and yaw jet lights work together to indicate how many yaw jets are being commanded to fire in response to a bank maneuver input. A single yaw jet light alone (left or right) indicates the command direction to fire two yaw jets, and the yaw plus roll jet lights indicate three or four yaw jets being commanded on.

Mach = 10

The SPBK begins to open according to its programmed schedule. The SPBK position is fed back into the pitch axis, where its effect can be taken into account in the elevator trim loop. After opening, the SPBK, which has been tightly closed, now has a minimum closure angle of 15°.

h = 125000

Yaw jet minimum on time is increased from 80 to 320 milliseconds. This is to ensure complete burning of propellants between fire commands.

Mach = 5

The rudder becomes active. The rudder is now able to offload the aileron trim load, allowing ailerons to be used more for vehicle control.

Mach = 4.0

The GALR gain begins to ramp down in order to blend the transition of early entry bank into late entry. In this region, the elevon can be commanded down to ensure that the yawing moment coefficient due to aileron ($C_{n\delta_a}$) has a negative sign. This is preferable for NO Y JET procedures.

Mach = 3.2

The SPBK closes to approximately 65 percent to increase rudder effectiveness.

Mach = 3.0

The elevon trim schedule may ramp up to prevent high hinge moments.

Mach = 2.5

TAEM begins (MM 305). N_z command replaces alpha command in the auto pitch loop. The pitch error needle now displays N_z error on the ADI. The maximum autopitch rate being commanded is a function of true airspeed and is limited to the maximum guidance commanded N_z deltas of $\pm 0.5g$. A yaw rate term is brought in for turn compensation in pitch ($r \tan \phi$).

Mach = 2.2

The BF is limited to a lower setting of 18.8° to protect against high hinge moments.

Mach = 2.0

The RHC gain begins increasing to provide higher commanded pitch rates. This commanded pitch rate will be a maximum of ± 9.2 deg/sec upon reaching a Mach number of 1.2.

Mach = 1.5

The maximum roll rate command begins increasing and will achieve a value of ± 27 deg/sec by Mach 0.6. The N_y feedback into the roll channel begins to decrease and reaches zero at Mach 0.9.

Mach = 1.25

When flying CSS R/Y, the aileron trim integrator ceases its trim function and holds the last value of aileron trim. Crew awareness of this is important should there be an RHC requiring constant displacement in roll later in the trajectory indicating an out of trim condition.

Mach = 1.1

BF lower limit is now restricted to 15.8° .

Mach = 1.0

The yaw jets terminate. Also, in passing from supersonic to subsonic flight, the crew needs to pay particular attention to the alpha limits.

Note: If the vehicle is allowed to pitch up to higher than the upper angle of attack limit, a loss of control of the vehicle can occur. In the automatic mode, the vehicle will, when following guidance under certain circumstances, such as when air data is not incorporated, pitch up past the alpha limit and lose control.

All three control axes are \dot{q} -limited to a minimum value of 90 psf. This is to prevent any system's being reactivated, such as jets turned back on, should the \dot{q} become

low enough. An example would be during rollout where \dot{q} is rapidly decreasing. The BF can now go to a full-down position if needed.

Mach = 0.95

The SPBK is now being commanded by TAEM/A/L guidance for q bar modulation

Mach = 0.6

The PCOR is now being used in the yaw channel as a yawing rate error to generate rudder commands. This essentially provides turn coordination through landing.

h = 10000 ft

At the nominal approach and landing interface, the guidance should command the BF to the trail position if in the BF AUTO mode.

h = 3000 ft

The SPBK closes to a calculated value based on wind, weight, density altitude, velocity error, and short field option.

h = 2000 ft

Preflare is commanded and is usually executed manually at an altitude of approximately 1850 feet AGL.

h = 500 ft

The SPBK can make an adjustment based on density altitude and wind velocity.

Main gear touchdown

Auto load balance begins. The N_y feedback loop and the rudder trim integrator loop are opened. SPBK goes full open. Flat turn flag is set.

Nose gear touchdown

The aileron trim loop is opened and the load balance signal is faded. The elevator feedback loop is opened and the elevators are commanded down in AUTO (will mode to AUTO if in CSS) to relieve the main tire load. Pitch can be moded back to CSS by the "hot stick" method or pushing the CSS pitch PBI.

The turn coordination loop is grounded and NWS is enabled.

Table 11-1. – Chronology of significant entry events - EI-5.

FCS: Aerojet DAP initialization - MM 304

Event	Roll	Pitch	Yaw
EI-5	$\delta a = 0^\circ$	$\delta e = -1^{**}$ $\delta b_f = 52\%*$ (active) $\delta s_b = 0^\circ$	$\delta r = 0^\circ$
	4 roll jets/side	4 pitch jets/side	2 yaw jets/side
	$\phi = 0^\circ$	$\theta = 40^\circ$	$\psi = 0^\circ$
Max commanded rates	Auto: CSS.	$p = \pm 5$ deg/sec $\dot{p} = \pm 6$ deg/sec	$q = \pm 0.5$ deg/sec $\dot{q} = \pm 3$ deg/sec
$\bar{q} = 0.5$ psf	Roll jets assist and damp during bank maneuvers	δe active for trim, responds to pitch jet firing	Yaw jet start bank maneuvers
$\bar{q} = 2.0$ psf	δa active for control	δe active for control	Inertial β through a wash-out filter used in FCS fdbk δa trim begins, driven by yaw channel
$\bar{q} = 8$ psf		δe does not respond to pitch jets for trim any longer	
$\bar{q} = 10$ psf	Roll jets end		
$\bar{q} = 20$ psf		δe position fdbk replaces twd loop trim integrator	4 yaw jets/side "Scaled A_y " on AD yaw error needle; N_y fdbk and trim loops begin; replaces inertial β
$\bar{q} = 40$ psf	Pitch jets end		
$\bar{q} = 50$ psf		- RCS jet activity lights reconfigure - indications now are:	
	3 or 4 yaw jets commanded	δe rate saturation (± 20 o/s ≥ 2 auxiliary power unit (APU)) (± 14 o/s 1 APU)	2 yaw jets commanded

*Flight dependent.

Table 11-1. – Continued

Event	Roll	Pitch	Yaw
Mach = 10		δ_{SB} open per schedule δ_e trim accounts for δ_{SB} minimum $\delta_{SB} = 15^\circ$	
$h = 125,000$ ft			Jet minimum on time from 80 to 320 msec
Mach = 5			Rudder active
Mach = 4	GALR gain begins ramping down for conventional δ_a	$\delta_e = 5^\circ$ (down)* to ensure $-C_{n\delta_a}$	
Mach = 3.2		δ_{SB} begins closing to 65% in anticipation of rudder use	
Mach = 3.0		δ_e trimmed up to prevent high hinge moments	
Mach = 2.5		-----TAEM-----	
		Auto pitch loop becomes N_z CMD, replaces α CMD	
		N_z error displayed on pitch needle	
		Max auto pitch rate commanded is f (TAS), limited to max guid- ance CMD ΔN_z of 0.5g	
		r tan ϕ to compensate for q required in turns	
Mach = 2.2		δ_{bf} lower limit = 18.8° to protect against high hinge moments	
Mach = 2.0		RHC gain increases for higher pitch rates (max commanded rate = -9.2 deg/sec by Mach = 1.2)	
Mach = 1.5	Max rate cmd increasing to 27 deg/sec by Mach = 0.5		
	N_y fdbk going to zero by Mach = .9		

*Flight dependent.

Table 11-1. – Concluded

Event	Roll	Pitch	Yaw
Mach = 1.25	In CSS, δ_a trim integrator stops, holds last value of δ_a trim		
Mach = 1.1		δ_{bf} = lower limit = 15.8°	
Mach = 1.0		ITBE aware of α limits!!	Yaw jets terminate
		All axes \dot{q} limited to minimum value of 90 psf	
		δ_{bf} lower limit = 22.5°	
Mach = 0.95		δ_{sb} now commanded by TAEM/AVL guide for \bar{q} modulation	
Mach = 0.6			P_{body} used to generate error for δ_r CMD
h = 10,000 ft		AVL guidance may CMD δ_{bf} to trail	
h = 3000 ft		δ_{sb} goes to calculated value based on wind, weight, density altitude, velocity error, and short field option	
h = 2000 ft		Preflare commanded (manually executed at \approx 1850 ft AGL)	
h = 500 ft		δ_{sb} can make adjustments based on density altitude and wind velocity	
Main gear touchdown	Auto load balance for δ_a	SPBK goes to full open	N_y fdbk loop grounded δ_r trim integration open
Nose gear touchdown	δ_a trim open Auto load balance faded	δ_e fdbk open Switches to auto for load relief bias (CSS still available for downmode)	Turn coord grounded Nosewheel steering available

Table 11-2. – RCS activity light summary.

Event	Roll	Pitch	Yaw
EI-5	Left or right light indicates jet has been commanded to fire	Up or down light indicates jet has been commanded to fire	Left or right light indicates that two jets have been commanded to fire
Qbar = 10 psf	(Roll jets deact.)		
Qbar = 40 psf	No use	(Pitch jets deact.)	
Qbar = 50 psf	Both lights simo indicate ≥3 yaw jets commanded to fire	Both lights simo indicate elevon rate saturation: (± 20 deg/sec, 2(3) APU ± 14 deg/sec, 1 APU)	
Mach = 1.0			(Yaw jets deact.)
NGTO			No use

Note: From Qbar = 20 to 50, four yaw jets are available for firing, while the yaw light activates for two commanded. Only at Qbar = 50 does the crew have insight into ≥ two yaw jets commanded.

Questions

1. When is the aerojet DAP initialized?
2. When do the RCS activity lights reconfigure?
3. What do the RCS activity lights indicate after they have reconfigured?
4. When are yaw jets deactivated?

Answers

1. DAP is initialized at the beginning of MM 304.
2. RCS activity lights reconfigure when $\dot{q} = 50$ psf.
3.
 - The roll activity lights mean three or four yaw jets are commanded.
 - The pitch jet lights mean elevon rate limit has reached saturation.
 - The yaw jet lights mean two yaw jets are commanded.
4. Yaw jets are deactivated at Mach 1.0.

Section 12: Entry Cue Cards

Objectives

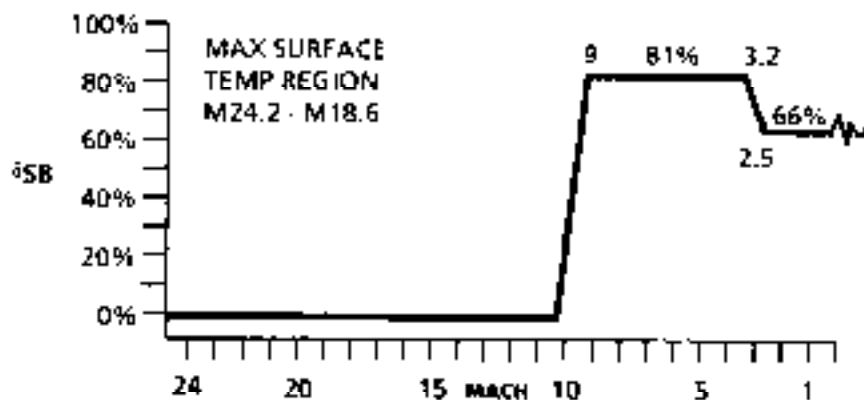
At the end of this section, the student will be able to interpret the ENTRY DATA and ENTRY ALPHA cue cards.

Entry Cue Cards

An example of an ENTRY DATA cue card is shown in figure 12-1.

An ENTRY ALPHA cue card is shown in figure 12-2. For the different velocities (V_R) the expected angle of attack (α) is shown. Also shown for easy reference are the range (R), altitude (H), and reference bank angle (R_{ref}). The angle of attack shown is the design flight profile. At the high Mach numbers (velocities), the alpha has a $\pm 3^\circ$ allowable band. The high Mach numbers show a constant alpha during the temperature control phase and the equilibrium glide phase. Shortly after going to the constant drag phase, the alpha comes down a little in maintaining a constant drag acceleration. The alpha continues to come down during the transition phase from high angles of attack to low.

From TAEM, at Mach 2.5, the angle of attack continues to decrease to a final value of 7° as the vehicle begins to go subsonic. At the base of the card is a table which gives the alpha to be flown for maximum L/D ratio for several Mach numbers.



TRIM/OSC

JETS OPPOSE ROLL, INCR RATE
DURING ROLL REVERSAL (Alpha Error)

1. R/Y - CSS,
DECR ROLL RATE $\leq 5^\circ/\text{sec}$
2. When $\phi = \phi_{\text{CMD}}$:
R/Y - CSS or AUTO

AIL TRIM SAT ($\pm 3^\circ$)
POSSIBLE ROLL - OFF:

1. BF - UP to lower ELEV until
 $M < 2$; then BF - AUTO
2. M12 to M8 decr α to α limit
M6 to RUD TRIM act incr α to α limit

HIGH REQ OSC OR SURFACE/JET
LIMIT CYCLE

1. P, R/Y - CSS
2. ENTRY MODE - LO GAIN
If returning payload > 10K lb:
2: GNC 51 OVERRIDE
ALT FILTER - ITEM 21
3: BFS, GNC 51 OVERRIDE
ALT FILTER - ITEM 21
3. After OSC stops:
ENTRY MODE - AUTO
P, R/Y - AUTO

ENT-9b/A, E/C

Figure 12-1.—ENTRY DATA cue card.

**ENTRY ALPHA
EDW 22**

VR	α			R	H	Href	Rref
24.5	40			4300	400		
24	40			2810	250	-42	L84
23	40			2290	240	-58	73
22	40			1895	235	-76	66
21	40			1585	230	-96	62
20	40			1340	220	-113	60
19	40			1145	215	-135	60
18	40			990	205	-158	61
17	40			865	200	-176	62
16	40			765	195	-187	R63
15	HI	42	LO	680	190	-203	63
14	43	41	37	610	185	-127	61
13	43	40	37	540	175	-137	60
12	43	39	37	477	171	-156	59
11	42	39	36	419	165	-199	57
10	41	37	35	366	159	-176	52
9	39	36	33	316	153	-210	47
8	36	35	30	269	148	-241	L42
7	33	31	27	223	138	-267	39
6	29	27	23	178	125	-270	42
5	26	23	20	136	112	-272	44
4	22	18	17	100	98	-265	R41
3	19	15	15	70	85	-270	36
2.5	13			59	79	-268	
2	11			49	73	-299	
1.5	9			37	63	-345	
1	7			27	48	-269	

$\frac{\alpha}{\text{MACH}}$ - L/D MAX	17	15	12
	3	2	1

ENT-14b/A,EA

Figure 12-2.- ENTRY ALPHA cue card.

Questions

1. Using figure 12-1, state the speedbrake position at Mach 2.5.
2. Using figure 12-2, find the following for Mach 17
 - Reference alpha
 - Range
 - Altitude
 - Vertical velocity (H)
 - Bank angle

Answers

1. The SPBK at Mach 2.5 is 66 percent.
2.
 - Reference alpha = 40°
 - Range = 870 n. mi.
 - Altitude = 202,000 feet
 - Vertical velocity (H) = -170 fps
 - Bank angle = 62° left bank

Section 13: Automatic Program Test Inputs

Objectives

At the end of this section, the student will be able to state the purpose of PTIs.

Automatic PTIs

Figures 13-1 and 13-2 present information concerning PTIs. The purpose of the PTIs is to provide automatic test maneuvers during flight in order to obtain flight data from which aerodynamic coefficients can be extracted postflight. The data are used to define the aerodynamic characteristics of the vehicle, allow expansion of the operational envelope, and reduce aero data base uncertainty.

PTIs are executed automatically by the entry DAP and are input into the control system downstream of the gains and filters so that a known control deflection (for example, a 5° aileron sweep) or jet firing can be made (refer back to figures 5-3, 8-3, and 9-3). Being automatic, they can be more precise and reduce the crew workload.

Certain flight constraints must have been met for 4 seconds in order for a maneuver to be executed. These constraints (figure 13-1) include restrictions on body rates, altitude acceleration, and heading to ensure that the vehicle is in the proper condition (stabilized attitude) prior to PTI initiation. It should be noted that the vehicle control has to be in AUTO in all axes.

The maneuvers are restricted to certain regions of the entry trajectory ("windows") and are cued by Mach number or \dot{q} . Once the vehicle is inside a maneuver window, but the constraints have not been met, PTI begins flashing on the CRT displays. The PTI becomes static when the maneuver is executed and will disappear when out of the window, whether the maneuver was executed or not.

The PTI logic, which has been I-loaded prior to flight, generates the signals sent to the DAP when the maneuver criteria have been met. These signals usually form doublets (example, left rudder input, followed by right rudder input, then back to neutral) which are superimposed on the normal commands. The axes affected and the controls utilized in each maneuver are decided preflight, and a series of pulses can be executed in one maneuver.

Since the idea of the maneuver is to obtain controlled input and response for flight data extraction, it becomes obvious that all other control inputs should be

minimized. Therefore, the commanded roll rate is zero, the aileron and rudder trim integrator inputs are zero, and the pitch jet input for elevator trim is zeroed.

A PTI can be terminated or inhibited at any time in one of three ways. An item 1 on SPEC 50 PTI inhibit (INH)/enable (ENA) indicator will inhibit execution of a PTI, as well as going to CSS in either axis by means of the PBIs or "hot sticking it" with the RHC. Once any maneuver has been inhibited, it or any of the succeeding PTIs will have to be enabled by returning the control to AUTO in all axes and executing item 1 on SPEC 50 to ENA.

PTI logic

The following constraints must be met for ≈ 4 sec:

- Body rates $p < 1.5$, $q < 0.5$, $r < 0.5$ (deg/sec)
- Altitude acceleration $\dot{h} < 4$ ft/sec²
- Not outside heading error limits (inhibit PTI if near a roll reversal)
- Roll reversal not started in last 42 sec
- ADTA providing air data to DAP if $M < 2.5$
- Pitch and roll/yaw in AUTO mode
- Crew sets enable flag

Maneuver selection

- PTIs are executed only inside certain trajectory windows
- Cued by Mach or dynamic pressure
- Average of 8 to 10 maneuvers during earlier flights

Crew displays

- If trajectory is inside PTI window, but constraints are not met, "PTI" flashes
- Once maneuver is executed, PTI becomes static

Figure 13-1. – Automatic program test inputs.

Maneuver execution

Once maneuver criteria have been met, the PTI logic generates signals which are sent to DAP

- Signals are in the form of doublets which are integrated
- These signals are superimposed on normal commands
- Controls effectors are δe , δr , δa , roll-pitch-yaw jets
- Series of pulses can be executed in a single maneuver

While pulse is being executed

- Commanded roll rate is set = 0
- δa , δr trim integrator inputs = 0
- GJET is grounded (pitch jet to elevator crossfeed)

Maneuver can be terminated at once by

- Keyboard (item 1 on SPEC 50)
- Pushing either pitch or roll/yaw CSS PBs
- Pushing control stick, "hot sticking it"

Note: To reenable PTIs, return to AUTO and execute item 1 on SPEC 50

Figure 13-1.- Concluded.

Questions

1. State the purpose of PTIs.

Answers

1. PTIs provide automatic test maneuvers during flight to obtain flight data from which aerodynamic coefficients can be extracted postflight. These data might define characteristics to allow expansion of the operational envelope and reduction of aero data base uncertainty.

Section 14: FCS Monitoring

Objectives

At the end of this section, the student will be able to state the aerojet software conditions on PASS guidance, navigation, and control (GNC) SPEC 51, OVERRIDE.

Figure 14-1 shows the FCS display monitoring. Through the use of SPEC 51, OVERRIDE, the crew can check or alter by keyboard inputs two software conditions of the entry DAP. The first, shown in figure 14-2, is the software position of the Entry mode switch. As can be seen in the figure, the Entry mode switch is indicating AUTO. Moving the switch itself, first to the low gain (L GAIN) position, then to the NO Y JET position changes the displays as shown in figures 14-3 and 14-4. With a keyboard input, the software selection of the switch function can be changed to AUTO, regardless of the actual switch position. In other words, with the switch physically in NO Y JET, the logic can be made to be in the AUTO position by executing an item 42, AUTO SEL. The display will be as shown in figure 14-2. The entry DAP will be functioning normally with the normal gains, while the switch resides in NO Y JET. With the switch still in NO Y JET, executing item 42 again will put the software back in agreement with the switch position, as in figure 14-4. The BFS SPEC 51 is shown in figure 14-5. Note there is no software selection to AUTO in the BFS (no item 42).

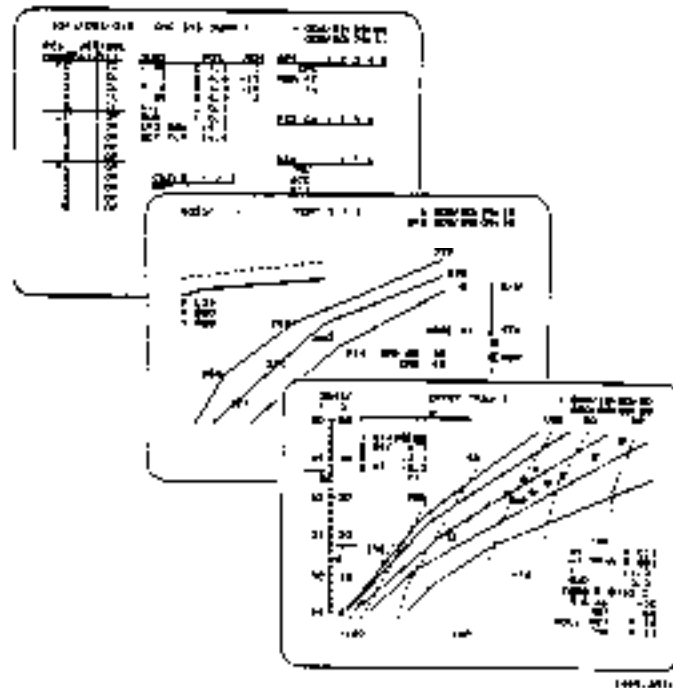


Figure 14-1. – FCS display monitoring.

```

XXXX/051/      OVERRIDE      XX X DDD/HHH MM:SS
                                DDD/HHH MM:SS
ABORT MODE      ENTRY FCS
TAL/ACA  1X      ELEVON  FILTER  ATMOSPHERE
ATO      2X      AUTO  :7X  NOM  20X  NOM  22X
ABORT    3X      FIXED  :8X  ALT  21X  N POLE 23X
MAX THRDT 4X      S POLE 24X

      PROPLT DUMP
OHS DUMP TIG XXX
XXXXXXXXXXXXXXXXX
      XXXX CENT
ARM      6X      9X
START    7X      10X
INERT    11X
STOP     8X      12X

AFT RCS 13      XXX
  14 TIME      XXX

FWD RCS 15      XXX
  16 TIME      XXX

      L 15 XXXXXX 2XX.X X.XX 34X
      R 25 XXXXXX 2XX.X X.XX 36X
      35 XXXXXX 27X 25 29X 32X
      35 XXXXXX 33X
      L 15 XXXXXX 2XX.X X.XX 34X
      R 25 XXXXXX 2XX.X X.XX 36X
      35 XXXXXX 27X 25 29X 32X
      35 XXXXXX 33X
      ET SEP      ROLL MODE AUTO
      ALIC 38X    ALTO SEL 42X
      SEP 39X
      ET UNB OR  VENT DOOR CNTL
      CLOSE 40X  OPEN 43X
      RCS RM MANF  CLOSE 44X
      CL OVRD 41X
                                (XX)

```

TD1012142. CRT: 3

Figure 14-2.—Entry DAP software.

```

XXXX/051/      OVERRIDE      XX X DDD/HHH MM:SS
                                DDD/HHH MM:SS
ABORT MODE      ENTRY FCS
TAL/ACA  1X      ELEVON  FILTER  ATMOSPHERE
ATO      2X      AUTO  :7X  NOM  20X  NOM  22X
ABORT    3X      FIXED  :8X  ALT  21X  N POLE 23X
MAX THRDT 4X      S POLE 24X

      PROPLT DUMP
OHS DUMP TIG XXX
XXXXXXXXXXXXXXXXX
      XXXX CENT
ARM      6X      9X
START    7X      10X
INERT    11X
STOP     8X      12X

AFT RCS 13      XXX
  14 TIME      XXX

FWD RCS 15      XXX
  16 TIME      XXX

      L 15 XXXXXX 2XX.X X.XX 34X
      R 25 XXXXXX 2XX.X X.XX 36X
      35 XXXXXX 27X 25 29X 32X
      35 XXXXXX 33X
      L 15 XXXXXX 2XX.X X.XX 34X
      R 25 XXXXXX 2XX.X X.XX 36X
      35 XXXXXX 27X 25 29X 32X
      35 XXXXXX 33X
      ET SEP      ROLL MODE LO GAIN
      AUTO 38X    AUTO SEL 42X
      SEP 39X
      ET UNB OR  VENT DOOR CNTL
      CLOSE 40X  OPEN 43X
      RCS RM MANF  CLOSE 44X
      CL OVRD 41X
                                (XX)

```

TD1012143. CRT: 4

Figure 14-3.—OVERRIDE, LO GAIN.

Another feature on SPEC 51 (figure 14-3) provides the crew with the information concerning the selection of the body bending filters and the elevon schedule being used by the entry DAP. In the upper center portion of the display, items 17 and 18 represent the AUTO and FIXED elevon schedules, respectively, while items 20 and 21 are the nominal (NOM) and alternate (ALT) body bending filters, with an asterisk beside the elevon schedule and filter currently selected. During a normal entry (going from OPS 2 to OPS 3), the entry DAP would come up initialized in the AUTO configuration for the elevon and NOM for filters. For cases involving heavy or flexible payloads during an otherwise normal entry, the crew would have to select ALT by keying in an item 21 on this page. The reason, as previously stated, would be either a heavier payload being returned or a payload whose flexibility would interact with the orbiter structure in such a way as to require a change in the body bending filters.

An example of the need for this alteration of the entry DAP by the crew is the flight of a Spacelab. The normal procedure in this flight is to manually select item 21, ALT, on entry because of the return from orbit of a large, flexible payload, the Spacelab.

XXXX/0517		OVERR DE	XX X	DDD/HH:MM:SS	SS
ABDR ^T MODE		ENTRY FCS		DDD/HH:MM:SS	
TAL/ACA	1X	ELEVON	FILTER	ATMOSPHERE	
A70	2X	AUTO	17X	NOM	22X
ABDR ^C	3X	FIXED	18X	ALT	21X
MAX THRST	4X			N POLE	23X
				S POLE	24X
PROFLT DUMP		TRU STAT	A ^T T	DES	PR_
OHS DUMP TTG XXX		15	XXXX	Y	25X
XXXXXXXXXXXXXXXX		25	XXXX	XX	26X
		35	XXXX		27X
				SYS	AUT
				15	28X
				25	29X
				35	30X
				DES	
XXXX CENT		ADTA	H	O	H
ARM	6X 9X	L 15	XXXXXX	XXX.X	X.XX
START	7X 10X	35	XXXXXX	XXX.X	X.XX
INERT	11X	R 25	XXXXXX	XXX.X	X.XX
STOP	8X 12X	45	XXXXXX	XXX.X	X.XX
A ^T RCS 13		PT SFP		ROCT MODF NO YJET	
14 TIME	XXX	AUTO	38X	AUTO SEL	
FWD RCS 15		SEP	39X		
16 TIME	XXX	ET LNB CR		VENT DOOR CNTL	
		CLOSE	40X	OPEN	
		RCS NM MANF		CLOSE	
		CL OVRD	41X		
				(XX)	

FD1012144, CR1, 3

Figure 14-4. - OVERRIDE, NO YJET.

XXXX/DELT	OVERRIDE	XX X	DDO/HH:MM SS
		BFS	DDO/HH:MM SS
ABORT MODE		ENTRY PCS	
CL/ACZ 1X	LEVO 17X	FILTER	ATMOSPHERE
ATD 2X	ALTC 17X	NOP 20X	NON 22X
ABORT 3X	TEXT 16X	A.T 21X	N POLE 23X
MAX THRST 4X			S POLE 24X
PROP. T DUMP	IMP. DES		
	1	25X	
OMS CLMF TTD XXX	2	26X	
XXX ICNST 5	3	27X	
	OMS CEN		
ARM 6X	9X		
START 7X	10X		
INERT	11X		
STOP 8X	12X		
ATT RCS 13	XXX	ET SFP	VENT DOOR ENTL
14 TIME	XXX	AUTO 28X	OPEN 43X
		SEP 29X	CLOSE 44X
FWD RCS 15	XXX	ET UPB DR	
16 TIME	XXX	CLOSE 30X	

(XX)

TD10:2145, CRT 2

Figure 14-5. - OVERRIDE (BFS).

Questions

1. State the three aerjet software conditions that can be seen on PASS GNC SPEC 51, OVERRIDE.
2. State how to change the software status of the Entry mode switch back to AUTO if the switch is physically stuck in NO Y JET or LO GAIN.

Answers

1. The three aerobjet software conditions that can be seen on PASS GCN SPEC 51, OVERRIDE, are
 - AUTO or FIXED elevons
 - NOM or ALT body bending filters
 - Software status of Entry mode switch
2. To change the software status of the Entry mode switch back to AUTO if the switch is physically stuck in NO Y JET or LO GAIN, type in ITEM 42 EXEC on PASS GCN SPEC 51, OVERRIDE.

Section 15: Estimated Beta

Objectives

At the end of this section, the student will be able to state the two purposes of Estimated Beta.

Estimated Beta

The schematic for Estimated Beta is shown in figure 15-1. Estimated Beta becomes active at a \bar{q} of 20 psf, as shown previously in the yaw channel (figure 9-1), and has two functions. First, it provides a value called "scaled A_y " to the yaw error needle of the ADIs. Scaled A_y is an approximation of the magnitude of beta with which the vehicle is flying. A full-scale deflection of the needle would indicate a lateral acceleration driven by a sideslip angle which would require 2.5 yaw jets to trim.

Second, an estimated beta goes into the air data system (ADS) redundancy management (RM), where it can be used to resolve a dilemma created by sideslip angles.

To get the estimated beta and scaled A_y , the lateral acceleration is corrected through various summations and differences with compensated yaw rate and past values of the number of yaw jets commanded and control surface deflections. This value is then divided by a gain to give estimated beta for the ADS RM. It is also multiplied, separately, by another gain as a function of angle of attack which determines the A_y for ADI use. The alpha function gain is determined assuming nominal aerodynamics, and although it attempts to compensate for β tolerance as a function of alpha, it may give large errors in the magnitude of A_y in the Mach 2 to 1 region. However, the indicated sign of A_y (β) in this region should be correct.

70:012A

15-2

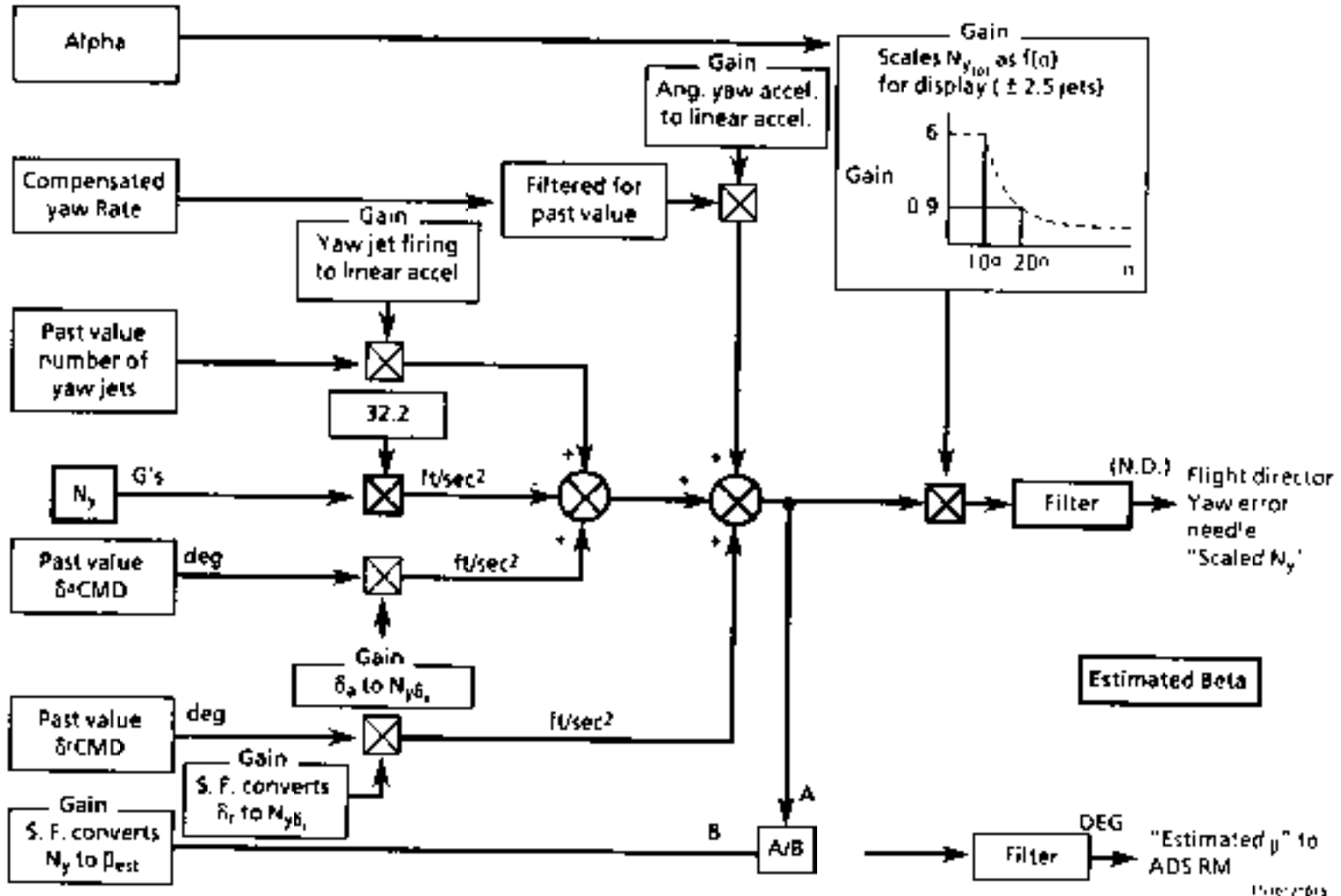


Figure 15-1.- Estimated Beta.

Questions

1. State the two purposes of Estimated Beta.

Answers

1.
 - Estimated Beta provides the value "Scaled Ay" to the yaw error needle of the ADI.
 - Estimated Beta goes into the ADS RM, where it can be used to resolve a dilemma created by sideslip angles.

Section 16: Landing Discrettes

Objectives

At the end of this section, the student will be able to do the following

- State the actions required in case one of the WOW discrettes disagrees with the other WOW discrettes for 7 seconds
- State how load relief is accomplished when landing in CSS P

Landing Discrettes

The landing of the orbiter is broken into two distinct phases: touchdown and rollout. The touchdown naturally occurs at the moment when the main landing gear contacts the ground under controlled conditions. At touchdown, several discrettes are set which prompt changes in the entry DAP. These discrettes, as shown in figure 16-1, are no WOW (set false), weight on wheels locked on (WOWLON), and the flatturn (FLATTURN). These discrettes are initiated by either main gear touchdown or crew initiation of either the ET SEP or SRB SEP switch and PBIs. A dilemma will occur if one of the WOW discrettes disagrees with the other for 7 seconds. In a dilemma case, the crew must use the ET SEP or SRB SEP switches and PBIs to set the landing discrettes.

In the pitch axis, ADI pitch rate commands are generated as a function of pitch angle, main gear touchdown, the equivalent airspeed, and the vehicle weight. These rates are converted into elevator commands if in AUTO P mode.

An auto balance is computed for the ailerons in the roll axis. This is designed to help equalize the loadings on the main tires and gear. The auto balance command is based on true airspeed, N_y , and the yaw rate and attempts to prevent an imbalance in main loads. From these sensed parameters, the ailerons are being commanded to remove any asymmetric loading on the tires, especially any resulting from a crosswind by rolling into the wind to reduce the effect of the sideslip angle.

The rudder trim integration loop is opened at touchdown.

Following nosewheel touchdown, rollout discrettes are set by the combination of certain events (figure 16-2). These are nose gear touchdown itself or pushing the ET or SRB SEP PBI and having had WOWLON/FLATTURN for 2 seconds, and the pitch attitude must be less than 0° . The rollout discrettes are WONG, rollout discrete (ROLLOUT), and GSENLB, and upon initiation the turn coordination is ended in all axes.

In the pitch axis, the elevator trim feedback is grounded (as opposed to having a zero command to the filters). In AUTO P, the elevators will be driven down to assist in relieving the loads on the main landing gear. If in CSS P, the DA² will mode to AUTO once the load relief flag is set. The elevator position will be based on a schedule which is a function of ground speed. CSS pitch can be regained by the "hot stick" method or pushing the CSS pitch PBI.

- Initiated by**
- 1 Main gear touchdown
or
 - 2 Placing ET SEP or SRB SEP switches to MAN and depressing appropriate dbi
- Pitch axis**
- 1 Flight director pitch rate commands generated as a function of θ , MGTD, EAS, and weight
 - 2 These pitch rate commands are converted into δ_e commands for auto control prior to roll out
- Roll axis** Auto balance computed for iterations, a function of TAS, N_y , and r
- Yaw axis** Opens rudder integration input

Touchdown discretes
WOW (actually WOW set false)
WOWLON
Flatturn

Figure 16-1.— Shuttle touchdown discretes.

- Initiated by**
- 1 Nosegear touchdown
or
 - 2 Pushing ET SEP or SRB SEP switches and pbis and
- All axes**
1. WOW/flatturn for 2 sec
 2. Theta less than 0° ($\theta < 0$)
- Turn-coord is set
- Pitch axis**
1. Open δ_e feedback (steady state $\delta_e = 0$)
 2. In auto (mode to AUTO if in CSS) steady state δ_e driven to load relief bias
- Roll axis**
1. In auto, δ_r trim integrator loop is opened (flatturn)
 2. Auto load balance CMD faded out over 100 sec
- Yaw axis** Nosewheel steering with nosewheel switch in GPC

Rollout discretes
WONG
Rollout
GSENB

Figure 16-2.— Shuttle rollout discretes.

The aileron trim integrator loop is opened at rollout and the auto load balance command is faded out over a period of 100 seconds.

NWS is functional in the yaw axis. There are three choices for the type of NWS available, and the choice is made with the positioning of the NWS switch on panel L2.

1. In the OFF position, no steering commands are accepted, the nosewheel simply casters. Steering is accomplished with rudder and differential braking.
2. In DIRECT, the steering is commanded manually using the rudder pedals to command the nosewheel angle.
3. With the switch in GPC, the steering can be either automatic or manually accomplished. The choice of automatic or manual is selected by pushing the roll/yaw PBI for AUTO R/Y or CSS R/Y.

Questions

1. State actions required in case one WOW discrete disagrees with the other WOW discrete for more than 7 seconds.
2. State how load relief is accomplished when landing in CSS P.

Answers

1. If WOW discretes differ from each other for more than 7 seconds, the crew must use the ET SEP or SRB SEP switch and PBI to set landing discretes.
2. If CSS P, the DAP will mode to AUTO once, the load relief flag is set. CSS Pitch can be regained by the "hot stick" method or pushing the CSS pitch PBI.

Section 17: GRTLS Differences

Objectives

At the end of this section, the student will be able to state the reason that there are differences between the nominal entry DAP and GRTLS DAP.

GRTLS Differences

The differences between the nominal entry DAP and the GRTLS DAP are listed in figure 17-1. A significant number of the differences are gain reductions in GRTLS as compared to the normal entry. These gain reductions are made to account for the heavier return weight, different angle of attack versus Mach number profiles, and higher anticipated dynamic pressures. In the pitch axis, the elevators are active for control immediately, and the turn compensation still is available only at the extended TAEM interface ($r \tan \phi$ at Mach 3.2). Also, the SPBK schedule is wholly contained in guidance during GRTLS. In GRTLS, the SPBK follows a guidance-computed algorithm to assist in pitch trim; the deflection algorithm probably will not change until after an abort has been flown.

Pitch axis

- CSS gain reduction on GTRE - gain scheduling elevator trim rate
- GJET trim not active
- δ_e active for control immediately
- $r \tan \phi$ term not active in phases: α recovery, N_z hold, α transition (i.e., prior to TAEM)
- Gain reduction on GOAL - gain converting auto α CMD to pitch rate error
- Body bending filter coefficients applicable for payload return

Yaw axis

- Gain reduction on GRAY - gain used to convert N_y error to yaw error

Roll axis

- Gain reduction on GDA - gain used to convert roll rate error to preliminary δ_a command, gain also made a function of angle attack

SPBK

- Commands scheduled in TAEM guidance

Body flap

- Elevon trim scheduled for heavy weight, payload return

Figure 17-1. – GRTLS FCS differences.

Questions

1. Why are there differences between nominal entry DAP and GRTL5 DAP?

Answers

1. The main reason for differences between entry DAP and GRTL5 DAP are gain reductions in GRTL5 compared to nominal entry. Gain reductions are made to account for heavier return weight, different angle of attack versus Mach number profiles, and higher anticipated dynamic pressures.

Appendix A: Acronyms and Abbreviations

A/L	approach and landing
ADI	attitude director indicator
ADS	air data system
ADTA	air data transducer assembly
AGL	above ground level
ALT	alternate
AOA	abort once around
APU	auxillary power unit
AUTO	automatic control mode
AUTO P	pitch axis in automatic mode
AUTO R/Y	roll/yaw axes in automatic mode
BF	body flap
BFS	backup flight system
c.g.	center of gravity
CRT	cathode ray tube
CSS	control stick steering
CSS P	pitch axis in control stick steering mode
CSS R/Y	roll/yaw axes in control stick steering mode
DAP	digital autopilot
DIRECT	direct position
DRAG ACTUAL	actual drag acceleration
DRAG REF	reference drag
DRPRM	compensated yaw rate feedback term in yaw channel
EDW	Edwards Airforce Base, CA
EI	entry interface
ENA	enable
ET	external tank
FCS	flight control system
FLATTURN	landing/rollout discrete
GALR	gain in roll channel
GNC	guidance, navigation, and control
GPC	general purpose computer
GRTLS	gliding return to launch site
GSENB L	ground speed enable

HAC	heading alignment cone
INH	inhibit
JSC	Lyndon B. Johnson Space Center
JSL	jet select logic
L/D	lift to drag
LGAIN	low gain
MM	major mode
MOD	Mission Operations Directorate
NOM	nominal
NWS	nosewheel steering
OPS	operations sequence
PASS	primary avionics software system
PBI	pushbutton indicator
PCOR	compensated roll rate feedback term in roll channel
PRL	priority rate limiting
psf	pounds per square foot
PTI	programmed test input
RCS	reaction control system
RGA	rate gyro assembly
RHC	rotational hand controller
RM	redundancy management
ROLLOUT	rollout discrete
RPTA	rudder pedal transducer assembly
RTLS	return to launch site
SEP	separation
SOP	subsystem operating program
SPBK	speedbrake
SPI	surface position indicator
SRB	solid rocket booster
TAEM	terminal area energy management
TAL	transoceanic abort landing
WONG	weight on nose gear
WOW	weight on wheels
WOWLON	weight on wheels locked on

Appendix B: Symbols

A_y	scaled lateral acceleration, g
b	wingspan, ft
C_A	axial force coefficient
C_L	rolling moment coefficient
$C_{L\beta}$	rolling moment coefficient due to sideslip angle
$C_{L\delta_a}$	rolling moment coefficient due to aileron
C_N	normal force coefficient
C_n	yawing moment coefficient
$C_{n\beta}$	yawing moment coefficient due to sideslip angle
$C_{n\delta_a}$	yawing moment coefficient due to aileron
g	acceleration due to gravity, ft/sec ²
H, h	altitude, ft
\dot{H}	altitude rate, ft/sec
L/D	lift to drag ratio
N_y	lateral acceleration, g
N_z	normal acceleration, g
$N_{z_{cmd}}$	commanded normal acceleration, g
$N_{z_{err}}$	difference between commanded and feedback normal accelerations, g
p, q, r	vehicle rotational rates, deg/sec (roll, pitch, yaw)
p_b, q_b, r_b	vehicle body axis rotational rates, deg/sec (roll, pitch, yaw)
p_s, q_s, r_s	vehicle stability axis rotational rates, deg/sec (roll, pitch, yaw)
p_{cmd}	commanded roll rate, deg/sec
p_{ss}	steady state roll rate, deg/sec
q_{cmd}	commanded pitch rate, deg/sec

\bar{q}	dynamic pressure, psf
R	range, nautical miles
r_{err}	difference between commanded and feedback yaw rates, deg/sec
R_{ref}	reference bank angle, deg
r_{ss}	steady state yaw rate, deg/sec
V	velocity, ft/sec
VR	relative velocity, ft/sec
x,y,z	principal axes
Δy	center of gravity offset in y axis, inches
α	angle of attack, deg
α_{cmd}	commanded angle of attack, deg
β	sideslip angle, deg
$\dot{\beta}$	rate of change of sideslip angle, deg/sec
δa	aileron angle, deg
δa_{trim}	trim aileron angle, deg
δe	elevator angle, deg
θ	pitch angle, deg
ϕ	bank angle, deg
Ψ, ω	vehicle heading angular rate, deg/sec

References

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2. **Flight Procedures Handbook, Entry; JSC-11542.** NASA-JSC, February 26, 1982.