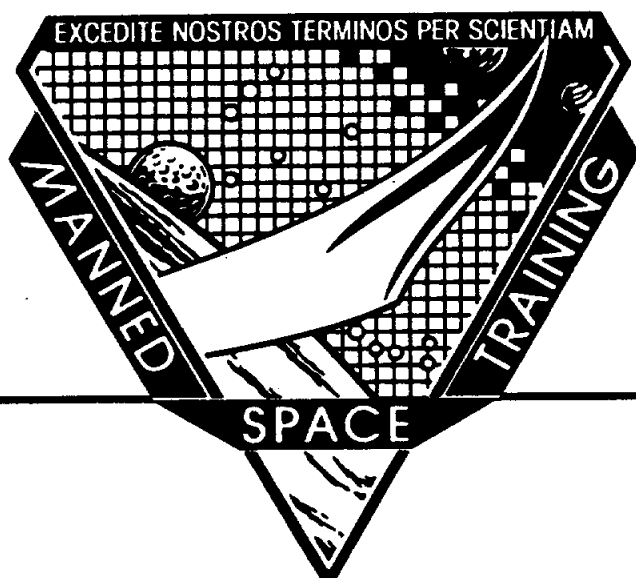


Navigation Aids

NAV AIDS 2102

Mission Operations Directorate

June 1991



NASA

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Navigation Aids

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Foreword

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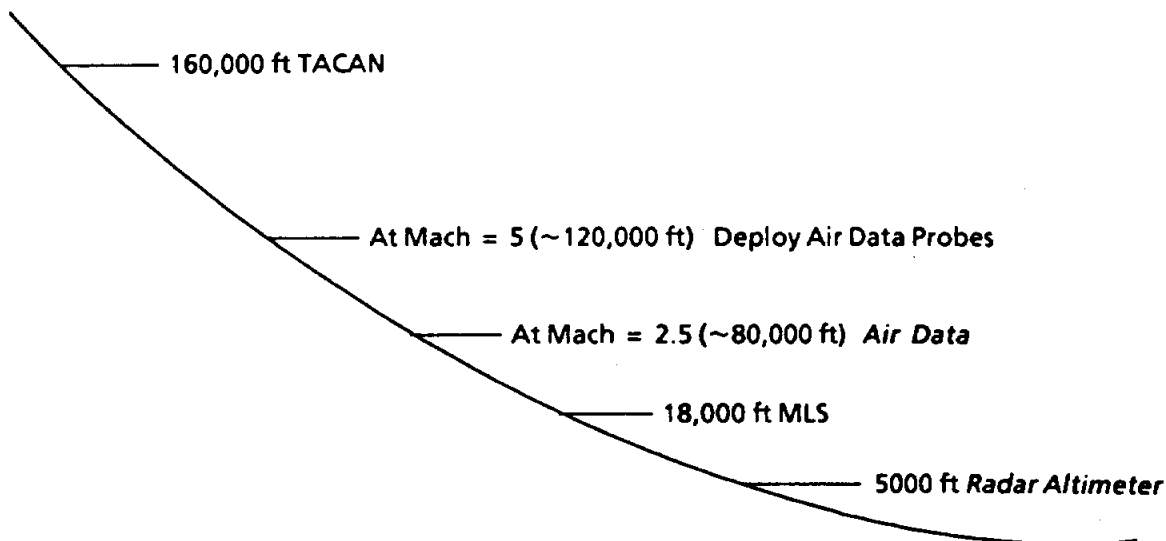
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Preface

The function of Navigation is to maintain an accurate estimate of the vehicle position and velocity. This estimate is called a *state vector*. The current state vector is mathematically determined from the previous state vector by integrating the equations of motion using accelerations of the vehicle. These accelerations are sensed by the Inertial Measurement Units (IMUs) and/or computed from the gravity and drag models. The alignment of the IMUs, and hence the accuracy of the resulting state vector, deteriorates as a function of time. Celestial navigation instruments are used to keep the IMUs aligned while in orbit. The accuracy of the IMU-derived state vector is, however, insufficient by itself for either guidance or the crew to bring the Orbiter to a pinpoint landing. Data from Entry Navigation Sensors (TACANs, ADTA, MLS, and RAs) are utilized by GPC navigation and/or the crew during the Entry phase to provide the necessary accuracy. The Air Data System (ADS 2102) workbook is dedicated exclusively to the Air Data Transducer Assembly (ADTA) Navigation Sensor. This workbook describes the operation of the TACANs, Microwave Landing System (MLS), and the Radar Altimeter (RA) Navigation Aids.

Typical Entry Flight Profile



Contents

Section	Page
Foreword	iii
Preface	iv
1 TACANS	1-1
Introduction	1-1
Performance Objectives	1-1
TACAN Ground Station Hardware and Operation	1-2
Orbiter-related Hardware	1-6
TACAN Crew Controls	1-7
TACAN CRT Displays	1-13
TACAN System Software	1-18
Redundancy Management (RM)	1-21
Selection Filter	1-28
Fault Detection, Identification, and Reconfiguration	1-30
TACAN Usage in Navigation	1-34
Launch Commit Criteria Requirements	1-41
BFS Differences	1-41
Questions	1-43
Answers	1-44
2 Microwave Landing System	2-1
Introduction	2-1
Performance Objectives	2-1
Microwave Landing System Operation	2-2
Microwave Landing System Crew Controls	2-8
Microwave Landing System CRT Displays	2-13
Orbiter Microwave Landing System Software	2-16
Microwave Landing System Usage in Navigation	2-21
Launch Commit Criteria Requirements	2-22
BFS Differences	2-22
Questions	2-23
Answers	2-24
3 Radar Altimeter	3-1
Introduction	3-1
Performance Objectives	3-1
Radar Altimeter Operation	3-1
Radar Altimeter Crew Control	3-2
Radar Altimeter CRT Displays	3-4
Radar Altimeter Software	3-7
Launch Commit Criteria Requirements	3-8
BFS Differences	3-8
Questions	3-9
Answers	3-10
Appendix	
A HSI and Waypoints	A-1
B Abbreviations and Acronyms	B-1

Tables

Table		Page
1-1	Landing site data chart from entry checklist	1-20
1-2	TACAN RM summary for PASS and BFS	1-33
2-1	Landing site data chart from entry checklist	2-3
2-2	MLS-GS/MLS-JR hardware	2-5
2-3	MLS FDIR RM limits	2-19

Figures

Figure		Page
1-1	TACAN output data	1-1
1-2A	Rotating omnidirectional signal with fixed reference	1-2
1-2B	Rotating antenna makes signal directionally sensitive	1-3
1-2C	Bearing determination	1-4
1-3	Orbiter's TACAN antenna locations	1-6
1-4	TACAN ac power	1-7
1-5	TACAN system controls	1-9
1-6	TACAN ID controls	1-10
1-7	HSI and HSI switch location	1-11
1-8	HSI	1-12
1-9	PASS and BFS GNC SYS SUMM 1 display	1-13
1-10	PASS and BFS GNC HORIZ SIT display	1-15
1-11	Sensor test SPEC 40	1-16
1-12	Sensor self-test SPEC 101	1-17
1-13	Redundancy management processing	1-21
1-14	Bearing cone of confusion	1-25
1-15	Forty degree bearing glitches	1-27
1-16	RM Fail TAC	1-31
1-17	RM DLMA TAC	1-32
1-18	Entry pocket checklist TACAN RM summary	1-34
1-19	NASA JSC Flight Rules	1-37
1-19	No COMM TACAN MGMT.	1-41
2-1	MLS beams and measurement geometry	2-2
2-2	MLS-GS major components	2-4
2-3	Orbiter MLS-related hardware and interfaces	2-6
2-4	MLS antenna locations on Orbiter	2-7
2-5	MLS power control	2-8
2-6	MLS channel select	2-9
2-7	Horizontal Situation Indicator and controls	2-10
2-8	Horizontal Situation Indicator	2-11
2-9	HUD display format 1 (approach and landing)	2-12
2-10	GNC system summary 1	2-13
2-11	Sensor test	2-14
2-12	Sensor self-test	2-15
2-13	Redundancy management processing	2-17
3-1	RA antenna location	3-1
3-2	RA power control	3-2
3-3	AVVI/RA select	3-3
3-4	On-orbit sensor self-test	3-5
3-5	Sensor self-test	3-6
3-6	HUD display with radar altimeter	3-7
A-1	ENTRY display mode	A-2
A-2	TAEM display mode	A-4
A-3	A/L display mode	A-6

Section 1: TACANS

Introduction

The Orbiter contains three airborne Tactical Air Navigation (TACAN) units operating in a triply-redundant mode. The TACAN is a military L-band air navigation system that determines slant range and magnetic bearing of the Orbiter with respect to a ground station (figure 1-1). The TACAN range and bearing data are used to update and increase the accuracy of the Navigation State Vector during the Entry and Terminal Area Energy Management (TAEM) flight phases, from an altitude of approximately 160,000 feet until MLS acquisition or until 1500 feet if the MLS is not available.

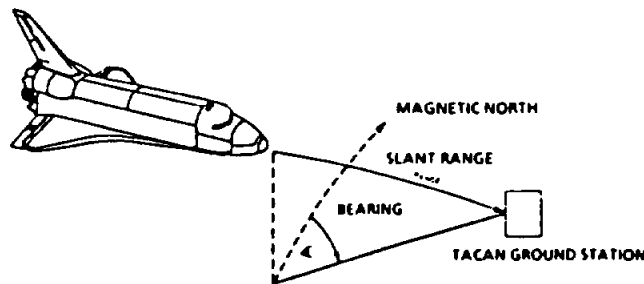


Figure 1-1.– TACAN output data.

Performance Objectives

As a result of studying this section, the student should be able to do the following:

- Describe which two parameters TACAN provides to Navigation
- State when TACAN data is used
- Describe how a TACAN station operates
- State the source of power for the old and new TACANS and where their cbs are located
- Describe the operating modes of the onboard TACAN system
- Describe how the crew can solve TACAN DLMA's
- List two basic functions TACAN RM performs
- List the RM limits for each TACAN parameter
- Describe the TACAN range and bearing two-lock requirement
- Describe the no COMM TACAN MGMT cue card

TACAN Ground Station Hardware and Operation

The ground equipment consists of a rotating antenna for transmitting bearing information and a receiver-transmitter for transmitting distance (range) information. Permanent TACAN ground stations usually contain dual-transmitters with automatic switchover capability.

Bearing

Bearing measurements are obtained from pulsed signals transmitted by a rotating omnidirectional antenna from the central element of the ground station. This omnidirectional signal has a fixed reference that is embedded within the signal that identifies the start of each cycle (East reference). This fixed reference pulse is normally referred to as the Main Reference Bearing Pulse. This omnidirectional signal may be thought of as a song on a record. This record has only one groove so the needle of the turntable will continually play the same phrase over and over much like a record does when it skips. The beginning of the song is the main reference bearing pulse and the sound is omnidirectional. See figure 1-2A.

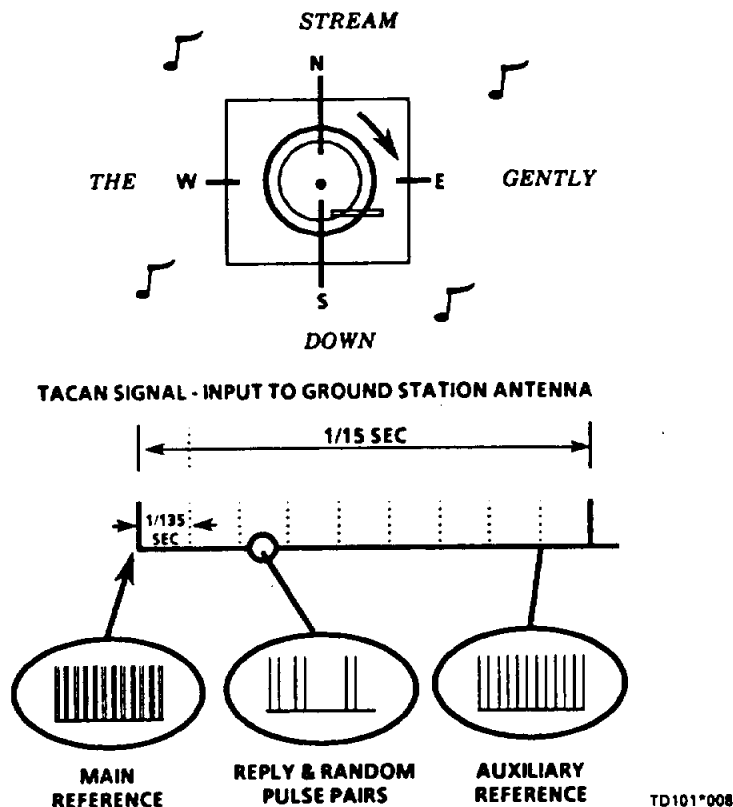


Figure 1-2A.—Rotating omnidirectional signal with fixed reference.

This omnidirectional signal is made into a directionally sensitive signal pattern by rotating a cylinder around the central element of the antenna at 15 revolutions per second (rps). A metal wire embedded vertically in the plastic cylinder distorts the radiated signal into a cardioid (heart-shaped) pattern, and the cylinder's rotation causes the cardioid pattern to also revolve at 15 rps. The rotating cylinder can be thought of as a sound shield (muffler) rotating around a turntable, or as a light shade rotating around a lighthouse beacon. With this mechanism the Orbiter receives a 15 cycle per second (cps) amplitude modulation signal. This means that the strength of the signal goes from maximum to minimum and back to a maximum at the rate of 15 cps. As the cardioid forming antenna rotates around the center omnidirectional signal, the Orbiter will receive the strongest signal strength when the bottom of the cardioid is pointing toward the Orbiter and the weakest signal when the top of the cardioid is pointing toward the Orbiter. See figure 1-2B.

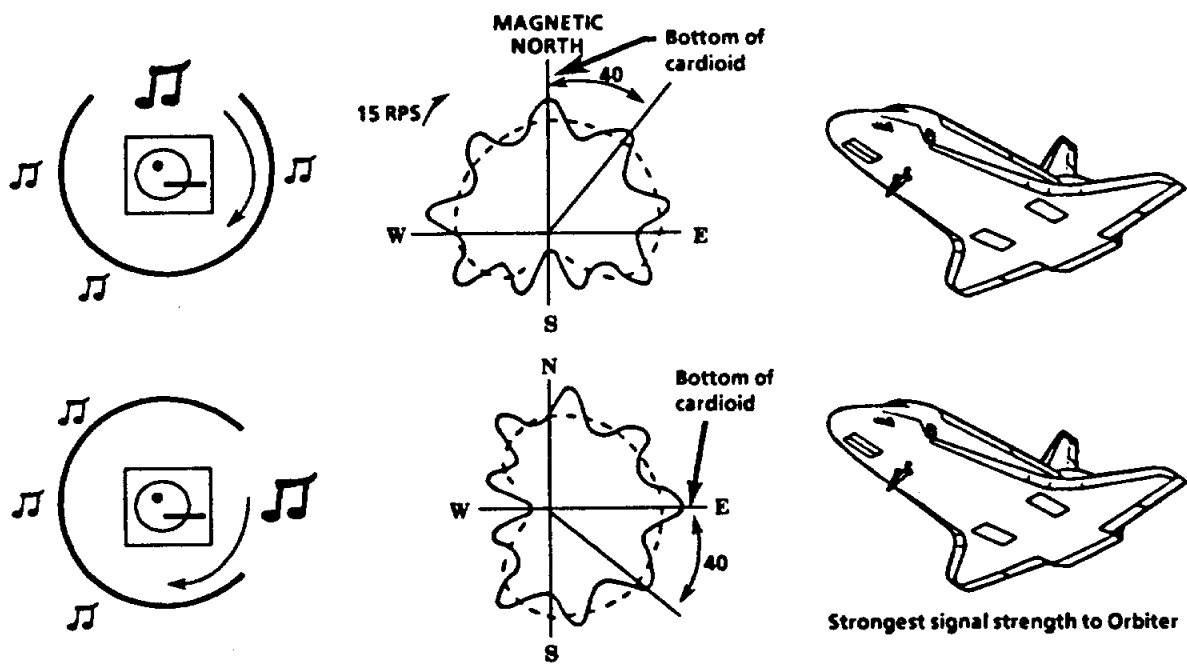


Figure 1-2B.—Rotating antenna makes signal directionally sensitive.

Another larger cylinder, with 9 wires in it, is mounted around the central element and also rotates at 15 rps. This is the fine antenna which superimposes nine lobes on the previously formed cardioid pattern. This forms a 135 cps signal (9 lobes or cycles x 15 rps).

To determine the Orbiter's position in bearing from the station, a phase angle must be electronically measured from a fixed reference. This fixed reference pulse, normally referred to as the Main Reference Bearing Pulse, is used to identify the start of each cycle which points in the East direction. One Main Reference Pulse occurs with each revolution of the antenna. In addition to the Main Reference Pulse, 8 auxiliary reference pulses also occur during 1 revolution of the ground antenna. Therefore, a reference pulse occurs each 40 degrees of antenna rotation (360 deg/9 pulses). See figure 1-2C.

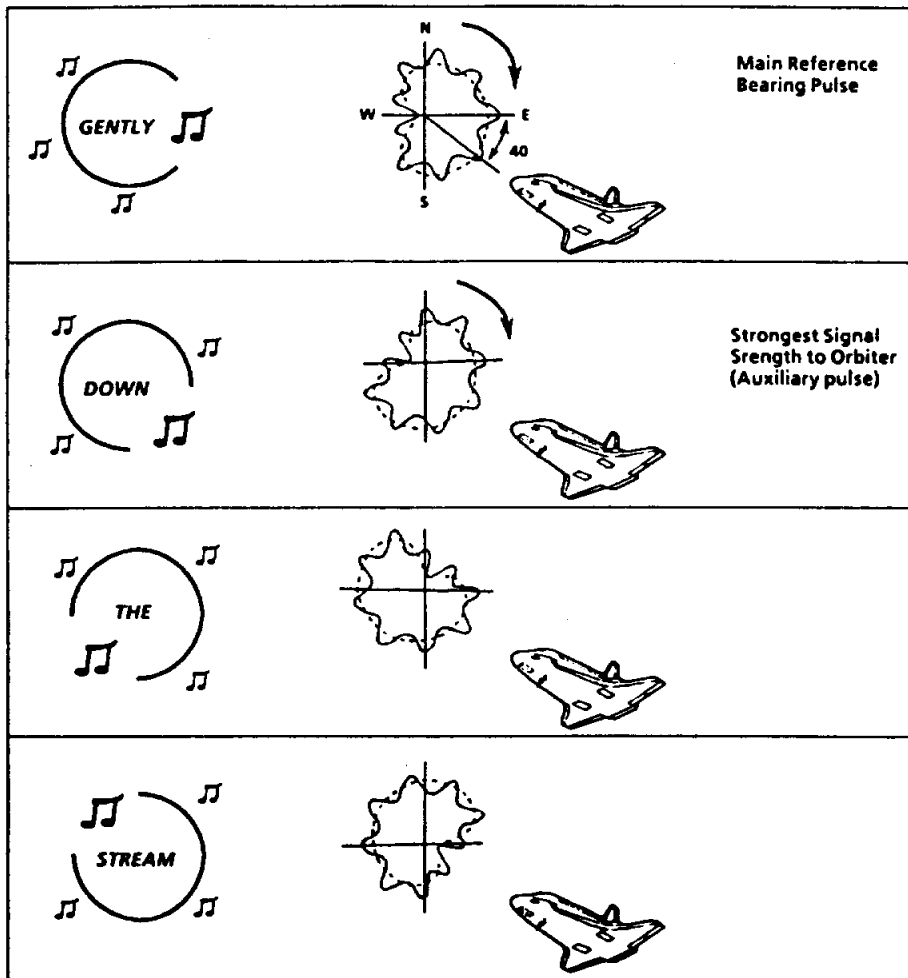


Figure 1-2C.- Bearing determination.

Bearing is determined by electronically measuring the time lapse between the start of the main reference pulse (East reference) and the strongest signal received from an auxiliary reference pulse (recall that the auxiliary pulse that is pointing in the direction of the Orbiter will give the strongest signal strength). This determines the Orbiter's bearing from the station within a 40 degree sector. Then, the time lapse between the measured amplitude of auxiliary reference pulse and the maximum amplitude of the auxiliary (135 cps) signal is used to determine the Orbiter's position within the 40 degree sector.

Range

Range (RNG) or distance is determined by measuring the time difference between transmission of pulses from the airborne TACAN unit to the ground station and reception of the reply pulses from the ground station back to the airborne unit. The Orbiter transmitter starts the process by sending out the distance interrogation pulse signals. Reception of these signals by the ground station receiver triggers its transmitter to send out the distance reply pulse signals. Since a large number of aircraft could be interrogating the same TACAN station as the Orbiter, the airborne TACAN unit must sort out only the pulses which are replies to its own interrogations. Interrogation pulses are transmitted on an irregular, random basis by the airborne TACAN unit which then "searches" for replies which are synchronized to its own interrogations.

Orbiter-Related Hardware

Onboard the Orbiter is the receiver/transmitter portion of the TACAN system. Three identical units are located in the forward avionics bays. Each TACAN unit is equipped with two antennas located on the upper and lower side of the Orbiter nose area (figure 1-3). Each unit requires 115 volts AC power which is supplied through AC 1, 2, and 3 phase C for TACAN 1, 2, and 3, respectively. Essential Bus power from 1BC, 2CA, and 3AB is also utilized by TACANs 1, 2, and 3, respectively, to power the Auto Self-Test discrete which enables the TACANS to do an automatic self-test when commanded by the general purpose computers (GPCs). NOTE: The new TACANs which are slowly replacing the old TACANs, starting with Endeavor will be powered by MNA, MNB, and MNC to supply TACAN 1, 2, and 3, respectively.

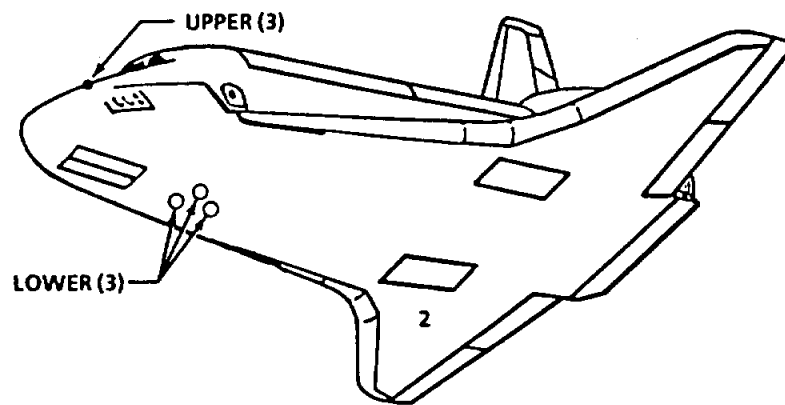


Figure 1-3.- Orbiter's TACAN antenna locations.

Range and bearing data for each TACAN is transmitted to and from the GPCs over the flight critical (FC) data buses to the flight forward (FF) multiplexer/demultiplexers (MDMs). TACAN 1, 2, and 3 data is routed through FF MDM's 1, 2, and 3, respectively. Data flow between the TACAN and the MDM is controlled by a special dedicated TACAN/Radar Altimeter Input/Output Module (TAC/RA IOM) in the MDM (this scheme was implemented to accommodate off-the-shelf TACAN and RA equipment). The module interfaces with the TACAN control panel, the TACAN, and the Radar Altimeter. If this module fails a BCE STRG X TAC fault message will be annunciated. This will inhibit TACAN and RA data inputs from that MDM to the GPCs.

NOTE: A useful point to remember is that because the TACANs and RAs are connected to this special IOM in the MDM, no I/O RESET is needed when these units are powered ON. The GPCs will automatically upmode the TACANs and RAs when power is seen. Also when these units are powered OFF, no message is annunciated. The only cause of the BCE STRG X TAC fault message is when the special IOM fails in the MDM. TACANs and RAs are the only Line Replaceable Units (LRUs) that operate in this manner.

TACAN Crew Controls

The onboard TACANs receive power from AC 1, 2 and 3 phase C through circuit breakers (cb) on panels L4 (figure 1-4). NOTE: The new TACANs which are slowly replacing the old TACANs, starting with Endeavor, will be dc powered by MNA, MNB, and MNC. The dc cb will be on PNL 014, 015, and 016 for TACAN 1, 2, and 3, respectively. When the cbs are closed, power is applied to the TACANs Control Head switches on panel O7.

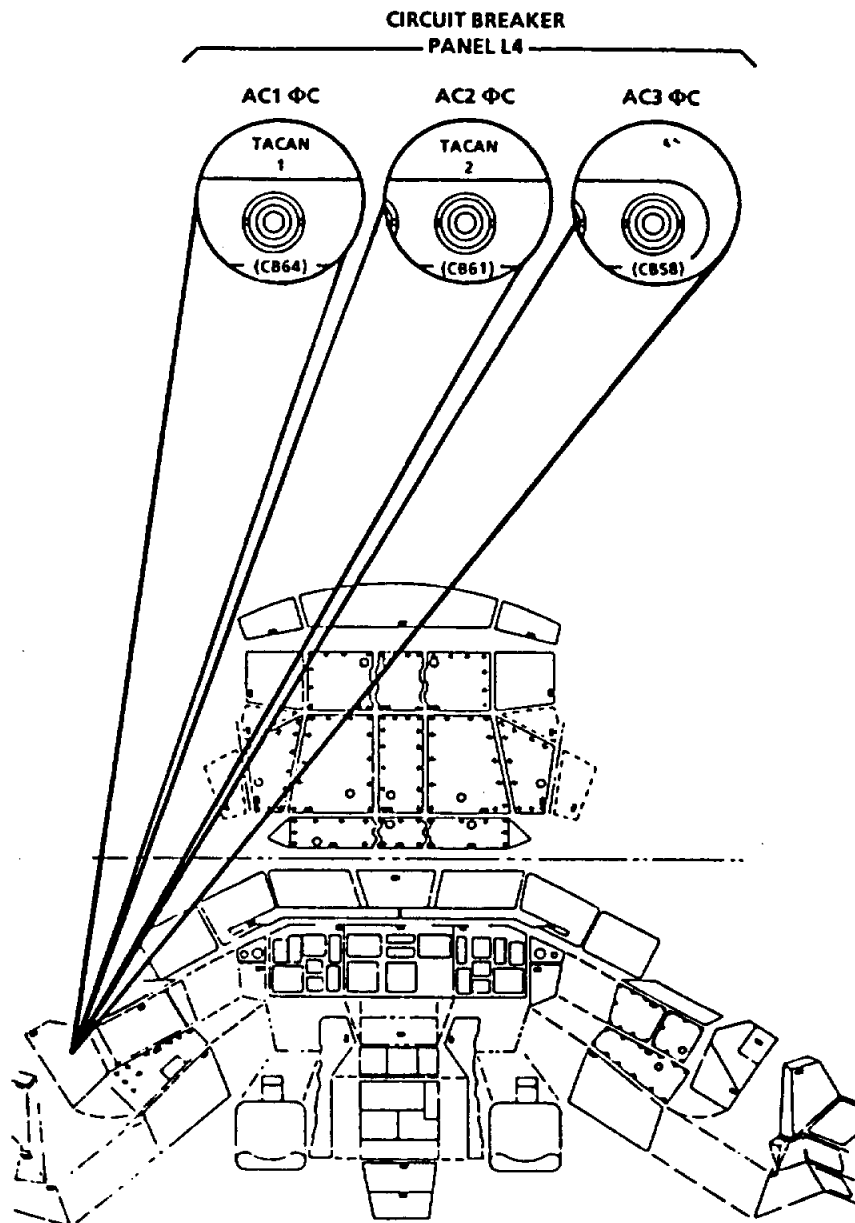


Figure 1-4.- TACAN ac power.

Ultimate control of each TACAN is through its associated control panel (figure 1-5). Three identical yet independent control heads are mounted side-by-side. Each controls the MODE, CHANNEL, and ANTENNA of its respective TACAN. Mounted on each control head is a four-position rotary MODE switch which controls the operational mode of the TACAN. The four positions are:

- OFF - no power to TACAN
- RCV (receive) - only bearing data processed by the hardware. (This mode is not currently used in Orbiter operations)
- T/R (transmit/receive) - both bearing and range are processed in this mode. Channel selection is manually accomplished by selecting a channel on the thumbwheels.
- GPC - both bearing and range are processed in this mode. Channel selection is controlled automatically by guidance, navigation, and control (GNC) software. GPC-commanded self-test is supported in this mode for PASS only.

Each control head also has a set of three thumbwheel switches for selecting TACANS CHANNEL, numbers 1 through 126. There is a fourth thumbwheel which determines the mode of the ground station (X or Y). This essentially doubles the available frequencies which can be accessed from 126 to 252. The channel is manually selectable from the control head when in the T/R mode or automatically selectable through the GNC software when in the GPC mode.

Control of the TACAN upper and lower antennas is through the ANT SEL (antenna select) switch mounted on each control head. This is a three-position switch:

- UPPER - upper antenna is selected.
- AUTO - the antennas are controlled by the GPCs, allowing it to automatically select the best antenna based on signal strength. This function is independent of the TACAN mode switch.
- LOWER - lower antenna is selected.

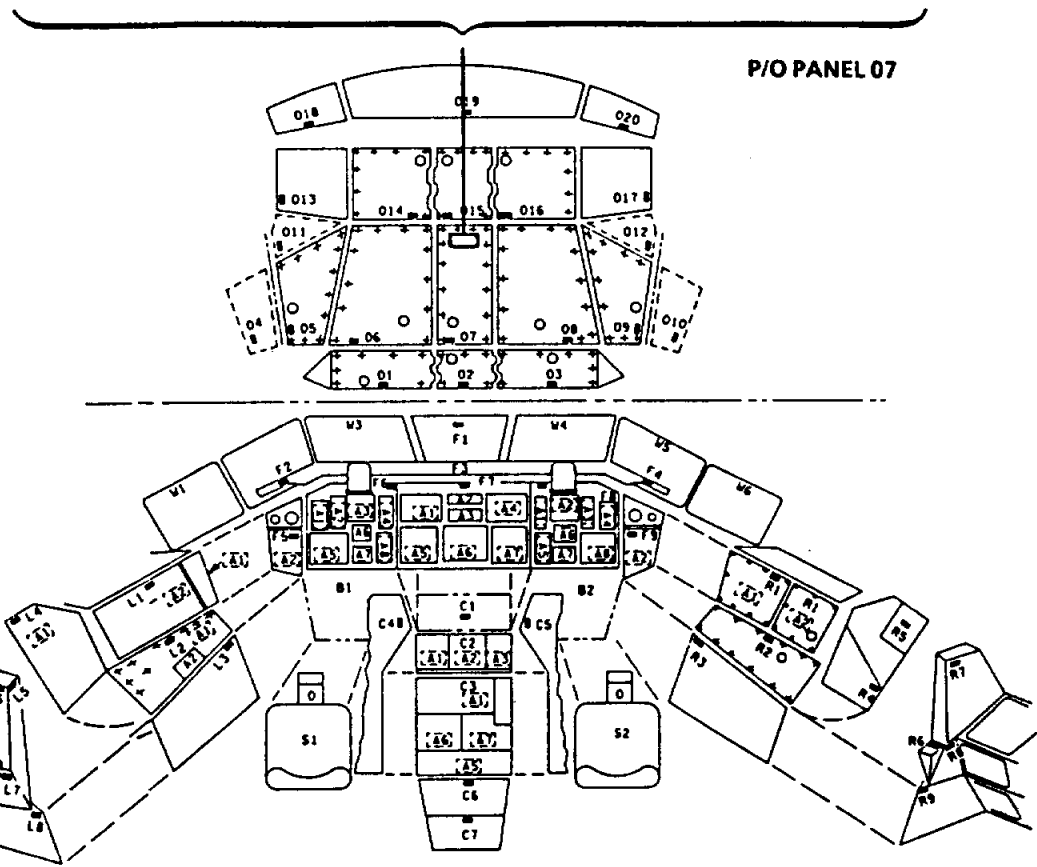
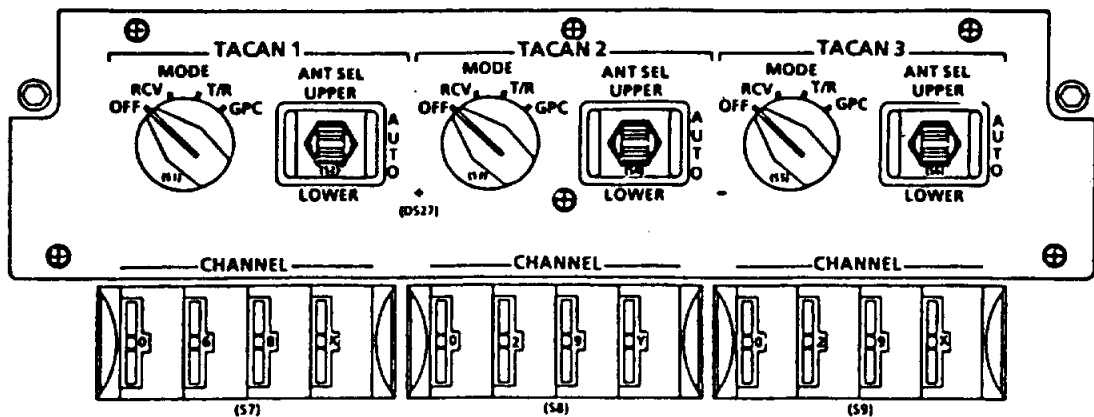


Figure 1-5.- TACAN system controls.

The TACAN ID switches are found on panel O5 and O9, for the commander and pilot, respectively (figure 1-6). By selecting the TACAN ID switch to ON, any one of the three TACANs can be monitored to verify proper station acquisition. The TACAN station produces a tone that consists of a three-letter Morse Code signal that identifies the station. Also found on panel O5/O9 is the TACAN volume thumbwheel which controls the volume of the audio tone. In practice, the crew does not use this feature for a nominal landing; however, it could be necessary during a contingency deorbit.

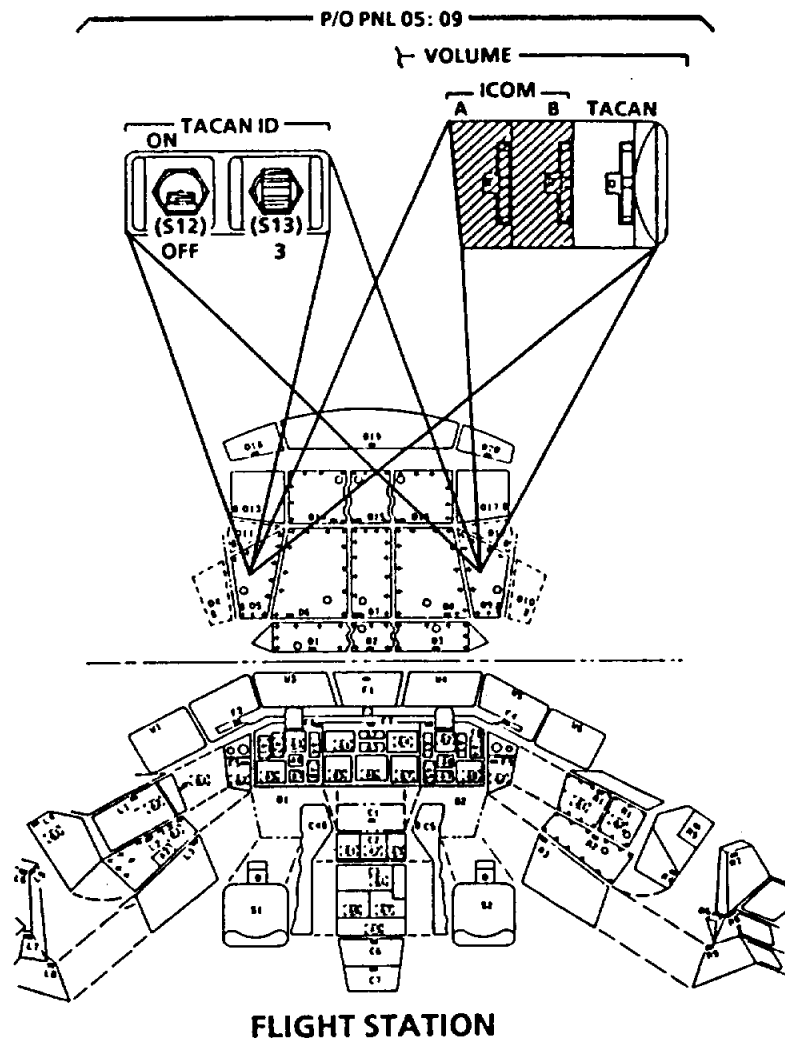


Figure 1-6.- TACAN ID controls.

The horizontal situation indicator (HSI) SELECT switches, which are located on panels F6 and F8 (figure 1-7), control the data input to the HSIs. The MODE switch provides a signal to the GPCs which select data to display for the Entry, TAEM, or Approach phase of flight (if the Entry mode is selected, the HSI will automatically display the data for Entry, TAEM, and Approach phases of flight). When the SOURCE switch is set to TACAN, the HSI will display area navigation data calculated using raw TACAN data from one of the three onboard TACAN units, as selected on the adjacent toggle switch. When the SOURCE switch is set to NAV, the HSI will display data from GPC navigation.

NOTE: Each TACAN unit can be compared to NAV using the HSI SOURCE switches. This is one available tool that the crew can use to solve TACAN dilemmas. Also the crew can select TACAN data on the HSI and use it for a guidance source (cues for manual flying) when they have determined that the onboard GPC navigation is bad and the Orbiter must be flown manually.

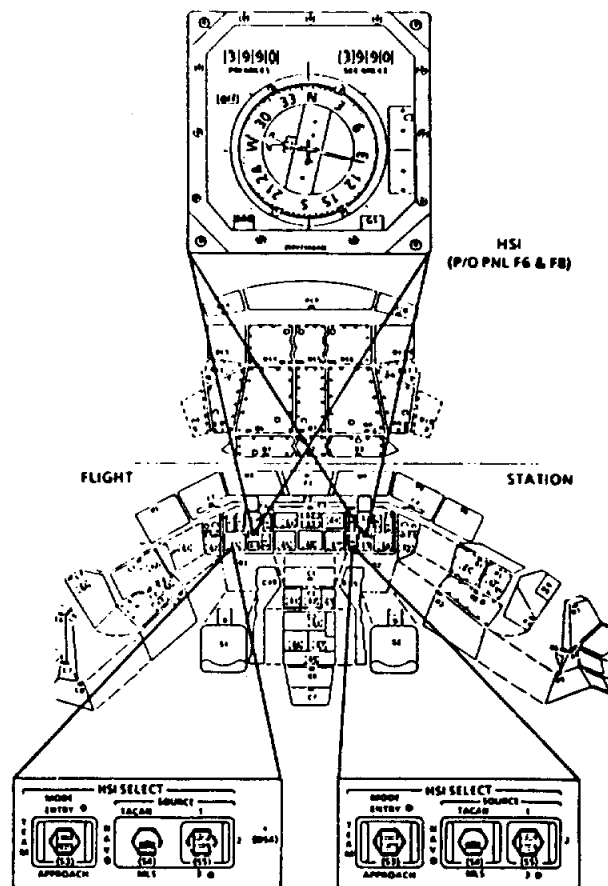


Figure 1-7.- HSI and HSI switch location.

Raw TACAN data or TACAN-derived GPC navigation is presented to the crew on the HSI (depending on the position of the source switch). The course deviation indicator (CDI) is displaced from the center of the HSI by TACAN azimuth data. A displacement of the bar toward the dots on the right tells crewmen to fly toward the right. Corrections are always made by flying in the direction of displacement. Range information is displayed in the upper left and right corners. This range is the distance to the primary and secondary waypoints (guidance's points along the entry trajectory) respectively. See figure 1-8 and Appendix A for more information concerning HSI and waypoints.

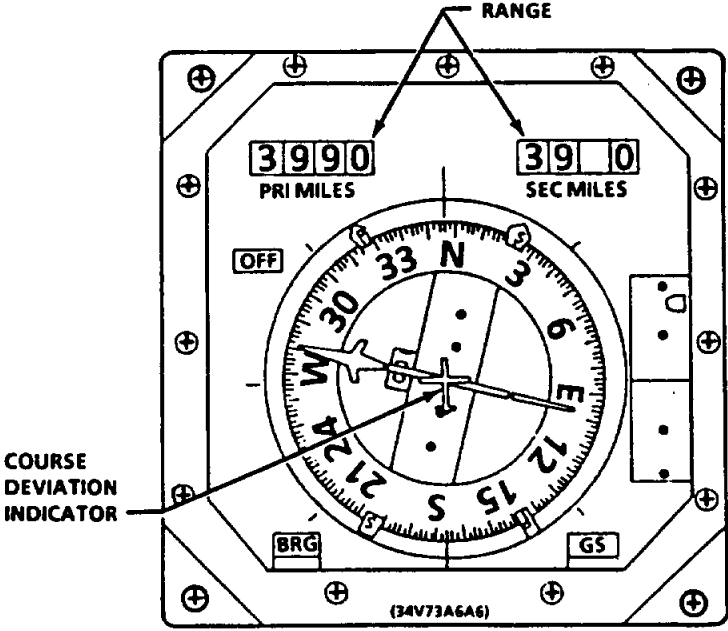


Figure 1-8.- HSI.

TACAN CRT Displays

TACAN information is displayed on four CRT displays: GNC SYS SUMM 1 in OPS 3 and 6, HORIZONTAL SITUATION DISPLAY (HSD) in OPS 3 and 6, SENSOR TEST in OPS 8, and SENSOR SELF-TEST in OPS 9.

The SYS SUMM display (figure 1-9) provides overall monitoring of the GNC systems and supports the GNC caution and warning (C&W) system. This display is available in OPS 3 and 6 in both Primary Avionics Software System (PASS) and Backup Flight System (BFS) by using the SYS SUMM key or by SPEC 18 PRO. The lower right corner of the display shows the status of the NAV systems, including the TACANs. The status columns for each unit may show blank (system OK), a down arrow (unit downmoded), "M" (data missing due to commfault or loss of lock), or "?" (dilemma) in PASS (BFS status indications are slightly different; see figure 1-9). GNC SYS SUMM 1 is a display only with no interactive command capability.

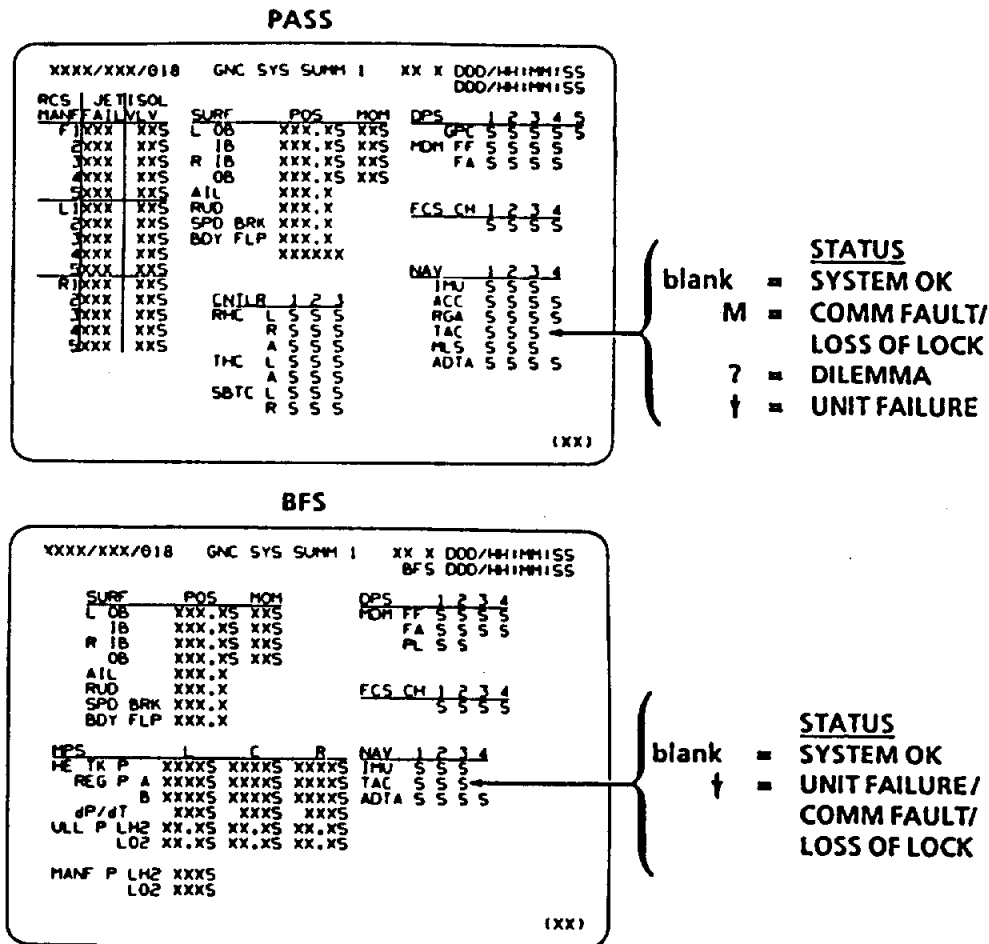


Figure 1-9.—PASS and BFS GNC SYS SUMM 1 display.

The Horizontal Situation Display (SPEC 50) allows control and assessment of the navigation filter performance as well as the three TACANs (figure 1-10). A "TAC AZ" and a "TAC RNG" row are identified on the bottom left of SPEC 50 and extends across the display. NOTE: The BEARING is incorrectly labeled as AZIMUTH (AZ) and to prevent confusion "Azimuth" will be used to refer to Bearing.

The TACAN data presented in the lower right corner of the display represents actual slant range and magnetic bearing of each airborne unit to the TACAN ground station if ABS (ITEM 34) is selected. If DELTA (item 35) is selected, the difference between the airborne TACAN-measured data and the navigation-derived data is displayed (BFS supports only ABS mode). The bearing or azimuth parameters are in degrees and the range parameters are in thousands of feet.

The TACAN ground station channel that TACANs 1, 2, and 3 are locked onto is also displayed in the lower right corner. A status is provided for the Bearing (AZ) and Range (RNG) for each TACAN, the same status legend used on GNC SYS SUMM 1 applies. ITEMS 31-33 allow a failed TACAN to be deselected/reselected. The word "TEST" is displayed if the self-test is being conducted (PASS only).

The navigation filter displays and controls for TACANs azimuth and range are provided in the lower left of SPEC 50. For each parameter, the output from its Selection Filter minus the composite NAV state vector estimate of that data forms the residual (RESID). The ratio (RATIO) of actual residual to the maximum allowable residual is displayed in the RATIO column.

ITEM 19 (AUT) is used to allow navigation to automatically select data to be used if it passes the Ratio Edit Test. If the RATIO is greater than one for three consecutive NAV cycles, the Ratio Edit Test fails. A status column to the right of the RATIO column contains a down arrow when the parameter has failed the Ratio Edit Test. ITEM 20 (INH) inhibits the incorporation of TACAN data into the state vector (the display is initialized in this position). ITEM 21 (FOR) will bypass the Ratio Edit Test and force the NAV filter to use TACAN data regardless of the Ratio. NOTE: If TACAN data is being FORCED, MLS data will not be incorporated into NAV. TACANs must be in INH or AUT for MLS data to be incorporated into NAV (PASS only).

SPEC 50 also provides the capability to select either of two TACAN stations associated with a selected landing area by toggling ITEM 5. When a landing site is selected through ITEM 41, the primary TACAN station is automatically selected. The selected station ID is displayed next to ITEM 5. Selection of the primary or secondary runway at a landing site (ITEMs 3 and 4) does not affect the selected TACAN station. The TACAN mode switch on panel 07 must be in the GPC position in order for ITEM 5 to actually change the station. If the mode switch is in any other position, the airborne TACAN unit will be tuned to the channel selected on the TACAN channel thumbwheels, regardless of the station or channel selected by ITEM 5 on SPEC 50.

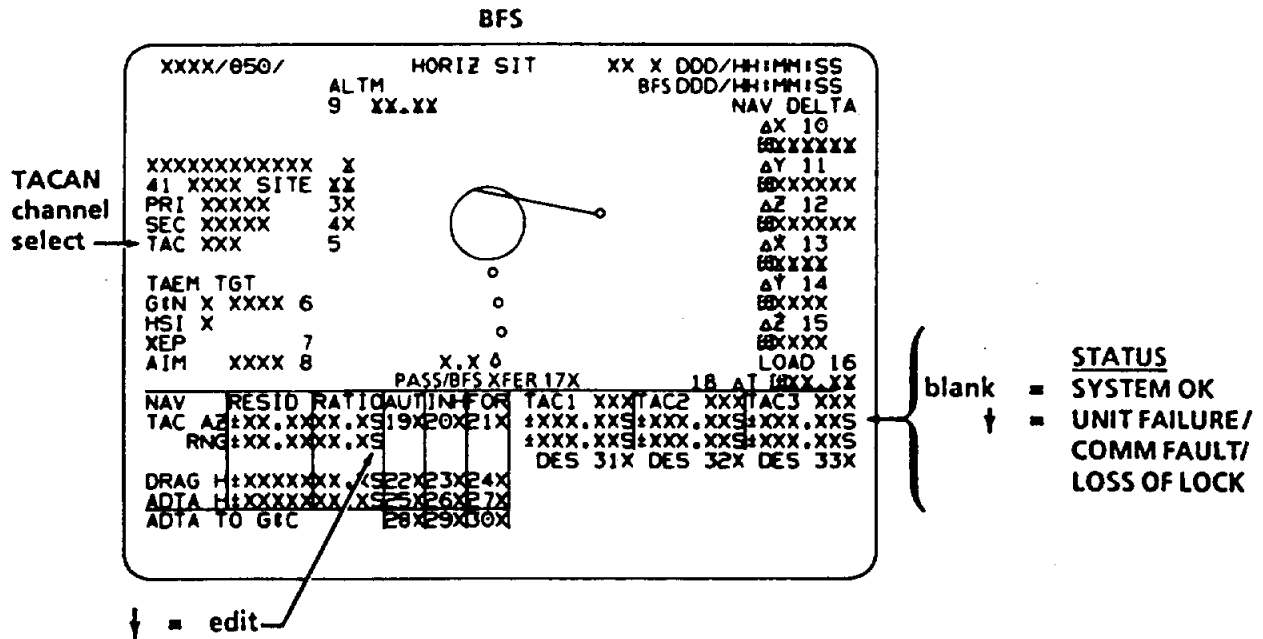
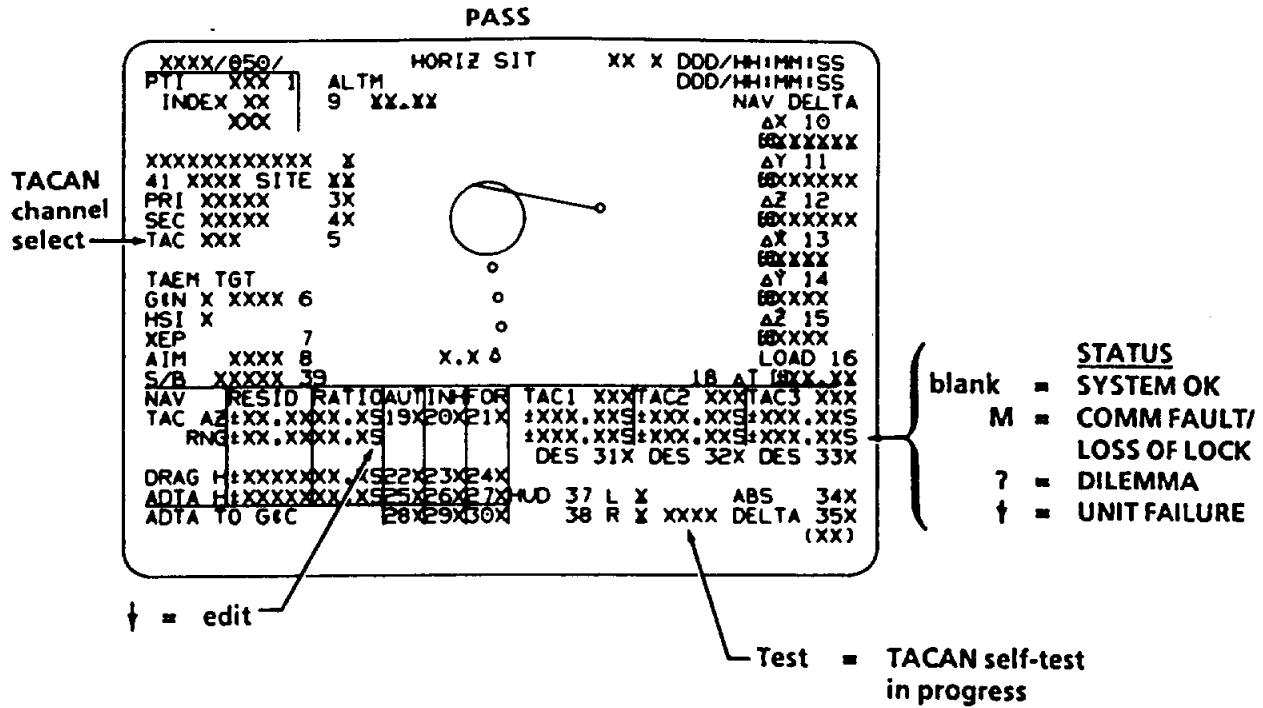


Figure 1-10.—PASS and BFS GNC HORIZ SIT display.

The SENSOR TEST display (figure 1-11), which is available in OPS 8 and can be called up through SPEC 40 PRO, provides a means of initiating, monitoring, and terminating the self-test of the TACANs (BFS does not support OPS 8). It also provides control of the Selection Filter.

Execution of a DES (ITEM 4, 5, or 6) changes the status of that Candidate's availability to the Selection Filter. An "*" appears next to the item number if the corresponding unit is deselected as a Candidate. The Selection Filter configuration from this display is carried over into OPS 3.

RNG in nautical miles and AZ in degrees are displayed for each TACAN. These values are compared to the self-test limits and a status indicator is displayed beside each test parameter indicating the results of the tolerance check. The self-test controls are shown at the bottom of the display. Execution of ITEM 13 starts the self-test on all the displayed sensors. Execution of ITEM 14 stops the self-tests. An "*" appears next to ITEMS 13 or 14 to indicate, respectively, test underway or test stopped. Items 13 and 14 are initialized blank.

XXXX/040/		SENSOR TEST				XX X	DDD/HH:MM:SS	DDD/HH:MM:SS
		DES	STAT	RNG	AZ	EL		
MLS	1	1X	XXXX	XX.XS	±X.XXS	X.XXS		
	2	2X	XXXX	XX.XS	±X.XXS	X.XXS		
	3	3X	XXXX	XX.XS	±X.XXS	X.XXS		
		DES	STAT	RNG	AZ			
TAC	1	4X	XXXX	X.XS	XXX.XXS			
	2	5X	XXXX	X.XS	XXX.XXS			
	3	6X	XXXX	X.XS	XXX.XXS			
		DES	STAT	ALT				
RA	1	7X	XXXX	XXXXXS				
	2	8X	XXXX	XXXXXS				
		DES		Y	Z			
AA	1	9X		±XX.XS	±XX.XS			
	2	10X		±XX.XS	±XX.XS			
	3	11X		±XX.XS	±XX.XS			
	4	12X		±XX.XS	±XX.XS			
		START 13X		STOP 14X				
								(XX)

Figure 1-11.— Sensor test SPEC 40.

The SENSOR SELF-TEST display is available in OPS 9 through SPEC 101 PRO for pre-flight and postlanding checkout of the TACANs (figure 1-12). It is the ground test equivalent of the on-orbit SENSOR TEST (SPEC 40). BFS does not support OPS 9.

```

XXXX/101/      SENSOR SELF-TEST  XX X DDD/HH:MM:SS
                                   DDD/HH:MM:SS

  ENA  STAT  RNG   AZ   EL
M1  1X  XXXX  XX.XS ±X.XXS X.XXS
L2  2X  XXXX  XX.XS ±X.XXS X.XXS
S3  3X  XXXX  XX.XS ±X.XXS X.XXS

  ENA  STAT  RNG   AZ
T1  4X  XXXX  X.XS  XXX.XXS
A2  5X  XXXX  X.XS  XXX.XXS
C3  6X  XXXX  X.XS  XXX.XXS

  ENA  STAT  ALT
R1  7X  XXXX  XXXXS
A2  8X  XXXX  XXXXS

  ENA          Y      Z
A1  9X        ±XX.XS ±XX.XS
A2 10X        ±XX.XS ±XX.XS
  3 11X        ±XX.XS ±XX.XS
  4 12X        ±XX.XS ±XX.XS

TEST CONTROL:
START          13X
AUTO SEQ      14X
TERM          15X

INH ALL 16X

(X)

```

Figure 1-12.— Sensor self-test SPEC 101.

Five possible TACAN-related fault messages can be generated by the GPCs and displayed on the CRTs:

- "RM FAIL TAC" - Range or bearing parameter failure based upon two out of three comparison at the three level for PASS only (see RM for more details).
- "RM DLMA TAC" - Data from two TACANs differ beyond the FDIR threshold and RM is unable to resolve the discrepancy. Automatic self-test at the two level tries to resolve a dilemma if both TACAN units have the GPC mode selected (see RM for more details). This applies to PASS only.
- "NAV EDIT TAC" - Annunciated below 140 kft when TACAN data is not incorporated into NAV after 7 NAV cycles (approx. 30 sec.). This applies to PASS only.
- "NAV EDIT" - TACAN range or bearing ratio > 1 for three consecutive NAV cycles (BFS only).
- "BCE STRG X TAC" - Within the MDM is a special Input/Output Module or "card" which is dedicated to RAs and TACANs. If this module fails, a BCE STRG X TAC fault message will be annunciated. This will inhibit TACAN and RA data inputs from that MDM to the GPCs. NOTE: there is no commfault annunciation for TACANs other than an "M" in PASS or a down arrow in BFS on GNC SYS SUMM and SPEC 50 unless the card is loss. Also no I/O Reset is required when powered ON.

TACAN System Software

The TACAN Subsystem Operating Program (SOP) is one of many program modules contained in the GPC's main memory. It is active during entry Major Mode (MM) 304-305 and during RTLS aborts in MM 602-603, in both the PASS and BFS. The TACAN SOP contains the software associated with TACAN range and bearing data processing, auto channel command processing, upper/lower antenna selection, and Redundancy Management processing.

Slant range measurements are obtained through pulsed transmissions from both the TACAN and the ground station. The onboard unit starts the process by transmitting a signal to the ground station. The station detects the signals and transmits a signal back to the onboard TACAN unit. Range is calculated from the round-trip travel time of the signal between the TACAN and the ground station.

Bearing measurements are obtained from pulsed signals transmitted by a rotating directional antenna system at the ground station. This rotating antenna system produces a pattern of pulses which goes from a maximum to a minimum and back to a maximum at a fixed rate (remember the lighthouse beacon and light shade analogy). Embedded within this signal pattern is a main reference pulse to identify the start of each cycle which is the East reference. Eight auxiliary reference pulses spaced 40 degrees apart are also present in the signal pattern. Bearing is determined by electronically measuring the time between the main reference pulse (East reference) and the strongest auxiliary reference pulse (auxiliary pulse that is pointing in the direction of the Orbiter will give the strongest signal strength).

A table of available landing sites and their associated TACAN stations is maintained by the GPC in the OPS (operational sequence) 1/6 - ascent/RTLS and OPS 3 - entry software. This table is formatted based on an area concept. An area is defined as any potential landing site. Associated with each area are two runways (primary and secondary), two MLS stations (if existing), and two TACAN stations. Table 1-1 shows a typical list of available landing areas and their associated primary and secondary channel ID's from the Entry Checklist. A maximum of 15 areas have been allocated for OPS 3. This includes landing sites for a transoceanic abort landing (TAL), abort once around (AOA), and the nominal end of mission (EOM). In OPS 1/6 (RTLS) there are only five areas allocated.

If the antenna switch on Panel 07 is manually placed in either UPPER or LOWER, the corresponding antenna will be selected. If the switch is in AUTO, the GPC will control antenna selection.

Each TACAN unit has an internal self-test feature whereby the range and bearing circuits can be exercised independently (PASS only). However, an external self-test command is required to initiate the test. This command may be generated automatically by TACAN Redundancy Management (RM) in response to data miscomparisons at the 2-level in OPS 3 and 6 or manually from the keyboard in OPS 8 and 9. In both cases, the mode switches on panel 07 must be in GPC to execute the self-test.

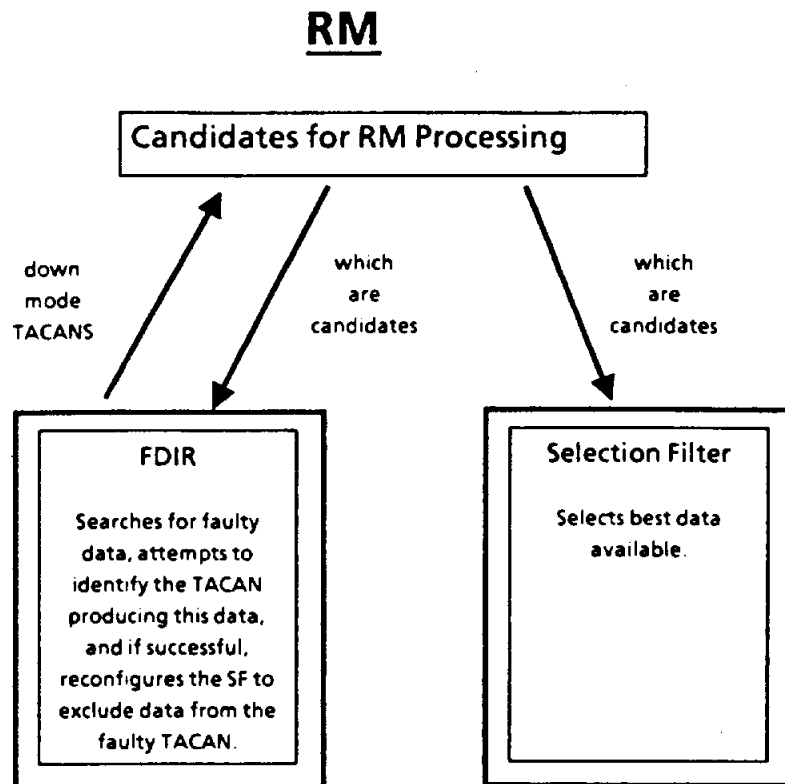
Table 1-1.- Landing site data chart from entry checklist.

**LAND SITE DATA CHART
ETR Low Inclination
(OPS 3)**

SITE	LOCATION	RWY	TACANS		MLS CH	LENGTH
			(PRI)	(SEC)		
1	KSC	KSC 15 KSC 33	TTS 59Y TTS 59Y	COF 97 COF 97	8 6	15000 15000
2	BEN GUERIR	BEN 36 BEN 18	BEN 118 BEN 118	CBA 116 (DME) CBA 116 (DME)	6 -	12730 12730
3	MORON	MRN 21 MRN 03	MRN 100 MRN 100	AOG 23 AOG 23	6 -	11800 11800
4	LAS PALMAS AMILCAR CABRAL	GDV03 AML 02	TG 103 CVS100 (DME)	- -	- -	9900 10890
5	BANJUL	BYD 32 BYD 14	BYD 121Y BYD 121Y	BJ76 (DME) BJ76 (DME)	6 -	10410 10410
6	ROBERTS FIELD KINSHASA	ROB 04 KIN 25	ROB 85 (DME) BZ 78 (DME)	- -	- -	11160 15510
7	HOEDSPRUIT DARWIN	HDS 18 DDN 29	HS 73 (DME) DN 84	- -	- -	13120 11260
8	DIEGO GARCIA	JDG 31 JDG 13	NKW 57 NKW 57	- -	- -	12040 12040
9	KING KHALID	KKI 15 KKI 33	RIY 92 RIY 92	KIA 80 KIA 80	- -	13770 13770
10	HONOLULU	HNL 08 HNL 26	HNL 95 HNL 95	CKH 86 CKH 86	- -	12000 12000
11	GAM HAO	GUA 06 HAO 12	UAM 54 HA 80	- -	- -	11220 11090
12	NORTHROP	NOR 17 NOR 23	SNG 121Y SNG 121Y	HMN 92 HMN 92	6 -	15000 15000
13	EDWARDS NORTHROP	EDW 04 NOR 35	EDW 111 SNG 121Y	- -	- -	15000 15000
14	EDWARDS	EDW 23 EDW 15	EDW 111 EDW 111	PMD 92 PMD 92	- -	14880 15000
15	EDWARDS	EDW 22 EDW 17	EDW 111 EDW 111	PMD 92 PMD 92	8 6	15000 15000

Redundancy Management (RM)

TACAN RM performs two basic functions (figure 1-13). A Selection Filter (SF) selects a single range and bearing from multiple data sources (or Candidates). Range and bearing failures are then declared failed through Fault Detection, Identification, and Reconfiguration (FDIR). The SF and FDIR run in PASS software in both OPS 3 and 6. BFS software has only a SF in OPS 3 and 6; no FDIR is available. TACAN RM information is displayed on the GNC SYSTEM SUMMARY 1 display, the GNC Horizontal Situation display (SPEC 50), and on the HSI dedicated display in both PASS and BFS.



Selection Filter and FDIR are processed on a parameter-by-parameter basis. Therefore, the status of the range parameter does not affect the status of the bearing parameter.

The first step in TACAN RM is to determine which TACANs are Candidates for selection by the Selection Filter. Candidacy is determined by the following criteria:

1. Not powered Off.
2. Not manually deselected.

3. Not currently failed (PASS only).
4. Not commfaulted.
5. Not involved in SELF-TEST at two level (PASS only).
6. Not in the BEARING CONE OF CONFUSION.
7. Not experiencing Multiple of 40 DEG BEARING Glitches at the three level.
8. Not in a TWO-LOCK REQUIREMENT scenario, PASS only.

A brief description of each follows:

(1) Not Powered OFF

The TACAN unit must be powered ON before it can be considered a Candidate for RM processing. All three TACANs are powered ON at deorbit minus 2 hours and 20 minutes while in the Deorbit Prep Checklist. NOTE: TACANs do not require an I/O Reset to establish Input/Output transactions (I/O).

(2) Not Manually Deselected

The TACAN unit must be selected (not deselected) to be considered available. Since selection and deselection is on a unit basis, both the range and the bearing will be affected.

(3) Not Currently Failed (PASS only)

A TACAN parameter is considered available if it has not been declared failed by FDIR. Failure on one parameter will not affect the availability of the other parameter associated with that unit. FDIR exists only in PASS for TACANs, so TACANs cannot be declared failed by RM in BFS.

(4) Not Commfaulted

On any given cycle, data availability is dependent upon a valid input/output transaction. If the data is determined to be unavailable (commfaulted), the entire TACAN (range and bearing) will be bypassed.

(5) Not Involved in SELF-TEST at the Two Level (PASS only)

TACAN Self-Test is controlled by the TACAN SOP and commanded by TACAN FDIR software to assist in resolving a dilemma situation. Self-test is performed on both the range and bearing parameters regardless of which one is in dilemma. One parameter must be above RM limits before FDIR will command a Self-Test:

RM Limits: Range - 3006 ft
Bearing - 6 deg

The TACAN SOP sends Self-Test commands to each unit separately and the TACAN units process only self-test data while in Self-Test (i.e., the Selection Filter cannot use the TACANs as Candidates). Each TACAN then receives a predefined range and bearing signal of 0.0 nautical miles and 180 deg, respectively. After about 19 seconds, the TACAN SOP checks the output range and bearing signals against high and low limits listed below:

	HIGH	LOW
Range	0.5 n.mi.	0.0 n.mi.
Bearing	182.5 deg	177.5 deg (+/- 2.5 deg)

A range or bearing value outside of these limits is interpreted as a failure and the respective range or bearing fail flag is set True. In addition, the SOP checks the status of the Test Status Monitor (TSM) hardware discretes for each TACAN. The TSM reflects the results of an internal hardware test performed in much the same way as the previous test. The TSM limits are listed below:

	HIGH	LOW
Range	0.2 n.mi.	0.0 n.mi.
Bearing	182.0 deg	178.0 deg (+/- 2.0 deg)

It will always hold true that if the software limit check fails for a given TACAN parameter, the TSM hardware discrete will also indicate failed since the hardware limits are tighter than the software limits. However, if the signal is biased between the two limits (i.e., 0.3 n.mi.) only the TSM hardware discrete will indicate failed.

The SOP then tallies the fail votes and attempts to declare a failure. If only one TACAN parameter fails the limit test (either the software limit or the TSM hardware limit), it is declared failed and self-test is exited. If self-test determines a failure of the range and/or bearing parameter on both TACANs or no parameter is determined to be failed on either TACAN, then the test is exited without resolving the dilemma (see FDIR section for more information on unresolved self-test). If a failure was identified, it will be annunciated on the CRT. The Candidates for Selection Filter processing will then be updated to reflect the failed parameter.

NOTE: The TACAN SOP will not place either of the two TACANS into Self-Test unless both units in dilemma are in the GPC MODE on panel O7. If this requirement is not satisfied the two LRUs remain in a dilemma situation, requiring crew intervention.

NOTE: No Self-Test capability exists in BFS; however, BFS responds to the situation when PASS is performing a TACAN Self-Test. BFS will cease using TACAN data until PASS Self-Test is completed (ratio/residuals blank and down arrows appear next to the bearing and range on BFS SPEC 50).

(6) Not in the BEARING CONE OF CONFUSION

Because of the horizontal directivity of the ground station antenna radiation pattern, a volume of weak and/or poor radio frequency energy is created which causes bearing data to be erroneous. The volume has the shape of an inverted cone whose included angle varies from 60 deg to 120 deg, typically 90 deg. It is usually termed the "Bearing Cone of Confusion" (figure 1-14).

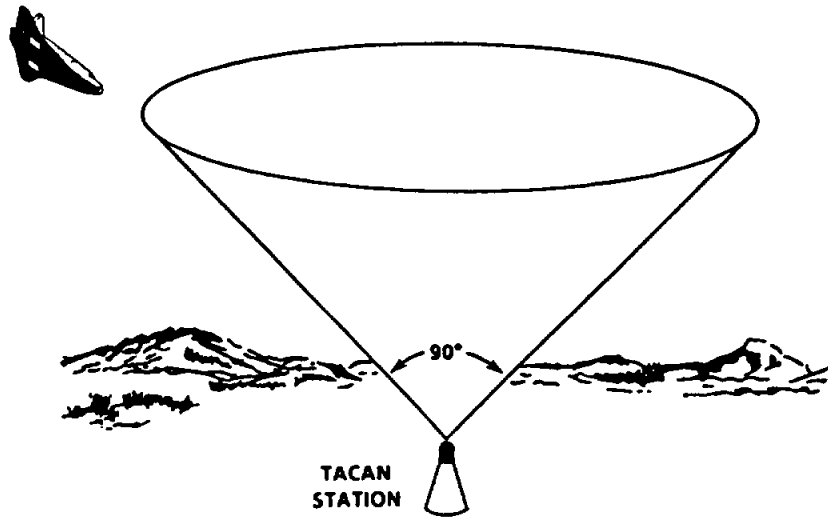


Figure 1-14.- Bearing cone of confusion.

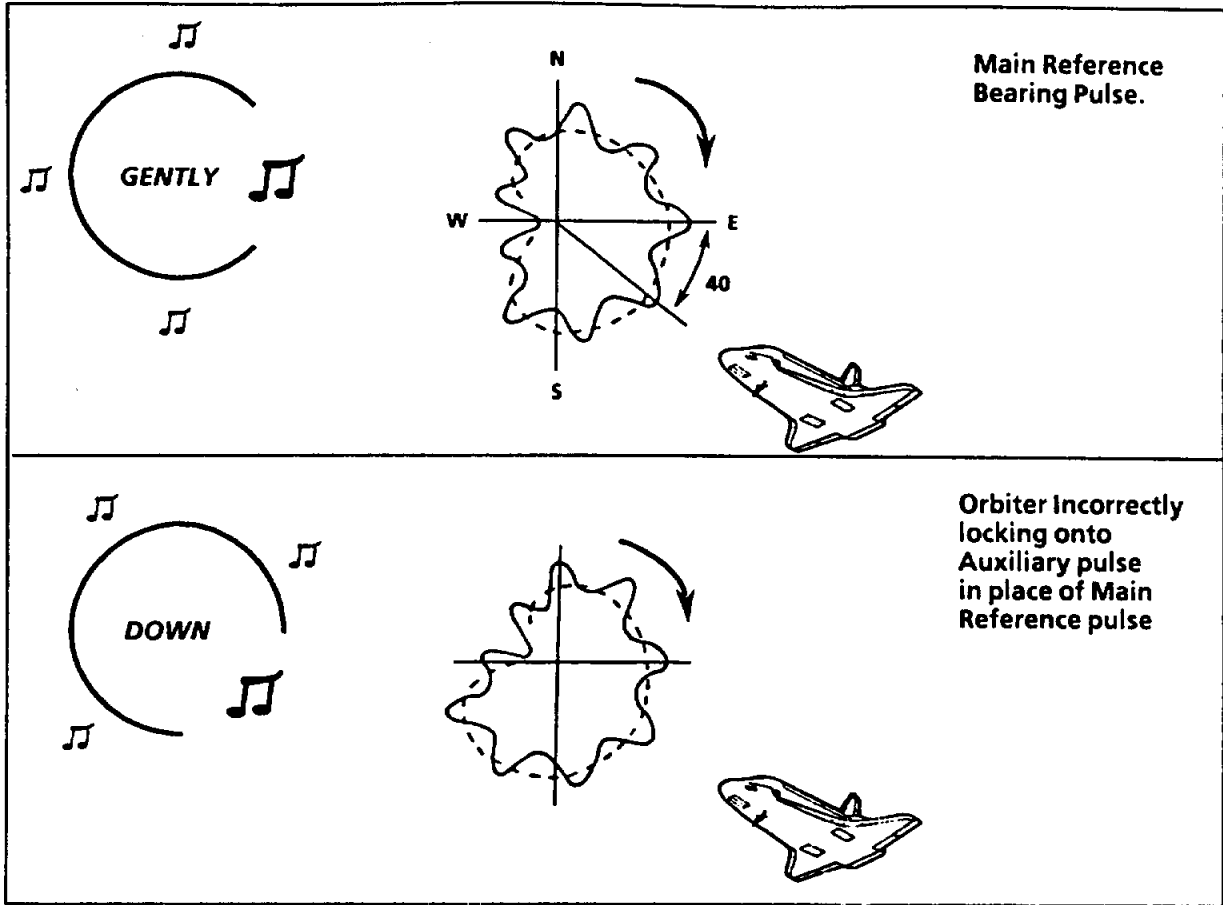
The GPCs compare the elevation difference between the Orbiter's position vector and the TACAN's position vector. This is compared against the threshold elevation limit to determine if the Orbiter is in the Bearing Cone of Confusion. If within the calculated Bearing Cone of Confusion, the TACAN's bearing is not a Candidate for RM processing and the ratio/residuals for bearing will blank on SPEC 50.

Since the Bearing Cone of Confusion is determined from the NAV position vector, a bad NAV state onboard the Orbiter will cause the Bearing Cone of Confusion calculation to be in error (i.e., bearing data may be available when it is in error and not available when it should be).

(7) Not experiencing multiple of 40-DEGREE BEARING Glitches at the three level.

The onboard TACAN unit, nominally, will lock-on to the main bearing reference pulse (East reference pulse) from the ground station at 90-degrees. With a weak onboard TACAN receiver, the TACAN receiver may miss the main reference pulse and lock-on to one of the auxiliary positions in place of the main reference pulse (giving the TACANs an incorrect East reference). When this occurs, bearing will be 40-degree or some multiple of 40-degree in error. This is often referred to as a "40-Degree Bearing Glitch." This condition will usually not last more than a few seconds at a time.

If the 40-degree bearing glitches occur at the three level, RM recognizes this type of bearing anomaly and handles these biases differently than other types of bearing biases. No annunciation occurs and FDIR does not declare the bearing parameter failed. Bearing from those TACANs will not be used as a Candidate for the Selection Filter for the duration of the glitch. At the one and two level, normal FDIR/SF processing occurs for these glitches/biases (i.e., at the two level a miscompare will cause a dilemma and at the one level the data will be used). (figure 1-15)



TD101*011

Figure 1-15.—Forty-degree bearing glitches.

- (8) Not in a TWO-LOCK REQUIREMENT scenario, PASS only.

The TACAN provides a status signal that indicates if it has locked onto a ground station. The Selection Filter treats a unit NOT locked on as a POTENTIAL Candidate. The TACAN SOP for PASS software has a two-lock requirement for both Range and Bearing when two or more TACAN parameters are Candidates for the Selection Filter. The two-lock Range requirement goes away about 30 seconds after processing by NAV; i.e., TACANs have been placed in AUTO or FORCE on SPEC 50 and have been that way for more than 30 seconds. The two-lock Bearing requirement never goes away.

NOTE: If at any time the crew performs a Zero Delta State Update on SPEC 50, the two-lock RNG requirement is reinstated.

A Zero Delta State Update or a NAV Delta Zero Update is done by executing ITEM 16 on SPEC 50 with ITEMS 10 through 15 having zeros in their data field.

For example: TACAN 1 is deselected, TACAN 2 does not lock on in range or bearing, and TACAN 3 has no problems. Neither two-lock requirement is met and no ratios/residuals for either parameter will be displayed on SPEC 50. If, however, TACAN 2 locks on in range and bearing, both two-lock requirements would be met and NAV can start processing TACAN data upon taking TACANs to AUTO on SPEC 50 (ITEM 19). Now if TACAN 2 lost lock 30 sec after being taken to AUTO, the bearing two-lock requirement would not be met and ratios/residuals for bearing would blank. The range two-lock requirement would be met. If the crew executed a NAV Delta State Update on SPEC 50, the two-lock range requirement would be reinstated and the range ratios/residuals would also blank.

If TACAN 1 is deselected, TACAN 2 bearing fails, and TACAN 3 has no problems, only one bearing parameter is available (TACAN 3's bearing). This does not violate the two-lock bearing requirement, because only one bearing is available as a Candidate. The two-lock requirement only applies when two POTENTIAL Candidates are available. If TACAN 1 is deselected and the bearing for TACAN 2 never locks-on, TACAN 2 would have to be deselected in order to meet the Bearing two-lock requirement.

There is no two-lock requirement in BFS for TACANS. The only conditions in BFS are:

- * At least two TACANs tuned to the same station as seen on SPEC 50.
- * One TACAN locked on.

Selection Filter

Three-Level (SF)

Selection filtering utilizes a midvalue select (MVS) scheme (both for PASS and BFS) to provide a single range and bearing data when three valid inputs are available. This is accomplished by computing the difference between each TACAN. This results in three error values: 1-2, 2-3, and 3-1. The data from the TACAN which is common to the two smallest differences is selected for output.

Two-Level (SF)

At the two level a data output value is provided that is the average of the two available inputs for the PASS TACAN Selection Filter. The BFS prime-selects the lowest-numbered TACAN unit at the two-level.

One-Level (SF)

At the one level the data from the only available TACAN is used.

Zero-Level (SF)

The no-available-sensor level does not provide a new data output value; i.e., the output value will remain unchanged from its previous valid value. The data is labeled invalid and therefore is not used.

"Data Good" Protection

The Selection Filter provides transient protection through a DG (Data Good) flag whenever out-of-tolerance range or bearing data is detected. The DG flag will always be set True for the three-level and one-level and False for the zero-level. The flag for the two-level will be set False if the difference between the two available data sources is greater than the FDIR limits (range limit - 3006 ft and bearing limit - 6 deg).

In BFS engage cases, at the two-level if the TACANs miscompare the DG flag will be set FALSE and no TACAN data will be processed. The ratios/residuals will blank and the crew will have to take actions to solve the TACAN miscompare. Since BFS has no FDIR, only a SELECTION FILTER, the BFS will not annunciate this "Silent Dilemma."

Post Selection Filter Protection

After the single range and bearing data has been selected for use by the Selection Filter, it is checked once more for any large spikes or glitches in the data. Each processing cycle, the selected data is checked against the data from the last cycle. If the selected data differs by more than a predefined limit, it is flagged invalid and the data from the last cycle is used. The range and bearing limits are:

- * Range Post Selection Filter Limit = 10,000 ft
- * Bearing Post Selection Filter Limit = 4.5 deg

Fault Detection, Identification, and Reconfiguration

Fault Detection (FD) - compares redundant input data to determine if an out-of-tolerance condition exists.

Fault Identification (FI) - determines whether a failure has occurred and attempts to identify the failed parameter.

Fault Reconfiguration (FR) - modes the Selection Filter in response to crew commands and identified failures.

The FD process will always precede FI which always precedes FR. FDIR is not performed at the one-level and zero-level and not in the BFS (remember, the BFS has no FDIR).

Fault Detection

TACAN Fault Detection is performed whenever two or more data values are available. A failure is determined by comparing the differences between each TACAN unit and comparing these differences to the range and bearing RM limits. The TACAN range and bearing RM limits are:

* Range Threshold = 3006 ft

* Bearing Threshold = 6 deg

A state of miscomparison exists whenever the TACANs differences exceed these RM limits. At the two-level, a miscomparison is equivalent to ONE out-of-tolerance value. At the three-level, a miscomparison is considered to exist when there are TWO simultaneous, out-of-tolerance values. Each miscomparison and the identity of the TACAN unit is passed to the FI function.

Fault Identification

FI will monitor the differences indicated from FD and will declare the existence of a failure whenever a predetermined number, N, of consecutive miscomparison values are detected. The range and bearing miscomparison (N-counter) limits are:

* Range Counter Limit = 5

* Bearing Counter Limit = 10

Whenever there is a good comparison and the number of consecutive miscomparison values are less than the limit, the N-counters (three counters for three-level tracking and two for two-level tracking) will be reset to zero. N-counters will neither reset nor increment if any of the associated data from the TACANs have not been updated (i.e., due to commfault or lock on). Whenever the number of consecutive miscomparisons values equal or exceed the limit, a failure is considered to exist.

After FI determines a failure has occurred, it will annunciate a failure message on the CRT and either identify the failed parameter or annunciate that a failure has occurred and FI is unable to identify the failed unit (dilemma).

Three-Level (FDIR)

When a miscompare is detected by two of the three TACAN error pairs (1-2, 2-3, 3-1), FI will identify the unit that is common to these pairs as having the failed parameter (i.e., if the range fail counters for TACAN error pairs (1,2) and (2,3) are greater than or equal to the counter limit, then fail the range parameter on TACAN 2). When a parameter is declared failed by PASS RM, a down arrow is displayed on GNC System Summary 1, a "RM FAIL TAC" fault message appears on all active PASS CRTs, a down arrow is displayed on GNC SPEC 50 next to the failed parameter, and a SM alert light and alarm tone is generated. (See figure 1-16 for ASCENT/ENTRY SYSTEM PROCEDURE "RM FAIL TAC" procedure.)

```
RM FAIL TAC  G50
(RM LIMITS:  6 DEG, 0.5 NM)
  1.  If data good:  desel, resel  >>
  2.  If failure verified - desel in BFS
```

Step 1 handles a transient failure in one of the TACAN's parameters. If the data looks good, reselect the failed TACAN.

Step 2 deselects the failed TACAN in BFS. Remember BFS has no FDIR.

Figure 1-16.- RM Fail TAC.

Two-Level (FDIR)

When a failure is determined to exist at the two-level, FI will annunciate a dilemma and set the appropriate range or bearing dilemma flag to TRUE. The DG flag will be set FALSE in the Selection Filter as long as the miscomparison exists (i.e., no TACAN data will be used for that parameter). FI will then attempt to discriminate the failed units parameter through a TACAN Self-Test to isolate the failure. If Self-

Test can discriminate, FI will identify both the failed parameter and the unit, then reset the dilemma flag to FALSE. If the failure cannot be identified, or Self-Test was not executed (TACANs in T/R or RCV mode), then the dilemma flag and indications will remain set TRUE and the crew must manually deselect one of the TACANs. In a PASS RM dilemma case, a "RM DLMA TAC" fault message will appear on all active PASS CRTs, two dilemma markers "?" will be displayed on GNC SYS SUMM, two dilemma markers "?" will be displayed on GNC SPEC 50 next to the parameters in dilemma, and a SM alert and alarm tone will be generated. When Self-Test is in progress "TEST" will appear on SPEC 50. Upon completion of Self-Test (if the dilemma is solved) a "RM FAIL TAC" fault message would be generated and associated signatures (see RM FAIL signature discussion figure 1-16). See figure 1-17 for ASCENT/ENTRY SYSTEM PROCEDURE of "RM DLMA TAC."

RM DLMA TAC G50

1. If both data good - dese1, rese1 one TACAN in DLMA >>
2. ✓TACAN MODE (three) - GPC
3. If 'RM FAIL TAC' - dese1 failed TACAN in BFS >>
4. If continous self test - select T/R (three)
5. If one bad TACAN identified - bad TACAN OFF

Step 1 handles a transient 40 degree bearing bias or a range bias. This step has the crew solve the dlma by dese1/rese1 one TACAN.

Step 2 has the crew check that the GPC MODE is selected, this mode allows self-test to solve dlmas automatically.

Step 3 has the crew deselect a failed TACAN in BFS, since BFS has no FDIR.

Step 4 has the crew select the T/R MODE if the TACANs remain in self-test. In the T/R MODE, TACANs do not have the automatic self-test capability, so this will stop the continuous self-test.

Step 5 is self explanatory.

Figure 1-17.- RM DLMA TAC.

Fault Reconfiguration

Fault Reconfiguration modifies the Selection Filter by dictating which TACANs may be considered Candidates. It responds directly to crew deselect/reselect commands and to identified range or bearing failure indications. If a failure existed at the two-level thereby setting the dilemma flag TRUE, it will be reset to FALSE upon moding to either the three-level or the one-level. See Table 1-2 for SF and FDIR summary; also see figure 1-18 for ENTRY POCKET CHECKLIST RM summary.

Table 1-2.- TACAN RM summary for PASS and BFS.

RM

** Selection is performed on a parameter basis for candidate units **

SELECTION FILTER

	PASS	BFS
3 Level	Component by component MVS	Same as PASS
2 Level	Average each component. DLMA - do not use	Use lowest numbered TACAN. DLMA - do not use
1 Level	Use	Same as PASS
0 Level	Data not used	Same as PASS

FDIR

	PASS	BFS
3 Level	Down modes based upon two out of three comparison	No FDIR for TACANs in BFS
2 Level	Automatic Self-Test (if in GPC mode)	
1 Level	None	
0 Level	None	

** RM limits: Range - 3,006 ft **
Bearing - 6 deg

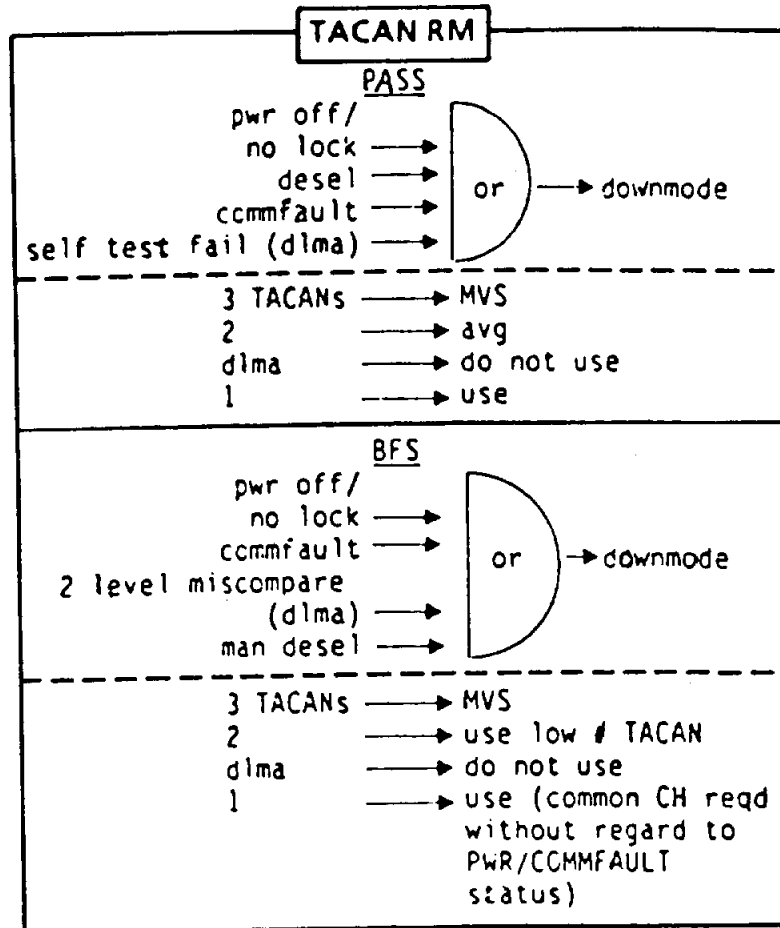


Figure 1-18.—Entry pocket checklist TACAN RM summary.

TACAN Usage in Navigation

TACANs are moded to GPC and the ANT SEL switch is checked for the AUTO position (panel O7) in the DEORBIT PREP CHECKLIST in preparation for entry. The TACANs are also set in this configuration for launch in case of an abort. The TACAN SOP starts processing in MM 304 and MM 602. The ENTRY MANEUVERS CUE CARD calls for the crew to check TACANs at V = 7k for nominal End Of Mission (EOM) and the ASCENT CUE CARDS direct the crew when to check the TACANs for abort cases.

TACAN acquisition and operation are completely automatic under nominal conditions. The crew is provided with necessary controls and displays to evaluate the TACAN system performance.

The TACAN scheme is based on common channel operation of the three onboard units; i.e., all three TACANs tuned to a common ground station. Because the three TACAN units have different antenna locations, they will not all initially lock on at the same time. Other factors that affect TACAN lock on are vehicle bank angle and ground station location. At MM 304, the onboard units will start searching for range and bearing lock. They will interrogate with the lower and upper antennas alternately approximately 12 seconds each until a range lock is acquired.

MCC (GNC flight controllers) check the TACAN's Automatic Gain Control (AGC) in MM 304 (before the TACANs have locked on to a ground station) for TACAN failed-off Blanking Pulse. TACANs nominally lock on to ground stations around 160 kft; therefore, at high altitudes in MM 304 the TACANs are sending full strength range interrogating pulses (5 volts AGC) trying to lock on to a ground station. When the onboard TACAN units lock on, the pulse strength will slowly decrease as the ground station range is reduced. The onboard TACAN units are communicating with one another; when one unit sends range (DME) interrogating pulses, the other units receive a blanking pulse to inform the TACAN units that a signal is being sent. If the TACANs are experiencing a failed-off blanking pulse, (TACANs are not receiving any blanking pulses from any other TACAN) the units are not communicating with one another, thus the units will interfere with one another and affect locking on to the ground station. If the AGC value is high at the MM 304 transition, no failed-off blanking pulse exists. However if AGC shows low at the MM 304 transition, the TACAN units believe that they are acquiring lock on with a ground station and a failed-off blanking pulse exists. The units are not communicating with one another and are locking on to one another's transmitted range signals. Testing has shown that with this failure the TACANs will not lock on at all during entry if only upper antennas are selected. With lower antennas selected the TACANs will lock on but slightly higher signal strength is required. Upper antennas are located closer together than the lower antennas so the failure will affect the upper antenna more. The upper antennas are normally used at higher altitudes and the lower antennas used at lower altitudes, so the result of a failed-off blanking pulse is late lock on of TACANs.

In order for NAV to process range or bearing, each component must separately satisfy a two-lock requirement (see RM Candidacy for more detail on two-lock requirement). The columns for the bearing and range data on SPEC 50 will remain blank until the two-lock and acquisition filter requirements are satisfied (10 consecutive cycles required for RNG if ground velocity > 4500 ft/s, and 5 consecutive cycles if ground velocity < 4500 ft/s, and 12 consecutive cycles required for BRG). The acquisition filter guarantees that there is a steady lock on before the data can be used. Since RM operates at 1Hz, there will be 10 to 12 seconds before data will appear in the RESID/RATIO column on SPEC 50. Once lock on is lost, the acquisition filter cycle starts all over again. Typically, two LRUs have locked on in both RNG and BRG at approximately 150 to 145 kft.

Because Bearing data is not reliable when flying over a ground station, there is a "Bearing Cone of Confusion" check where no bearing data will be processed (see RM Candidacy for more information). The crewmen can determine the presence of the bearing cone by observing that the bearing data has blanked in the bearing RESID/RATIO columns on SPEC 50.

The following excerpt from the FLIGHT RULES explains in detail the criteria that the crew and MCC use to assess the value of the TACAN data and its incorporation into navigation. Please read this excerpt carefully for the OPERATIONAL portion of the TACAN system!

4-85 NAVIGATION FILTER MANAGEMENT AUTO/INHIBIT/FORCE (AIF)

This rule provides direction to the crew and ground for the management of external sensor data incorporation into the navigation filter. It assumes that the crew AIF switches are initially in INHIBIT for TACAN and BARO and in AUTO for drag altitude processing. The rule is presented in matrix form to facilitate correlation of various situations to the action to be taken for those situations

A. TACAN-INITIAL PROCESSING (INITIALLY IN INHIBIT):

	RATIO <1	RATIO >1		1-LOCK
		BAD TACAN	BAD STATE VECTOR	
PRE-COMM (ASSUME NO COMM IF VREL < 6000 ① FPS, NOM AOS +2 MIN, H = 130K FT)	REMAIN IN INHIBIT	REMAIN IN INHIBIT	REMAIN IN INHIBIT	REMAIN IN INHIBIT
COMM	GROUND CALL; AUTO ③	GROUND CALL; INHIBIT IF STATION, SWITCH TO B/U CH IF LRU, Δ STATE UPDATE AS REQD	GROUND CALL; Δ STATE OR FORCE RETURN TO AUTO WHEN RATIO <1	GROUND CALL; Deselect MISSING TACAN'S (RESELECT NON-FAILED TACAN LRU'S WHEN 2 LOCK)
NO COMM	AUTO	TROUBLESHOOT TO DETERMINE CAUSE OF EDITING A. SWITCH GROUND STATIONS B. CHECK IMU STATUS C. OBSERVE RESIDUAL, RATIO BEHAVIOR D. MONITOR WITH HSI		WAIT UNTIL VREL < 5500 FPS ② THEN Deselect MISSING TACAN'S (DO NOT FORCE)
		AUTO	FORCE	

NOTES:

- ① FOR RTLS, VREL < 6500 FPS.
- ② FOR RTLS, VREL < 4700 FPS.
- ③ EVEN THOUGH THE RATIO IS <1, TACAN DATA WILL NOT BE ACCEPTED IF GROUND RADAR INDICATES THAT INCORPORATION OF DATA WILL DEGRADE THE NAVIGATION STATE.

Figure 1-19.- NASA JSC Flight Rules (1 of 4).

4-85 NAVIGATION FILTER MANAGEMENT AUTO/INHIBIT/FORCE (AIF) - Continued

This matrix defines the actions to be taken for initial TACAN processing. For a nominal entry, the TACAN AIF switch is in INHIBIT and the TACAN transceivers are turned to the primary site TACAN channel with the rotary switch in the GPC position. When two TACAN LRU's have locked up, RM passes data to the navigation filter; but, because the AIF control is in INHIBIT, the data will not be processed by navigation. This configuration allows the ground to evaluate the TACAN data compared to radar tracking data and to give the crew a GO to mode the AIF switch to AUTO, so that navigation may process TACAN if it is acceptable. This plan also protects the validity of the ground delta state computation in the event that a ground-initiated vector update is required. (The ground delta state processor requires that external data not be taken in since it assumes that the state errors are linear). The PRE-COMM row of the rule matrix supports this mode of operation by having the crew wait for COMM in order to have ground assistance. However, there is a limit to how long the crew should wait before they try to independently troubleshoot the lack of good TACAN data. For EOM, this limit was chosen to be about nominal AOS plus 2 minutes, which occurs at a V_{rel} of approximately 6000 fps and an altitude of about 130k feet. At this altitude, it is becoming more urgent to correct the vehicle state since the footprint is shrinking (for RTLS, 130k feet altitude corresponds to a V_{rel} of approximately 6500 fps)

In the COMM row, for TACAN data that agrees with the navigation, the ratios will be less than one. Upon ground evaluation of the TACAN data and of the onboard vector compared to tracking data, a GO will be given for the crew to go to AUTO. However, if the ground evaluation shows that incorporation of the TACAN data will degrade the navigation state, the TACAN data will be held out until it will improve the onboard state. One of two failures can cause the ratios to be greater than one. Either the TACAN data or the state vector could be at fault. If the ground determines that the TACAN data compared to the radar data is bad and if all three LRU's indicate a bias, the recommendation will be to try another ground station. If that does not solve the problem, the fault lies with the onboard system; and, if the delta state update criteria are exceeded, an update will be initiated. If the ground determines that the vehicle state is erroneous and the TACAN residuals indicate that forcing the data will correct the state error, then the crew will be advised to force the data until the ratio is less than one at which time they will be advised to return to AUTO. Otherwise, a delta state update will be performed.

The final entry in the COMM row deals with only one LRU locking up. At initial acquisition, the onboard redundancy management requires that two LRU's be locked on before data is passed to navigation. If only one LRU locks on, the crew/ground should verify that the data is good for that LRU, and the crew should deselect the missing LRU's to override the two-lock requirement. Once data is processed initially, the range two-lock restriction is satisfied, but two LRU's are still required to be locked on prior to processing bearing data. Therefore, it is advisable to wait until two LRU's are locked on prior to reselecting non-failed LRU's. This provides RM protection for both range and bearing. However, if the ground deems it necessary to process data from one LRU, then this procedure would be used and, during the period of one LRU lock, the ground would carefully monitor the quality of the data from the single LRU.

Figure 1-19.- NASA JSC Flight Rules (2 of 4).

4-85 NAVIGATION FILTER MANAGEMENT AUTO/INHIBIT/FORCE (AIF) - Continued

In the NO-COMM case, the crew must make decisions in the operations of the AIF controls independently from the ground. The NO-COMM case may be assumed by the crew if they are entering to a landing site that has no COMM with the ground or to a site that has COMM, but COMM has not been established by $V_{rel} = 6000$ fps. If the TACAN deltas on the HSD look good and the ratios are less than one, then the crew should mode the AIF switch to AUTO. If the ratio is greater than one, the crew must use onboard displays to determine whether the TACAN or state vector is bad. The following procedures are available to the crew:

- a. *Switch ground stations - The onboard I-loads for the TACAN table are such that, with the rotary switch in the GPC position, the landing site TACAN should be acquired. If data is not acquired or if the ratio is greater than one, the crew may execute item 5 on GN:SPEC 50 to select the alternate or backup TACAN and evaluate that data. If the ratios for the alternate station are less than one, then the problem is probably with the prime TACAN ground station. If the ratios are greater than one, it would probably indicate a bad navigation state, although there is a very small probability that two or more LRU's would fail in the same manner.*
- b. *Check IMU status - If the IMU mission performance has been nominal and a good IMU alignment was performed pre-deorbit, and no IMU failures have occurred during entry, it is unlikely that the navigation state could be in error by a sufficient magnitude to cause ratios greater than one. Therefore, the TACAN data should be suspect. However, if the IMU's have had problems or an alignment was not performed pre-deorbit, or an IMU has failed RM during entry, the crew should suspect that the navigation state is in error.*
- c. *Observe residual/ratio behavior - If the residuals/ratios are steady or show a constant trend, it is likely that the navigation state is in error. If the residuals/ratios are erratic, it is likely that the TACAN data is erroneous.*
- d. *Monitor with HSI - The crew can select raw TACAN data to drive the HSI and compare the range and bearing with the navigated position and a visual estimate of the real position. This would be a difficult procedure since the values on the HSI will be continually changing and the magnitude of the errors would have to be so large that the source of the error should have already been detected by one of the other methods.*

The final situation in the NO-COMM row is the case where only one LRU locks on. In this case, the crew should wait as long as possible before the footprint shrinks to the point that the state error really has to be removed (5500 fps for EOM and 4700 fps for GRTLS). At this point, the nonlocked on LRU's should be deselected and the data from the single LRU passed to navigation by moding the AIF switch to AUTO. It should not be moded to FORCE to protect the navigation from bad TACAN data.

Figure 1-19.- NASA JSC Flight Rules (3 of 4).

4-85 NAVIGATION FILTER MANAGEMENT AUTO/INHIBIT/FORCE (AIF) - Continued

B. TACAN - POST CONVERGENCE (INITIALLY IN AUTO):

	RATIO <1	RATIO >1	
		BAD TACAN	BAD STATE VECTOR
COMM	GROUND CALL; AUTO	GROUND CALL; INHIBIT IF STATION, SWITCH TO B/U CH IF LRU, Δ STATE UPDATE IF RQ'D. (BACK TO AUTO IF RATIO <1)	REMAIN IN AUTO PERFORM A ZERO Δ STATE UPDATE. IF RATIO STILL >1; FORCE
COMM	GROUND CALL; AUTO	TROUBLESHOOT TO DETERMINE CAUSE OF EDITING A. OBSERVE RESIDUAL, RATIO BEHAVIOR B. CHECK IMU STATUS C. MONITOR WITH HSI D. SWITCH TACAN STATIONS	
		REMAIN IN AUTO	REMAIN IN AUTO PERFORM A ZERO Δ STATE UPDATE. IF RATIO STILL >1; FORCE

This rule shows the actions to be taken once TACAN data has been processed by navigation. For a nominal entry, the crew action would be to remain in AUTO for either COMM or NO-COMM since the ratio should not grow above one. If, for any reason, the ratio does become greater than one, then the ground or the crew can utilize the same techniques to isolate the problem as were used at initial acquisition. If the problem is bad TACAN data, the actions are the same as at initial acquisition. If the problem is the navigation state, the procedures change slightly in that a zero delta state update is performed prior to applying the same procedure used for the initial acquisition case. This is done to reinitialize the covariance if TACAN data has already been processed and it is required to force TACAN in order to fix the navigation state, since the processing of TACAN data might have converged the covariance matrix to the point where even forcing the TACAN data would not remove the state errors.

Figure 1-19.- NASA JSC Flight Rules (4 of 4).

The detailed matrix which is displayed in the above FLIGHT RULE 4-85 is not flown; however, a shorter version called the NO COMM TACAN MGMT CUE CARD shown in figure 1-20 is flown.

V = 6K **NO COMM TACAN MGMT**

RATIO < 1	RATIO > 1		ONE TACAN LOCKED	NO LOCK
AUTO	TROUBLESHOOT		BELOW V = 5.5K DESELECT MISSING TACANS, then - AUTO	BELOW V = 5.5K TOGGLE TACAN
	IF BAD TACAN	IF BAD NAV STATE		
	AUTO	If 1st acq - FORCE IF NOT - ZERO Δ STATE		

Figure 1-20.- No COMM TACAN MGMT.

Launch Commit Criteria Requirements

Two of three TACANs are required for launch up until T-31 seconds at RSLs (Redundant Set Launch Sequencer) start. AGC must also be within limits for launch up until RSLs start at T-31 seconds. Two of three range and two of three bearing values must be valid at the one time verification test prior to GLS (Ground Launch Sequencer) start at T-9 minutes. All of the above criteria must be met or an auto hold will take place.

BFS Differences

1. The right instrument switch positions are slaved to the left instrument positions when BFS is engaged.
2. BFS has different status indicators than PASS on SPEC 50 (Horiz sit) and SPEC 18 (GNC SYS Summ 1). Down arrows are used for Comm fault/Loss of Lock and Unit Failed. PASS uses an "M" for Comm fault/Loss of Lock.
3. BFS does not support the "TEST" function on SPEC 50 because it has no FDIR, only a Selection Filter. BFS also does not support DELTA mode on SPEC 50, only the ABS mode.
4. BFS will issue a "NAV EDIT" fault message when TACAN range or bearing ratio > 1 for three consecutive NAV cycles, PASS will not.

5. BFS will not issue a "NAV EDIT TAC" fault message if TACAN data is not incorporated into NAV after 7 NAV cycles, PASS will issue the message only.
6. BFS does not support the "RM FAIL TAC" and the "RM DLMA TAC" fault messages because BFS has no FDIR.
7. BFS does not support OPS 8 Sensor Test and OPS 9 Sensor Self-Test displays. BFS is not informed of sensors deselected on SPEC 40 (Sensor Test) in OPS 8; therefore, it is important to turn these units off or deselect them in the BFS.
8. No two-lock requirement in BFS, only two conditions:
 - At least two TACANs tuned to the same station as seen on SPEC 50.
 - One TACAN locked-on.
9. The BFS Selection Filter at the two-level is different than PASS. The BFS uses the lowest numbered TACAN and if a miscompare exists, the BFS does not use any date.

Questions: TACANS

1. What two parameters do TACANs provide to navigation?
2. When is TACAN data used? (altitude)
3. How does the Orbiter TACAN unit measure range?
4. When would you get a BCE STRG X TAC fault message?
5. Where are the new TACAN cbs found and what bus powers them?
6. The HSI can be used as a tool to solve TACAN dilemmas. True or False
7. What are the two basic functions TACAN RM performs?
8. BFS software has only a selection filter, no FDIR. True or False
9. What are the TACAN RM limits?
10. Can BFS annunciate a RM Fail TACAN fault message if a miscompare exists at the two - level?

Answers: TACANS

1. Slant range and magnetic bearing
2. TACAN data is used from approximately 160K until MLS acquisition or until 1500 ft if MLS is not available.
3. Range is determined by measuring the time difference between transmission of pulses from the airborne TACAN unit to the ground station and reception of the reply pulses from the ground station back to the airborne unit.
4. If the special TACAN/RA IOM fails in the MDM
5. PNL 014, 015, 016, MNA, MNB and MNC
6. True, each TACAN unit can be compared to NAV using the HSI source switches.
7. Selection Filter
FDIR
8. True
9. Range: 6 degrees
Bearing: 3006 ft
10. No. BFS has no FDIR - only SF.

Section 2: Microwave Landing System

Introduction

The Orbiter contains three Microwave Landing System (MLS) units operating in a triply redundant mode. Upon switchover from TACANS at an altitude of approximately 18,000 feet, the Shuttle MLS provides the Orbiter with precise azimuth angle, elevation angle, and distance (slant range) information with respect to the runway during the final approach and landing phase.

Performance Objectives

As a result of studying this section, the student should be able to do the following:

- State when MLS data is used
- Describe what parameters MLS provides to NAV
- Name the two channels that have been cleared for Orbiter landing operations
- Describe when MLS FDIR is processing
- Describe the MLS RM limits
- Explain what parameters are required for MLS processing
- Explain the difference between Preland NAV and Entry NAV

Microwave Landing System Operation

Figure 2-1 illustrates the transmitted microwave beams and measurement geometry of the MLS. The MLS consists of a Ground Station (MLS-GS) and an airborne Navigation Set (MLS-NS). The MLS-NS is composed of two LRUs: the Radio Frequency (RF) Assembly and the Decoder Assembly. The ground station is a split-site configuration: Azimuth and Ranging information are transmitted from the Azimuth and Distance Measurement Equipment (DME) transmitter, and Elevation information is transmitted from the Elevation transmitter. The Azimuth and DME transmitter is located beyond the end of the runway, while the Elevation transmitter is located near the touchdown point. The surveyed locations of the three MLS transmitters are stored in memory onboard the Orbiter and are used in conjunction with the Azimuth, Elevation, and Range data to determine the Orbiter position with respect to the runway.

The MLS has 10 frequency channels between 15.4 and 15.7 GHz. However, since there are other users of this system, only channels 6 and 8 have been cleared for Orbiter landing operations. Each Shuttle ground station is permanently assigned to either channel 6 or 8. For entry and landing, the channel number for the designated runway is selected onboard the Orbiter with a set of thumbwheels.

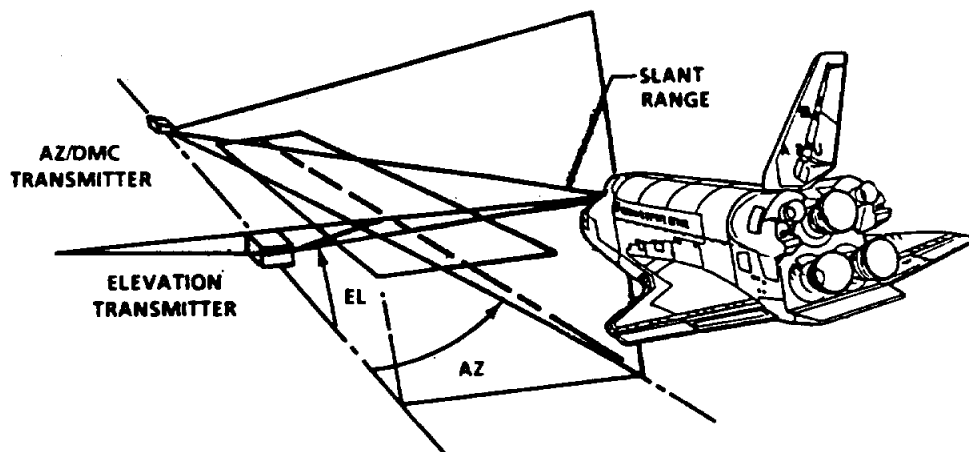


Figure 2-1.—MLS beams and measurement geometry.

Ground Station Hardware

Table 2-1 from the Entry Checklist lists the landing sites, runways, and assigned channels where MLS Ground Stations are installed. The MLS ground station consists of two equipment shelters, two external monitoring antennas, and a remote control unit. One shelter contains the AZ and DME assemblies; the other contains the EL assembly. Each shelter contains redundant sets of equipment, one set forming a primary string, the other a backup string. One of the external monitoring antennas monitors AZ/DME performance, and the other monitors EL equipment performance. The two external monitoring antennas house three redundant antenna sets. The remote control unit allows the operator to concurrently monitor the operation of the primary and backup strings, and to intervene and override the automatic controls as necessary.

Table 2-1.—Landing site data chart from entry checklist.

LAND SITE DATA CHART			(OPS 3)		ETR Low Inclination	
S I T E	LOCATION	RWY	TACANS		MLS CH	LENGTH
			(PRI)	(SEC)		
1	KSC	KSC 15 KSC 33	TTS 59Y TTS 59Y	COF 97 COF 97	8 6	15000 15000
2	BEN GUERIR	BEN 36 BEN 18	BEN 118 BEN 118	CBA 116 (DME) CBA 116 (DME)	6 -	12730 12730
3	MORON	MRN 21 MRN 03	MRN 100 MRN 100	AOG 23 AOG 23	6 -	11800 11800
4	LAS PALMAS AMILCAR CABRAL	GDV03 AML 02	TG 103 CVS100 (DME)	- -	- -	9900 10890
5	BANJUL	BYD 32 BYD 14	BYD 121Y BYD 121Y	BJ76 (DME) BJ76 (DME)	6 -	10410 10410
6	ROBERTS FIELD KINSHASA	ROB 04 KIN 25	ROB 85 (DME) BZ 78 (DME)	- -	- -	11160 15510
7	HOEDSPRUIT DARWIN	HDS 18 DDN 29	HS 73 (DME) DN 84	- -	- -	13120 11260
8	DIEGO GARCIA	JDG 31 JDG 13	NKW 57 NKW 57	- -	- -	12040 12040
9	KING KHALID	KKI 15 KKI 33	RIY 92 RIY 92	KIA 80 KIA 80	- -	13770 13770
10	HONOLULU	HNL 08 HNL 26	HNL 95 HNL 95	CKH 86 CKH 86	- -	12000 12000
11	GAM HAO	GUA 06 HAO 12	UAM 54 HA 80	- -	- -	11220 11090
12	NORTHRUP	NOR 17 NOR 23	SNG 121Y SNG 121Y	HMN 92 HMN 92	6 -	15000 15000
13	EDWARDS NORTHRUP	EDW 04 NOR 35	EDW 111 SNG 121Y	- -	- -	15000 15000
14	EDWARDS	EDW 23 EDW 15	EDW 111 EDW 111	PMD 92 PMD 92	- -	14880 15000
15	EDWARDS	EDW 22 EDW 17	EDW 111 EDW 111	PMD 92 PMD 92	8 6	15000 15000

Each ground station string is powered by batteries which are continuously charged from ac input power. If ac power is lost, the ground station will continue to function from the batteries for at least 15 min.

Each ground station is aligned with respect to the runway to within 0.015 deg in azimuth and elevation, and periodically verified by ground test and flight inspections. Figure 2-2 shows the MLS-GS hardware configuration.

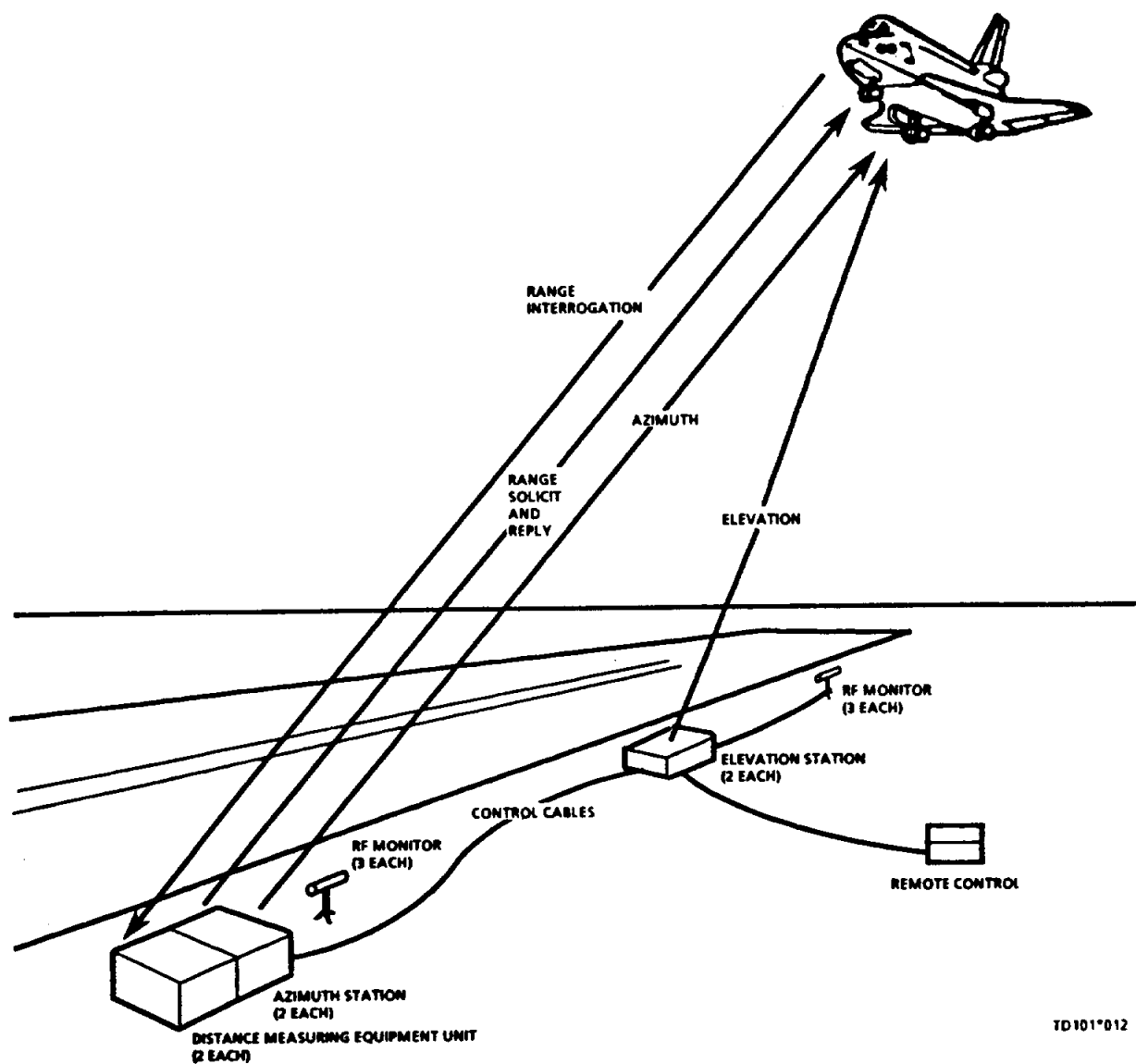


Figure 2-2.- MLS-GS major components.

A low cost MLS ground station for Space Shuttle contingency landing sites also exists. It has a single shelter, no ground station redundancy, and no battery backup. See Table 2-2 for MLS-JUNIOR details.

Table 2-2.– MLS-GSI MLS-JR hardware.

MLS-GS Hardware

- * Separate Elevation and Azimuth/Range shelters
 - * Dual redundant ground stations
 - * Triply redundant field monitoring antenna at each shelter
 - * Manual monitoring and control at remote control unit
 - * Continuous automatic monitoring and switchover/shutdown logic
 - * Dual redundant ac power
 - * Fifteen minute battery backup
-

MLS-JR Hardware

- * Single collocated Elevation/Azimuth/Range shelter
- * No ground station redundancy
- * Single non-redundant field monitoring antenna
- * Manual monitoring and control at shelter
- * Continuous automatic monitoring and shutdown logic
- * Dual redundant ac power
- * No battery backup

Orbiter Related Hardware

The Orbiter MLS-related hardware and interfaces are illustrated in figure 2-3.

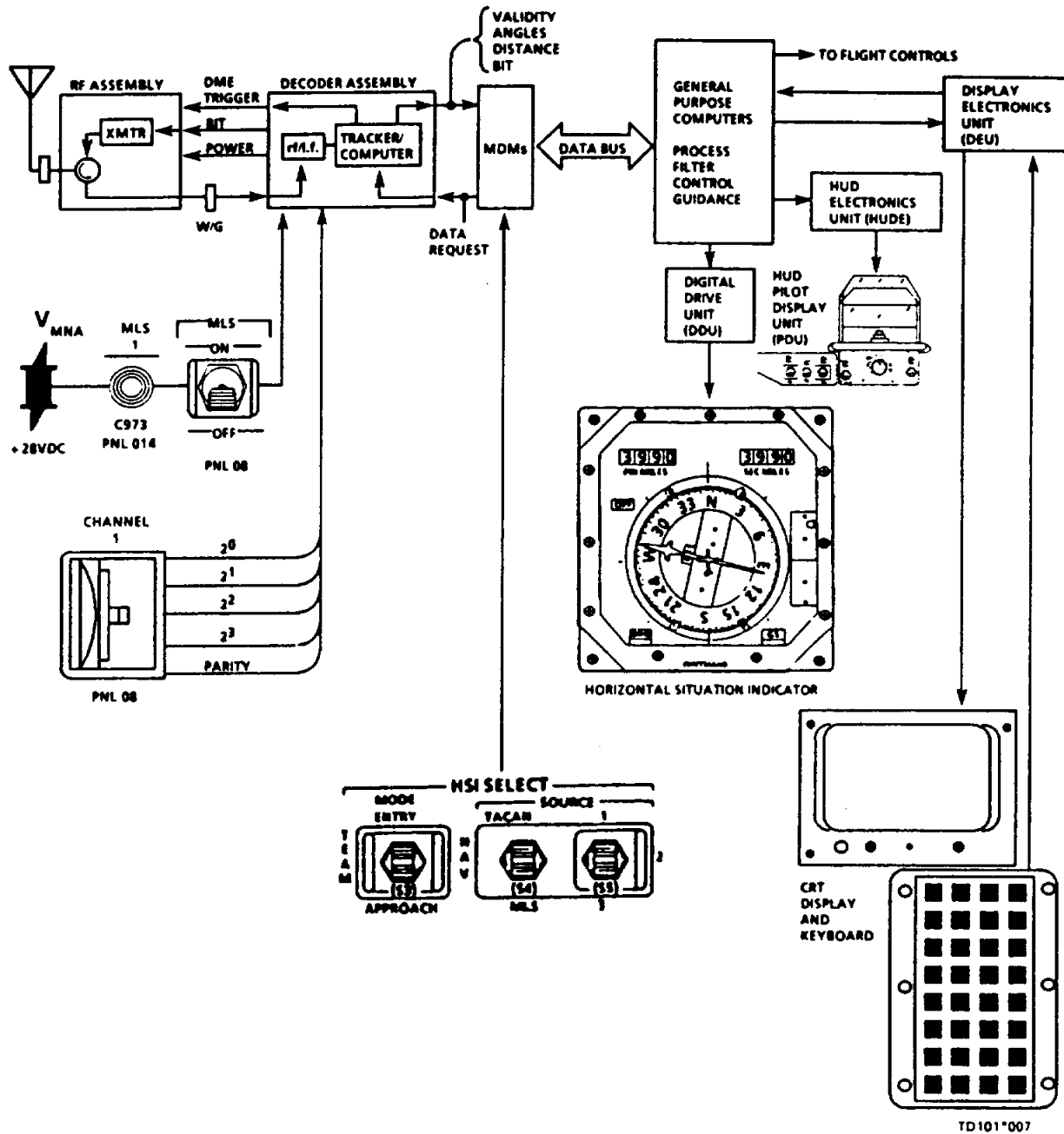


Figure 2-3.- Orbiter MLS-related hardware and interfaces.

Uplink and downlink MLS signals are coupled simultaneously to each of the three redundant MLS-NS through three dedicated forward-looking antennas, shown in figure 2-4. Separate antennas and hardware interfaces permit each MLS-NS to operate independently.

The MLS-NS LRU Assemblies are triply-redundant units which are shock-mounted in the Orbiter's forward avionics bays 1 and 2. The Accuracy of the MLS-NS is as follows:

ANGLE: +/- 0.01 DEG
 RANGE: +/- 50 FEET

Data transfer between MLS 1, 2, and 3 and the Data Processing System (DPS) is through flight-critical forward MDMs FF1, FF2, and FF3, respectively. Raw MLS data is also downlinked to the ground by Pulse Code Modulation (PCM) telemetry through Operational Instrumentation (OI) MDMs at 1 sample/sec.

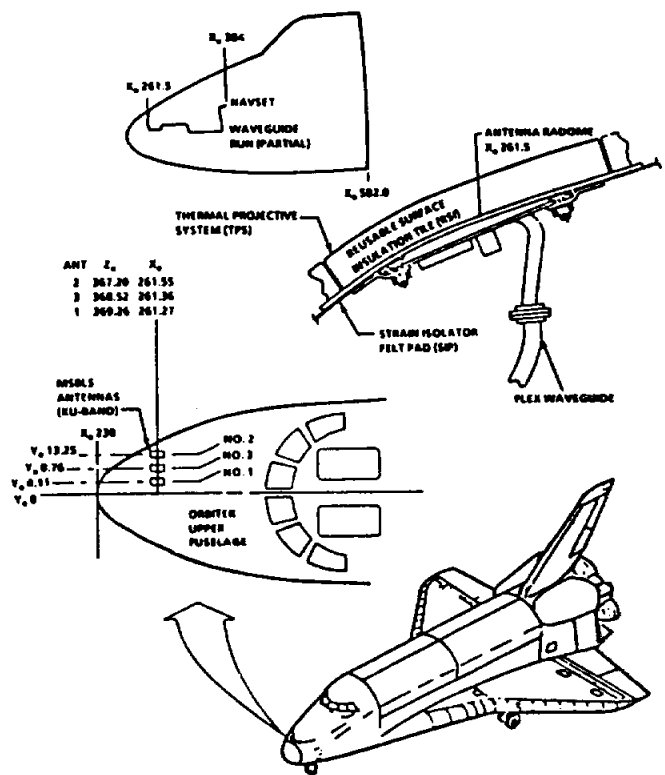


Figure 2-4.—MLS antenna locations on Orbiter.

MLS-NS Built-In-Test-Equipment (BITE) circuitry provides a method to check for failures throughout the functional path of the system continuously during normal operation and during a specially commanded self-test routine in OPS 8 or OPS 9. Self-test causes a reply signal to be simulated providing fixed known outputs for evaluating the operation of this system. In OPS 8 and 9, self-test causes BITE to be displayed on the SENSOR SELF-TEST Display (SPEC 40) if a BITE is detected.

Microwave Landing System Crew Controls

The MLS receives power from Main Buses A, B, and C through the circuit breakers (cb) on panels O14, O15, and O16 (figure 2-5). When the cb's are activated, power is applied to the MLS power ON/OFF toggle switches on panel O8.

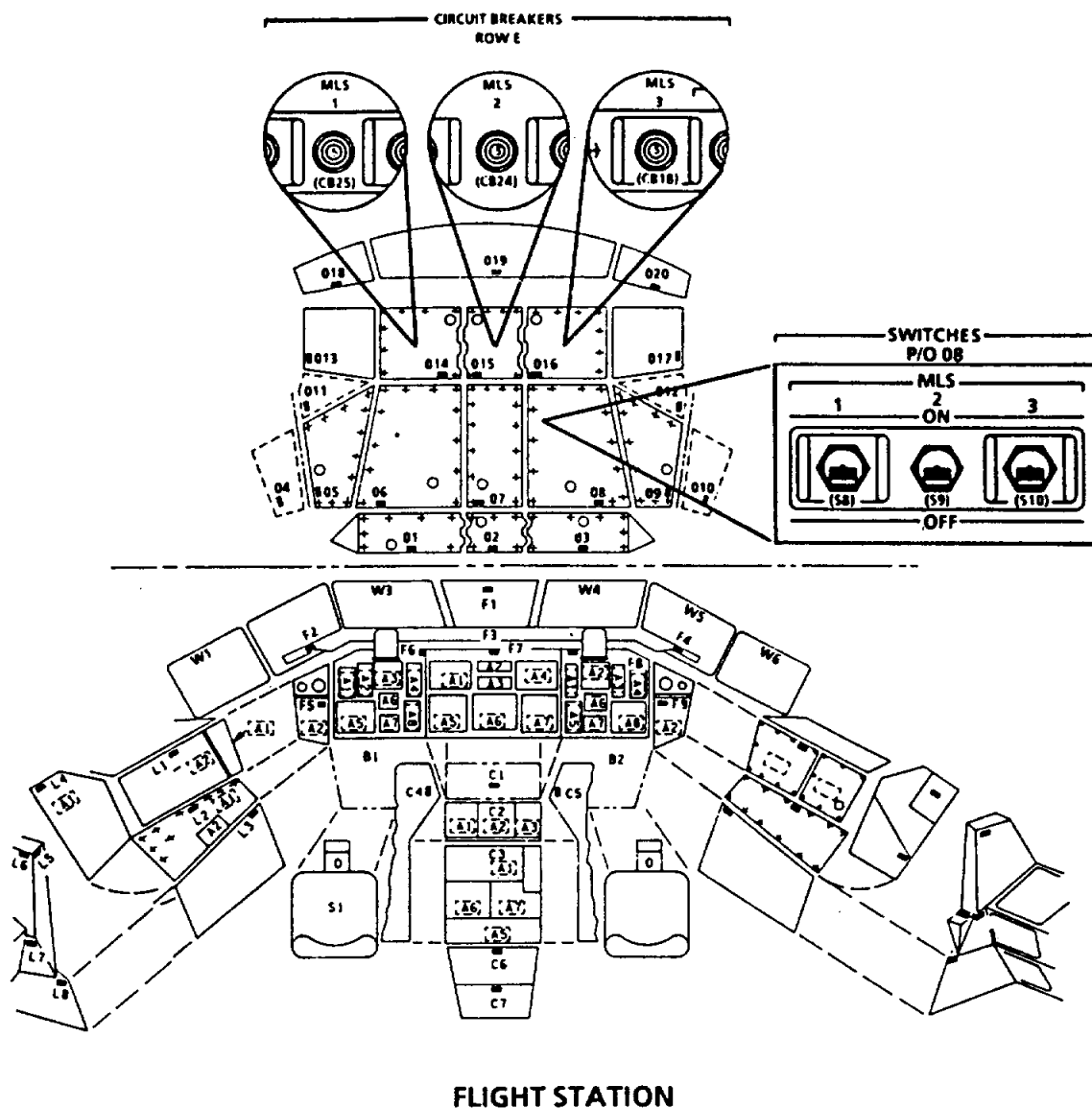


Figure 2-5.- MLS power control.

The CHANNEL select switches are located on panel O8 (figure 2-6). A separate CHANNEL select switch is dedicated to each MLS. The CHANNEL select switch is a 10-position thumbwheel switch (0-9) that allows the crew to select the MLS channel for the ground station located at the selected runway.

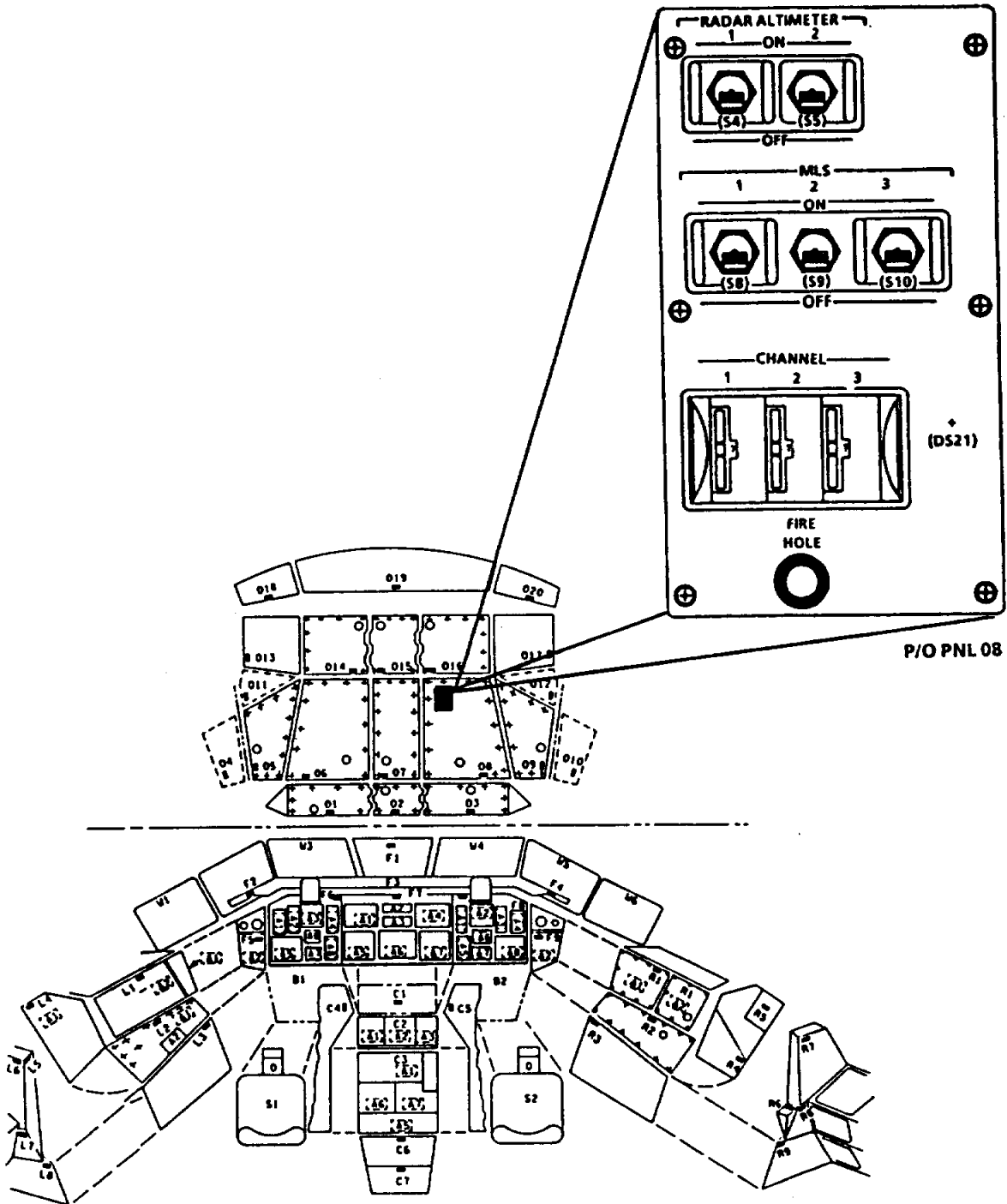


Figure 2-6.- MLS channel select.

The Horizontal Situation Indicator (HSI) SELECT switches, which are located on panels F6 and F8 under each HSI (figure 2-7), control the data input to the HSIs. The MODE switch provides a signal to the GPCs which select data to display for the Entry, TAEM, or Approach phase of flight. When the SOURCE switch is set to MLS, the HSI will display area navigation data calculated using raw MLS data (as opposed to TACAN) from one of the three MLS Navsets, as selected on the adjacent toggle switch. When the SOURCE switch is set to NAV, the HSI will display data from GPC Navigation. (NOTE: Each MLS unit can be compared to NAV using the HSI SOURCE switches. This is one of the tools available for the crew to use to solve MLS dilemmas.)

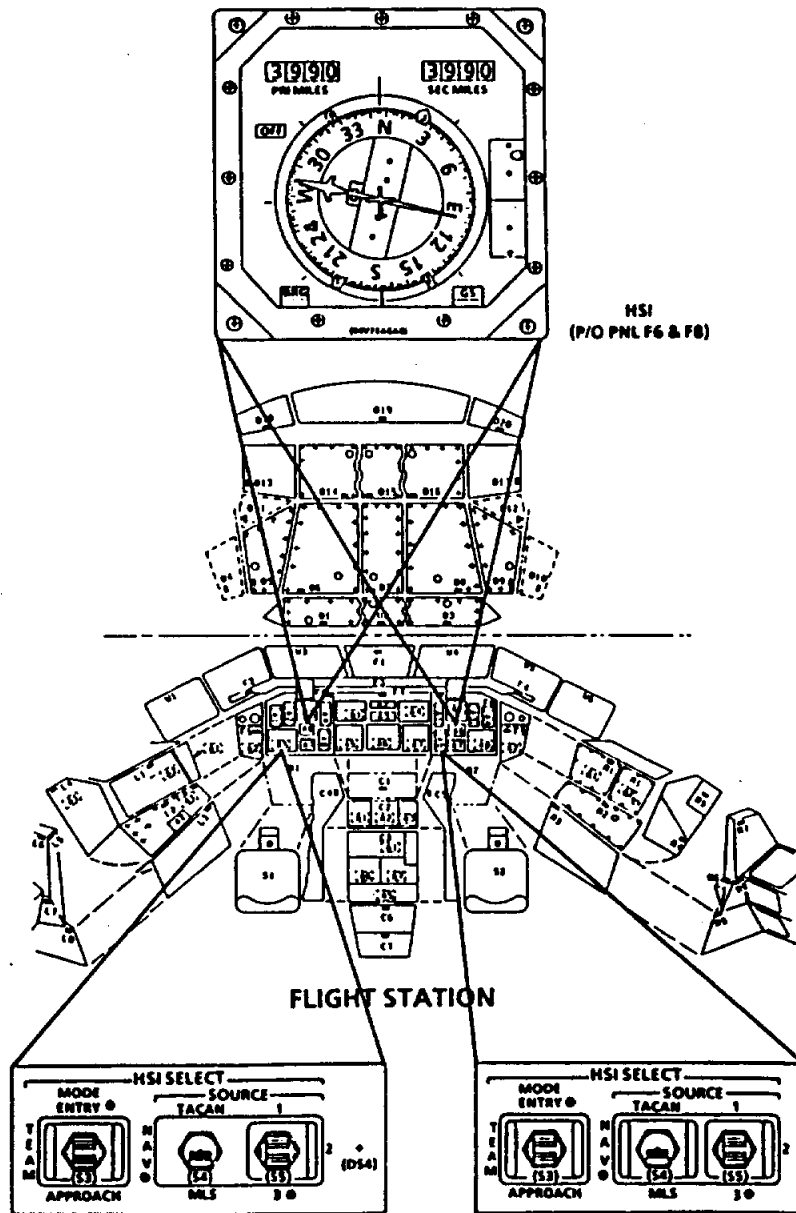


Figure 2-7.- Horizontal Situation Indicator and controls.

Raw MLS data or MLS derived information from GPC NAV are presented to the crew by two dedicated display instruments, the HSI (depending on the position of the source switch) and the Heads-Up Displays (HUD).

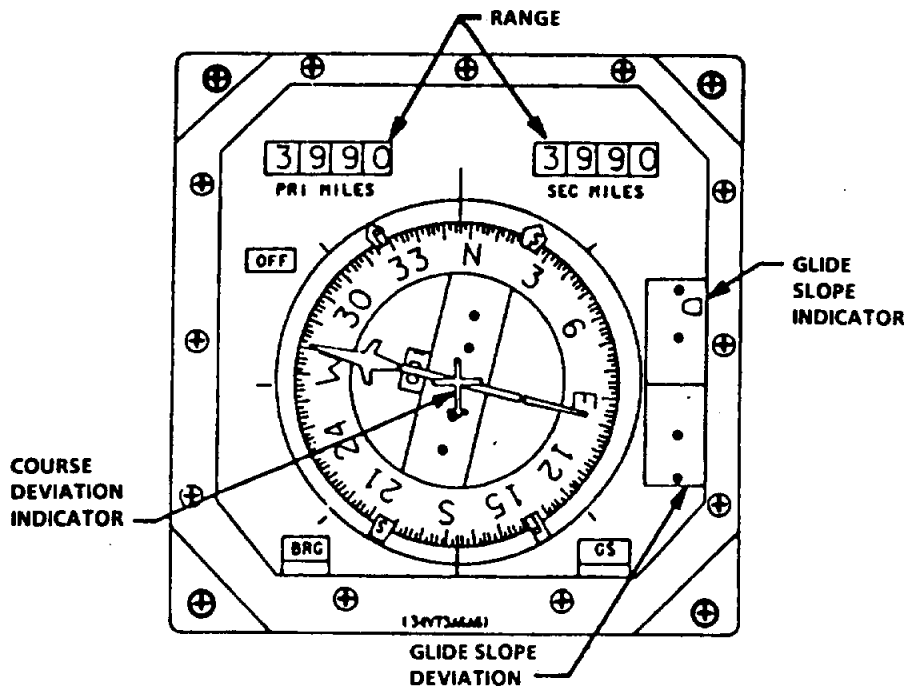


Figure 2-8.- Horizontal Situation Indicator.

The course deviation indicator (CDI) is displaced from the center of the HSI by MLS azimuth data. Displacement towards the dots on the right tell crewman to fly toward the right. Corrections are always made by flying in the direction of displacement.

Elevation data drives the glide slope deviation indicator. Elevation angle is represented by a pointer and accompanied by a scale. When the Orbiter is below the desired flight path angle, the pointer indicates this by moving to a position above the HSI centerline. In this manner, the pointer is a fly-to indicator.

Range information is displayed in the upper left and right corners. This range is the distance to the primary and secondary waypoints (guidance's points along the entry trajectory).

Guidance information is presented to the crew on two Heads-Up Displays (HUDs). Images of flight critical information in various formats are projected from a

cathode ray tube into the commander's and pilot's line of sight. This allows the crew to see the displayed information while looking out the window. Display format 1 (approach and landing) is shown in Figure 2-9.

Note: This figure is not a valid flight configuration

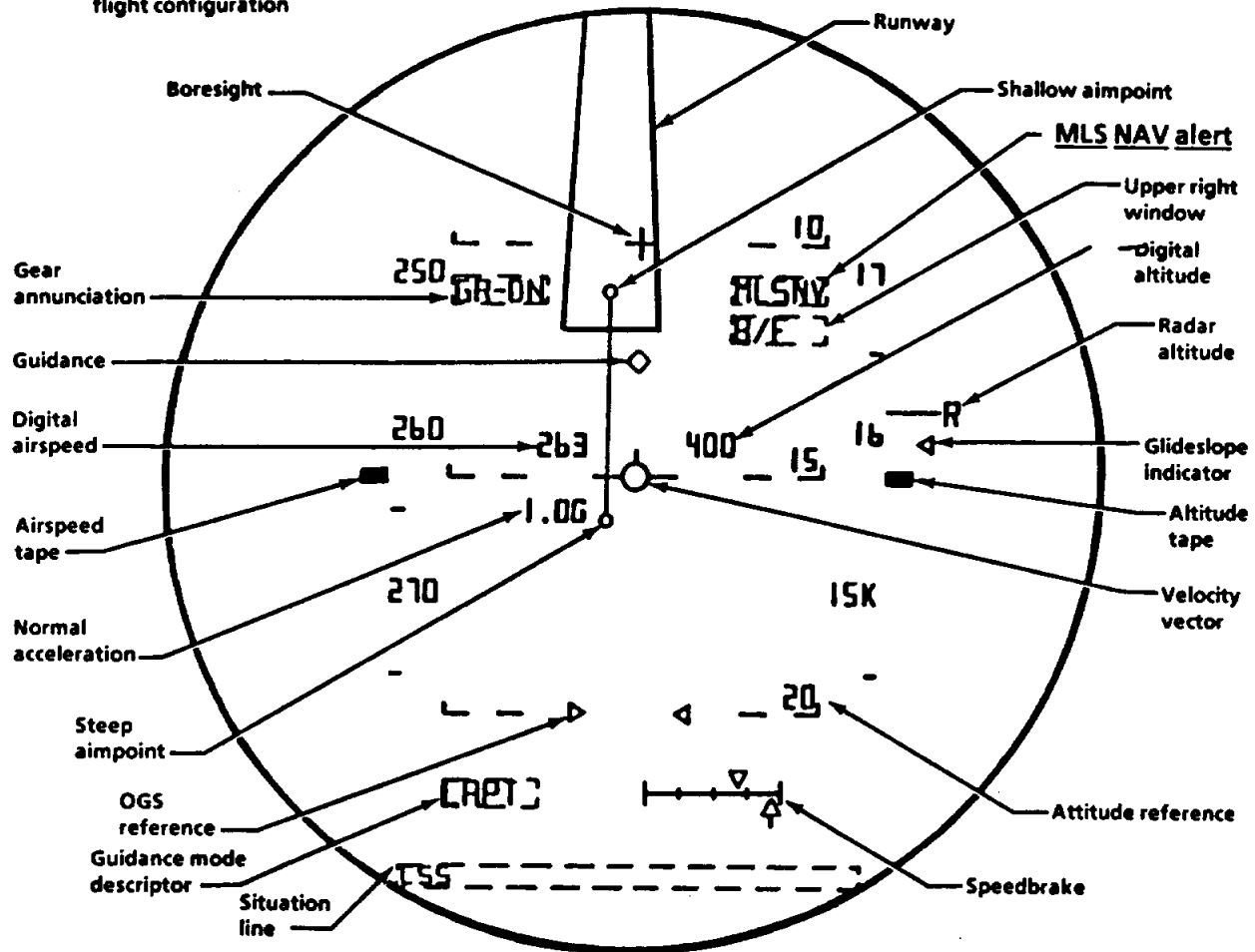


Figure 2-9.- HUD display format 1 (approach and landing).

Event cues and crew alerts are displayed (flashing) in the upper right windows of the HUD displays. NAV is continuously checking for MLS data at an altitude of 12,000 ft and below. If MLS data is lost for more than 6 sec after having once been acquired, an "MLS NV" alert message will be displayed.

Microwave Landing System CRT Displays

MLS information is displayed on three CRT displays: GNC SYS SUMM 1 (the MLS portion is supported in OPS 3 and 6), SENSOR TEST in OPS 8, and SENSOR SELF-TEST in OPS 9.

The GNC SYS SUMM display shows the operational status of the GNC systems and supports the GNC C&W system (figure 2-10). The display is available by using the SYS SUMM key or by calling up SPEC 18. The lower right corner of the display shows the status of the Nav systems including the MLS. The status columns for each unit may show blank (system OK), a down arrow (unit failed), "M" (data missing due to commfault or loss of lock), or "?" (dilemma). GNC SYS SUMM 1 is a non-interactive display.

XXXX/XXX/018		GNC SYS SUMM 1			XX X DDD/HH:MM:SS DDD/HH:MM:SS					
RCS	JETISOL	SURF	POS	MOM	DPS					
MANFFA	LVLV				1	2	3	4	5	
F1XXX	XXS	L OB	XXX.XS	XXS	GPC	S	S	S	S	S
2XXX	XXS	IB	XXX.XS	XXS	MDM	FF	S	S	S	S
3XXX	XXS	R IB	XXX.XS	XXS	FA	S	S	S	S	
4XXX	XXS	OB	XXX.XS	XXS						
5XXX	XXS	AIL	XXX.X							
L1XXX	XXS	RUD	XXX.X		FCS CH 1 2 3 4					
2XXX	XXS	SPD BRK	XXX.X			S	S	S	S	
3XXX	XXS	BDY FLP	XXX.X							
4XXX	XXS		XXXXXX		NAV					
5XXX	XXS				1	2	3	4		
R1XXX	XXS	CNTLR			1	2	3			
2XXX	XXS	RHC	L	S	S	S				
3XXX	XXS		R	S	S	S				
4XXX	XXS		A	S	S	S				
5XXX	XXS	THC	L	S	S	S				
			A	S	S	S				
		SBTC	L	S	S	S				
			R	S	S	S				

(XX)

Figure 2-10.— GNC system summary 1.

The SENSOR TEST display (figure 2-11), which is available in OPS 8 and can be called up with SPEC 40 PRO, provides a means of initiating, monitoring, and terminating the self-test of the MLS. It also provides control of the Selection Filter.

Execution of a DES item number changes the selection of a MLS unit as a candidate for the selection filter. An "*" appears next to the item number if the corresponding unit is deselected as a candidate. The selection filter configuration from this display is carried over into OPS 3.

XXXX/040/		SENSOR TEST				XX X	DDD/HH:MM:SS	DDD/HH:MM:SS
		DES	STAT	RNG	AZ	EL		
MLS	1	1X	XXXX	XX.XS	±X.XXS	X.XXS		
	2	2X	XXXX	XX.XS	±X.XXS	X.XXS		
	3	3X	XXXX	XX.XS	±X.XXS	X.XXS		
		DES	STAT	RNG	AZ			
TAC	1	4X	XXXX	X.XS	XXX.XXS			
	2	5X	XXXX	X.XS	XXX.XXS			
	3	6X	XXXX	X.XS	XXX.XXS			
		DES	STAT	ALT				
RA	1	7X	XXXX	XXXXS				
	2	8X	XXXX	XXXXS				
		DES		Y	Z			
AA	1	9X		±XX.XS	±XX.XS			
	2	10X		±XX.XS	±XX.XS			
	3	11X		±XX.XS	±XX.XS			
	4	12X		±XX.XS	±XX.XS			
		START 13X		STOP 14X				
								(XX)

Figure 2-11.-- Sensor test.

RNG in nautical miles, azimuth (AZ) in degrees, and EL in degrees are displayed for each MLS. These values are compared to the self-test limits and a status indicator is displayed beside each test parameter indicating the results of the tolerance check. If the BITE indicator is set, BITE will appear in the status column; it will blank once the condition is corrected. The self-test controls are shown at the bottom of the display. Execution of item 13 starts the self-tests on all the displayed sensors. Execution of item 14 stops the self-tests. An "*" appears next to item 13 or 14 to indicate, respectively, tests underway or tests stopped. Item 13 and 14 are initialized blank.

The SENSOR SELF-TEST display is available in OPS 9 through SPEC 101 PRO for pre-flight and postlanding checkout of the MLS and other sensors (figure 2-12). It is the ground test equivalent of the on-orbit SENSOR TEST (SPEC 40).

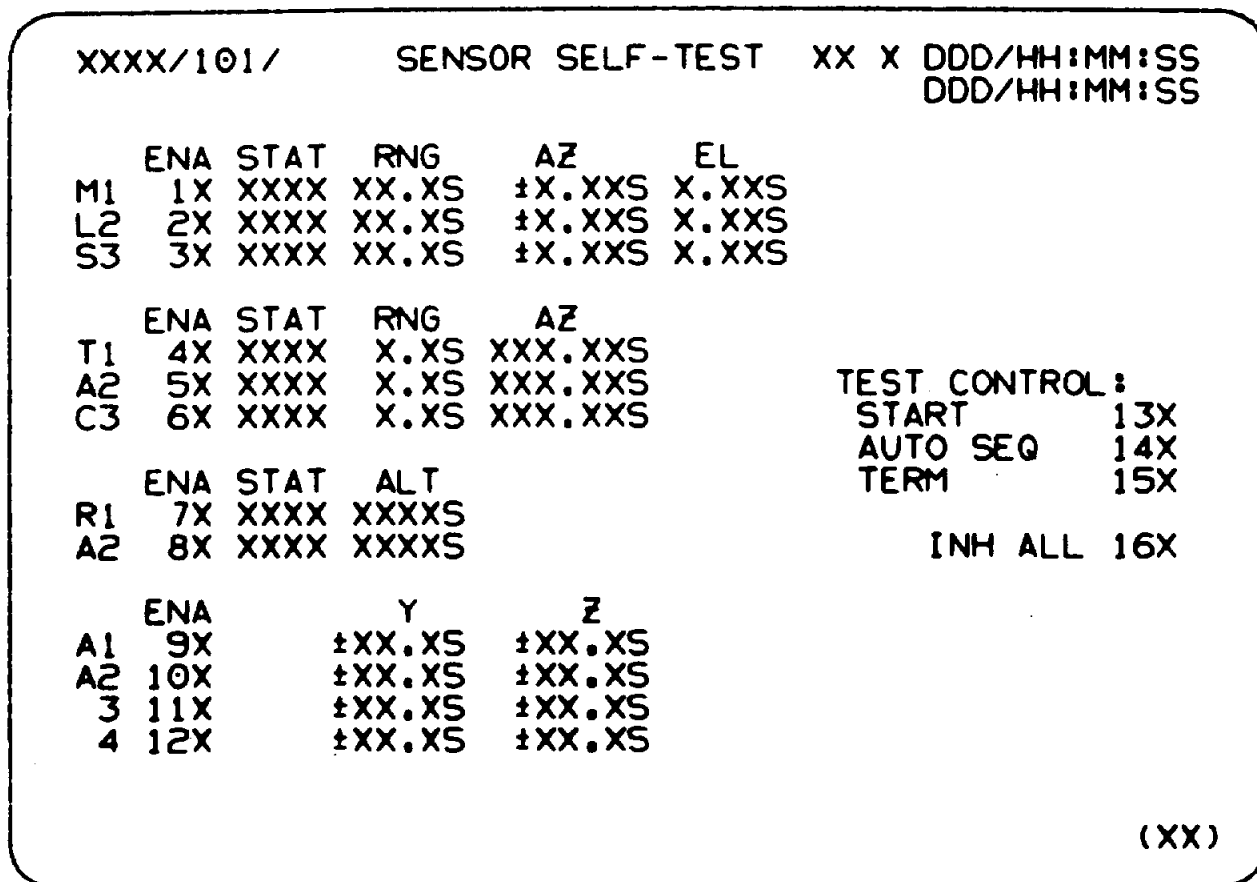


Figure 2-12.— Sensor self-test.

Orbiter Microwave Landing System Software

The three MLS units provide azimuth, elevation, and range data for navigation updates and crew display. The MLS software begins processing in the PASS upon transition to Major Mode (MM) 305 from MM 304 and MM 603 from MM 602. It is also tested in the on-orbit self-test (GNC OPS 8) prior to deorbit. MLS is not processed by the BFS.

MLS units are selected as Candidates for software processing in OPS 8. The capability for manual deselection (downmoding) of MLS units through software is only provided in OPS 8. MLS units deselected in OPS 8 remain deselected across OPS transitions. Automatic deselection capability is only provided by RM starting in MM 305 and once deselected cannot be reselected.

Subsystem Operating Program

The MLS Subsystem Operating Program (SOP) converts the MLS data into a format that can be used by other software modules and routes it to them. The SOP sends three sets of range, azimuth, and elevation data to RM. RM then sends to NAV the RM-selected range, azimuth, and elevation to be used as a source in state vector updates. The three sets of data are also sent to the GPC NAV module of navigation software for HSI display processing at a rate of 3.125 Hz.

To minimize errors due to weak signal strength, a limit check is performed on the raw data against the I-loaded limits listed below:

- * Shuttle heading with respect to selected runway centerline must be within +/- 40 DEG to satisfy EL and AZ.
- * $0.5 < \text{Elevation} < 29 \text{ DEG}$.
- * $\text{Azimuth} < 13.5 \text{ DEG}$.
- * $\text{Range} < 15 \text{ NM}$.

Redundancy Management

The MLS Redundancy Management (RM) software performs two major functions (figure 2-13). The SF is used to select a range, azimuth, and elevation parameter from multiple data sources or Candidates. These parameters can then be declared failed through the FDIR. The FDIR function presently runs only in OPS 3 in PASS and not in any other OPS nor in the BFS. NOTE: starting with STS-43 (OI-20 software) FDIR will function in both OPS 3 and in OPS 6 of PASS. The SF runs in OPS 3 and OPS 6 in PASS only. MLS RM information is displayed on the GNC SYSTEM SUMMARY 1 display, the HSI, and the HUD.

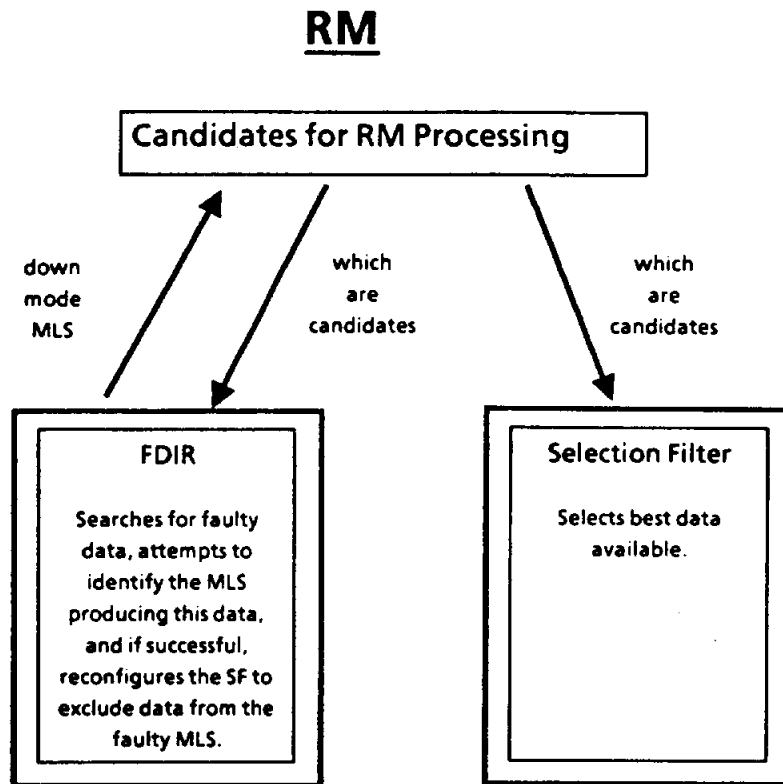


Figure 2-13.-Redundancy management processing.

Selection Filter

The purpose of the MLS SF is to select single values of range, azimuth, and elevation (from the available Candidates) to provide to other software modules/routines. The SF module, which runs at a rate of 0.52 Hz (2 sec/cycle), determines the selected data to be used by navigation software. This is accomplished by monitoring Comm-faults, Lock-On Status, BITE Flag Status, Crew Select/Deselect Status, and Comparison of Data Values between the MLS Units. The DG FLAG is set True if the MLS units are available for processing or considered Candidates.

Three Level SF

Selected output data is midvalue selected from the three available units. In this case, the DG flag is set to a true state to notify Navigation (NAV) that good data is available to be processed. If one of the MLS units starts putting out data outside the RM limits, mid-value selection protects against its use by NAV until the unit is downmoded by FDIR.

Two Level SF

At the two level, the selected data is the average of the data from two available units. The RM limit test performed in FDIR is also performed in the SF to determine whether the units disagree. If the difference between the two units exceeds the RM limits for only one count, the DG flag will be set to false so that the data will not be used. Meanwhile, FDIR will continue to attempt to isolate the failure. The rationale for immediately setting the DG flag to false is to avoid averaging bad data. If the miscompare goes away with subsequent data, the DG flag will be set to true again and MLS data will once again be used. NOTE: Since presently there is no FDIR in OPS 6, if a miscompare exists, the DG flag will be set bad for that parameter and the data will not be used; no annunciation.

If the miscompare is in elevation, elevation data will not be used. If the miscompare is in range or azimuth, no MLS data will be used and NAV will resume using TACAN and Air Data information again (if above 1500 feet). Ratios/residuals for TACANs and Air Data will reappear on SPEC 50 when their data is being used. Also remember since there is presently no FDIR in OPS 6 no annunciation will be present for this miscompare... a silent dilemma!

One and Zero Level SF

At the one level, the only data available is selected and the DG flag is set true automatically. When there are no MLS units available, the DG flag is set false and no new data will be sent to Nav.

Fault Detection, Identification, and Reconfiguration

The MLS FDIR function detects errors and faults in the azimuth, elevation, and range data and determines which MLS unit(s), if any, should be declared failed. Declaring a parameter failed results in fault annunciation and FDIR downmoding of that MLS unit.

The FDIR function utilizes the same Commfault, Lock-on, and Bite States as in the SF module to determine the available MLS units. The DG flag status determines which MLS units are available for processing or considered Candidates. A parameter is temporarily withheld from FDIR, but not declared failed, for Loss of Lock or Commfault.

Based on availability, the absolute data difference between units is compared against a RM tolerance or limit. The RM limits for azimuth, elevation, and range are listed in table 2-3.

Table 2-3.- MLS FDIR RM limits.

Maximum MLS parameter differences	Az	EI	Rng
	0.5°	0.4°	2000 ft (0.329 n.mi.)

Three Level FDIR

For the case of three MLS candidates a parameter is declared failed if it is the common parameter (P) in two miscomparisons for three consecutive FDIR cycles.

$$(P1 - P2) > k, (P1 - P3) > k, (P2 - P3) > k,$$

k is the RM limit

That MLS unit is then removed from further processing. At an FDIR rate of 0.25 Hz (approx. 4 sec/cycle), three consecutive miscompares take 12 sec. Downmoding causes a down arrow to be displayed on GNC System Summary 1, a "RM FAIL MLS" fault message to appear on all active PASS CRTs, and a SM alert light and alarm tone to be generated.

Two Level FDIR

When one MLS unit has been downmoded, a MLS RM limit comparison is made by FDIR between the two remaining units. If RM is exceeded, the presence of BITE is

checked to resolve the dilemma. If the BITE indication is present for an MLS, that MLS unit is declared failed and the FDIR is downmoded to the case of one good MLS. If no BITE or a BITE on both MLS unit are present, the disagreement is annunciated and FDIR continues in dilemma until the crew solves the dilemma. In the dilemma case, two dilemma markers "?" would be displayed on GNC System Summary 1, a "RM DLMA MLS" fault message would appear on all active PASS CRTs, and an SM alert light and alarm tone would be generated. NOTE: Once an MLS unit has been downmoded by FDIR, it cannot be upmoded.

The HSI is the only place where MLS data can be displayed for the crew to use to solve MLS dilemmas; however, there are several tricks that can be used to help identify what parameter is in the dilemma. After MLS locks on, the MLS data must pass the limit checks listed below before it is considered valid data:

- * Shuttle heading with respect to selected runway centerline must be within ± 40 DEG to satisfy Elevation and AZ requirements.
- * $0.5 < \text{Elevation} < 29$ DEG.
- * Azimuth < 13.5 DEG.
- * Range < 15 NM.

Therefore, range is considered valid anytime it is less than 15 n. mi. AZ and elevation are considered valid only when the Orbiter's heading is within 40 deg of the runway. As the Orbiter goes around the HAC (Heading Alignment Cone) range data is considered valid but azimuth and elevation are not because the Orbiter is outside 40 deg with respect to the runway centerline. If a dilemma is annunciated while going around the HAC, it will be a Range Dilemma.

Once MLS range and azimuth data are valid, the residuals and ratios for both TACANs and Air Data vanish. If an MLS dilemma is annunciated and the TACAN and Air Data residuals/ratios remain blank, then the dilemma is an Elevation Dilemma because range and azimuth data are still valid. Range and azimuth parameters are required for MLS to be processed but elevation is not required; more to follow on this subject under MLS Usage in Navigation section.

The last trick: As the Orbiter flies around the HAC the TACAN's residuals/ratios should eventually blank as the Orbiter's heading with respect to the runway centerline becomes less than 40 deg, allowing the azimuth to become valid. Remember both azimuth and range must be valid for Nav to process MLS. If a MLS dilemma is annunciated while the Orbiter's heading is within 40 deg and the TACAN's residuals/ratios remain blank, then most likely it is an Azimuth Dilemma. The TACAN's residuals and ratios never go away because either range or azimuth is not valid and the best guess is that it is an azimuth dilemma because the Orbiter went around the HAC without a dilemma. This last conclusion rests on the assumption that any MLS range problem would have happened long before rounding the HAC. If the problem occurs after the HAC, then this could be either a range or an azimuth dilemma. See summary below:

1. Dilemma while Orbiter heading is > 40 deg with respect to runway (i.e., going around the HAC) is a Range Dilemma.
2. Dilemma after MLS locks on, but TACAN residuals and ratios remain blank, is an Elevation Dilemma.
3. Dilemma while Orbiter heading is < 40 deg with respect to runway, TACAN residuals and ratios never appear, is most likely an AZ Dilemma. There is a small possibility it could be a RNG Dilemma.

One and Zero Level FDIR

No FDIR exists at the one and zero level.

Microwave Landing System Usage in Navigation

During approach and landing, NAV uses MLS data to estimate the Orbiter's position and velocity (the state vector) relative to the runway. The crew must dial up the MLS channel number corresponding to the selected runway for the proper MLS data to be supplied to NAV. MLS channel selection is not downlinked on telemetry, so ground controllers cannot tell if the wrong channel is selected. If a runway is selected which does not have MLS, NAV sets the MLS AVAIL flag to OFF which inhibits NAV processing of any MLS data which may be received from another runway.

When MLS azimuth and range are acquired, NAV stops processing TACAN and Baro (Air Data) data and starts processing MLS data in addition to IMU data to update the state vector. Elevation data is incorporated into NAV if valid, but elevation data is not necessary for azimuth and range data to be used. However, neither azimuth nor range data is incorporated into NAV without the other. NAV must see a Data Good flag set true for azimuth and a DG flag set true for range for at least one unit for MLS data to be used.

GNC SYS SUMM is monitored by the crew for MLS lock-on status and GNC SPEC 50 for navigation incorporation. When the "M's" on SYS SUMM blank next to the MLS status, both azimuth and range MLS data has locked on. NAV will stop processing TACAN and baro data and start processing MLS data as indicated by the residuals and ratios becoming blank on GNC SPEC 50. If TACAN data is being FORCED on SPEC 50, MLS data will never get incorporated into NAV.

Preland Navigation is automatically initialized when Entry Navigation first receives a "Data Good" flag from MLS RM. Once preland navigation is initiated, it will continue through touchdown and rollout even if the MLS data drops out. In Preland Navigation, only one state vector is propagated as compared to three state vectors (one for each IMU) in Entry Navigation. There are two reasons for downmoding to one state vector. First, since accurate information is very important near the ground, Preland Navigation cycles once every 1.92 sec as compared to once every 3.84 sec for Entry Navigation. With the shorter cycle time, fewer calculations can be performed in Preland Navigation. Second, and more significantly, the MLS data is much more accurate than any of the sensor data available in Entry Navigation. The safety factor of having a state vector from each IMU to minimize errors due to an IMU failure is not needed. NAV will revert back to processing TACAN and baro data if MLS data are lost above 1500 feet for more than 6 seconds. Baro data will only be used above 500 feet to prevent transients at low altitudes.

Near touchdown, NAV latches out all further MLS elevation data when the selected MLS elevation data drops below 1.2 Deg. This is to prevent incorporation of erroneous data as the elevation angle increases as the Orbiter passes the elevation ground station.

Launch Commit Criteria Requirements

Two of three MLS are required for launch if both Radar Altimeter (RA) are good. However, three of three MLS units are required if one RA is failed.

BFS Differences

BFS does not support MLS.

Questions: Microwave Landing System

1. When is MLS data used?
2. What parameters does MLS provide?
3. List the two channels that have been cleared for Orbiter landing operations.
4. MLS is processed by BFS and PASS. True or False
5. MLS FDIR processes in OPS 3 and 6 for PASS. True or False
6. What are the MLS RM limits?
7. What two parameters are needed to process MLS?
8. What is Preland Navigation?

Answers: Microwave Landing System

1. MLS is used upon switchover from TACANS at an altitude of approximately 18,000 feet.
2. a) azimuth angle
b) elevation angle
c) slant range
3. Channels 6 and 8
4. False, BFS does not use MLS
5. Presently in OPS 3 only! However, STS-43 will have FDIR in both OPS 3 and 6 for PASS (OI-20 software).
6. AZ - ~0.5 degree
EL - ~0.4 degree
RNG - ~2,000 ft
7. AZ and RNG are needed. EL is optional and used if available.
8. Preland Navigation is automatically initialized when Entry Navigation first receives a "Data Good" flag from MLS RM. Only one state vector is propagated as compared to three state vectors (one for each IMU) in Entry Navigation.

Section 3: Radar Altimeter

Introduction

The Orbiter uses two Radar Altimeters (RAs) which operate concurrently. The RA is a low-altitude terrain-tracking radar system. Accurate tracking is maintained at altitudes between 0 and 5000 feet. The RA can measure absolute altitude to the nearest terrain and can track altitude rate changes up to 2000 ft/s. The RA is used only for displaying altitude data on the Altitude/Vertical Velocity Indicator (AVVI) and the Heads Up Display (HUD).

Performance Objectives

As a result of studying this section, the student should be able to do the following:

- Explain when RAs are available
- Describe whether or not RA data is fed to NAV
- Explain what is required to establish RA communications
- Identify which RA BFS will use

Radar Altimeter Operation

Each Radar Altimeter has two antennas, one transmitting and one receiving. The antennas are located on the underside of the Orbiter's nose (Figure 3-1). The antenna beam width is a 40 deg cone about the Orbiter's z-axis.

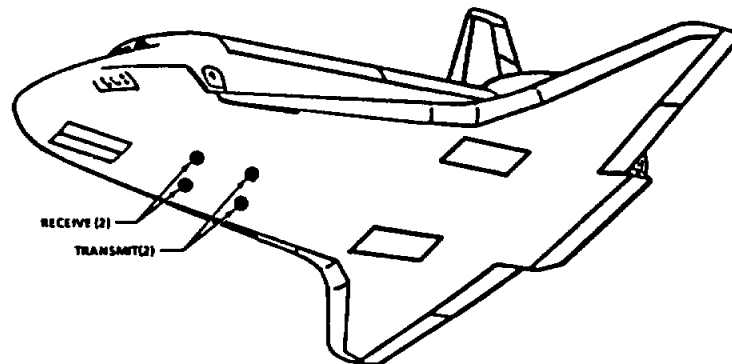


Figure 3-1.– RA antenna location.

Altitude information is derived from tracking the reflected ground pulse. Altitude signals are proportional to the elapsed time required for a pulse to return from the ground. The returning pulse is a function of height or distance from the nearest terrain. The RAs remain locked onto the return pulse during altitude change rates up to 2000 feet per second. This allows tracking of mountain or cliff sides ahead of or adjacent to the vehicle if these obstacles are nearer than the ground below, and provides warning of rapid changes in absolute altitude.

RA 1 is connected to Flight Forward (FF) MDM 1 and RA 2 to FF MDM 2. Within the MDM is a special Input/Output Module (IOM) or "card" which is dedicated to RAs and TACANs (this scheme was implemented to accommodate off-the-shelf TACAN and RA equipment). If this Module fails a BCE STRG X TAC fault message will be annunciated. This will inhibit TACAN and RA data inputs from that MDM to the GPCs. NOTE: A useful point to remember is that because the TACAN and RA are attached to this special IOM, no I/O RESET is needed when these units are powered ON.

Radar Altimeter Crew Controls

The RA requires 28 Vdc which is controlled by circuit breakers on Panel O14 and O15 and by power ON/OFF switches located on Panel O8 (See Figure 3-2). Both RAs are powered ON for Ascent and Entry. An I/O RESET is not required to establish communication with the RAs or TACANs after they are powered ON.

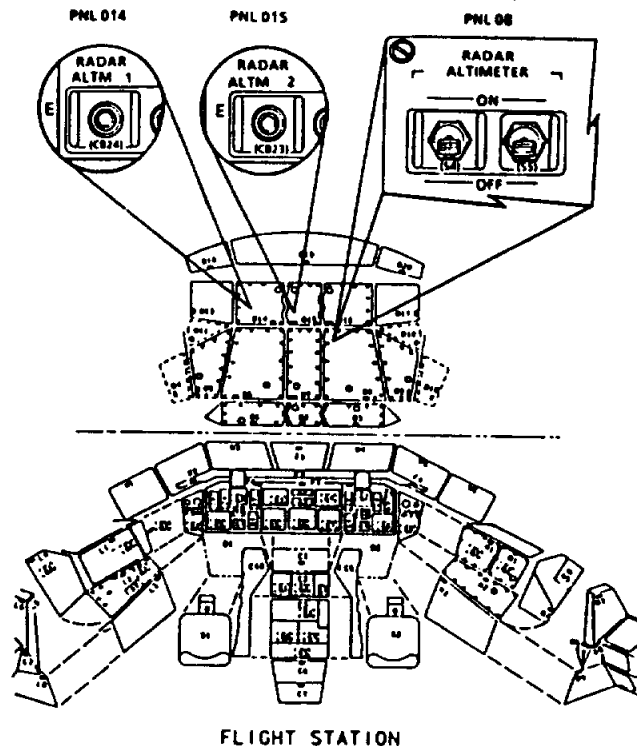


Figure 3-2.- RA power control.

The RA select switches are located on Panel F6 and F8 near the AVVIs. These switches allow the crew to select which radar altimeter (RA1 or RA2) is to be displayed on the AVVIs (Figure 3-3). When the RAs lock on at 5000 feet it is important for the crew to evaluate them to detect any altitude bias. One method used is to flip the RA switch from 1 to 2 and watch for the tapes to jump. If they jump, one RA is biased. To determine which RA is biased, they can be compared to NAV selected altitude by selecting NAV on the Air Data switch on Panel F6/F8. Nav altitude will drive the altitude tape to the left of the RA altitude tape on the AVVIs. (NOTE: Figure 3-3 shows that the scale of the RA tape changes at 1500 feet. Because of this scale change it is harder to see small RA altitude biases at higher altitudes, while below 1500 feet they seem significant.) Nominally the CDR will select RA 1 and the PLT will select RA 2.

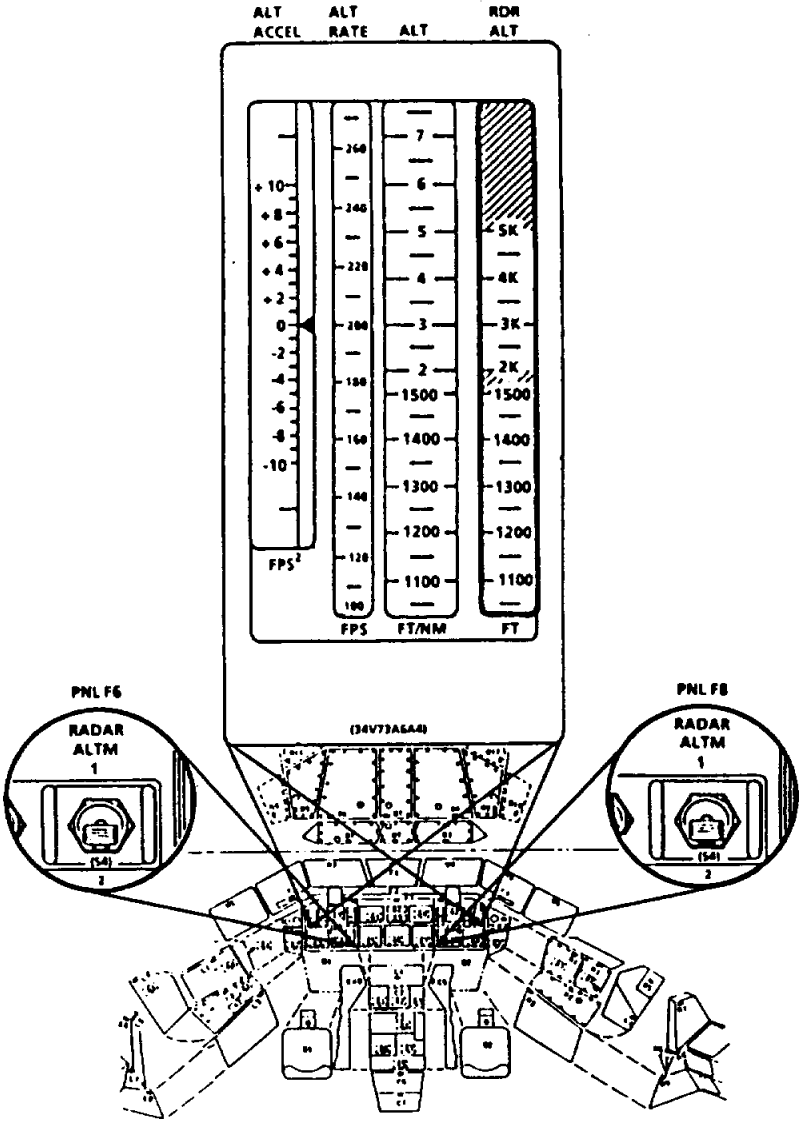


Figure 3-3.- AVVI/RA select.

If FF 1 MDM fails, several Line Replaceable Units (LRUs) which are connected to FF 1 are also bypassed to include RA 1. An FF 1 failure also fails the CDR's instruments to their GREEN DOT positions, which means the instrument switches support only one position. Small green dots are placed next to these positions on the instrument panels. When an instrument panel has a failure such that the switches support only the GREEN DOT positions, the crewmembers move the switches to these positions. Since an FF 1 failure takes out RA 1 and makes the CDR's instruments GREEN DOT, the GREEN DOT position for the RA switch on the CDR's instruments is RA 2. The CDR GREEN DOT position is RA 2 and PLT position is RA 1, opposite their normal position (see Reference Data FDF for Green Dot positions).

Radar Altimeter CRT Displays

RA information is displayed on two CRT displays: SENSOR TEST in OPS 8 and SENSOR SELF-TEST in OPS 9.

The SENSOR TEST display (Figure 3-4) is available in OPS 8 and can be called up through SPEC 40 PRO for the on-orbit FCS Checkout. SPEC 40 provides a means of initiating, monitoring, and terminating the self-test of the RA. Altimeter (ALT) in feet is displayed for each RA. These values are compared to the self-test limits and a status indicator is displayed next to the ALT parameter indicating the result of the tolerance check. The self-test controls are shown at the bottom of the display. Execution of item 13 starts the self-tests on all the displayed sensors. Execution of item 14 stops the self-tests. An "*" appears next to item 13 or 14 to indicate, respectively, tests are underway or tests are stopped. Item 13 and 14 are initialized blank.

SPEC 40 also provides control of the Selection Filter. Execution of a DES item number changes the RAs as a Candidate for the selection filter. An "*" appears next to the item number if the corresponding unit is deselected as a candidate. The selection filter configuration from this display is carried over into OPS 3. Once the crew deselects a RA, it cannot be selected for display on an AVVI because only the OFF flag will be showing on the tape. (The BFS is not informed of sensors deselected on SPEC 40; therefore, it is important to turn these units OFF.)

XXXX/040/		SENSOR TEST			XX X	DDD/HH:MM:SS
						DDD/HH:MM:SS
		DES	STAT	RNG	AZ	EL
MLS	1	1X	XXXX	XX.XS	±X.XXS	X.XXS
	2	2X	XXXX	XX.XS	±X.XXS	X.XXS
	3	3X	XXXX	XX.XS	±X.XXS	X.XXS
		DES	STAT	RNG	AZ	
TAC	1	4X	XXXX	X.XS	XXX.XXS	
	2	5X	XXXX	X.XS	XXX.XXS	
	3	6X	XXXX	X.XS	XXX.XXS	
		DES	STAT	ALT		
RA	1	7X	XXXX	XXXXS		
	2	8X	XXXX	XXXXS		
		DES		Y	Z	
AA	1	9X		±XX.XS	±XX.XS	
	2	10X		±XX.XS	±XX.XS	
	3	11X		±XX.XS	±XX.XS	
	4	12X		±XX.XS	±XX.XS	
				START 13X	STOP 14X	
						(XX)

TEST LIMITS ARE AS FOLLOWS:

- TACAN

RANGE	0 ± 0.5 NM
BEARING	180 ± 2-1/2°

- MLS

RANGE	15.1 ± 0.2 NM
AZIMUTH	3.0 ± 0.1°
ELEVATION	6.0 ± 0.1°

- RA

ALT	1000 ± 100 FT
-----	---------------

- AA

NORMAL	2.0 ± 0.2
LATERAL	0.5 ± 0.5

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Figure 3-4.- On-orbit sensor self-test.

The SENSOR SELF-TEST display is available in OPS 9 through SPEC 101 PRO for preflight and postlanding checkout of the RA and other sensors (Figure 3-5). It is the ground test equivalent of the on-orbit SENSOR TEST (SPEC 40).

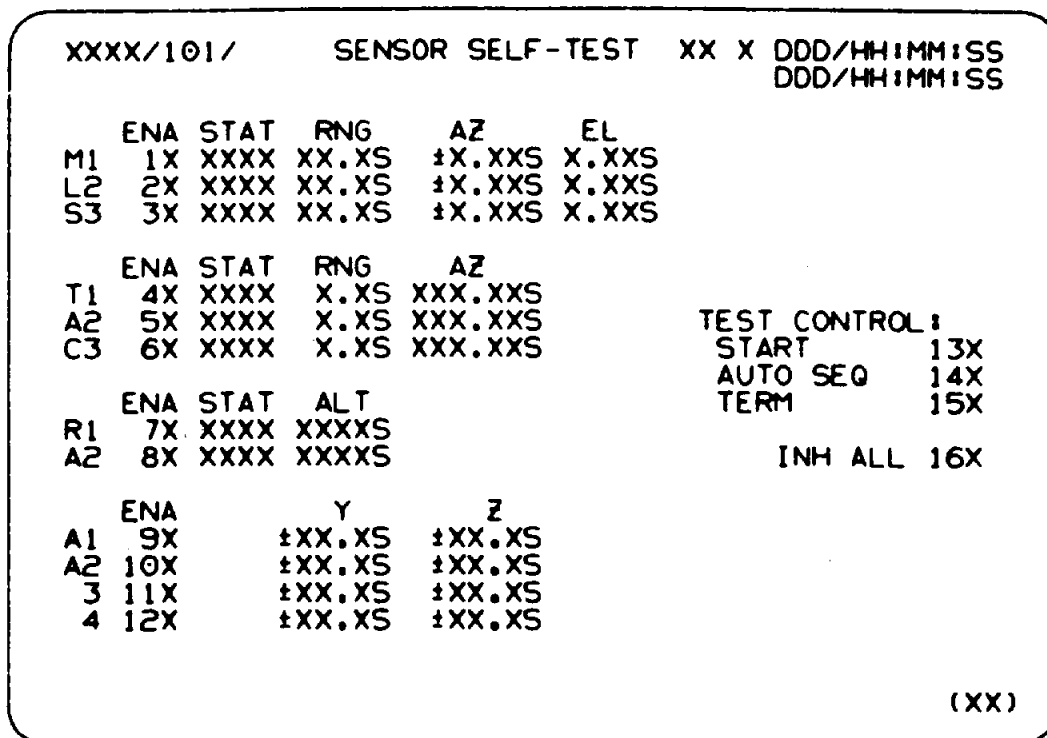


Figure 3-5.- Sensor self-test.

Radar Altimeter Software

The RA software provides the data needed to drive the AVVI and the Heads Up Display (HUD). See figure 3-6. This software provides the crew with the Orbiter's altitude in feet, from the Orbiter's rear wheels to the runway, together with the altitude validity and lock-on indications.

All RA software processing is performed at 6.25 Hz rate (0.16 sec/cycle), and is dispatched by the Ascent, RTLS, and Entry major functions. However, even though the software is working onboard, the only times MCC receives RA telemetry are during OPS 8 FCS Checkout, OPS 6 RTLS, and OPS 3 Entry.

Raw altitude data is processed as long as the RA is locked-on, not commfaulted, and not deselected by the crew. Crew deselection can only be accomplished in OPS 8, but will carry across OPS transitions.

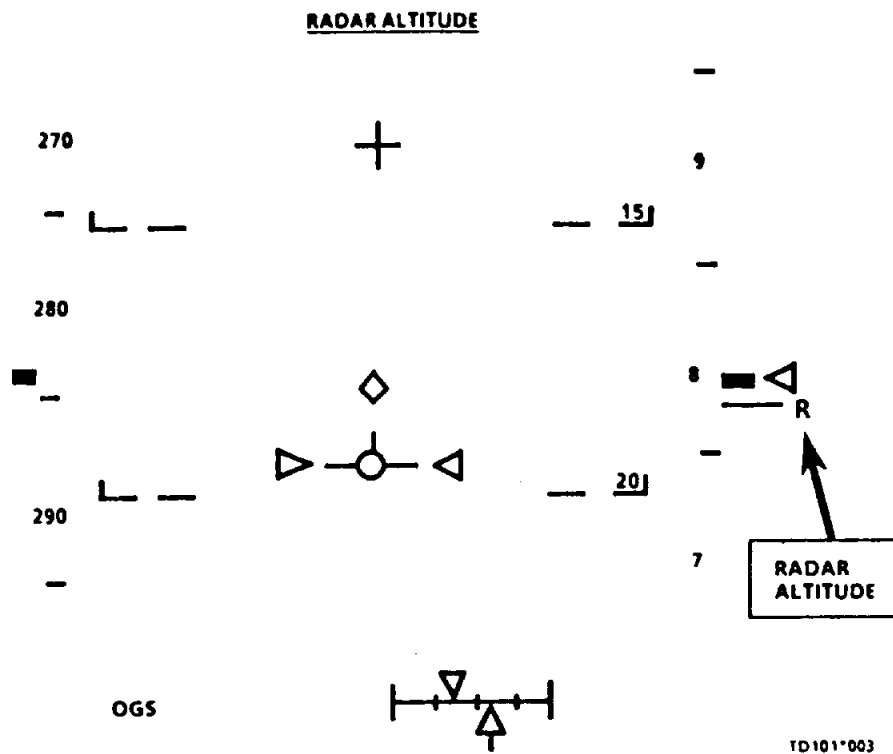


Figure 3-6.- HUD display with radar altimeter.

The RA software does not contain any Fault Detection, Identification, or Reconfiguration (FDIR) logic. The RA data, even though it is not used by navigation (NAV), does go through a Selection Filter (SF) which determines the status and usability of the data depending on the data available. RA data is currently bypassed by the Autoland software and used for display purpose only.

The BFS processes RA for display only on the AVVI during MM 603 and MM 305. The BFS dedicated display processor will output the RA's (the RA that has the first valid lock-on) altitude to both AVVIs. BFS does not read RA select switch positions. In the event RA 1 does not have a valid lock-on or is commfaulted, RA 2 will be utilized. The BFS dedicated display processor will continue to switch between the two RAs in an attempt to obtain one with a valid lock-on. Therefore, if RA 1 locks on late, the BFS would be using RA 2. (If BFS engaged and RA 1 is biased, the only way to display RA 2 is to commfault RA 1. To do this, the RA 1 power switch can be placed to the OFF position.) There is no RA telemetry data from the BFS.

Launch Commit Criteria Requirements

One of two RAs are required for launch. However, two of two RA units are required if one MLS is failed or a night landing is planned.

BFS Differences

1. BFS does not read RA switch positions. The RA that has the first valid lock-on is displayed on both AVVIs.
2. BFS does not support OPS 8 Sensor Test and OPS 9 Sensor Self-Test displays. BFS is not informed of sensors (RAs) deselected on SPEC 40 (Sensor Test) in OPS 8; therefore, it is important to turn these units off.

Questions: Radar Altimeter

1. When is RA used?
2. RA data is fed to NAV to update SV. True or False
3. RA requires no I/O RESET when these units are powered ON. True or False
4. BFS uses RA 1 for display purposes only. True or False

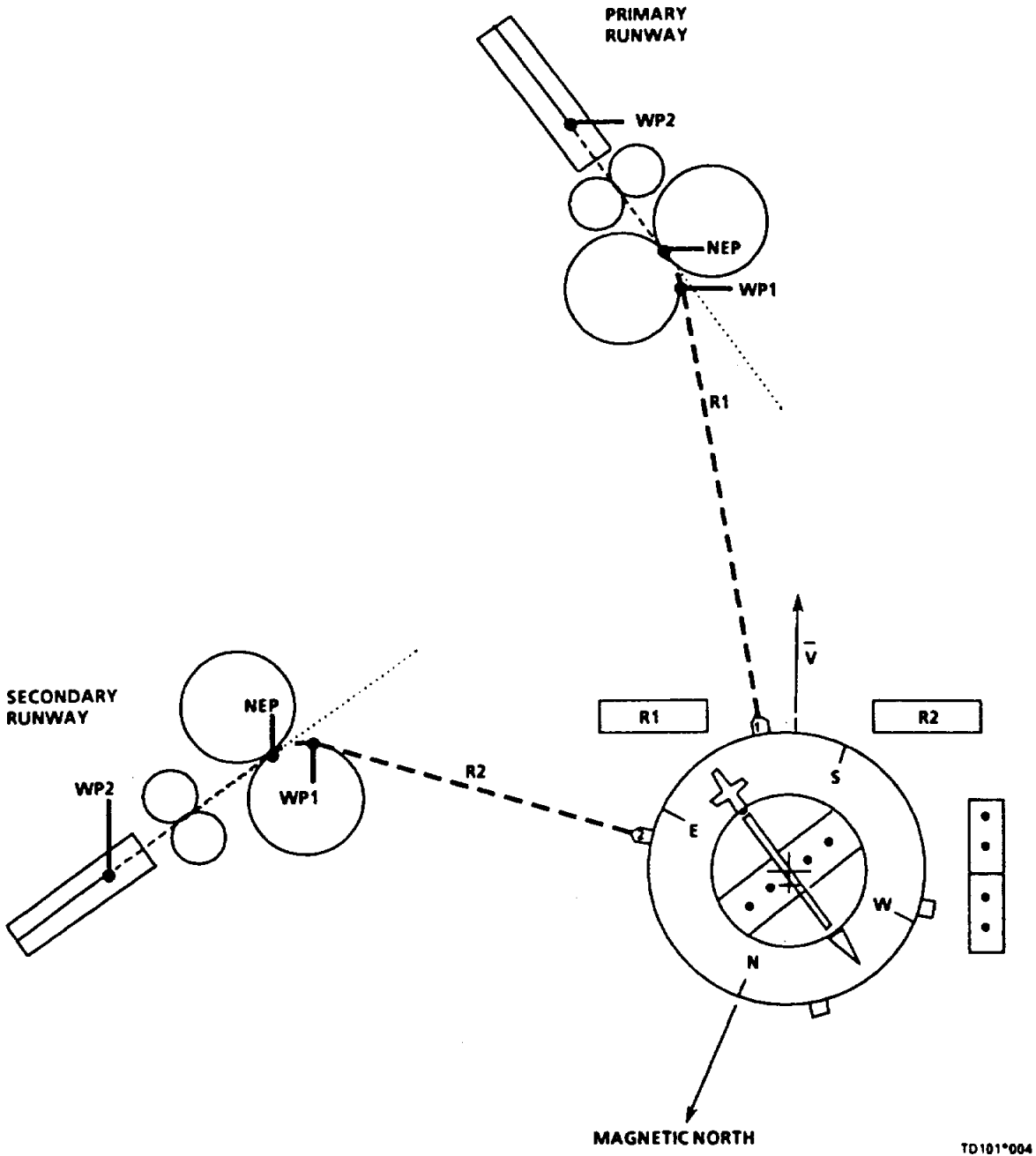
Answers: Radar Altimeter

1. Accurate tracking is maintained at altitudes between 0 and 5,000 feet.
2. False - display purpose only.
3. True - because the TACAN and RA are attached to this special IOM.
4. False - BFS will use the first RA that locks on. RA 1 and 2 switches are not supported in BFS.

Appendix A: HSI and Waypoints

Mode switch and guidance phase = ENTRY (and MM = 304)

- PRI BRG** Spherical angle in degrees (measured positive eastward) between true north and the great circle direction to the Way Point 1 (WP-1) for the selected HAC at the primary landing runway.
- PRI RNG** Great circle surface distance in nautical miles from the Shuttle to Way Point 2 (WP-2) on the primary landing runway through the selected HAC WP-1. This distance includes the distance from the Shuttle to WP-1, the arc length around the normal entry heading alignment circle (HAC) from WP-1 to the normal entry point (NEP), and the distance from the NEP to WP-2.
- SEC BRG** Same as PRI BRG except for secondary landing runway.
- SEC RNG** Same as PRI RNG except for secondary landing runway.
- GSI** Not computed; GS flag displayed.
- CDI** Valid zero; CDI flag not displayed.
- Heading** Heading of the Earth-relative velocity vector with respect to magnetic north.

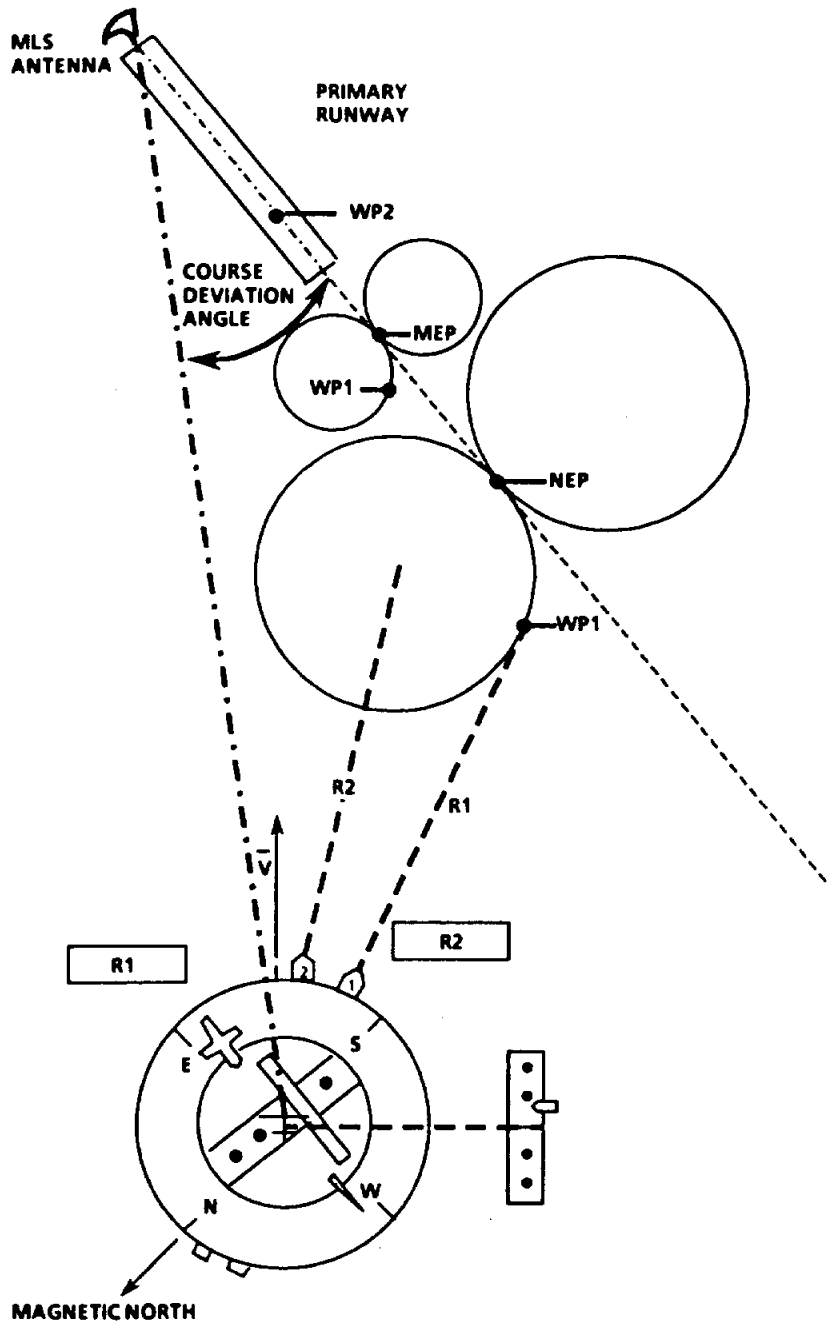


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Figure A-1.- ENTRY display mode.

Mode Switch = TAEM (or = ENTRY, during TAEM guidance)

- PRI BRG** Angle in degrees (measured positive eastward) between direction to magnetic north and the direction WP-1 on the selected HAC as viewed from the Shuttle.
- PRI RNG** Horizontal distance from the Shuttle to WP-2 via WP-1 on the selected HAC. This distance includes the distance from the Shuttle to WP-1, the arc length around the selected HAC from WP-1 to the EP and the distance from the EP, and the distance from the EP to WP-2.
- SEC BRG** Bearing to center of selected HAC at primary landing runway.
- SEC RNG** Horizontal distance to center of selected HAC at primary runway via WP-1 for MEP.
- CDI** The deviation in degrees of the Shuttle from the extended runway centerline. (The apex of this angle is located on the runway centerline directly opposite the MSBLS AZ/DME antenna.) The CDI display full scale is 10 degrees.
- GSI** The vertical deviation in feet of the Shuttle from the TAEM guidance reference altitude (positive when Shuttle is above glide path). The GSI display full scale deflection is 5000 ft.
- Heading** Heading of the body X-axis with respect to magnetic north.

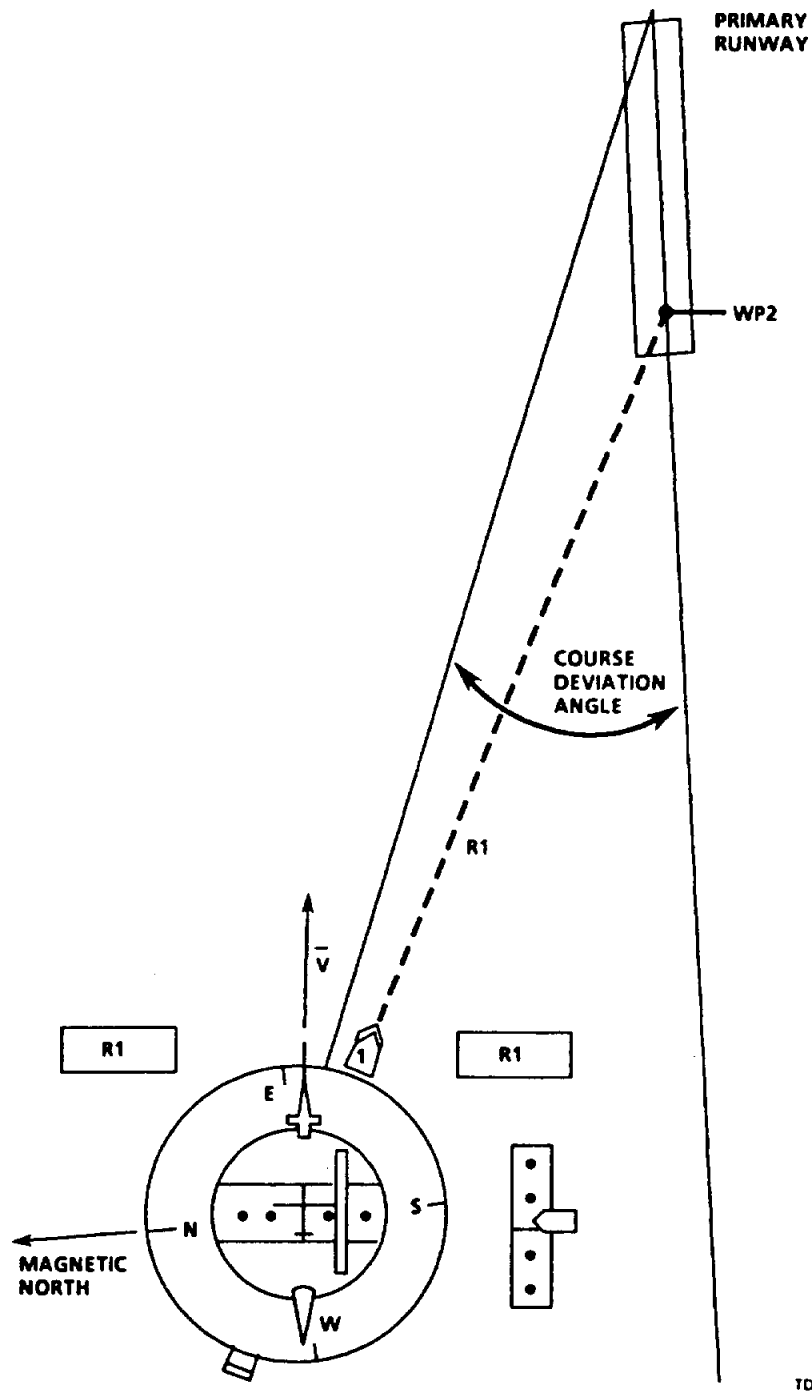


TD101*005

Figure A-2.- TAEM display mode.

Mode Switch = A/L (or = ENTRY during A/L guidance)

- PRI BRG** Angle in degrees (measured positive eastward) between the direction to magnetic north and the direction to WP-2 as viewed from the Shuttle.
- PRI RNG** Horizontal distance in nautical miles from the Shuttle directly to WP-2.
- SEC BRG** Same as PRI BRG.
- SEC RNG** Same as PRI RNG.
- CDI** Same as CDI in TAEM Mode switch setting, with the exception that full scale is 2.5 degrees.
- GSI** Vertical deviation in feet of the Shuttle from the A/L guidance reference altitude (linear segment) (is positive when the Shuttle is above glide path). Below 1500 ft (final flare), GSI is no longer computed and the GS OFF flag is displayed. Full scale deflection is 1000 ft.
- Heading** Same as Heading in TAEM Mode switch setting.



TD101*006

Figure A-3.- AIL display mode.

Appendix B: Abbreviations and Acronyms

ac	alternating current
ADS	air data system
ADTA	air data transducer assembly
AGC	automatic gain control
ANT SEL	antenna select
AOA	abort once around
AUT	automatic
AVVI	altitude/vertical velocity indicator
AZ	azimuth
BFS	backup flight system
BITE	built-in-test equipment
cb	circuit breaker
CDI	course deviation indicator
CPS	cycles per second
C&W	caution and warning system
dc	direct current
DES	deselect
DLMA	dilemma
DME	distance measurement equipment
DPS	data processing system
EL	elevation
EOM	end of mission
FC	flight critical
FDIR	fault detection, identification, and recovery
FF	flight forward
FI	fault identification
FOR	force
GLS	ground launch sequencer
GNC	guidance, navigation, and control
GPC	general purpose computer
GSI	glide slope indicator
HAC	heading alignment circle

HUD	heads up display
IDSO	Integrated Documentation Support Operation (Omniplan)
IMU	inertial measurement units
INH	inhibit
IOM	input/output module
JSC	Lyndon B. Johnson Space Center
LRU	line replaceable units
m	data mission
MCC	Mission Control Center
MDM	multiplexer/demultiplexer
MLS	microwave landing system
MLS-GS	MLS ground station
MLS-NS	MLS navigation set
MM	major mode
MSBLS	microwave scanning beam landing system
NASA	National Aeronautics and Space Administration
NAV	navigation
NEP	normal entry point
OI	operational instrumentation
P	parameter
PASS	primary avionics software system
PCM	pulse code modulation
PLT	pilot
PRI	primary
RA	radar altimeter
RCV	receive
RESID	residual
RF	radio frequency
RM	redundancy management
RNG	range
rps	revolutions per second
RSLs	redundant set launch sequencer
RTLS	return to launch site
SEC	secondary
SF	selection filter

SOP	subsystem operating plan
STSOC	Space Transportation System Operations Contract
SYS SUMM	system summary
TAC/RA IOM	TACAN/radar altimeter input/output module
TACAN	tactical air command and navigation system
TAEM	terminal area energy management
TAL	transoceanic abort landing
T/R	transmit/receive
WP	way point
?	dilemma
↓	unit downmoded

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LESSON CRITIQUE SHEET

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Please evaluate this lesson by answering the questions below. This information will be used to improve the lesson materials. Use the back of the sheet if required.

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TD101