Space Program Operations Contract

Intact Ascent Aborts
Workbook 21002

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Final Version

This document has been reviewed and updated. No subsequent updates to this document are anticipated or required due to the approaching shuttle program closure.

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Intact Ascent Aborts
Workbook 21002

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Basic		Supersedes TD147 and TD344. The ATO/AOA/TAL Training Manual as been merged with the RTLS Abort Training Manual and was renamed Intact Ascent Aborts Workbook. In addition, this revision includes FDF current for STS-116 and updated graphics to reflect heads-up attitude at MECO, and OI-30 flight software updates	08/17/2004
A		Changed manager's name. Added final version statement. Applied SPOC template.	10/10/2006

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LIST OF EFFECTIVE PAGES

The current status of all pages in this document is as shown below:

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Preface	Rev. A
i – v	Rev. A
1-1 – 1-12	Rev. A
2-1 – 2-9	Rev. A
3-1 – 3-7	Rev. A
4-1 – 4-12	Rev. A
5-1 – 5-12	Rev. A
6-1 – 6-32	Rev. A
A-1 – A-3	Rev. A
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C-1	Rev. A

PREFACE

The content of this document was provided by the Control/Propulsion Department, Space Flight Training Division, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical documentation support was provided by Integrated Documentation Services (IDS), Hernandez Engineering Inc. Any questions concerning this workbook or any recommendations should be directed to any of the book managers.

This material is for training purposes only and should not be used as a source of operational data. All numerical data, displays, and checklist references are intended as examples. To determine any prerequisites before using this document, consult the applicable Certification Plan. For shuttle manuals, consult the appropriate flight controller's certification guide (Blue Book), or the Crew Training Catalog. For Space Station manuals, consult the appropriate Space Station Certification Guide or Training Administration Management System (TAMS). The applicable training package should be studied before attending any classroom session or lesson for which this is a prerequisite.

If this workbook is being read as part of a formal syllabus, the reader should complete the training materials evaluation form at the end of the document. The eval form does not need to be signed.

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1.0   ASCENT AND ABORT OVERVIEW

1.1   OBJECTIVES

Upon completing this section, the student should be able to

- State the definition of a Main Engine Cutoff (MECO) underspeed

- Describe the four types of intact abort modes

- Describe the redundant methods used to initiate an Abort-to-Orbit (ATO), Transoceanic Abort Landing (TAL) abort, and Return To Launch Site (RTLS) abort

1.2   NOMINAL ASCENT

The space shuttle ascent flight phase begins at launch with a vehicle composed of the orbiter, External Tank (ET), and two Solid Rocket Boosters (SRBs). The three Space Shuttle Main Engines (SSMEs) ignite just after T - 7 seconds. When the main engines are throttled to 100 percent of their rated thrust level, the two SRBs ignite and lift-off occurs. SRB ignition and lift-off requires three SSMEs at 90 percent or greater rated thrust.

After lift-off, the space shuttle follows the ascent profile shown in Figure 1-1. The early part of ascent, when the SSMEs are burning in parallel with the SRBs, is defined as first stage. After about 2 minutes, the SRBs burn out, separate from the orbiter and ET, and are recovered for use on a later flight. Second-stage ascent begins after SRB Separation (SEP) and continues until MECO. The period from lift-off to MECO is known as the powered flight phase.

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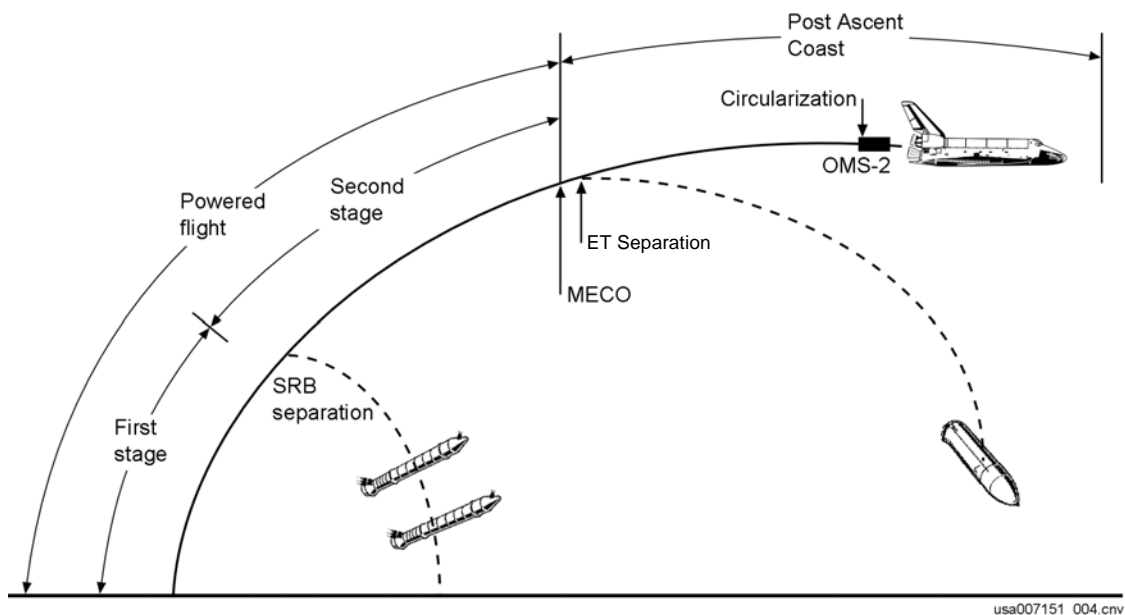
Figure 1-1. Nominal ascent profile

After MECO, the ET is jettisoned from the orbiter and the Reaction Control System (RCS) jets are used to maneuver away from the tank. The ET enters the Earth's atmosphere, breaks up, impacts in a remote ocean area, and is not recovered.

At this point, the orbiter may or may not have achieved orbital velocity, depending on whether a direct or standard insertion was planned. A standard insertion uses the Orbital Maneuvering System (OMS) engines to supply the additional thrust needed to reach orbit. The first burn (OMS-1) occurs soon after MECO and results in an elliptical orbit. With a direct insertion ascent, the main engines are burned slightly longer to achieve the desired apogee altitude, such that an OMS-1 maneuver is not required. Both insertion profiles require a circularization burn (OMS-2). This burn is performed at the apogee of the initial orbit.

At the start of the Space Shuttle Program, standard insertion was the only type of insertion planned. STS 41-C was the first direct insertion flight, and this type of insertion has been used since STS-30. Standard insertions were used on early flights when less information was available on SSME performance and targeting precision. Some of the other aspects considered for standard or direct insertion are mission objectives, ascent performance, ET impact, and orbital altitude. At present, a standard insertion would be used only for flights to low-orbital altitudes, where the ET impact point is outside of limits using direct insertion.

The main advantage of direct insertion is that higher orbital altitudes are possible because more OMS propellant is saved for orbital maneuvers.

1.3   PERFORMANCE

The performance capability of the shuttle is defined as the measure of the shuttle's ability to achieve a desired orbit. If shuttle performance is better than predicted, the desired MECO velocity is achieved with a surplus of propellant that is discarded. If, however, the shuttle does not perform as well as predicted, the desired MECO velocity may not be achieved.

A MECO velocity that is less than the target velocity is called a MECO underspeed. The most probable cause of a MECO underspeed is a main engine failure. Underspeeds of up to several hundred feet per second can be recovered by increasing the ΔV provided by the OMS-1 and OMS-2 burns. If the underspeed is too large to be made up using excess OMS propellant, the shuttle will not be able to reach the desired orbit, and an ATO or an Abort-Once-Around (AOA) will be performed. If an engine fails early, orbit cannot be achieved at all, and a TAL or RTLS abort will be performed. Figure 1-2 illustrates the availability of these aborts depending on engine fail mission elapsed time. The time period during which these aborts are available is approximate and varies with each flight.
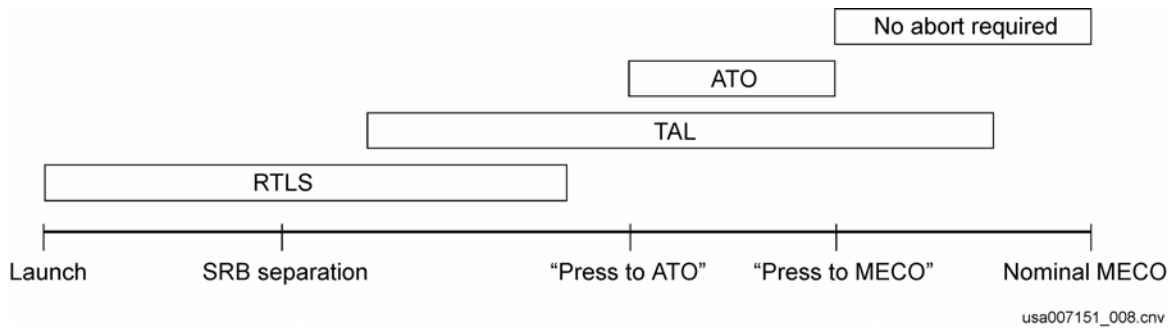
Figure 1-2. Abort mode as a function of SSME failure time

1.4 ASCENT ABORT MODES

Selection of an ascent abort mode becomes necessary when a failure affects vehicle performance as described previously and when a vehicle system failure jeopardizes crew safety, such as a cabin leak.

There are two basic types of ascent abort modes, intact and contingency. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed for crew survival and may result in loss of the vehicle. The type of abort required will depend on the severity and time of the failure.

The Space Shuttle Program, through flight design, guarantees intact abort capability after a single failure. For multiple failures, contingency abort is often the only option.

The four types of intact abort modes are shown in Figure 1-3.
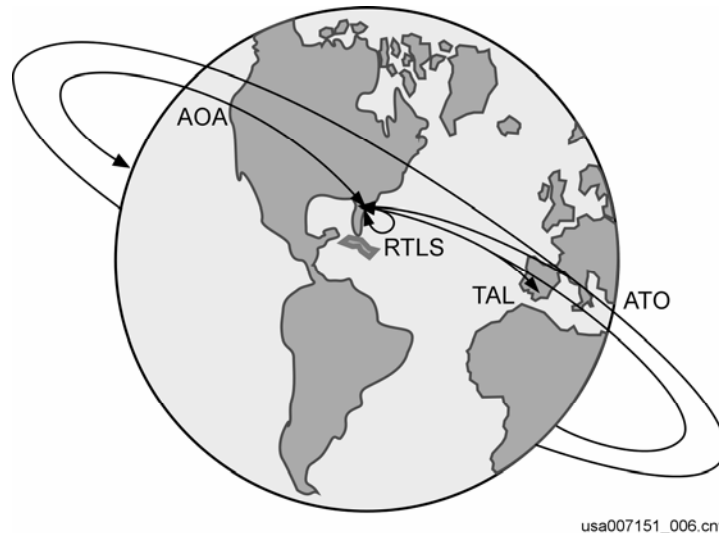
Figure 1-3. Intact abort modes

An ATO is designed to achieve a temporary orbit (typically 105 nautical miles (nm), which is lower than the nominal orbit (Figure 1-4). This abort requires less performance and allows time to evaluate problems and then choose either an early deorbit burn or an OMS maneuver to raise the orbit and continue the mission.
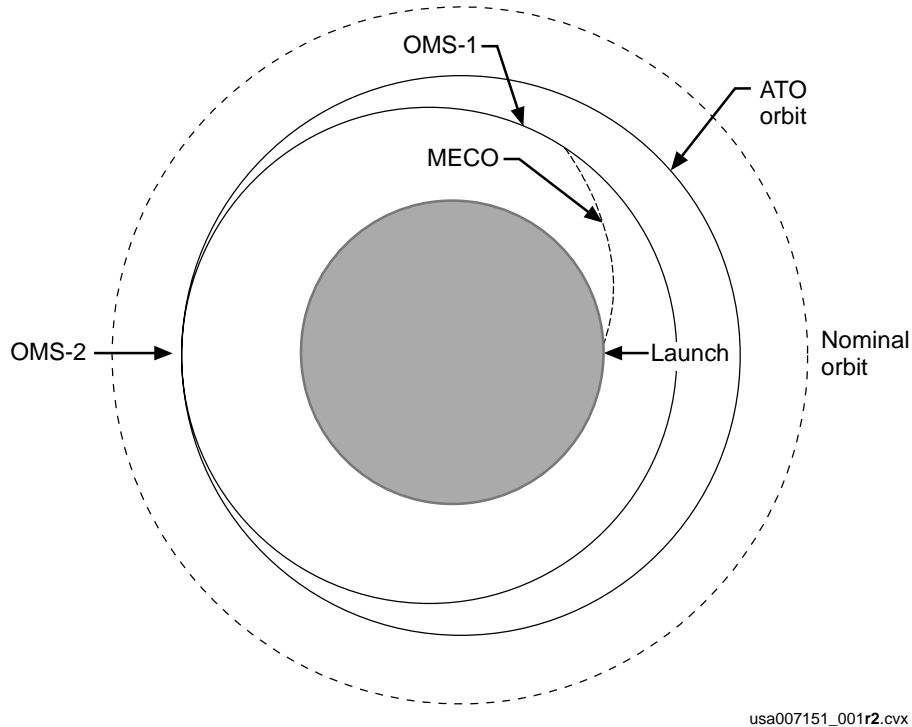
Figure 1-4. Typical ATO profile

An AOA is performed when orbit cannot be achieved and maintained. This abort mode is designed to use the existing performance to make a revolution of the Earth and land at Edwards Air Force Base (EDW), Northup Flight Strip (NOR), or Kennedy Space Center (KSC) (Figure 1-5). There are two types of AOA trajectories, AOA-steep and AOA-shallow (AOA-S). The entry trajectory for AOA steep is similar to the nominal End-of-Mission (EOM) entry trajectory. An AOA-S results in a flatter entry trajectory but uses less propellant in the OMS maneuvers. The shallow entry trajectory is less desirable because it exposes the vehicle to a longer period of atmospheric heating and to less predicable aerodynamic drag forces, the latter of which introduces the small risk of not obtaining aerocapture.
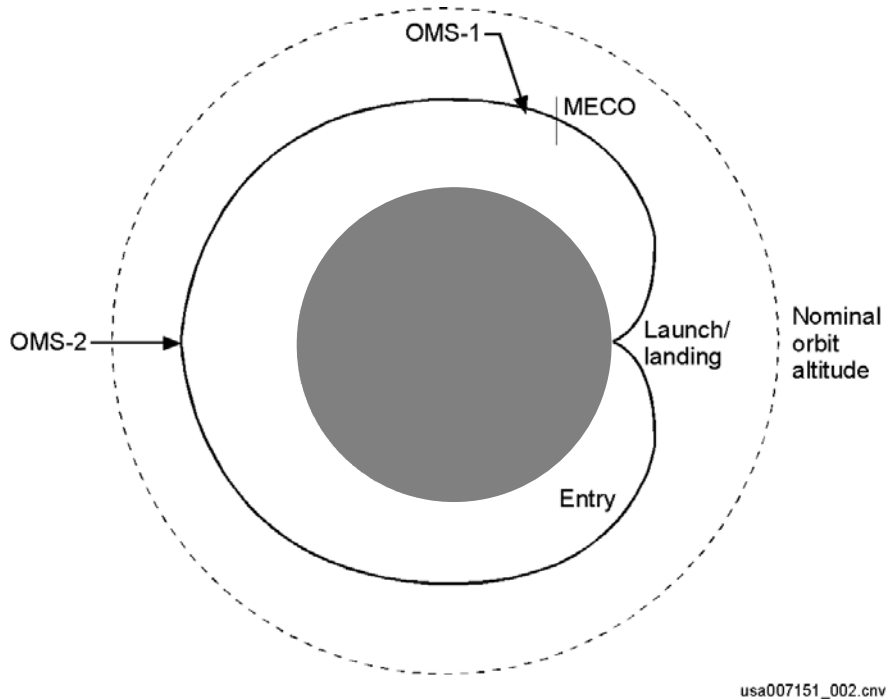
Figure 1-5. Typical AOA profile

The TAL abort is designed to allow the vehicle to achieve a suborbital trajectory that results in the orbiter landing on a runway in Canada, Europe, or Africa depending on the orbital inclination and performance (Figure 1-6).
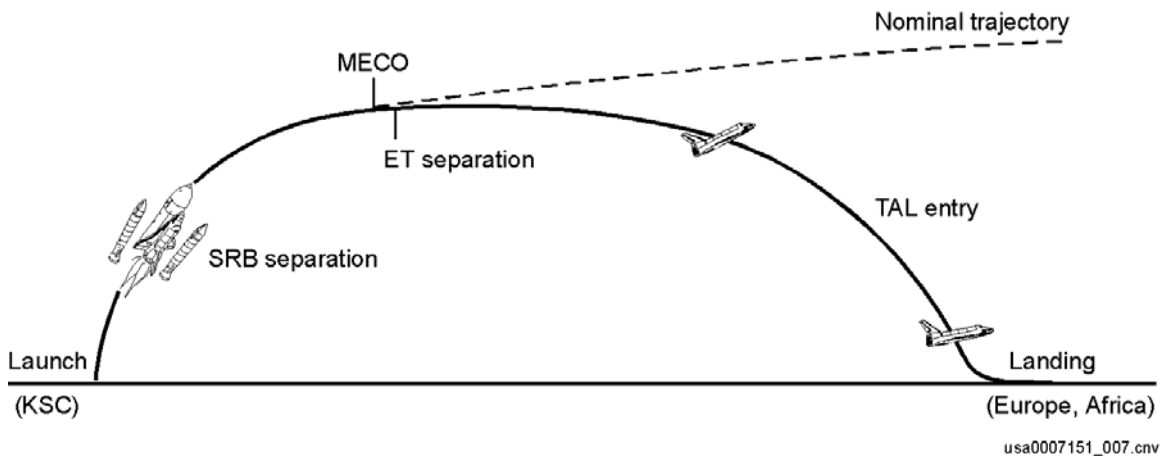
Figure 1-6. Typical TAL profile

RTLS is designed to allow the vehicle to fly downrange to dissipate propellant and then turn around during powered flight to return for landing at a runway near the launch site.

There is a definite order of preference for the various abort modes. The type of failure and the time of failure determine abort selection. During powered flight, intact abort priorities for loss of performance are ATO, TAL, and RTLS. These priorities were established to provide the highest probability of safe return. For a specific systems

failure, such as a cabin leak or loss of vehicle cooling capability, the abort priorities are RTLS, TAL, and AOA. These priorities are established to provide the earliest available landing time or to avoid continuing to orbit after a loss of capability. A contingency abort, which often results in crew bail out, is an abort option only when no other option exists.

1.5   ABORT MODE SELECTION

Intact ascent abort is initiated during powered flight with the abort rotary switch on panel F6 (Figure 1-7). In arm-fire fashion, the rotary switch is turned to the best possible abort option, and the abort pushbutton is then pushed in order to initiate the abort. The positions on the switch are RTLS, OFF, ATO, and TAL.

As a redundant line of communication, the abort pushbutton will be illuminated via command from Mission Control Center (MCC). When the abort light is illuminated by MCC, it will be extinguished by MCC once the crew has received and executed the abort request. In the absence of voice communication, this light will indicate to the crew an abort selection is required. It cannot, of course, specify the appropriate abort mode.
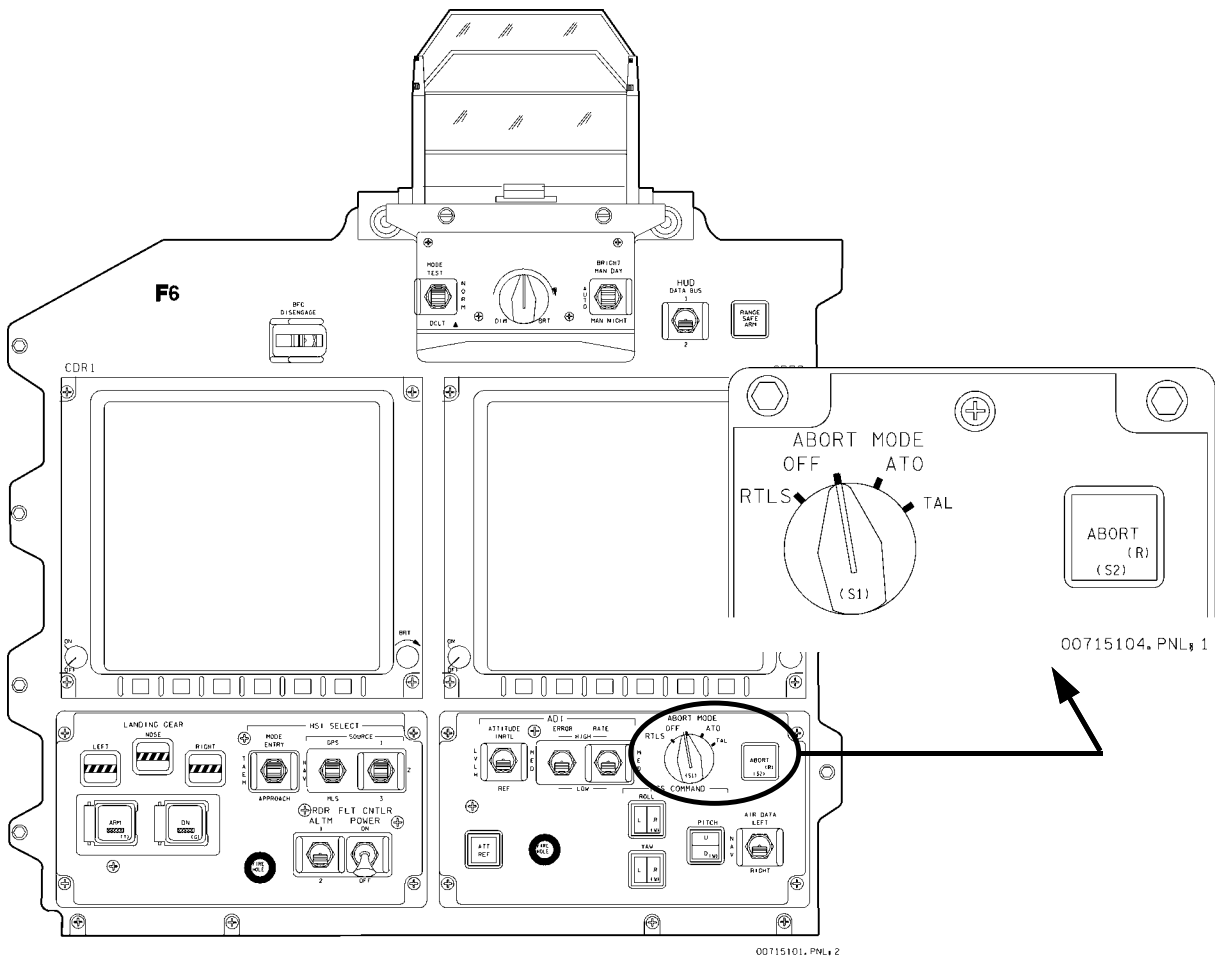
Figure 1-7. Abort rotary switch and pushbutton on panel F6

1.5.1 Redundant Abort Mode Selection

As a redundant method, the crew can initiate an ATO or TAL abort via item entry to the OVERRIDE display (SPEC 51) shown in Figure 1-8. Items 1 and 2 allow the crew to select a TAL abort in Major Mode (MM)103 or MM104 or ATO abort in MM102, MM103, and MM104. These items are mutually exclusive, the selected mode is indicated by an "*". The abort sequence is initiated by execution of item 3 and is also indicated by "*". Execution of item 3 must be preceded by selection of item 1 or 2. Notice that no option exists for selecting an RTLS on this display. As a redundant method, the crew can request RTLS by selecting OPS 601 PRO.

```
 6011/051/          OVERRIDE          1 000/00:02:40
                                        000/00:02:40
ABORT MODE                   ENTRY FCS
  TAL       1      ELEVON     FILTER     ATMOSPHERE
  ATO       2    AUTO  17*   NOM 20*    NOM      22*
ABORT       3    FIXED 18    ALT 21     N POLE 23
THROT MAX 4      SSME REPOS 19 ENA     S POLE 24
      ABT 50     IMU STAT ATT DES          PRL
      NOM 51      1        1   25     SYS AUT DES
    PRPLT DUMP    2            26      1  28* 31
ENA ICNCT 5       3            27      2  29* 32
OMS DUMP                              3  30* 33
    ARM       6   ADTA      H      a      M    DES
    START     7    L 1                        34
    STOP      8      3                         35
  9 QUAN/SIDE  83  R 2                        36
OMS DUMP TTG 200    4                          37
                  ET SEP          ROLL MODE AUTO
                    AUTO    38      AUTO SEL    42
AFT RCS 13  ENA     SEP     39      WRAP MODE 45
    14 TIME   0   ET UMB DR         VENT DOOR CNTL
                    CLOSE   40      OPEN      43
FWD RCS 15  ENA  RCS RM MANF        CLOSE     44
    16 TIME  25     CL OVRD 41

 SPEC 51 PRO
```

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Figure 1-8. OVERRIDE display (SPEC 51)

1.6 ABORT DUMPS

When the shuttle is launched, it carries enough OMS propellant to perform the shuttle mission and the deorbit burn to return to Earth. This load of OMS propellant, which can be as much as 24,000 pounds, is stored in tanks located at the back end of the orbiter. This causes the shuttle c.g. to be farther aft of the point where the shuttle is designed to fly. For normal end-of-mission entry this situation is not a problem because most of the OMS propellant is consumed. For RTLS and TAL, however, this propellant must be dumped due to OMS tank landing constraints and in order to get the c.g. within limits for entry. There is no AOA dump, rather the OMS prop that is not needed for the AOA deorbit burn is spent by adding an out-of-plane component during the deorbit burn. For ATO dumps please see details in section 3.

The term "OMS dump" is somewhat of a misnomer because the word dump implies the propellant is piped overboard. This is not the case, rather, the OMS dump is performed by burning the propellant through the OMS engines, or in some cases, through the OMS engines and the aft RCS jets, referred to as "interconnected dumps." To date the RTLS and TAL abort dumps have been interconnected dumps. ATO dumps may or may not be interconnected.

To burn OMS propellant through the RCS jets, an OMS to RCS interconnect must be performed. This interconnect, if required, is performed automatically, as soon as the abort is selected. But while the OMS engines begin burning immediately, the RCS jets are not turned on until 3 seconds after the interconnect is complete. This 3-second interval can be used by the crew to verify proper positioning of the OMS and RCS valves. Failure to position the valves properly can result in burning up all of the RCS propellant and, in turn, cause the vehicle to be uncontrollable after MECO.

When interconnected the dump normally selects all 24 aft RCS primary jets for the dump. However, if smart interconnect detects a problem in the configuration for the dump, 10 RCS jets or no jets may be selected. Smart interconnect is a software sequence that confirms the valve positions to ensure OMS propellant reaches the RCS jets. If one RCS leg is unavailable due to failures to any of the above, that leg is unavailable on both sides to ensure symmetric dumps. The affected manifolds are returned to feed from the RCS tanks, and the resulting OMS propellant burn rate is adjusted accordingly to provide an accurate SPEC 51 value for propellant burned. Therefore, the interconnected dump is limited to just 10 jets if any one leg is unavailable. This is done to prevent unwanted pitching moments from asymmetric jet firings. After the necessary burn has been accomplished, all propellant feed paths are returned to the normal configuration.

Null jets are a group of jets that have been selected because the force on the vehicle is zero when these jets are fired together. In general, for any interconnected abort dump, all of the 20 aft pitch and yaw jets are fired together resulting in no rotational or translational perturbations on the vehicle. Also dumping, but not in the null set, are the 4 + X jets, which fire directly aft. These groups of jets, as well as the OMS engines, are fired independently according to a dump timetable in the abort control sequence. The dump times for a particular flight can be seen by checking the Abort Dump section of the Ascent Flip Book as shown in Figure 1-9.

After these dump times have expired, the OMS and RCS valves are returned to their normal configuration in preparation for MECO. The position of these valves and the OMS P_c on the OMS/MPS display are the only insight the crew has to the progress of the OMS dump. If required, the crew can turn off one or both of the OMS engines by taking the corresponding OMS ENG switch on panel C3 to OFF (Figure 6-8).

SPEC 51 is the crew's interface to the abort dump software (Figure 1-8). SPEC 51 displays the dump timer actively counting down (as OMS DUMP TTG). The status of the interconnect is also shown and may be toggled from Enable (ENA) to Inhibit (INH)

and back to ENA while the dump is in progress with an ITEM 5 EXEC. Items 6 through 8 enable the crew to manually start and stop a SPEC 51 dump.

If the BFS is engaged, similar capability exists on BFS GNC SPEC 51.
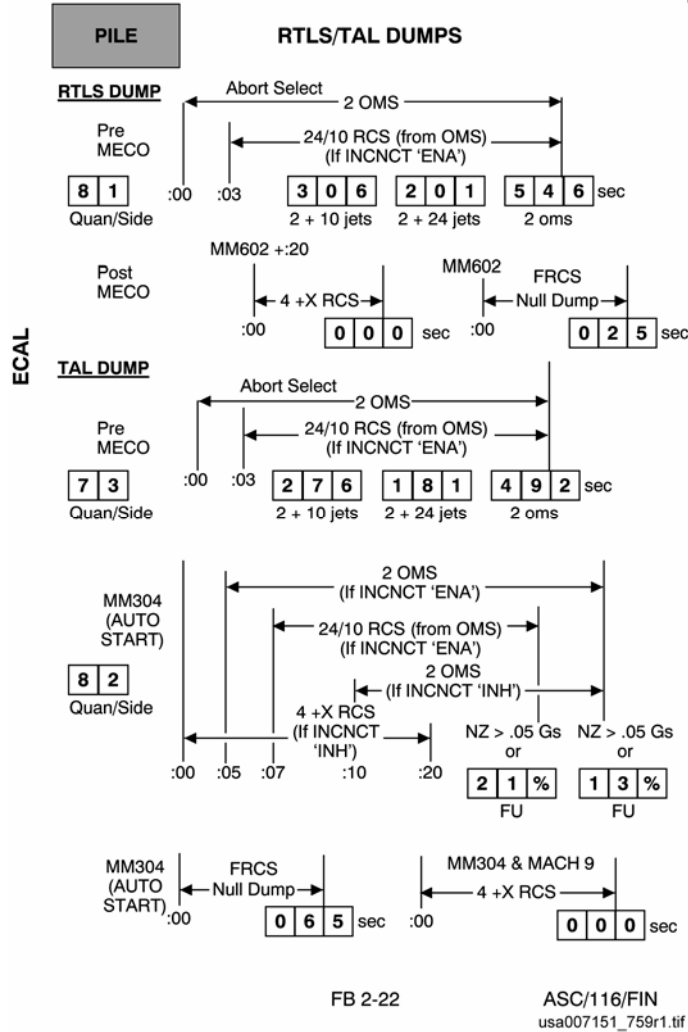
Figure 1-9. Abort Dumps cue card (RTLS/TAL)

1.7   SOFTWARE MAJOR MODES

The space shuttle is controlled using five General Purpose Computers (GPCs). The flight software in the computers is divided into several sections. Each section is called an Operational Sequence (OPS) and is tailored to a particular flight phase. For example, OPS 1 is software used during the ascent phase, while OPS 3 is used for entry.

Each operational sequence is subdivided into Major Modes, which are used to denote incremental changes in flight phases. MM101 contains software used pre-launch, and MM102 designates ascent flight between liftoff and SRB SEP. Immediately after SRB

SEP occurs, MM103 is initiated. MM103 is in effect until MECO is confirmed by software. Table 1-1 lists the major modes relevant to ATO, AOA, TAL, and RTLS aborts.

Table 1-1. Major modes relevant to ATO, AOA, and TAL

Operational Sequence	Major Mode	Mission Phase			
		NOM/ATO	**AOA**	**TAL**	**RTLS**
Ascent	101	Prelaunch			
	102	First stage			
	103	Second stage		Second stage	
	104	OMS-1 maneuver	OMS-1 maneuver	Transition coast	
	105	OMS-2 maneuver	Transition coast		
	106	Post OMS-2 coast			
	601				Powered Flight
Entry	301		Pre-deorbit coast		
	302		Deorbit maneuver		
	303		Post-deorbit coast		
	304		Entry	Entry	
	305		TAEM	TEAM	
	602				Entry
	603				TAEM

1.8 BACKUP FLIGHT SOFTWARE

The Backup Flight Software (BFS) is an independent software system that normally resides in the fifth GPC (GPC 5). If any failure or combination of failures renders the Primary Avionics Software System (PASS) computers unable to control the shuttle, the crew engages the BFS. Once engaged, the BFS assumes sole control of the shuttle vehicle and remains in control until after landing or until the problem with the PASS computers is found and fixed on orbit. Both the Commander (CDR) and Pilot (PLT) can engage the BFS by depressing the Pushbutton (PB) on top of the forward Rotational Hand Controllers (RHCs), as shown in Figure 1-10.
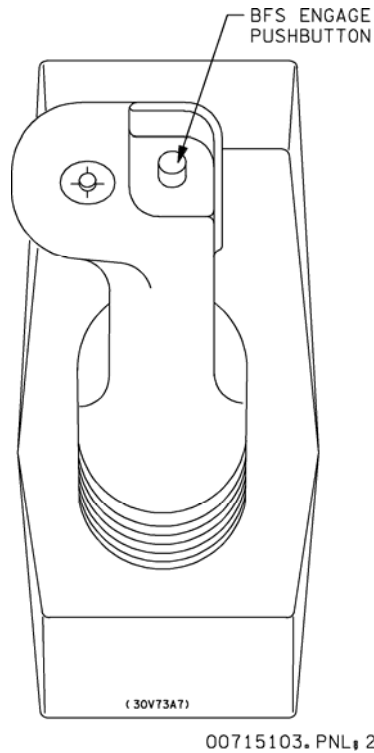
Figure 1-10. BFS engage PB

The BFS fully supports all intact abort modes, including RTLS. The abort targeting software and dump sequences work like the PASS. In powered flight, the major difference is that the BFS has only automatic flight control; Manual (MAN) takeover of steering and throttle commands is not possible during ascent if the BFS is engaged.

After ET SEP and continuing through landing, the situation is exactly opposite. For orbit and entry phases of flight, the BFS supports only MAN or Control Stick Steering (CSS). Therefore, control during Gliding Return to Launch Site (GRTLS) must be performed in CSS.

1.9   QUESTIONS

Answers to these questions are found in Appendix B.

1. What is the difference between a standard insertion and a direct insertion?

2. A MECO velocity less than target velocity is called a(n) _____?

3. List the four intact abort modes.

4. What is the typical orbital altitude for an ATO?

5. What are the consequences of an AOA-shallow (AOA-S)?

6. Describe the primary and backup methods of selecting an ATO or TAL.

2.0 ABORT MODE BOUNDARIES

2.1 OBJECTIVES

Upon completing this section, the student should be able to

- List the three types of abort mode boundary cues

- Define the seven boundary calls made to the crew by the MCC

- Determine the abort capability in a no-comm situation

- Define the RTLS and GO marks represented on the ASCENT TRAJ display

- Select aborts and cue cards for system failures pre-MECO

- Select aborts and cue cards for performance failures pre-MECO

- Select aborts and cue cards for system failures post MECO

- Select aborts and cue cards for underspeed conditions post MECO

2.2 PRE-MECO PERFORMANCE ABORTS

During powered flight, the crew must be aware of options in the event of failures. It is important to know which abort modes are available in the event of engine failure(s). The three ways the crew can determine abort capability are

a. Voice calls to the orbiter from the MCC

b. Inertial velocity boundaries listed on a cue card

c. Onboard trajectory displays

2.2.1 Voice Calls

The primary indication of abort boundary is via MCC. These calls represent abort mode boundaries and vary from one flight to another, depending on the vehicle weight, predicted engine performance, and mission requirements. For example, high-inclination flights require different TAL sites than low-inclination flights. Typically, the calls include the following:

1. **TWO-ENGINE (PRIME TAL)** – The earliest inertial velocity (V_I) or time a TAL abort can be accomplished to the primary TAL site if one main engine fails

2. **NEGATIVE RETURN** – The latest V_I or time an RTLS abort can be successfully completed (past this V_I, the orbiter has too much downrange energy to successfully return to KSC)

3. **PRESS TO ATO** – The earliest V_I or time that an ATO can be accomplished and drop the ET in a safe area if one main engine fails. Note: A pre-MECO OMS propellant dump is required at the open of the ATO window

4. **SINGLE ENGINE OPS 3 109** – For two-engines failed, the first point after which the crew can abort TAL (Droop procedure), then use OPS 3 software for entry. Prior to this point, the loss of two engines requires contingency abort procedures and OPS 6 software

5. **PRESS TO MECO** – The earliest V_I or time an orbit can be accomplished with no pre-MECO abort selection and no OMS dump, if one main engine fails

6. **SINGLE-ENGINE (PRIME TAL)** – The earliest V_I or time a TAL can be accomplished to the primary TAL site if two main engines fail

7. **SINGLE-ENGINE PRESS** – The earliest V_I or time that at least an ATO can be accomplished if two main engines fail. However, no protection is made for ET impact. A pre-MECO abort selection is not required

Figure 2-1 illustrates the approximate time the voice calls are made as a function of velocity and altitude.
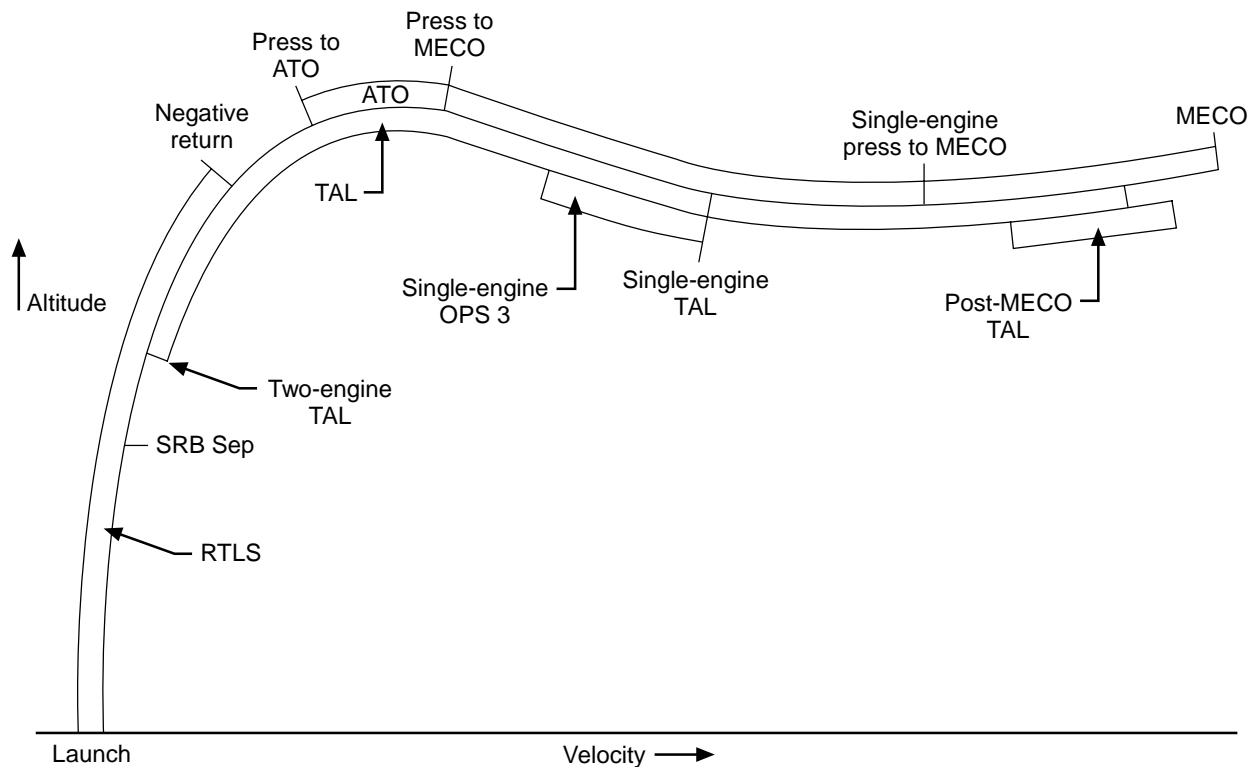
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Figure 2-1. Abort calls as a function of velocity and altitude

These boundaries can vary from prelaunch predictions due to changing atmospheric conditions and variations in SRB and main engine performance. Using this real-time information, a computer and software program called the Abort Region Determinator (ARD) allows MCC to predict the underspeed that will result from a loss of performance (engine failure, throttle lockup, degraded thrust, etc.). This information is then used to predict the actual abort mode boundaries on which the real-time voice calls are made. These boundaries vary from pre-flight predicted boundaries.

2.2.2   Inertial Velocity Boundaries

Pre-flight predicted boundaries are available to the crew as NO COMM MODE BOUNDARIES. They are provided to the crew in the Ascent Checklist and Flipbooks, as shown in Figure 2-2. These examples list the boundaries and an inertial velocity in feet per second at which the abort mode is available.

**Figure 2-2. Pre-determined abort boundaries
given in terms of inertial velocity**

The boundaries that are listed in bold are the ones typically voiced to the crew by MCC. Even though two or three 2 ENG (TAL) boundaries are given, only the flight day primary TAL site boundary is voiced to the crew. The boundaries that are not bold (i.e., NEG TAL site and LAST TAL site) alert the crew as to the last V_I at which the given TAL site can be reached. Past that V_I, the orbiter is too far downrange to successfully reach the TAL site. The LAST PRE MECO TAL boundary, just as the name implies, is the last opportunity to initiate a pre-MECO TAL abort.

NO COMM MODE BOUNDARIES do not reflect off-nominal performance, such as a stuck throttle. Only the ARD can calculate abort mode boundaries in real time, based on actual performance.

2.2.3   Trajectory Display Boundaries

Secondary indications of abort capability are the marks on the ascent trajectory displays shown in Figure 2-3. On this display, RTLS indicates the last point at which an RTLS abort should be selected. This mark usually corresponds to the Negative Return call from MCC. GO indicates the earliest point at which a main engine could fail and at least an ATO could be accomplished. The GO mark usually corresponds to the Press to ATO call from MCC. These marks are based on preflight analysis and may vary from actual flight day performance.
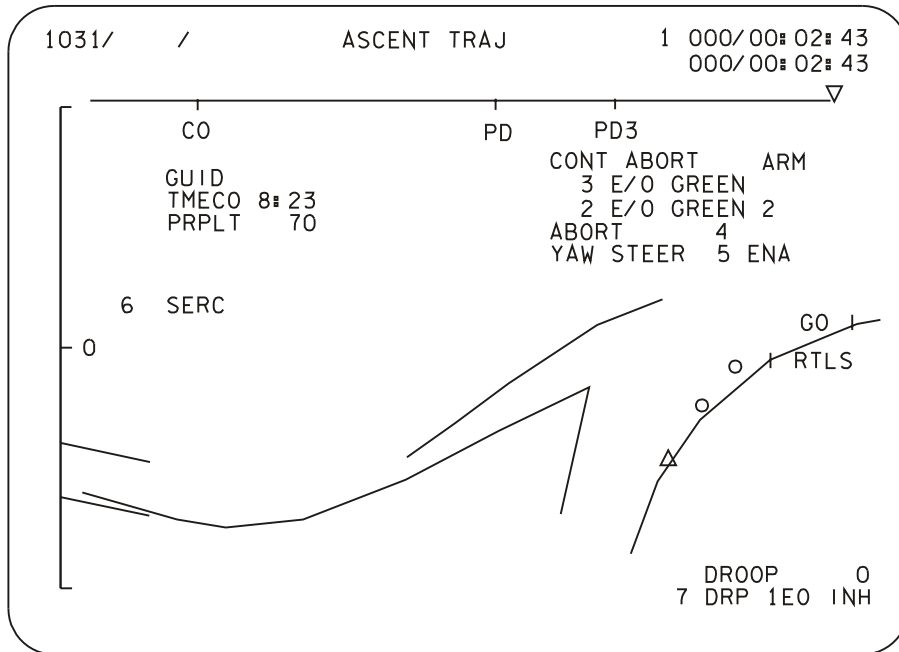
Figure 2-3. ASCENT TRAJ display

2.3 PRE-MECO SYSTEMS ABORTS

The SYS FLIGHT RULES information (Figure 2-4) provides the crew with abort selection for critical systems failures that may occur pre-MECO. In most cases, additional insight provided by MCC is necessary to accurately and fully diagnose a failure and select the best response. For loss of communication, however, this is available. If both RTLS and TAL abort options are possible, an RTLS abort is selected in order to achieve the earliest landing.

BAILOUT EGRESS

PILE

SYS FLIGHT RULES

	RTLS	TAL
OMS – 2 He TKs		X
– 1 OX & 1 FU TKs (diff pods)		X
– 2 OX or 2 FU TKs		X
APU/HYD – Impending loss of all capability	X	X
CABIN LEAK – (-EQ dP/dT > .15)	X	X
CRYO – All O2(H2)	X	X
2 FREON LOOPS ↓ [Accum Qty (↓ and decr) and/or Flow (↓)]	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

NO COMM MODE BOUNDARIES

NEG RETURN (104)	8200	2 ENG ZZA (104)	5800
PRESS TO ATO (104)	9900		
SE OPS 3 (109)	12100	ABORT TAL ZZA (4)	
SE ZZA (104)	14200	EO VI	
PRESS TO MECO (104)	14900	SE OPS 3 ZZA (109) (14)	
NEG BEN (2 @ 67)	18400	SE ZZA (104) (4)	
SE PRESS (104)	18600		
NEG MRN (2 @ 67)	20000	2 ENG MRN (104)	5700
LAST PRE MECO TAL	23000	ABORT TAL MRN (3)	
LAST TAL			
YJT	20100	EO VI	
YYT	20200	SE OPS 3 MRN (109) (13)	
YQX	21900	SE MRN (104) (3)	
LAJ	23400		
IKF	23700	2 ENG BEN (104)	5700
INN	24100		
MRN, BEJ, FFA	24300	ABORT TAL BEN (2)	
FMI, KBO	24500		
ESN	24900	EO VI	
ZZA	25000	SE OPS 3 BEN (109) (12)	
KKI	25100	SE BEN (104) (2)	
JDG	25200		

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Figure 2-4. SYS FLIGHT RULES cue card

2.3.1 OMS Capability

A severe loss of OMS capability can make it impossible to continue uphill and deorbit. For example, loss of two propellant tanks results in insufficient propellant to get to orbit; therefore, a TAL is required.

2.3.2   Auxiliary Power Unit/Hydraulics

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

2.3.3   Cabin Leak

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

2.3.4   Cryogenics

Loss of cryogenics, O_2 or H_2, results in a loss of fuel cells and all electrical power. An RTLS or TAL is required.

2.3.5   Freon Loops

Losing both Freon loops eventually results in loss of all three fuel cells because of a lack of cooling. Since this is time critical, RTLS is preferable over TAL.

2.3.6   Main Buses

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

2.3.7   Thermal Window Pane

Heating during nominal TAL entry is severe. With a thermal window pane failure, RTLS is preferable because of its more benign heating characteristics.

2.4   POST MECO PERFORMANCE ABORT BOUNDARIES

After MECO, MCC uses the Abort Maneuver Evaluator (AME) computer program to determine the abort options currently available. The AME also provides recommendations for selection of nominal, ATO, AOA, or AOA-S targets for OMS-1 and OMS-2 maneuvers.

The crew also has insight into post MECO abort options on their OMS 1/2 TGTING cue card, which is used for MECO underspeed cases. Figure 2-5 is an example of a direct insertion cue card. The card is based on preflight data and may vary from the AME.
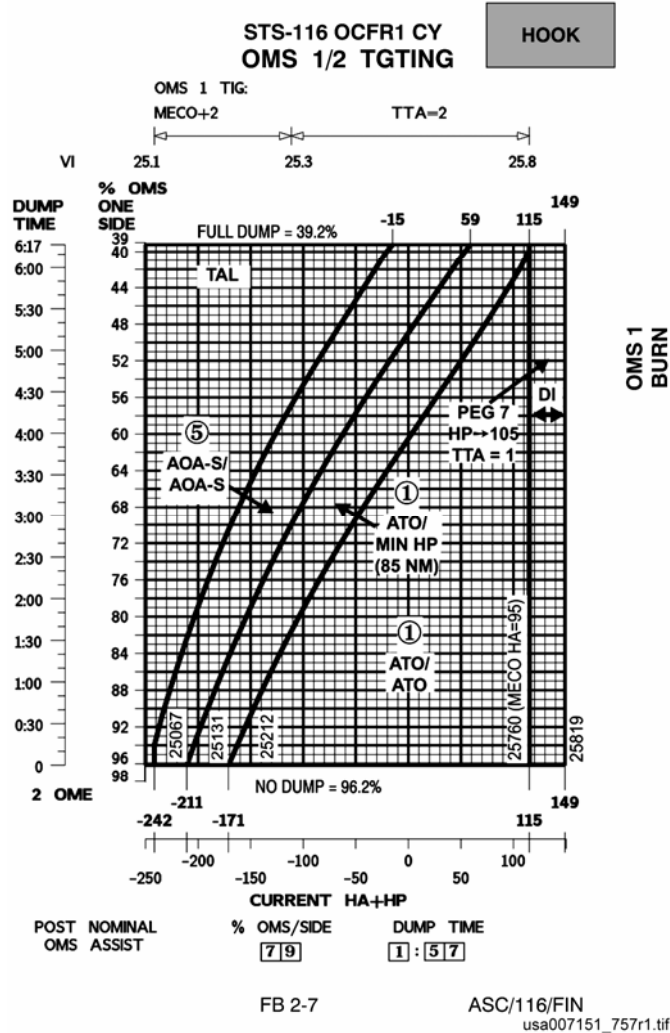
Figure 2-5. OMS 1/2 TGTING cue card

The abort boundaries are given as a function of the current energy state (Height of Apogee (HA) plus Height of Perigee (HP)) and the percent of OMS propellant remaining, and the smaller the value of HA + HP, the larger the underspeed. Depending on the magnitude of the underspeed, this cue card indicates to the crew which abort and/or OMS-1/OMS-2 targets are required. For example, if the MECO conditions fall to the right of the bold vertical line ("DI" area), an OMS-1 burn is not required, and a PEG 7 OMS-2 burn is performed 1 minute before apogee (Time to Apogee (TTA) = 1).

If the MECO conditions fall to the left of the bold vertical line, abort targets for OMS-1 and OMS-2 are used. For example, ATO/MIN HP (85 nm) means that an ATO target will be used for OMS-1, and a target that raises HP to 85 nm will be used for OMS-2. Above the target names, there are circled numbers indicating the target ID number that can be used to enter the targets with an Item 35 entry on the Maneuver display. This item entry will automatically bring up the abort target selected, but the Time-to-Ignition

(TIG) may still have to be adjusted. Then, the targets will need to be loaded with an Item 22 followed by an Item 23 to start the countdown timer to TIG.

The only abort given on this card that does not require an OMS burn is a post MECO TAL, which (as shown) may be required for a severe underspeed situation.

2.5   POST MECO SYSTEMS ABORTS

Another cue card that provides the crew with abort options is the OMS 2 TARGETING cue card (Figure 2-6). This cue card is used for critical systems failures or OMS failures that occur after OMS-1 and before the OMS-2 burn. For these systems failures, the capability to continue the mission or to reach the desired orbit has been lost. Therefore, an abort is required.

In the case of a MECO underspeed and a system failure, the worst-case abort is performed. For example, if there is a MECO underspeed that requires an ATO and there is a post MECO cabin leak that requires AOA, the AOA is performed.

PILE

OMS 2 TARGETING
(DIR INSERTION)

FAILURE	OMS 2 TARGET
OMS – 2 N2 TKs 　　　(Perform burn 　　　　Single OMS Eng) 　　– 2 OMS ENGs 　　– 1 He TK 　　– 1 PRPLT TK EPS – MNA & B, MNB & C 　　　MNA & C ET SEP	PEG 7; TTA = 1 CUTOFF HP = 85
OMS – 2 OX or 2 FU TKs 　　– 1 OX & 1 FU TK 　　　diff PODs 　　– 2 He TKs	AOA-S
2 FREON LOOPS [Accum Qty (↓ and decr) and/or Flow (↓)] 2 H2O LOOPS CABIN LEAK (-EQ dP/dT ≥ .08)	AOA
APU/HYD – impending loss of all capability	AOA
CRYO – All O2(H2)	AOA

OMS 1 BURN

OMS

He	%	He	%
4800	96	2960	50
4560	90	2560	40
4160	80	2160	30
3760	70	1760	20
3360	60	1360	10
		960	0

FB 2-10　　　　　　　ASC/116/FIN
usa007151_762r1.tif

Figure 2-6. OMS 2 TARGETING cue card

2.6 QUESTIONS

Answers to these questions are found in Appendix B.

1. During powered flight, what three types of cues are normally available to provide the crew with information about abort mode boundaries?

2. Define the following MCC voice calls:

   a. Two-Engine TAL

   b. Negative Return

   c. Press to ATO

   d. Single-Engine OPS 3

   e. Press to MECO

   f. Single-Engine TAL

   g. Single-Engine Press

3. Define the following boundaries listed on the NO COMM MODE BOUNDARIES cue card:

   a. NEG TAL

   b. LAST PRE MECO TAL

   c. LAST TAL

4. What do the marks RTLS and GO represent on the TRAJ display?

5. List three systems failures that require an abort pre-MECO.

6. When is the OMS 1/2 TGTING cue card used?

7. When is the OMS 2 TARGETING cue card used?

3.0 ATO/AOA POWERED FLIGHT PHASE

3.1 OBJECTIVES

Upon completing this section, the student should be able to

- Name three software functions that can aid ascent performance and are consequences of ATO selection during powered flight

- Describe the difference between a nominal MECO target and an ATO MECO target

- Describe the benefit of abort shaping

- Given certain initial conditions, determine the resulting inclination due to variable IY steering

- List two reasons for performing an abort OMS dump during powered flight

- Describe the ATO OMS dump configuration

- Describe how to initiate an ATO pre-MECO

3.2 ATO AND AOA ABORT OPTIONS

The implementation of the ATO and AOA abort options is highly dependent on mission-specific flight planning. Mass properties and mission objectives affect flight-specific performance. Flight software is designed to accommodate varying mission requirements for guidance, navigation, and flight control.

One way this accommodation is made is by defining parameters that can be changed for specific flights. These variables are called initialization loads, or I-loads. Many ascent guidance parameters, including the MECO target, are examples of I-loads. Some software functions can be inhibited for a given flight, setting certain I-loads equal to zero for example. Not all capabilities designed into the software are used for all flights. Therefore, ATO selection does not always affect ascent guidance. Initiation of an ATO is only required for flights in which OMS propellant must be dumped pre-MECO to decrease overall vehicle weight, which in turn increases performance. This sequence is required in order to prevent disposing of the ET in populated areas.

For systems failures, continuous RTLS/TAL/AOA-S/AOA/ATO capability exists from lift-off to a short time (mission dependent) before OMS-2 ignition. However, for an abort situation other than performance problems, the crew does not select an ATO/AOA abort until post-MECO. There is nothing to be gained by selecting the ATO or AOA abort pre-MECO.

Therefore, an ATO is usually initiated pre-MECO for a main engine failure or other known performance problem. If an ATO is selected, guidance may perform one or more of the following functions, as well as the functions performed during a nominal ascent:

a. Select ATO MECO targets

b. Initiate variable IY steering

c. Initiate abort dump sequence

Steering to inclinations higher than 28.45° (or due east) requires additional perform-ance. During powered flight, while steering to inclinations greater than 28.45°, a turn into the current inclination can conserve performance. While steering to 51.6°, for example, an engine failure at about 10,000 Vi would force a TAL. However, a steer inplane improves the performance to ATO.

Selection of an ATO at the ATO boundary will also start an OMS propellant dump. This dump adds a small amount of thrust while reducing weight.

From there, the expected ultimate orbit is approximately 105 nm by 105 nm with an inclination about 45° and greatly reduced OMS propellant. The mission objective is probably lost, but the shuttle has achieved orbit.

This discussion continues in more detail.

3.3   ATO MECO TARGETING

The ATO MECO target selection software determines whether the nominal or ATO MECO target will be used by ascent second-stage guidance post ATO selection.

An ATO MECO target set contains an I-loaded target consisting of a velocity magnitude, radius magnitude, and flightpath angle. The ATO OMS-1 and OMS-2 targets generate the ATO orbit, which typically is lower than the nominal orbit.

If an ATO has been requested, the software determines whether the guidance should remain targeted for nominal MECO or be retargeted for the ATO MECO. The decision is based on the velocity when the main engine fails.

The ATO switch velocity is a maximum I-loaded velocity at which the ATO MECO target will no longer be used. If the velocity at engine fail is less than this switch velocity, guidance will be targeted for the ATO MECO. The nominal MECO target will be maintained if the velocity at engine fail is greater than or equal to the switch velocity. Currently, switch velocity is typically set well past nominal MECO velocity, so the ATO targets are always used.

3.4   VARIABLE IY STEERING

Variable IY steering is another abort function intended to reduce performance requirements and achieve earliest abort capability. This reduced performance is achieved by changing the orbital plane target at MECO from the nominal ascent value to a current, in-plane performance-optimum value for an ATO (Figure 3-1). By changing the orbital plane, the vehicle thrust is all in-plane, which optimizes fuel usage and

performance. This function is used for orbit inclination greater than 28°, where out-of-plane steering is done to achieve the required higher inclination and may also be used for 28° missions that use variable steering for ground-up rendezvous.
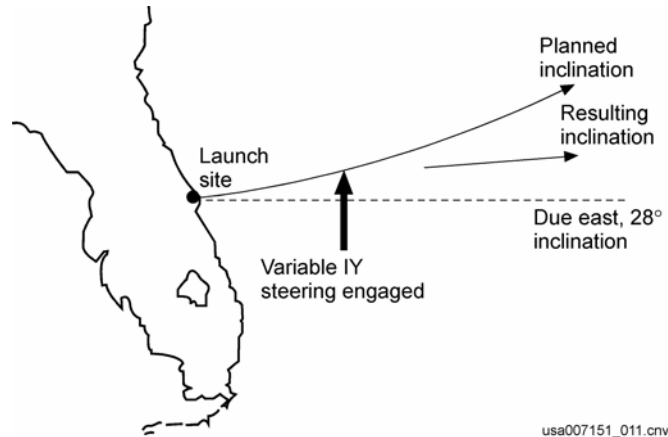
Figure 3-1. Result of variable IY steering

IY refers to a unit vector perpendicular to the desired orbital plane that implicitly specifies the inclination and node constraints. The most efficient way to launch a space vehicle is due east into an orbit with an inclination equal to the latitude of the launch site (28.5° for KSC). However, that will not always be the inclination that is desired for a mission. To achieve an orbit with a different inclination, the vehicle must gradually steer its velocity vector toward the desired orbital plane.

If an ATO abort is declared and the variable IY steering option is selected, guidance changes the nominal IY target to the current in-plane value. More concisely, the inclination is frozen and the energy reserved to increase inclination is pointed in plane. However, if the orbit inclination at the time of the abort is less than the minimum acceptable inclination that is defined pre-mission, then the IY target is set equal to a minimum IY value. As such, out-of-plane steering continues until this minimum inclination is reached.

An ATO abort will often arrive at the planned inclination but in an ATO orbit. After an SSME failure at a point post Press to ATO (PTATO) and pre-Press to MECO (PTM), an ATO orbit can be achieved at the planned inclination. That is, the optimum inclination can be achieved with an OMS dump and without an in-plane turn. The point at which this can be accomplished is known as V Mission Continue or V_MSSN_CNTN. ATO selection for post V_MSSN_CNTN on a 51.6° mission, for example, will result in a 51.6° inclination at an ATO altitude. V_MSSN CNTN is "no-opted" for 28.45° missions and for some others.

3.5   ATO PRE-MECO OMS DUMP

The pre-MECO OMS dump initiates immediately upon ATO selection and terminates based on either a constant or ramp dump timer. There are two reasons for performing

an ATO dump: (1) to control the Center of Gravity (c.g.) and (2) to reduce overall weight in order to improve performance in powered flight.

As is the case for all dumps, the ATO dump is controlled by the abort control sequence. The ATO dump configuration is flight specific and changes from flight to flight. As mentioned previously, the dump may be fixed in duration, variable, or a combination of the two. The software actually calculates the OMS dump time as a function of the main engine-out velocity. If an ATO is selected with three main engines running, the OMS dump time is based on the vehicle's velocity at ATO abort deceleration (i.e., when the abort pushbutton is pushed).

Figure 3-2 shows an example of a typical ATO dump. As shown for early ATO aborts (engine-out and/or abort velocity less than or equal to an I-loaded velocity known as V_LIN), a constant burn duration sequence is performed. Post V_LIN, the OMS propellant burn time is decreased linearly as the engine-out velocity increases in an effort to conserve OMS propellant for on-orbit usage. The V_ZERO I-load is placed where Ascent Flight Design has determined no dump is required for that particular mission.
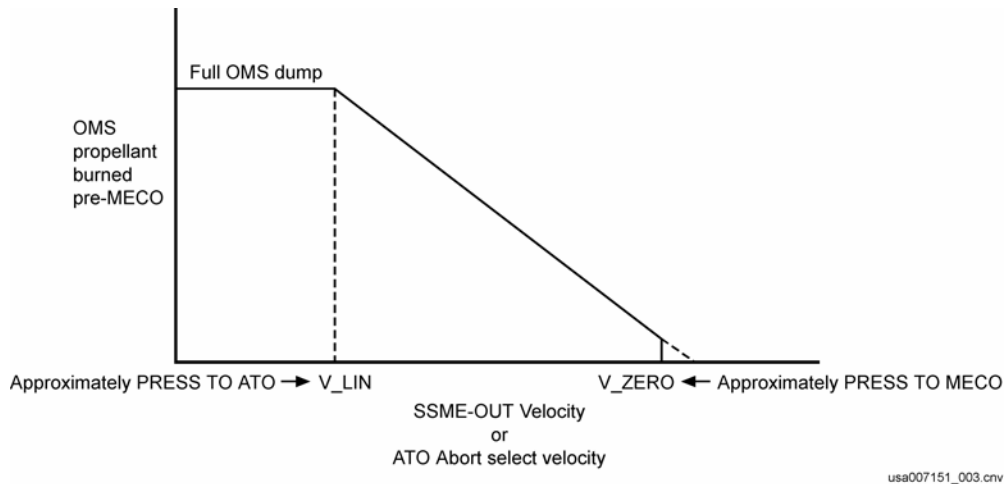
Figure 3-2. OMS burn duration scaling for ATO dump

Typical numbers:

V_MSSN_CNTN	12,000 Vi
V_LIN	11,500 Vi
V_ZERO	18,000 Vi

The ATO dump uses two OMS engines. If OMS propellant loading quantities require a higher burn rate than is available through two OMS engines, an OMS/RCS interconnect is performed, and the 24 aft RCS jets can assist the dump. Interconnecting with the RCS jets is determined by an I-load specific for the ATO abort dump.

The ATO dump is based on a timer. At abort selection, the appropriate I-loads set the timer and determine the interconnect configuration. The dump through the OMS engines occurs almost immediately. If interconnected, the RCS jets begin to fire 3 seconds after the OMS engines fire (see section 1). The interconnect status and abort dump time can be seen on SPEC 51 (Figure 3-4) after abort selection.

Interconnected or not, the dump continues until the expiration of the timer, as displayed on SPEC 51. The crew is also provided with the cue card that gives the dump time for interconnected and non-interconnected dumps (Figure 3-3).

Note: The dump terminates during fine count just prior to MECO independent of the time remaining.

The RCS portion of the interconnect dump will stop (but will not be returned to straight feed) in the event of a second SSME failure in order to preserve Single Engine Roll Control.
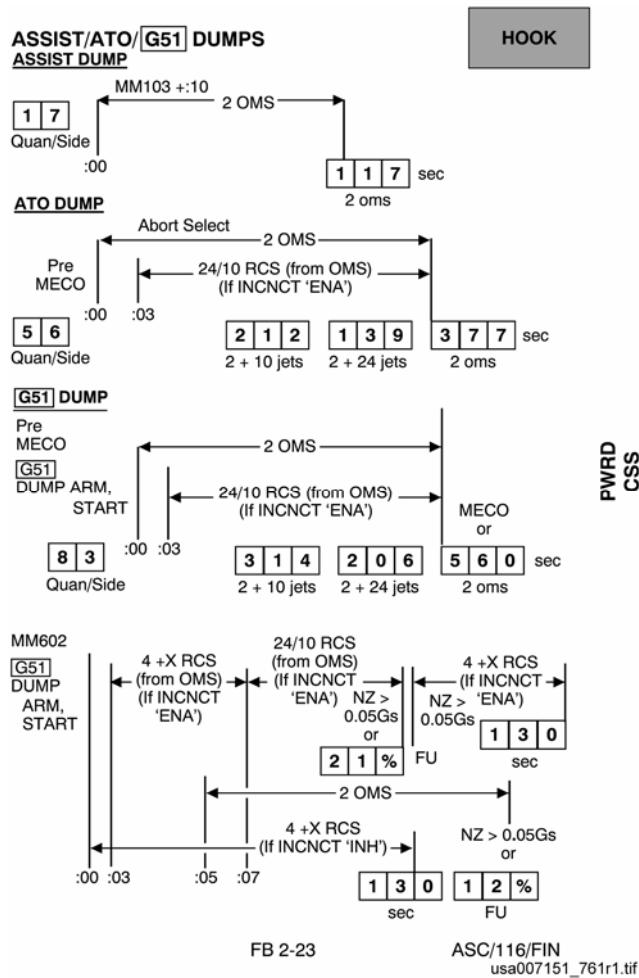
Figure 3-3. Abort Dumps cue card (Assist/ATO/SPEC51)

3.6 ATO ROLL TO HEADS UP

For ATO, the powered flight Roll to Heads Up (RTHU) is performed at the same velocity as in nominal powered flight. During both nominal and ATO, RTHU is performed at a *relative* velocity of 12,200 ft/sec with a 5 degree per second roll rate. With a constant *relative* velocity, the *inertial* velocity naturally changes as a function of inclination.

Inclination	RTHU V_{REL}	V_{REL} to V_I add:	RTHU V_I
57.00°	12,200	800	13,000
51.60°	12,200	1000	13,200
39.00°	12,200	1200	13,400
28.45°	12,200	1400	13,600

3.7 ATO PRE-MECO ABORT SELECTION

The crew can request an ATO by setting the abort mode rotary switch to the ATO position and pressing the abort pushbutton or by item entries on the OVERRIDE display (SPEC 51) shown in Figure 3-4. Item 2 EXEC followed by Item 3 EXEC allows an ATO abort in MM102, MM103, and MM104. If an ATO is selected during MM102, guidance selects ATO targeting upon transition to MM103. ATO targeting is scheduled immediately if an ATO is selected during MM103.

```
6011/051/          OVERRIDE           1 000/00:02:40
                                        000/00:02:40
ABORT MODE                    ENTRY FCS
  TAL       1       ELEVON      FILTER      ATMOSPHERE
  ATO       2     AUTO  17*   NOM 20*     NOM      22*
  ABORT     3     FIXED 18    ALT 21      N POLE 23
  THROT MAX 4      SSME REPOS 19 ENA      S POLE 24
        ABT 50    IMU STAT ATT DES            PRL
        NOM 51    1          1  25        SYS AUT DES
     PRPLT DUMP   2             26         1  28* 31
  ENA ICNCT 5     3             27         2  29* 32
  OMS DUMP                                 3  30* 33
     ARM    6     ADTA      H      a      M    DES
     START  7      L 1                         34
     STOP   8        3                         35
   9 QUAN/SIDE  83  R 2                        36
  OMS DUMP TTG 200   4                         37
                   ET SEP           ROLL MODE AUTO
                     AUTO     38      AUTO SEL    42
  AFT RCS 13   ENA   SEP      39      WRAP MODE 45
     14 TIME    0   ET UMB DR         VENT DOOR CNTL
                     CLOSE    40       OPEN      43
  FWD RCS 15   ENA  RCS RM MANF       CLOSE     44
     16 TIME   25    CL OVRD 41

     SPEC 51 PRO
```

usa007151_741.tif

Figure 3-4. Abort selection on OVERRIDE display (SPEC 51)

3.8   QUESTIONS

Answers to these questions are found in Appendix B.

1. Name three software functions that can aid ascent performance and are consequences of ATO selection during powered flight.

2. What would you expect to be the major difference between the nominal MECO target and the ATO MECO target?

3. If the planned inclination for a flight is 57° and the I-loaded minimum inclination is 32°, what inclination results if an ATO is selected because a main engine has failed at one of the following points?

    a. Very early, when the current IY vector represents an inclination of 28°.

    b. Later, when the current IY vector represents an inclination of 40°.

    c. Near MECO, when the current IY vector represents an inclination of 57°.

4. List two reasons for performing an OMS dump during powered flight.

5. What normally stops an ATO OMS dump, a software timer or a quantity limit?

6. During an ATO OMS dump

    a. Is OMS propellant ever dumped through RCS jets?

    b. Are OMS engines and RCS jets ever burning at the same time?

7. Describe how to select an ATO before MECO.

8. If the abort rotary switch does not work, how is an ATO select before MECO?

4.0   ATO/AOA POST-MECO ACTIONS

4.1   OBJECTIVES

Upon completing this section, the student should be able to

- Identify the cue card used for MECO underspeed situations

- Identify parameters on the Maneuver (MNVR) display that are used in determining the target for an underspeed situation

- Given an underspeed scenario, determine the abort target required

- Describe the three OMS-1 burn target options on a direct insertion mission

- Describe the OMS-2 burn target options on a direct insertion mission

4.2   MANEUVER DISPLAY

The MNVR display appears automatically at the transition to MM104 (Figure 4-1). Items that apply to abort targeting are described below. For more information on this display, see the Displays and Controls Flight Software Subsystem Requirements (FSSR) Volume 1 or the Data Processing System (DPS) Dictionary.

```
1041/   /       ATO-1 MNVR EXEC        1 000/00:10:24
OMS BOTH 1*                             000/00:01:35
         L 2           BURN ATT
         R 3            24 R  ___      ΔVTOT
RCS SEL   4             25 P           TGO
5 TV ROLL __0           26 Y
TRIM LOAD              MNVR 27 AUTO     VGO X
  6 P [+]0.4            TTG                 Y
  7 LY[-]5.7           REI                  Z
  8 RY[+]5.7           TTA 17:02
9 WT 243481               GMBL             HA    HP
10 TIG                  L     R        TGT
  _0/00:11:59.1     P +3.5  +3.5      CUR   74  +  9
TGT PEG 4            Y +4.0  -4.0
  14 C1      ____0
  15 C2  []0.0000    PRI 28*  29*     35 ABORT TGT _1
  16 HT   104.000    SEC 30   31
  17 eT   220.000    OFF 32   33         FWD RCS
  18 PRPLT [1___0                         ARM   36
TGT PEG 7            GMBL CK  34          DUMP  37
  19 ΔVX [1____._                         OFF   38*
  20 ΔVY  [1__._                       SURF DRIVE
  21 ΔVZ  [1__._                          ON    39
LOAD 22/TIMER 23                          OFF   40*
```

00715122.CRT:1

Figure 4-1. ATO-1 MNVR EXEC display

4.2.1   Display Title

The MNVR title can have a variety of prefixes and suffixes, depending on major mode and abort mode, as shown in Table 4-1. The ATO and AOA prefixes appear whenever the respective abort is selected.

Table 4-1. Maneuver display titles

Major Mode	Title	Mission Phase
104	OMS 1 MNVR EXEC	Nominal OMS-1 burn
	ATO 1 MNVR EXEC	ATO OMS-1 burn
	AOA 1 MNVR EXEC	AOA OMS-1 burn
105	OMS 2 MNVR EXEC	Nominal OMS-2 burn
	ATO 2 MNVR EXEC	ATO OMS-2 burn
	AOA 2 MNVR EXEC	AOA transition (no burn)
106	OMS 2 MNVR COAST	Nominal after OMS-2
	ATO 2 MNVR COAST	ATO after OMS-2
301	DEORB MNVR COAST	AOA pre-deorbit burn
302	DEORB MNVR EXEC	AOA deorbit burn
303	DEORB MNVR COAST	AOA post deorbit burn

4.2.2   Time of Ignition

TIG is the Time of Ignition for the burn. It is displayed as "days/hours:minutes:seconds" in Mission Elapsed Time (MET).

4.2.3   Maneuver Display Target Parameters

Two types of targets are used by guidance, Powered Explicit Guidance (PEG) 4 and PEG 7. PEG 4 targets are stored in the software and are displayed automatically when the target ID is selected. PEG 4 targets can be used only in OPS 1 and OPS 3, and these targets are used unless the specific abort requires a PEG 7 target. PEG targets consist of the following individual parameters.

C1 and C2 determine the relationship of vertical and horizontal velocity at the target point. The equation used by guidance is $V_{vert} = C_2 \times V_{hz} + C1$. For OMS maneuvers in OPS 1, the target point is always an apogee or perigee point where the vertical velocity is zero; therefore, C1 and C2 are zero. For the deorbit burn in OPS 3, the target point is known as Entry Interface (EI). At EI, the vehicle must have a vertical velocity equal to some negative value, and the relationship of vertical to horizontal velocity must be carefully controlled to permit a safe entry. For the deorbit burn, C1 is a large positive number with units of ft/sec. and C2 will be a dimensionless number between 0 and -1.

HT is the height or altitude of the target point above the surface of the Earth in nautical miles. For the deorbit burn, the target point is EI, which is also the defined point of Free Fall and has an altitude of 400,000 feet (65.79 nm).

θT is defined differently in OPS 1 and OPS 3. In OPS 1, θT is the downrange angle from the launch site to the radius vector of the target, in degrees. In OPS 3, θT is the angle from the point of ignition to Entry Interface. Figure 4-2 depicts θT in OPS 1 and OPS 3.
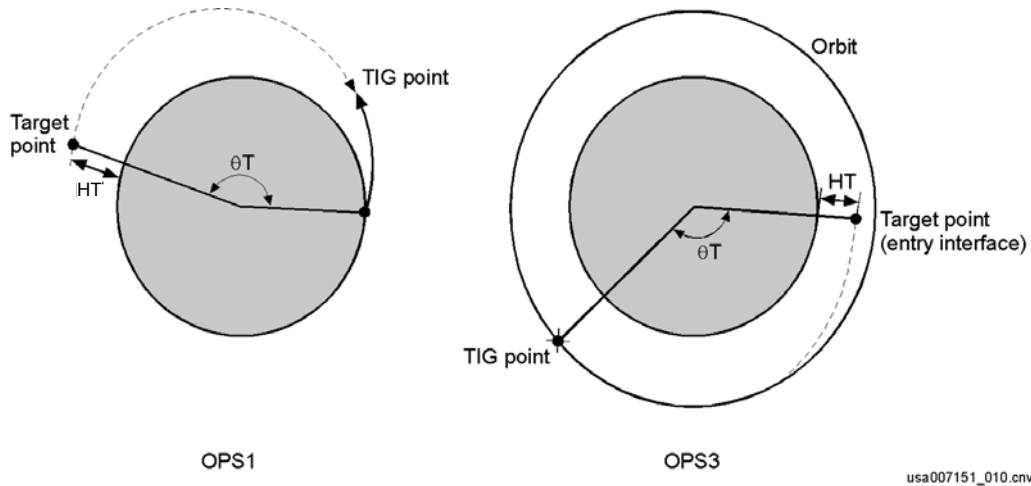
Figure 4-2. Definition of θT in OPS 1 and OPS 3

PRPLT refers to Propellant; the value displayed is total OMS propellant in pounds required for the OMS burn. This item entry is only supported in OPS 3. For some deorbit burns, it is desirable to burn excess propellant for c.g. control and weight reduction. Therefore, Item 18 is loaded with the number of pounds required for the burn plus the number of pounds to be "wasted." If the value displayed is zero or any amount less than the amount required for the burn, there is no impact; the amount required is still the amount used in the software and in reality.

4.2.4   Load and Timer Items

After a target is selected and displayed, it must also be loaded to determine a burn solution. A distinction should be made between "selecting" a target on the MNVR display and "loading" a target. Selecting a target is simply displaying the target parameters on the lower-left quadrant of the MNVR display. Loading a target causes guidance to calculate and display a burn solution on the upper-right quadrant of the MNVR display. Whenever an individual target parameter is changed, the target must be reloaded.

The targets for OMS-1 are loaded automatically, but, in all other cases, the word LOAD flashes on the display, and an ITEM 22 EXEC is required to load the target. The word TIMER never flashes; but, whenever a load entry is required, an ITEM 23 EXEC is also needed to start the Cathode-Ray Tube (CRT) timer, which counts down to TIG. The CRT timer is the second line from the top in the upper-right corner of the display.

4.2.5 Burn Solution

The burn solution includes ΔVTOT, TGO, VGOX, VGOY, VGOZ, TGT HA, TGT HP (see Appendix A for an acronyms list, if necessary), the Burn Attitude (R, P, Y), and Range from Entry Interface (REI) to the landing site. These parameters are displayed when a target is loaded. When a target parameter is changed by item entry, the burn solution parameters go blank until the new target is loaded.

Current (CUR) HA and CUR HP are the current apogee and perigee altitudes in nautical miles, they are displayed at all times.

Note: For extreme underspeeds, the HP display may be truncated. That is, the HA and HP fields contain three digits each. Therefore, a negative four digit (extreme underspeed) HP will appear as a negative three digit HP.

Below the REI display field, which is blank during OPS 1, is the TXX display field. During OPS 1, this display field displays Time to Apogee (TTA) or Time to Perigee (TTP), whichever is closer. If the difference between apogee and perigee is less than 5 nm Time to Circularization (TTC) is displayed, and the time field is blanked. During OPS 3, Time of Free Fall (TFF) (also known as time to EI) is displayed.

4.2.6 Abort Target

Item 35 is used to enter OMS targets via target ID numbers found in the checklist under OMS TGTS or on the OMS 1/2 TGTING cue card. This function is available only in OPS 1.

4.3 ABORT MODE DETERMINATION

MCC is prime for determining the proper abort mode. Post MECO, MCC uses the AME program to make this determination, based on the state vector and the OMS ΔV available.

The crew can also determine the abort selection in the absence of a recommendation from MCC by using the OMS 1/2 TGTING cue card (Figure 4-3). This chart is designed to show abort mode boundaries as a function of the current HA and HP versus available OMS propellant. The following steps are used to determine the required OMS targets, using the typical cue card shown:

1. Locate CUR HA and HP on the MNVR display, then add the two numbers.

2. Note the ATO OMS dump time or the percent of OMS in one pod (two pods are available). Remember the ATO dump is ramped; therefore, the dump time depends on the time of SSME failure.

3. Find the intersecting point on the OMS 1/2 TGTING Card for CURRENT HA + HP and OMS dump time. The region at that intersecting point illustrates the abort region.

4. MECO Vi is shown on the chart as a cross-check for HA + HP.

If the point lies to the right of the bold vertical line (MECO HA = 95), an OMS-1 burn is not required. If the point lies to the left of the bold vertical line, an OMS-1 abort target must be selected. In Figure 4-3, if the point lies to the left of the bold vertical line, either an ATO or AOA-S target is used for OMS-1. Each of these target sets are stored in the software and are identified by a target ID number that is the circled number located above the abort name. These target ID numbers are used to select the abort targets in OPS 104 and OPS 105.
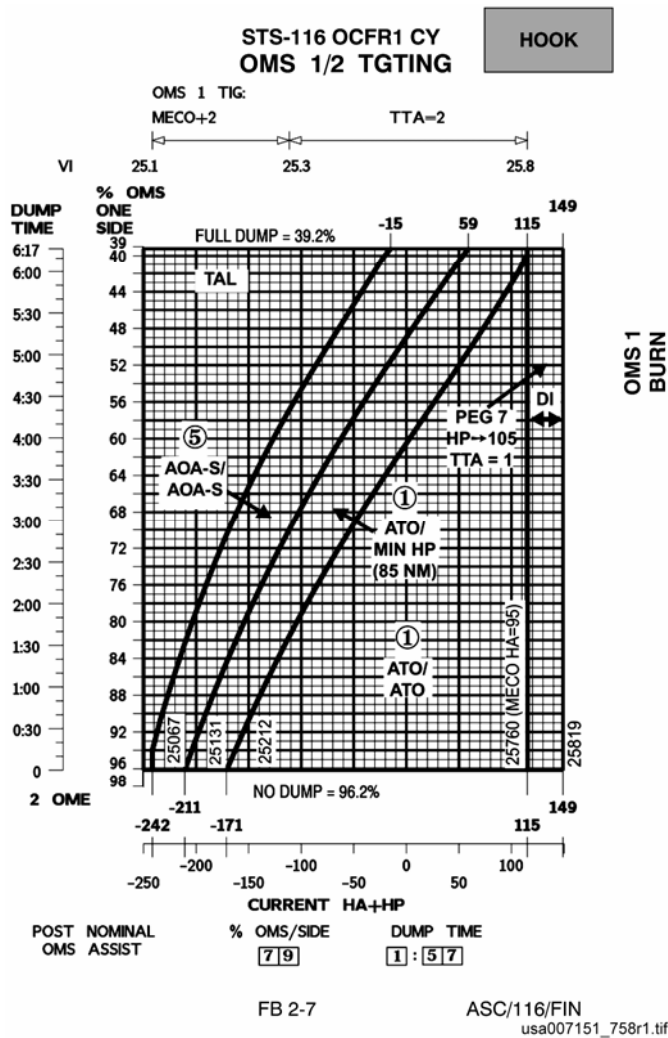
Figure 4-3. OMS 1/2 TGTING card

4.4   OMS TARGET CUE CARDS

The available OMS targets are given on cue cards in the Ascent Checklist under OMS TGTS (Figure 4-4). Each card gives the specific values for TIG, C1, C2, HT, θT and REI. The card also provides a range for ∆VTOT and a sign or a value for PRPLT. These cue cards can be used to verify targets and to follow the correct sequence of targets for OMS-1 (if applicable) and OMS-2. There are two cue cards provided in the checklist for each AOA site available. One card provides the OMS targets for direct insertion (OMS-1 not required), and one card provides the OMS targets if OMS-1 is required. For high inclination flights, there is usually only one set of cards, because NOR is typically the only AOA site available. For low inclination flights, three sets of cards are typically provided, one for KSC, one for EDW, and one for NOR.

4.5   TARGET SELECTION

Any stored target set can be selected manually using the ABORT TGT item on the MNVR display. To select the targets, type ITEM 35 + (desired ID) EXEC. After the ITEM 35 execution, the desired targets will appear on the MNVR display and a new display title will appear (ATO 1 MNVR EXEC, for example). If ATO is selected pre-MECO, the ATO OMS-1 target set and ID will automatically appear in MM104. The crew can refer to the appropriate OMS TGTS cue card in the Ascent Checklist to verify the targets.

If the crew is not satisfied with the current burn targets, based on their evaluation or on ground advice, they can select a better target set by executing another ABORT TGT (ITEM 35) entry. Individual target parameters can also be manually entered or changed by keyboard entries (Items 10 through 17 on the MNVR display). This method can be used for planned targets (those not stored in the software) by referring to the OMS TGTS cue card for the target parameters. More concisely, a target set shown as AOA/K, for example, is a planned AOA target set that is not stored and requires entry via keyboard. This method can also be used for new targets by using target parameters provided by MCC. In addition, MCC has the ability to uplink targets directly to the display.

4.6   OMS-1 TARGETING OPTIONS

All flights since STS-30 have been direct insertion flights; therefore, our discussion of OMS-1 is in regard to aborts only.

On direct insertion flights, OMS-1 is required only for significant MECO underspeeds. The following are the OMS-1 target options:

- ATO

- AOA

- AOA-S
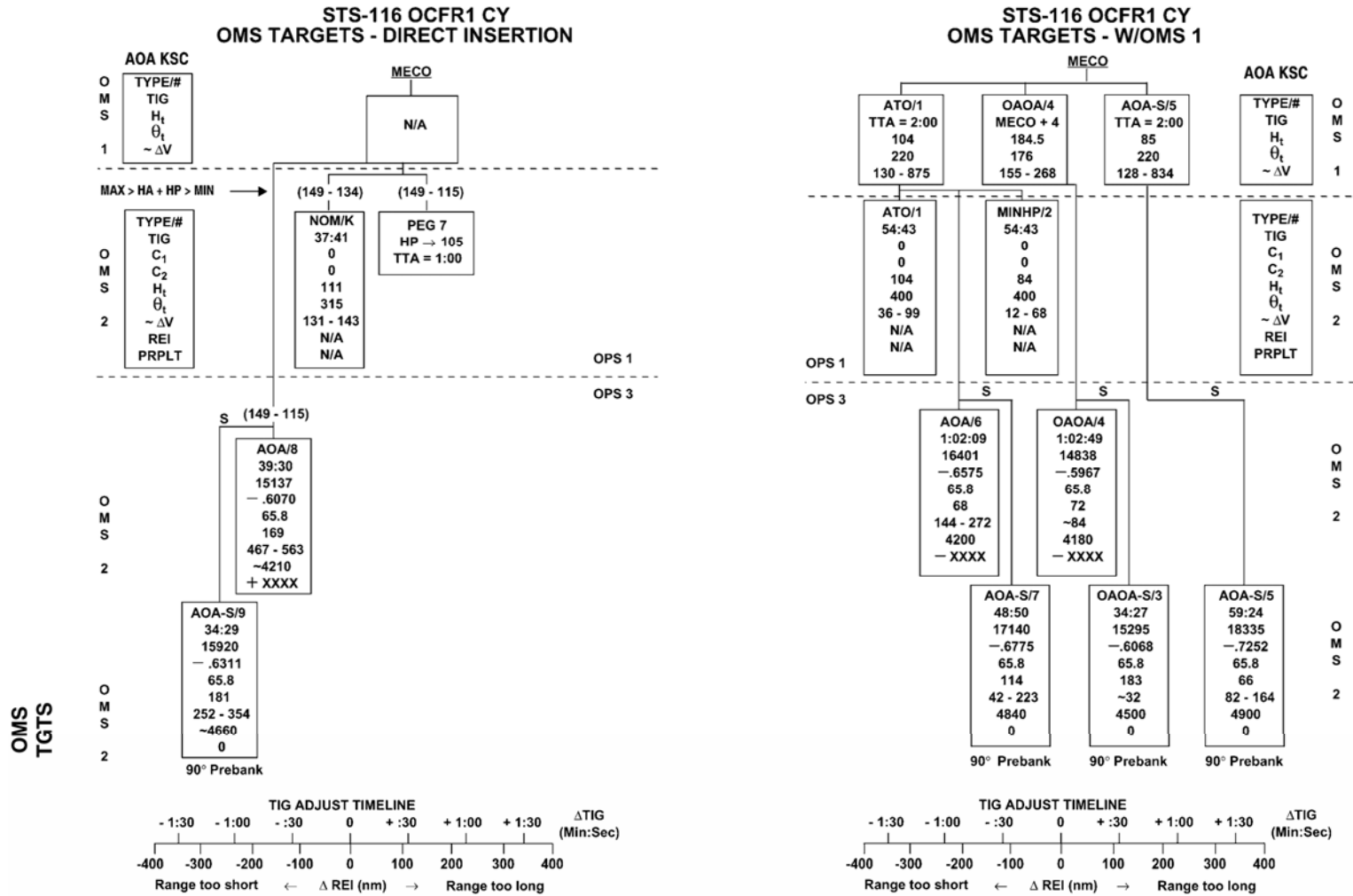
Figure 4-4. OMS targets cue card

All target options will not be available for all flights. Mission performance considerations and crew procedures will determine a specific set of target options for a particular flight.

ATO, AOA, and AOA-S targets are used for underspeed cases, depending on the magnitude of the underspeed.

Stored targets are designed to provide the best possible performance for the most critical case in which the target is used. At the same time, the targets must result in a trajectory that preserves further downmode capability and maintains an orbital altitude that is high enough to avoid significant orbital drag.

Satisfying such a range of targeting requirements results in certain compromises. The orbit resulting from an ATO OMS-1 burn is designed to increase apogee and, at the same time, place the line of apsides in the best orientation for an AOA deorbit. Thus, OMS burn attitudes are not always horizontal in relation to the Earth's surface. The horizontal component of a burn increases apogee, but a radial component is necessary to shift the line of apsides. A shift in the line of apsides will strategically place perigee and protect the deorbit option. In some AOA cases, the radial component can be quite significant.

4.7   OMS-2 TARGETING OPTIONS

The following target options are available for the OMS-2 maneuver on a direct insertion mission.

- No OMS-1 burn required.
    - Nominal
    - PEG 7 HP→HA TTA=1
    - PEG 7 HP→105 TTA=1
    - AOA
    - AOA-S

- OMS-1 burn required (severe MECO underspeed):
    - ATO
    - MIN HP
    - AOA
    - AOA-S

Note that all AOA and AOA-S OMS-2 burns are performed in OPS 3. (On an AOA, the OMS-2 burn is the deorbit burn.)

Nominal OMS-2 targets are used following a nominal MECO (very slight MECO underspeeds are often acceptable). Nominal targets will appear automatically on the MNVR display in MM105.

Slightly larger underspeeds may require PEG 7 targets in the X direction where the current perigee is raised to the same altitude as the current apogee or the current perigee is raised to an altitude of 105 nm.

For certain system failures that require immediate deorbit (identified on the OMS 2 TARGETING cue card, Figure 4-5), AOA or AOA-S targets are used for the OMS-2 burn.

PILE

OMS 2 TARGETING
(DIR INSERTION)

FAILURE	OMS 2 TARGET
OMS – 2 N2 TKs (Perform burn Single OMS Eng) – 2 OMS ENGs – 1 He TK – 1 PRPLT TK EPS – MNA & B, MNB & C MNA & C ET SEP	PEG 7; TTA = 1 CUTOFF HP = 85
OMS – 2 OX or 2 FU TKs – 1 OX & 1 FU TK diff PODs – 2 He TKs	AOA-S
2 FREON LOOPS [Accum Qty ($\downarrow$ and decr) and/or Flow ($\downarrow$)] 2 H2O LOOPS CABIN LEAK (-EQ dP/dT $\geq$ .08)	AOA
APU/HYD – impending loss of all capability	AOA
CRYO – All O2(H2)	AOA

OMS 1 BURN

OMS

He	%	He	%
4800	96	2960	50
4560	90	2560	40
4160	80	2160	30
3760	70	1760	20
3360	60	1360	10
		960	0

FB 2-10   ASC/116/FIN
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Figure 4-5. OMS 2 TARGETING cue card

The OMS TARGETS-DIRECT INSERTION cue card (Figure 4-4) shows the flow diagram for OMS-2 targeting options available when no OMS-1 is required. Remember, all target options are not available for all flights.

The OMS TARGETS-W/OMS 1 cue card (Figure 4-4) gives a similar flow diagram for the OMS-2 targeting options following an OMS-1 burn. For example, after an ATO OMS-1 burn is performed, ATO, MIN HP, AOA, and AOA-S OMS-2 burn targets become available. The ATO or MIN HP OMS-2 burn may be required for large MECO underspeed, and a down-mode to the AOA or AOA-S targets may be required for system failures that occur after the OMS-1 burn. For very large underspeeds, the AOA-S targets are used for the OMS-2 deorbit burn following an AOA-S OMS-1 burn.

4.8 ATO PROCEDURES

OMS-2 ATO insertion procedures are similar to nominal insertion procedures. However, Post ATO OMS-2, the orbit is safe for only several revolutions. In that timeframe, a decision will be made to increase the orbital altitude with additional uphill OMS maneuvers or deorbit early with an OMS deorbit maneuver.

There are special post insertion and deorbit preparation procedures for each of these possibilities. A deorbit and entry after ATO would be very similar to a nominal deorbit and entry. The landing site for an ATO is *likely* to be the same as the normal EOM landing site. However, the orbital ground track on some flights might necessitate landing at an off-nominal location after an off-nominal insertion.

4.9 AOA PROCEDURES

AOA procedures are quite different from nominal ascent procedures. AOA OMS-2 targets are selected (but not loaded) in MM105. The target ID must be entered in OPS 1 because the Item 35 function is not available in OPS 3. When an AOA target is selected (target number 3 or higher), the MNVR display will flash an "OPS 301" at the lower-center column, immediately to the right of the PEG 7 targets.

The "OPS 301" message indicates guidance software is ready for an OPS transition, and it is safe to proceed to MM301 and then to MM302. AOA targets should be loaded only in OPS 3 because θT has a different definition in OPS 1 than in OPS 3. As a result, an AOA burn solution loaded in OPS 1 is not correct.

The landing site for an AOA depends on the orbital ground track on the first revolution and the crossrange capability for a particular flight. The number of available sites varies with each inclination as follows:

Inclination	Available AOA Sites in order of preference		
28.45°	EDW	KSC	NOR
39.00°	EDW	KSC	NOR
51.60°		KSC	NOR
57.00°			NOR

Since AOA landings are typically heavyweight, the Edwards complex provides more landing and rollout margin for vehicle energy problems due to its lack of obstacles. KSC is secondary for its better logistics. Northrup is third. For 57.00° missions, Northrup is the only AOA landing site available due to the large crossrange enroute to a landing at Edwards and KSC.

AOA checklist procedures should be followed closely due to significant differences from the more often exercised nominal and ATO procedures. For example, the Auxiliary Power Units (APUs) are *not* turned off after OMS-1 if an AOA is in progress. If an AOA decision is made later, the APUs will be restarted. In addition, for certain underspeed cases, a special alpha (angle of attack) management procedure must be followed. The "ALPHA MANAGENT" procedure is used for ATOs and AOAs when post OMS-1 HP is less than 75 nm. With HPs less than 75 nm, orbital drag is quite high between the OMS burns. This procedure will minimize orbital drag by minimizing the frontal profile by minimizing angle of attack.

The OMS-2 burn is performed in OPS 3 and serves as the deorbit burn. If excess propellant must be burned to obtain the proper c.g. or to reach the OMS tank landing weight constraints, then propellant wasting is performed during the burn. However, for AOAs caused by OMS propellant failures, all of the available propellant may be required for the deorbit maneuver. If necessary, aft RCS and forward RCS propellant may also be used to complete the deorbit burn.

The entry and landing phase of an AOA is similar to a nominal entry and landing.

4.10   QUESTIONS

Answers to these questions are found in Appendix B.

1. Which cue card is used to help determine abort targets for underspeed situations?

2. What parameters on the MNVR display are most important for use in determining the target in an underspeed situation?

3. Using the MNVR display (see figure below), OMS 1/2 TGTING cue card (Figure 4-4), and OMS TARGETS (Figure 4-5), answer the following:

    a. Is an OMS-1 required?

    b. At MECO the left and right OMS has 40 percent a side. What target set should be selected?

    c. At what TTA is the TIG (TTA=2 or TTA=1)?

    d. What should the TIG (MET) be for this burn?

    e. What is the ΔV range expected for this burn?

    f. What target set is loaded on this MNVR display?

4. Describe two ways that ATO or AOA targets can be selected post-MECO.

```
1041/   /      ATO-1 MNVR EXEC     1 000/00:10:24
OMS BOTH 1*                          000/00:01:35
        L  2           BURN ATT
        R  3            24 R  ___    ΔVTOT
RCS SEL   4             25 P         TGO
5 TV ROLL  __0          26 Y
TRIM LOAD              MNVR 27 AUTO  VGO X
  6 P [+]0.4             TTG              Y
  7 LY[-]5.7           REI                Z
  8 RY[+]5.7           TTA 17:02
  9 WT 243481               GMBL         HA      HP
 10 TIG                    L      R    TGT
     _0/00:11:59.1     P +3.5   +3.5   CUR   74   +  9
 TGT PEG 4            Y +4.0   -4.0
   14 C1         ___0
   15 C2   [ ]0.0000  PRI 28*   29*  35 ABORT TGT _1
   16 HT    104.000   SEC 30    31
   17 eT    220.000   OFF 32    33      FWD RCS
   18 PRPLT [1___0                        ARM    36
 TGT PEG 7            GMBL CK   34        DUMP   37
   19 ΔVX [1____._                        OFF    38*
   20 ΔVY  [1__._                      SURF DRIVE
   21 ΔVZ  [1__._                        ON     39
 LOAD 22/TIMER 23                        OFF    40*
```

00715122.CRT;1

5.0   TRANSOCEANIC ABORT LANDING

5.1   OBJECTIVES

Upon completing this section, the student should be able to

- List the most common TAL sites that are used for high-inclination and low-inclination missions

- With the aid of the No Comm Mode Boundaries cue card, determine which boundaries relate to TAL capability

- Describe two methods to initiate a TAL in the shuttle software

- Confirm that a TAL has been selected in the onboard software

- Define the purpose of variable IY steering for TAL

- Describe the actions for proceeding to OPS 3 in a normal TAL sequence

- List four reasons for the MM304 post MECO dump

- Describe the requirements for TAL site redesignation

The TAL abort was developed during preparations for STS-1 and has evolved from a manual procedure into an automatic abort mode. The purpose of the TAL abort is to provide an intact abort option prior to the earliest Press to MECO boundary, for the loss of performance. For all two-engine cases, TAL capability will, by ground rule, close the gap between RTLS and ATO capability.

The TAL mode is also useful for systems failures that occur after the last RTLS opportunity (Negative Return). If a cabin leak or vehicle-cooling problem is found to be too severe to support an AOA, then a TAL could be initiated to permit the earliest possible landing. OMS tank failures that occur during ascent, which reduce the ΔV capabilities below that required to support an ATO or AOA, could be supported by a TAL abort. In this manner, TAL capability is any opportunity across the Atlantic Ocean before AOA capability is achieved. TAL aborts can also be declared post MECO.

5.2   LANDING SITES

Multiple TAL landing opportunities are available in order insure against weather and landing/navigation aid issues. Dependant upon inclination, three or four sites are carried in flight software to support *powered flight* guidance for TAL aborts. With the exception of FMI, each TAL site has both nominal and low cross-range options. Whereas, the nominal TAL targets are approximately 500 nm north of the site, low crossrange targets are about 350 nm north of the site. The flight software landing site table allotment is seven powered-flight targets to TAL landing sites. The seven slots are used as described (three sites, each with nominal and low cross-range targets and one

additional target for high inclination flights - nominal cross-range to FMI.) Actual TAL support is dependant upon the current political environment. However, NASA personnel will support at least two TAL sites for each mission.

Several more sites become available in flight software in *glided flight*.

Technically speaking, only one TAL site is available for each mission. That would be the site, which is deemed "prime TAL" for that day. Other available sites in powered flight software having NASA personnel support (but are not prime) are called ACLS or Augmented Contingency Landing Sites. They are "augmented" because of their people, hardware, and software support. All other sites would be called ELS, or emergency landing sites. In the case of 51.6° missions, ZZA will be the TAL site (provided weather and landing/navigation aids are go). FMI, MRN, and BEN could become ACLSs (if supported), while all other sites will be ELS.

From a flight design and ground rule standpoint, TAL sites chosen are those closest to the ground track of the orbiter in order to limit cross range when flying the entry portion. Figure 5-1 shows the location of overseas landing sites and the orbiter ground track for various inclinations.

usa007151_450r2_tif
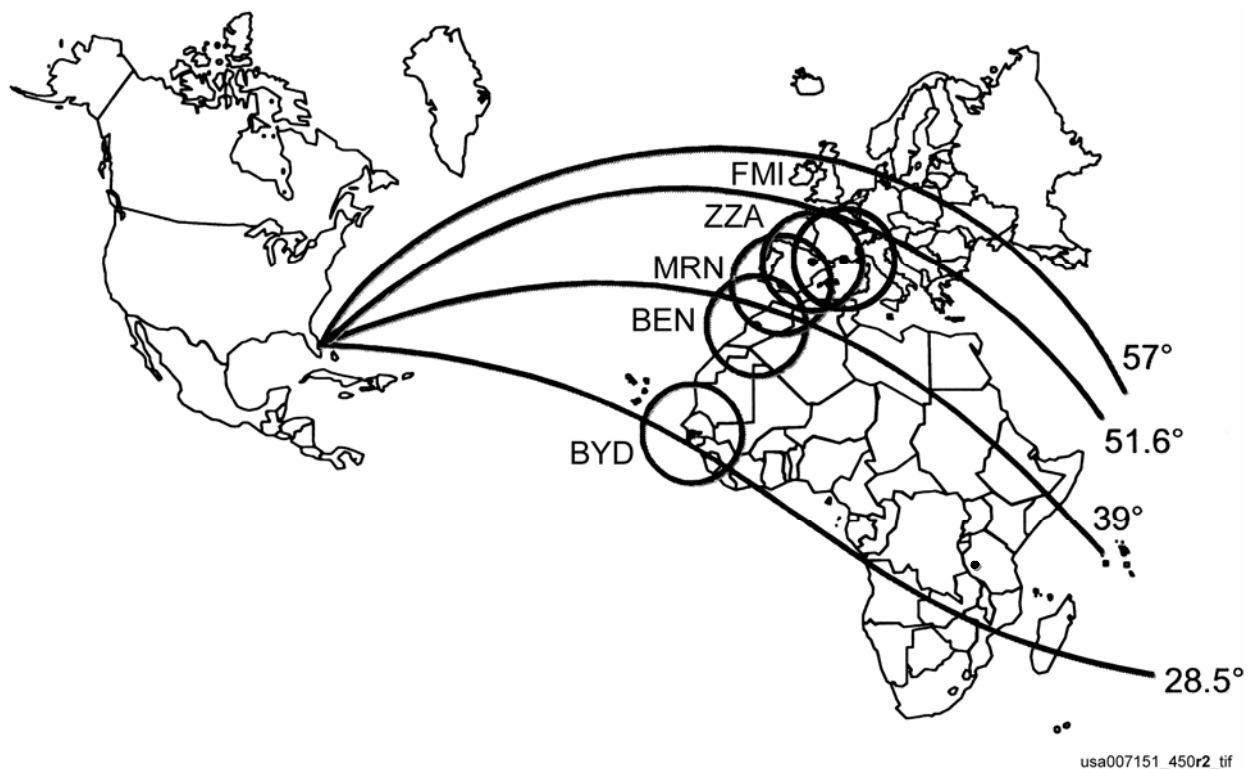
Figure 5-1. Orbiter ground tracks for various inclinations

Inclination	Available TAL Sites in *geographic* order of preference			
28.45°	BYD Banjul, The Gambia	BEN Ben Guerir, Morocco		MRN Moron, Spain
39.00°	MRN Moron, Spain	ZZA Zaragoza, Spain		BEN Ben Guerir, Morocco
51.60°	FMI Le Tube, France	ZZA Zaragoza, Spain	MRN Moron, Spain	BEN Ben Guerir, Morocco
57.00°	FMI Le Tube, France	ZZA Zaragoza, Spain	MRN Moron, Spain	BEN Ben Guerir, Morocco

More landing sites are available for post MECO TALs. The available landing sites in the software are listed in section 7 of the Ascent Checklist in the Landing Site Table.

5.3 ABORT MODE BOUNDARIES

The TAL boundaries are relayed to the crew from MCC. Determination of the boundaries is based on real-time evaluation using the ARD operated by the Flight Dynamics Officer (FDO). If communication is lost with MCC, the crew can use the No Comm Mode Boundaries cue card from the Ascent Flipbook (Figure 5-2). These boundaries are determined in the flight design phase. In addition, an Abort Summary cue card is also carried onboard. Figure 5-3 shows the Abort Summary cue card for STS-116, a 51.60° inclination flight.

Figure 5-2. No Comm Mode Boundaries for STS-116
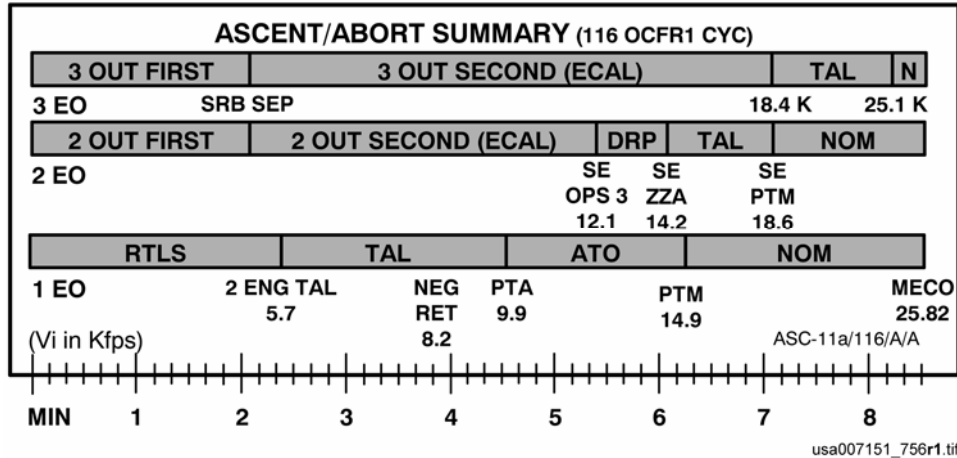
Figure 5-3. STS-116 ASCENT/ABORT SUMMARY cue card

In powered flight, TAL abort is selectable from the 2 ENG TAL Boundary through the LAST PRE MECO TAL Boundary. Post MECO, TAL is available until LAST TAL. There may be overlapping capability to TAL sites, and sites may or may not have identical boundaries because they vary with ground track.

The SE OPS 3 boundary represents the earliest point OPS 3 software will be available to execute an abort if a second SSME fails (or two SSMEs fail simultaneously). This boundary requires a maximum throttle setting (109 percent), which is selected by item entry on SPEC 51. The SE TAL boundary is the point that guarantees performance to reach the TAL site with a throttle setting of 104 percent.

For severe underspeeds, a TAL may be declared post MECO. This capability is available beginning around a V_I of 23K (flight specific) until AOA-S capability around a V_I of 25K. Post MECO, the TAL abort selection can be verified only with SPEC 50. That is, SPEC 50 will show that the TAL Flag is set only when the ITEM 41 value corresponds to a TAL site (see Figure 5-4 and Figure 5-5).

5.4   ABORT MODE SELECTION

TAL abort selection is accomplished using the rotary switch on panel F6. The abort is executed after the abort pushbutton is depressed. If the abort rotary switch or the pushbutton is inoperative, a TAL can be initiated using SPEC 51 and executing Item 1 and Item 3. During powered flight, replacement of the ASCENT TRAJ by the TAL TRAJ confirms that the TAL abort has been executed. Post MECO TAL declaration will not produce a TAL TRAJ. Therefore, Post MECO TAL abort selection can be verified only after the SPEC 50 ITEM 41 value corresponds to a TAL site (see Figure 5-4 and Figure 5-5).

Upon selection of TAL abort, the CDR and PLT begin using TAL cue cards from the Ascent Flipbook (Figure 5-6). Pre-MECO, the CDR verifies site selection and TAL capability, based on velocity. The PLT monitors the OMS dump. Actions associated with a second engine out are also executed by the PLT.

```
  1041/050/         HORIZ SIT        1 000/00:09:08
PTI    INH 1    ALTM                   000/00:00:00
  INDEX   0     9  29.92                  NAV DELTA
                                             ΔX 10
40 TAL  SITE  _4                          [ ]____0
41 RTLS SITE  _1                             ΔY 11
PRI KSC15     3                           [ ]    0
SEC KSC33     4*                             ΔZ 12
TAC- 59       5                           [ ]    0
GPS FOM       RA                             ΔX 13
       2      46                          [ ]__0
TAEM TGT                                     ΔY 14
G&N    OVHD 6                             [ ]   0
HSI                                          ΔZ 15
NEP        7                              [ ]   0
AIM   NOM  8              ⌂               LOAD 16
S/B   NOM 39                           18 ΔT [ 0.00
NAV   RESID RATIO AUT INH FOR TAC1   0 TAC2   0 TAC3   0
TAC AZ            19 20* 21
   RNG
GPS              42 43* 44    DES 31  DES 32  DES 33
DRAG H           22* 23 24    ABS 34  DELTA 35*
ADTA H           25 26* 27   GPS   RN       AZ
ADTA TO G&C      28 29* 30   AIF_G  47  48* 49   H
                                         usa007151_747.tif
```

Figure 5-4. SPEC 50 pre-TAL abort

```
  1041/050/         HORIZ SIT        1 000/00:09:36
PTI    INH 1    ALTM                   000/00:00:00
  INDEX   0     9  29.92                  NAV DELTA
                                             ΔX 10
41 TAL  SITE  _4                          [ ]____0
PRI ZZA30     3*                             ΔY 11
SEC ZZA12     4                           [ ]    0
TAC  64       5                              ΔZ 12
GPS FOM       RA                          [ ]    0
       2      46                             ΔX 13
TAEM TGT                                  [ ]__0
G&N    OVHD 6                                ΔY 14
HSI                                       [ ]   0
NEP        7                                 ΔZ 15
AIM   NOM  8              ⌂                [ ]   0
S/B   NOM 39                              LOAD 16
                                       18 ΔT [ 0.00
NAV   RESID RATIO AUT INH FOR TAC1   0 TAC2   0 TAC3   0
TAC AZ            19 20* 21
   RNG
GPS              42 43* 44    DES 31  DES 32  DES 33
DRAG H           22* 23 24    ABS 34  DELTA 35*
ADTA H           25 26* 27   GPS   RN       AZ
ADTA TO G&C      28 29* 30   AIF_G  47  48* 49   H
                                         usa007151_748.tif
```

Figure 5-5. SPEC 50 post-TAL abort

PILE		HOOK

TAL CDR

If $V_I > \boxed{23000}$ manual MECO $\boxed{23700}$, go to post MECO
ABORT TAL
$\boxed{G50}$ √SITE & RWY (PASS/BFS), √HDG

SITE	RWY	TACANS	ITEM 5	MLS	LENGTH
2	BEN 36/18	BEN 108	MAK 80 (DME)	6/–	13720/12720
3	MRN 20/02	MRN 100	AOG 23	6/–	11730/11730
4	ZZA 30L/12R	ZZA 64	ZZA 77 (DME)	6/–	12200/12200
12	*BEN 36/18	BEN 108	MAK 80 (DME)	6/–	13720/12720
13	*MRN 20/02	MRN 100	AOG 23	6/–	11730/11730
14	*ZZA 30L/12R	ZZA 64	ZZA 77 (DME)	6/–	12200/12200
19	YJT 09/27	YJT 78	YDF 80 (DME)	–/–	9500/9500
20	YYT 29/11	UYT 23	YYT 82 (DME)	–/–	8500/8500
21	YQX 22/31	YQX 74	IQX 32 (DME)	–/–	9700/8900
23	LAJ 15/33	TRM 109	LAJ 45	–/–	10870/10870
24	BEJ 01L/19R	MOJ 37	BEJ 105	–/–	10820/10820
25	IKF 20/29	KEF 57	IRE 28 (DME)	–/–	9520/9560
26	INN 06/24	SHA 80 (DME)	CRN 37 (DME)	–/–	9540/9540
27	FFA 27/09	FFA 81	BZN 56	–/–	9490/9490
28	KBO 14L/32R	GIX 18	DOR 23Y (DME)	–/–	12020/12020
29	FMI 33/15	NIM 53	ITR 104	–/–	11800/12300
30	ESN 03R/21L	BAG 78 (DME)	BUK 90 (DME)	–/–	11800/11800
31	KKI 15R/33L	RIY 92	KIA 80	–/–	13300/13300
32	JDG 31/13	NKW 57	NKW 57	–/–	12000/12000

* If second eng fails: $\boxed{TRAJ}$ √SERC ON
* $\boxed{G50}$ √ SITE (√Redes card) *

*LO XRNG

$V_I = \boxed{15.0K}$ √Roll Heads Up

– – – MECO $V_I \sim$24.0K @ CO mark $\boxed{BFS}$ – – – – – MECO – –

MECO+20 s √ET SEP, √AUTO -Z TRANS
MECO+37 s √MM104
Abort TAL (if reqd):
√TAL flag set: $\boxed{G50}$ ITEM 41 = TAL SITE (any site)
√MECO V_I vs HI/LO Energy (TAL PLT)
√Rates < .5°/sec; θ > 15°, Y = 0 ± 30°
PASS, OPS 301 PRO (√304)

* No joy in 68 sec: BFS – ENGAGE *
* BFS, OPS 301 PRO *

– – – – – – – – – – – – – MM304 – – –

BFS, OPS 301 PRO (√304)
$\boxed{G50}$ √SITE, RWY, TACAN
S/B & ALTM (PASS/BFS)
$\boxed{TRAJ}$ √BUGS, $\boxed{HSI}$ √Ⓗ, RANGE
$\boxed{AMI}$ √ α = 43°

* Low energy: $\boxed{TRAJ}$ ITEM 3 (Lo Energy ENA) *
V = 10K √SPDBK → 81%
V = 7K   Go to ENTRY MANEUVERS
(Cue Card)

	WINDS
50K	/
38	/
28	/
20	/
12	/
7	/
3	/
1	/
SURF	/
SPDBK @ 3000 FT	
ALT	
AIM PT	
SPDBK	

RTLS

FB 2-14   ASC/116/FIN

TAL PLT

√OMS DUMP

* If second eng fail: *
* $\boxed{G51}$ MAX THROT – ITEM 4 (*) (if reqd) *
* $\boxed{G51}$ DUMP – ITEM 6 (*), 7 (*) *
* If OMS He PRESS < 2K: DUMP STOP *
* Failed ME SHUTDN pb (two) – push *

√AUTO THROT

* If second eng fail or STUCK TAL: *
* When MPS PRPLT = 2%: *
* MAN THROT, P_c → 67% *
* Man MECO @ CO mark $\boxed{BFS}$ *

– MECO – – – $V_I \sim$24.0K @ CO mark $\boxed{BFS}$ – – – – – MECO – –

* If first SSME fail at Press to ATO,
subtract 200 fps from box velocities

LOW-ENERGY ENA (α: Variable)
NOMINAL (α: 43/40)
HIGH-ENERGY TAL
HIGH-ENERGY GANDER

3 EO MECO V_I (KFPS)

116 OCFR1

– – – – – – – – – – – – – MM304 – – –

√OMS DUMP
√ET DOORS – Closed and latched (MM304 +1:30)

V = 19K   HYD MPS/TVC ISOL VLV (three) – CL
(hold 5 sec) √tb – CL

V = 7K   MLS (three) – ON (√channels)
I/O RESET
Go to ENTRY MANEUVERS (Cue Card)

HI-ENER GANDER

FB 2-15   ASC/116/FIN

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(a) TAL CDR   **(b) TAL PLT**

Figure 5-6. TAL flipbook procedures

At MECO, the crew monitors ET SEP and software transition to MM304. In addition, runway capability is reevaluated for the site selection. After the transition to OPS 3, the TAL entry software is similar to nominal EOM entry software.

5.5   GUIDANCE

Post TAL select, the shuttle indicator and predicators on the BFS TAL TRAJ display begin following the upper TAL trajectory line. The MECO range target is about 2800 nm from the landing site with MECO velocity target around 24K V_I (this is often referred to as the targeted range-velocity or RV).

Variable IY (inertial yaw) steering is initiated at the time of abort to reduce the cross range or out-of-plane distances the shuttle is required to glide after MECO. The software attempts to bring cross range to within 500 nm at MECO. The landing site is selected using SPEC 50, and should be selected prelaunch.

5.6   TAL ROLL TO HEADS UP

For TAL, the powered flight Roll to Head Up (RTHU) is performed at a *relative* velocity of 14,000 ft/sec with a 5 degree per second turn rate. With a constant *relative* velocity, the *inertial* velocity naturally changes as a function of inclination.

Inclination	TAL RTHU V_{REL}	V_{REL} to V_I add:	TAL RTHU V_I
57.00°	14,000	800	14,800
51.60°	14,000	1000	15,000
39.00°	14,000	1200	15,200
28.45°	14,000	1400	15,400

5.7   OPS 3 TRANSITION

Post MECO, and after the TAL software is onboard (TAL flag has been set), OPS 301 PRO is required to be performed on the PASS and BFS. With OPS 3 Transition complete, the software will scroll automatically to MM304. If the orbiter is not already heads up (a rare case involving CSS), an RTHU is performed automatically after the MM304 transition.

5.8   AUTOMATED ALPHA-BETA MANEUVER DURING MATED COAST

In MM104, at a rate of .5° per second, the orbiter will maneuver to an angle of attack (α) > 15° and a β < 30°. Once in attitude, the OPS 3 transition may be performed. If not in attitude prior to MM304, a delay of the post MECO OMS Dump may occur. In MM304, a non-zero pitch attitude (θ) is required in order to prevent a non-zero roll rate. Additionally, a larger β at the MM304 transition will translate into a roll error. The

inability to roll or a roll error may delay the proper post MECO attitude and, subsequently, the post MECO dump. That is, in order to accomplish the MM304 Dump, the proper attitude (FCS_ACCEPT_ICNCT flag) must be achieved.

The automated alpha-beta maneuver is a PASS-only maneuver. If the BFS is engaged, this maneuver must be performed manually.

5.9   TAL ABORT DUMPS

A dump of OMS propellant is executed almost immediately after TAL abort selection. The dump will start automatically as a function of the TAL abort. This dump is accomplished to expedite separation from the ET, to meet OMS tank landing weight constraints, to meet orbiter gross weight constraints, and for c.g. management.

Some OMS propellant is reserved for the post MECO MM304 dump. This dump assists the separation from the external tank and helps reduce wing leading edge temperatures in addition to meeting weight and c.g. constraints cited earlier. In MM304, when below Mach 9, an aft RCS dump is executed to further reduce weight and manage orbiter c.g. Figure 5-7 shows the RTLS/TAL side of the abort dumps cue card from the Ascent Flipbook. For STS-116 the aft RCS dump at Mach 9 is no-opted.

TAL abort dumps, like all abort dumps, are based on an I-loaded timer. At abort selection, the appropriate I-loads set the timer and interconnect configured as specified by flight design. The dump through the OMS engines occurs almost immediately. If interconnected, the RCS jets begin to fire soon after the OMS engines fire. See Figure 5-7 for exact dump start/stop times.

The MM304 dump software will enable the interconnect if the pre-MECO dump is incomplete, such that greater than 36% OMS fuel remains at MECO. Please note, the I-load value for 36% is based on the equivalent time such that gauges and gauge failures do not affect this function. If the MM304 TAL dump interconnect is enabled, the OMS engines are commanded to fire 5 seconds after dump start with the RCS jets beginning to fire 2 seconds later. Smart interconnect software performs the same steps post MECO as it did pre-MECO.

If the MM304 TAL dump interconnect is inhibited, the RCS 4 +X jets begin firing at dump start then continue for a total duration of 20 seconds. The OMS engines will fire 10 seconds into the 20 second RCS dump, which allows an aft settling of the OMS propellant into the tank outlets.

The Forward RCS dump will start when MM304 is entered and continue for 65 seconds for this particular flight. This is a null-dump which means it does not put any translational or rotational rates on the vehicle.
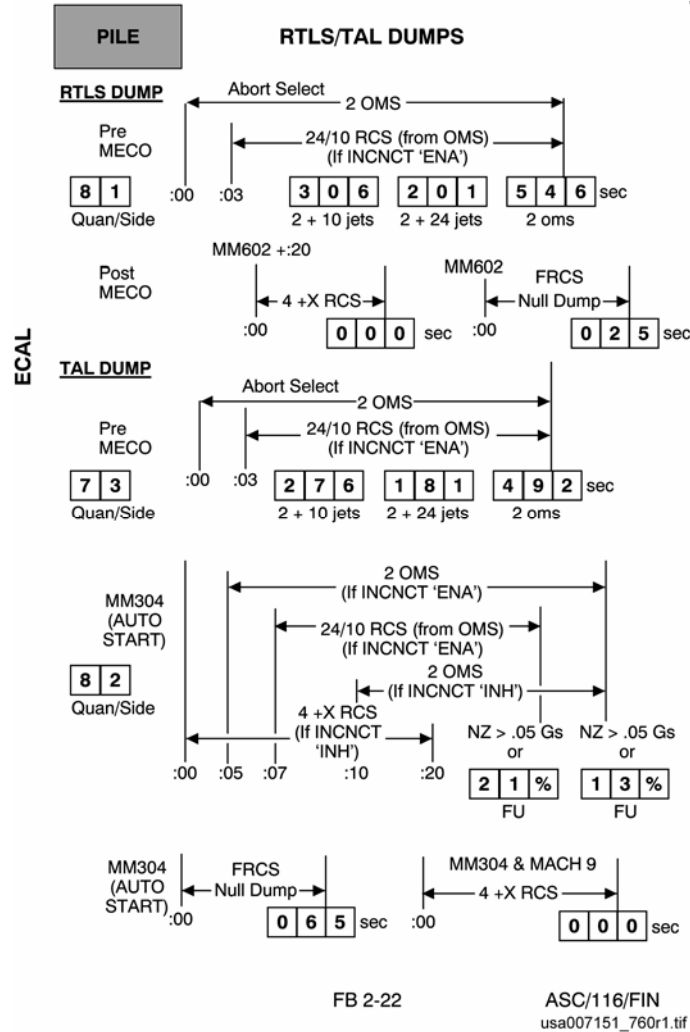
Figure 5-7. Abort Dumps cue card (RTLS/TAL)

Interconnect ENA or INH, the dumps will continue until the expiration of the dump timer as displayed on SPEC 51 or 0.05g. The ABORT DUMPS cue card shows a percentage as the cue for dump stop, but percent is used as a secondary cue to SPEC 51 time. If the normal loads on the vehicle (Nz) reach 0.05 times the acceleration of gravity (or 0.05g) the dump terminates regardless of time remaining. Tank design does not support dump operations under acceleration in axes other than the X-axis direction.

5.10   LANDING SITE SELECTION

The available TAL sites are listed on the No Comm Mode Boundaries cue card for each mission. Site selection is a function of geography, politics, and launch day weather. Sites for each inclination are chosen based on their ability to provide a landing site that closes the RTLS to ATO gap for a single SSME failure. Of the sites that fill this requirement, three sites have been made available within Flight Software (FSW). The sites available in FSW were chosen as a function not only of location but also politics (Table 5-1). Post landing crew safety, orbiter recovery, and gap closure are considered in this decision.

Table 5-1. TAL site preferences

Inclination	Available TAL Sites in *geographic* order of preference			
28.45°	BYD Banjul, The Gambia	BEN Ben Guerir, Morocco	MRN Moron, Spain	
39.00°	MRN Moron, Spain	ZZA Zaragoza, Spain	BEN Ben Guerir, Morocco	
51.60°	FMI Le Tube, France	ZZA Zaragoza, Spain	MRN Moron, Spain	BEN Ben Guerir, Morocco
57.00°	FMI Le Tube, France	ZZA Zaragoza, Spain	MRN Moron, Spain	BEN Ben Guerir, Morocco

The launch day TAL selection is based on the most inplane capability to an available field within weather constraints. Only one good TAL site is required for launch constraints to be met. Once a TAL site is selected, the remaining sites are deemed Augmented Contingency Landing Sites (ACLSs). They are "augmented" because they fill personnel and equipment requirements for TAL. On launch day, the best choice in the event of TAL would be the designated TAL site. If the status of that TAL site changes during powered fight, another TAL site is selected from the available ACLSs. In cases when both the TAL and ACLS sites become unavailable during powered flight, an Emergency Landing Site (ELS) would be considered.

For post MECO TAL Aborts, MECO velocity and current inclination will define the available sites. From there, the Guidance and Procedures Officer (GPO) and the FDO will select a landing site using the same (TAL, ACLS, ELS) priority. If MCC is not available, post MECO TAL landing site selection is made via the bar chart on the TAL PLT procedure in the flipbook. When using this chart, keep in mind it is only accurate for three SSMEs down simultaneously. With one SSME down at Press to ATO and the subsequent two SSMEs down simultaneously, this chart is accurate after subtracting 200 fps from the values shown on the chart.

5.11   QUESTIONS

Answers to these questions are found in Appendix B.

1. For ISS missions (51.6^o inclination), which sites are available for TAL?

2. What capability does the SE OPS 3 (109) boundary provide?

3. How does the crew select a TAL?

4. What confirming cues are available for the crew to determine that a TAL has been selected in the onboard software?

5. What is variable IY steering designed to accomplish?

6. In a normal TAL sequence, do you proceed to OPS 3 by doing an OPS 301 PRO or by an OPS 304 PRO?

7. Why is a post MECO OMS dump executed on a TAL?

8. When is a TAL site change required prelaunch?

6.0   RETURN TO LAUNCH SITE

6.1   OBJECTIVES

Upon completing this section, the student should be able to

* With the aid of the No Comm Mode Boundaries cue card, determine which boundary relates to RTLS capability

* Describe two methods to initiate an RTLS in the shuttle software

* Describe when an RTLS abort is necessary

* Confirm that an RTLS has been selected in the onboard software

* Describe the RTLS trajectory

6.2   RTLS OVERVIEW

If an engine fails during the first 4 minutes of ascent, the shuttle cannot achieve orbit. For the first 2 1/2 minutes or so of ascent, it cannot even reach a TAL. The only runway near enough to be reached is one near the launch site. In order to reach this runway, the shuttle must literally reverse course and fly back the way it came.

The turn to reverse course is called Powered Pitch-Around (PPA), and the timing of PPA is critically important. Since the orbiter is powerless once the main engines are shut down, these engines must be shut down when the orbiter has enough speed and altitude to glide to the runway. Also, in order to safely separate the orbiter from the ET, the ET should have no more than 2 percent propellant remaining. More propellant might slosh around and cause the tank to lurch and collide with the orbiter. Therefore, the shuttle must turn back toward the launch site at the exact instant that will allow it to arrive at MECO with the right amounts of speed, altitude, and propellant.

If the RTLS is declared before the time of PPA, the shuttle has to perform what is called fuel wasting. This means pointing the shuttle more vertical (called lofting) to minimize loss of altitude while still flying away from the launch site and runway. This continues until the shuttle must execute PPA and turn back toward the launch site. From this point on, the shuttle thrusts back toward the runway until it reaches MECO conditions. These conditions are specified as less than 2 percent propellant remaining at a specific altitude, flight path angle and on the Range-Velocity Line (R-V line).

Then the orbiter separates from the ET and begins to glide back to the runway. During this gliding flight, called GRTLS, the orbiter may perform certain maneuvers to fine-tune its glide range or energy. Finally, as the orbiter approaches the runway, it will perform a wide turn to align itself with the direction of the runway and then glide down to a landing (Figure 6-1).
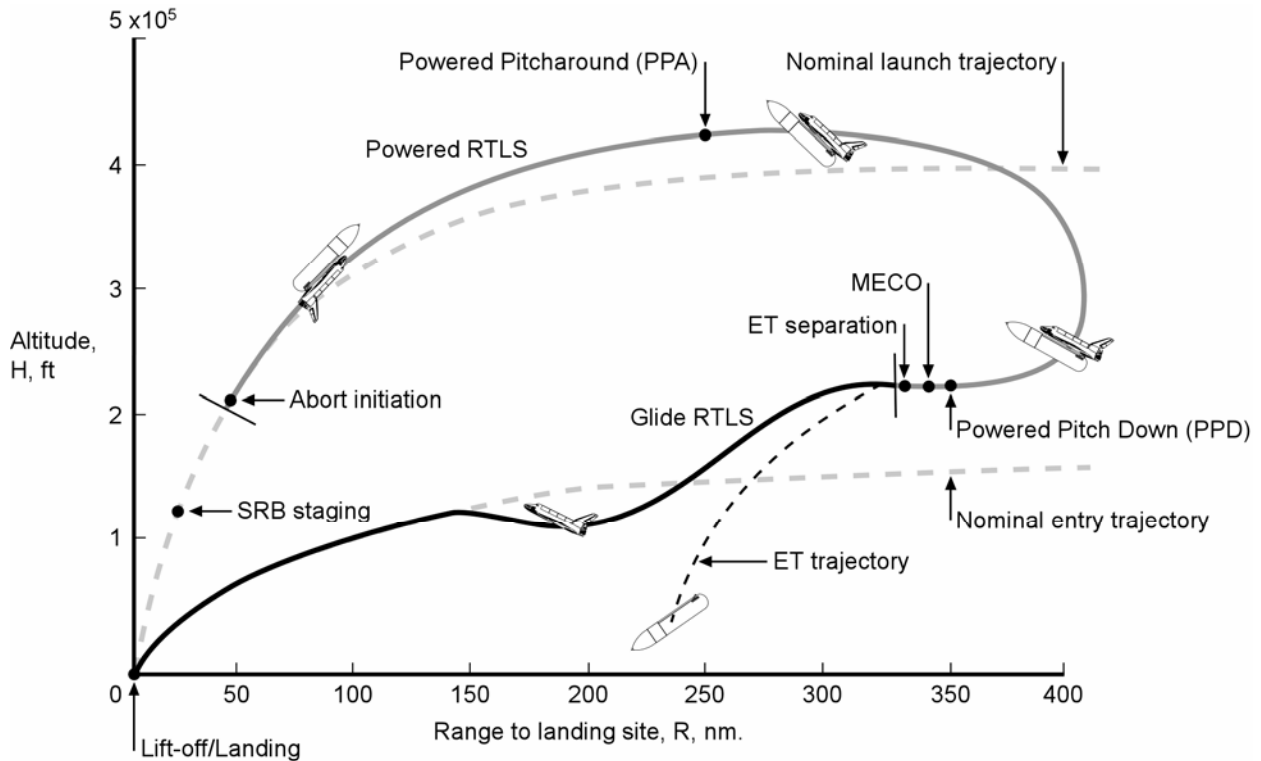
Figure 6-1. Typical RTLS profile

6.3   RTLS SELECTION

Although it may be apparent that an RTLS is necessary when an SSME fails, the actual time that the RTLS abort is declared is dependent on several factors. RTLS aborts for performance losses are generally performed at Liftoff (L/O) + 2m30s (referred to as 2+30). For example, if an engine fails during first stage, the RTLS abort is delayed until 2m30s. The earliest RTLS selection is made at 2m30s allowing time for SRB sep induced transients to be damped out, and for second stage guidance to converge. Therefore, an abort could be initiated before SRB sep, but the vehicle would not begin the RTLS flight profile until after 2m30s anyway. The result is that the RTLS abort is always delayed until at least 2m30s. If an engine fails after 2m30s, but before a TAL is possible, the RTLS abort is performed immediately.

For systems failures, an RTLS abort is delayed until L/O + 3m40s (referred to as 3+40). By aborting at 3m40s, ground controllers have more time to determine whether to abort RTLS or TAL.

Once the vehicle has passed a certain point, its range from the launch site and its downrange velocity are too great to safely return to the runway at the launch site. This point is called negative return; an RTLS abort should not be performed after negative return has been reached. 3m40s is usually at least 10 seconds before negative return. Therefore, there should always be a comfortable amount of time between the RTLS abort selection and negative return.

As soon as the ground determines that an RTLS abort is required, it directs the crew to abort RTLS at the proper time. For example, if an engine fails in first stage, the ground tells the crew to "abort RTLS at 2 + 30." Along with the voice call, the Flight Director, using a switch on his console, illuminates the abort Pushbutton Indicator (PBI) on panel F6.

At the proper time, the crew initiates the RTLS abort using the abort rotary switch on panel F6. The switch is moved to the RTLS position, and the abort PBI is pressed (Figure 6-2). If the abort rotary switch fails, the crew can also initiate an RTLS by typing OPS 601 PRO into any PASS keyboard. If the BFS is in control and the abort rotary switch fails, the abort is initiated by typing OPS 601 PRO into the BFS keyboard.
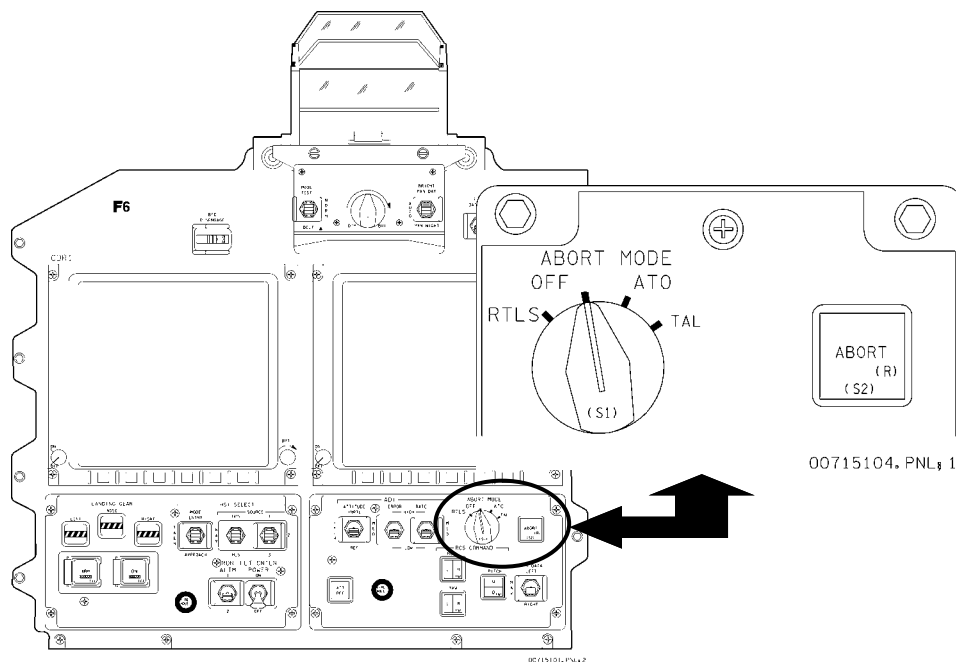
Figure 6-2. Abort mode select switch and PBI

6.4   POWERED RTLS OVERVIEW

After an RTLS abort has been declared, the Powered Return to Launch Site (PRTLS) guidance begins to function. This guidance scheme, named PEG 5, is designed to guide the shuttle from its current location to the proper conditions for MECO. This target location is defined as

- Altitude (I-load)
- Flightpath angle
- Velocity (as a function of range)

The design of these MECO targets is to provide the shuttle with sufficient glide range to the runway, while disposing of the ET in a safe fashion.

PEG 5 is called a closed-loop guidance system. This means that PEG 5 is constantly re-evaluating how well it is doing and makes corrections to account for any errors. It does this by electronically flying the entire powered RTLS profile every few seconds based on actual performance. The computed conditions just before MECO are then compared to the desired conditions to determine a miss vector. This miss vector is then used to compute corrections in steering and throttle commands. This process continues up until the last few seconds before MECO when a time is set for Cutoff (CO) and the closed loop process is suspended.

6.4.1   RTLS TRAJ Display

The shuttle cannot fly at all without its computers. This means that if a serious problem disables all the PASS computers, the crew has no choice but to engage the BFS. However, it is possible that some combination of software errors and/or hardware failures might cause the otherwise healthy PASS computers to be unable to fly the shuttle successfully.

To provide an alternative to engaging the BFS, the capability has been provided for crewmembers to fly the shuttle during ascent. The manual capability is called CSS.

To intelligently use this CSS capability, the crewmembers must have some means of monitoring the AUTO guidance system and the vehicle performance. They must also be able to perform whatever guidance is required if a MAN takeover is required. The information necessary to carry out these two tasks is provided by the computer-generated displays and printed procedures. Manual aborts and manual ascents are covered more extensively in the assigned crew training flow classes and handouts (Manual Ascent 31001 and Manual Abort 31001).

The primary display for the PRTLS portion of the flight is the RTLS Trajectory (TRAJ) display (Figure 6-3). Most of the information on this display is provided directly from navigational software and is completely independent of PEG 5 guidance. Therefore, even if PEG 5 guidance fails, the RTLS TRAJ displays provide sufficient information to fly the vehicle safely.
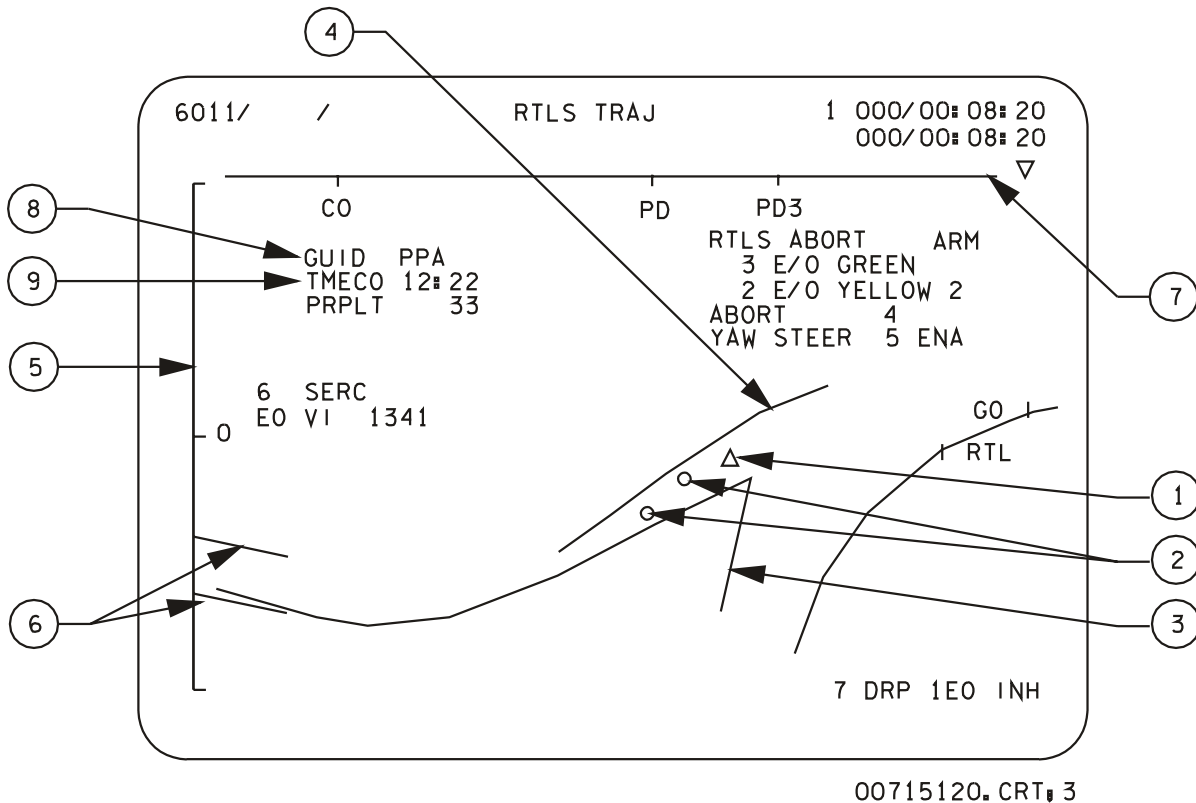
Figure 6-3. PASS RTLS TRAJ display

The central portion of the display is a plot of the vertical altitude versus the horizontal component of the shuttle-Earth-relative velocity with the zero velocity point approximately midway across the screen. The shuttle position is plotted with a triangle, Δ ①, and the two small circles ② are predictors that show the estimated shuttle position 30 and 60 seconds in the future.

The series of lines on the display are approximations of the lowest ③ and highest ④ predicted RTLS trajectory. These two trajectories describe a typical RTLS envelope that can be used in manually guiding the shuttle toward the proper MECO conditions. These lines are guidelines and not absolute boundaries.

The scale on the far left ⑤ is the delta H-dot (ΔḢ) and is used to achieve the proper rate-of-climb at MECO. A "canned" H-dot profile is loaded into the computers, and the H-dot computed from this profile is always represented as the zero tic on the scale. The shuttle H-dot is subtracted from this canned H-dot, and the difference is plotted as a triangle (called the bug) next to the delta H-dot scale. However, this delta H-dot scale is not currently used in the manual flight techniques.

The lines at the far left of the display ⑥ represent acceptable dynamic pressures ($\bar{q}$) for separation and are, from the top, $\bar{q}$ = 2 psf and $\bar{q}$ = 10 psf. The shuttle symbol should be between these two lines while approaching MECO.

The scale at the top of the screen ⑦ is the delta range (ΔR) scale and represents the shuttle current potential glide range. In other words, it displays the difference in a mission-dependent energy status minus current range to landing site. Near MECO, the bug moves from right to left as the glide range nears the proper value. The Pitchdown (PD) and PD3 tics indicate where PD should occur for a two- and three-engine RTLS, respectively. The CO point indicates the point where MECO should be initiated to obtain the proper glide range to the RTLS runway. The PD will be discussed in a later section.

The Guidance (GUID) line ⑧ indicates the status of the guidance solution for PPA. The GUID indicator will be discussed in the following section.

The remaining features of this display ⑨ are digital readouts of the guidance-computed MECO Time (TMECO) as well as the Main Propulsion System (MPS) PRPLT remaining in percent. The two display fields below PRPLT (PC <50 and SEP INH) are also used (not shown). PC < 50 indicates the SRB combustion chamber pressure is less than 50 psi. This indication signals the beginning of the SRB SEP sequence. SEP INH is displayed in the event of an SRB SEP INH or ET SEP INH.

The BFS also has an RTLS TRAJ display. This BFS display is called the RTLS TRAJ 2 display. It is similar to the PASS RTLS TRAJ display but contains some additions that make it useful for monitoring PASS versus BFS performance. Figure 6-4 shows BFS RTLS TRAJ 2.
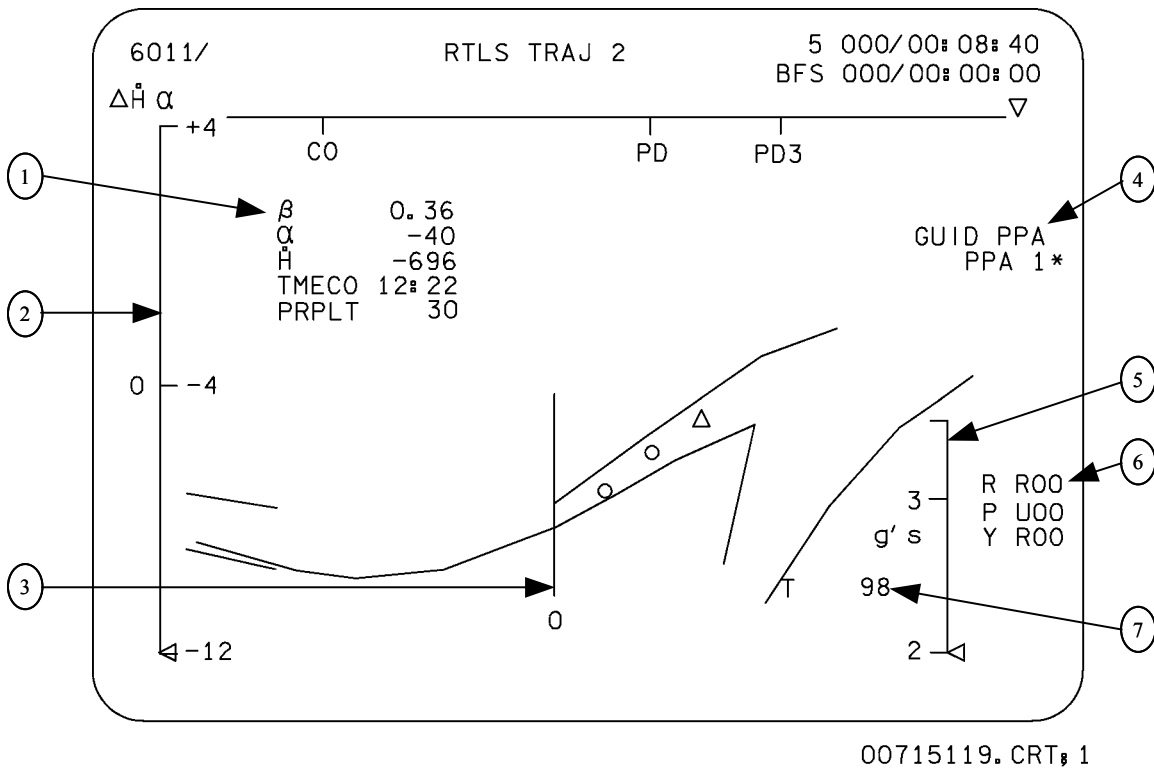

Figure 6-4. BFS RTLS TRAJ 2 display

①Digital readouts of BFS-computed values of sideslip angle (β) and angle of attack (α) and altitude rate $\dot{H}$ are shown. ②The Δ$\dot{H}$ scale is like the PASS but has an additional angle of attack display that shows α from +4° to -12°. ③The vertical line labeled 0 denotes zero horizontal velocity relative to the Earth. This point is usually referred to as "Vrel zero." This vertical line is not shown on the PASS RTLS TRAJ, but Vrel zero occurs where the upper TRAJ line stops.

④The PPA item is used to indicate when the BFS thinks PPA has occurred as well as to force the BFS into PPA mode by performing an ITEM 1 EXEC. GUID indicates the status of the guidance solution for PPA. The GUID indicator is discussed in the following section. ⑤Total vehicle forward acceleration (not N_z) is displayed on the g scale. The indicator or "bug" will flash if 3g is exceeded.

⑥The pitch, yaw, and roll errors computed by the BFS are displayed in a digital, fly-to fashion. ⑦Lastly, the BFS-computed throttle command is displayed. This throttle setting is what the BFS commands if it is engaged. The setting can be used as another independent check on both the PASS and BFS guidance computations.

6.4.2   Guidance Convergence

Guidance convergence is an indicator of how close PEG 5 computations are currently getting to the desired target. If the miss vector is large, larger than an I-loaded value, guidance is said to be unconverged. While this unconverged situation persists, the steering commands produced by guidance and flight control are not reliable. Radical changes in steering direction can result from one guidance cycle to the next. To preclude any violent or wasteful maneuvering, all steering commands are disabled whenever guidance is not converged. The shuttle holds its last attitude until guidance computes a good solution. Guidance is then said to be converged and steering inputs are enabled.

Whenever PEG 5 first begins computing, it is by definition unconverged and remains so for at least several computation cycles. Thus, steering inputs are disabled after PEG 5 is called while it computes a solution.

The crew can monitor whether or not RTLS guidance is converged in several ways. The first indication that guidance has converged on a good solution, after aborting RTLS, is the TMECOs in the PASS and BFS. Immediately after aborting RTLS, the TMECOs in the PASS and BFS will change and they will disagree. However, the TMECOs should be stable and should agree within about 10 seconds after the abort is initiated. If the TMECOs do not agree within about 10 seconds, this could indicate a problem with either the PASS or BFS guidance solution.

Before PPA, the crew also has direct insight into the status of the guidance solution. The GUID line on the PASS RTLS TRAJ display and on the BFS RTLS TRAJ 2 display shows the status of RTLS guidance. Once the RTLS is declared, GUID INIT is displayed. As the vehicle progresses toward the PPA point, GUID displays the percent deviation between

the predicted and final target masses at PPA. GUID INHB is displayed if guidance is unconverged, and GUID PPA is displayed once the PPA begins.

The crew can also monitor the status of guidance by observing the error needles on the Attitude Direction Indicator (ADI). If guidance is unconverged, the needles will stow and will no longer be visible. However, stowed error needles do not necessarily indicate unconverged guidance. Specifically, if guidance is unconverged in MM601, the error needles will stow. If the guidance remains unconverged (the needles remain stowed) until the transition to MM602, the needles will not unstow. In this case, the needles will remain stowed for the rest of the flight regardless of the status of guidance.

It is possible for guidance, once converged, to become unconverged under certain off-nominal circumstances. These periods of unconvergence can vary from one cycle (~2 seconds) to more or less permanently. If guidance does not converge or reconverge within a reasonable time, manual CSS of the shuttle is required. The decision to initiate CSS is made by the shuttle CDR in consultation with MCC.

6.4.3   Main Propulsion System Safing and RTLS INIT

Some of the information that PEG 5 guidance needs in order to do its job is based on events occurring before the RTLS abort is declared. Specifically, PEG 5 needs to know the shuttle speed at the time of the engine failure. Therefore, a software module called the SSME-out safing task is called whenever an engine fails. This module performs several tasks including saving the shuttle Earth-relative velocity at the time of the engine failure so that it will be available for subsequent use.

As soon as an RTLS abort has been declared, there are a few one-time-only computations that must be done in order to initialize the PEG 5 software. These initialization steps, in effect, tell PEG 5 what kind of an RTLS is to be flown. The software module that performs these initialization tasks is called the RTLS initialization task or simply, RTLS INIT.

There are three steps or subtasks contained within RTLS INIT. The first subtask sets a number of flags that change the guidance mode from PEG 1 to PEG 5, disable steering commands and fine countdown, and notify other guidance modules that RTLS INIT is being performed. The second subtask changes the MECO target from Nominal (NOM) to RTLS. The third subtask determines whether this is a two- or three-engine RTLS. If it is a two-engine RTLS, then nothing further is done. For the three-engine RTLS case, this module will compute a new throttle setting to simulate two good engines. This new throttle setting will be 69 percent because three engines at 69 percent equals two engines at 104 percent (207 percent total thrust versus 208 percent). Then RTLS INIT saves the shuttle speed just as if an engine had actually failed. With these preliminary steps completed, PEG 5 now begins to execute.

The crew's first function after an SSME failure is to note the engine-out speed and time. This is important because later procedures use this time to determine key trajectory

parameters. MCC should then confirm the engine failure and request the proper abort mode and time.

As previously discussed, RTLS is selected for any engine failure occurring up to the "2 ENG TAL" boundary. The abort mode cue card contains a list of orbiter systems problems that would necessitate an abort (Figure 6-5a).

If communications with MCC are interrupted, the crew selects the proper abort mode by referring to the "no comm mode boundaries" portion of the abort modes cue card (Figure 6-5b). To select the proper abort, the crew compares the actual engine-out velocity with the abort mode boundaries and selects the mode that the shuttle passed most recently. The abort mode boundaries on the card are computed prelaunch and are extremely conservative. This means that the boundaries are biased to favor the abort mode requiring the least amount of performance.

The time that the RTLS abort should be selected is noted at the top of the RTLS CDR cue card (Figure 6-6). This indicates that for a two-engine RTLS, the abort can be selected any time after 2m30s MET. The card also notes that if the abort switch does not work, RTLS can be selected by typing OPS 601 PRO into a PASS keyboard.

The pilot has his corresponding cue card, the RTLS PLT cue card (Figure 6-7). Upon RTLS selection, the PLT is to take manual throttle control if the CDR has CSS control of the shuttle. If manual throttle control is performed, the automatic engine shutdown logic in guidance is suspended so that MECO must be performed manually using the engine shutdown PBIs on panel C3 (Figure 6-8). If vehicle control is in the automatic mode, the PLT should check that auto guidance has set the proper throttle setting for the type of RTLS being performed.

BAILOUT EGRESS

PILE

SYS FLIGHT RULES

	RTLS	TAL
OMS – 2 He TKs		X
– 1 OX & 1 FU TKs (diff pods)		X
– 2 OX or 2 FU TKs		X
APU/HYD – Impending loss of all capability	X	X
CABIN LEAK – (-EQ dP/dT > .15)	X	X
CRYO – All O2(H2)	X	X
2 FREON LOOPS ↓ [Accum Qty (↓ and decr) and/or Flow (↓)]	X	X
2 MAIN BUSES ↓	X	
THERMAL WINDOW PANE	X	

NO COMM MODE BOUNDARIES

NEG RETURN (104)	8200	2 ENG ZZA (104)		5800
PRESS TO ATO (104)	9900	**ABORT TAL ZZA (4)**		
SE OPS 3 (109)	12100			
SE ZZA (104)	14200	EO VI		
PRESS TO MECO (104)	14900	SE OPS 3 ZZA (109)	(14)	
NEG BEN (2 @ 67)	18400	SE ZZA (104)	(4)	
SE PRESS (104)	18600			
NEG MRN (2 @ 67)	20000	2 ENG MRN (104)		5700
LAST PRE MECO TAL	23000	**ABORT TAL MRN (3)**		
LAST TAL				
YJT	20100	EO VI		
YYT	20200	SE OPS 3 MRN (109)	(13)	
YQX	21900	SE MRN (104)	(3)	
LAJ	23400			
IKF	23700	2 ENG BEN (104)		5700
INN	24100	**ABORT TAL BEN (2)**		
MRN, BEJ, FFA	24300			
FMI, KBO	24500			
ESN	24900	EO VI		
ZZA	25000	SE OPS 3 BEN (109)	(12)	
KKI	25100			
JDG	25200	SE BEN (104)	(2)	

FB 2-4   ASC/116/FIN

usa007151_755r1.tif

(a) Orbiter systems abort criteria

(b) NO COMM MODE BOUNDARIES

Figure 6-5. Abort modes cue card

PILE   RTLS CDR

Abort initiated:
 After 2:30 (2 eng)
 At 3:40 (3 eng)

ABORT RTLS

 * No joy: *
 * OPS 601 PRO *

√GUIDANCE STATUS on RTLS TRAJ
 Expect PPA when GUID % to go = 0

 * If GUID 'INHB': *
 * √UNCONVERGED GUID TABLE *
 * MAN PPA per PRPLT *
 * REMAINING *
 * After GUID CONVERGE: *
 * P,R/Y AUTO/AUTO THROTTLE *

After PPA: √BFS ITEM 1 (*)

TRAJ √Bugs, HSI √ ⬆, Ⓡ

Pitchdn (β = 0°, α = -2°)

WINDS

50K	/
38	/
28	/
20	/
12	/
7	/
3	/
1	/
SURF	/
SPDBK @ 3000 FT	

OMS 2 TGTING

- - - - - - MECO - - - - - - MECO - - - - - -
 ET SEP (MECO + 16 sec)
 √MM602 (α > 10° and SEP + 10 sec)
 √P,R/Y, SPDBK, BDY FLP – AUTO
 α = 50° until ~1.8g, maintain 2.2g

 Adjust seat

$\dot{H}$ = -320↑   VERT SIT √ α vs Mach
V = 5K   AIR DATA PROBES (two) – Deploy (√Heat)
 √RUD, AIL TRIM
M = 3.2   √SPDBK → 65%
M = 2.7   L HUD PWR – ON

 * If M < 2.5, P CSS for ADTA to G&C incorp *

M = 2.0   Ensure ADTA to G&C else THETA limits
M < 1.0   P,R/Y – CSS, √SPDBK CMD vs POS
 √NWS – 1
 Lock Inertia Reels
POST LANDING: ENT, POST LDG

FB 2-12   ASC/116/FIN

RTLS PLT   **HOOK**

If CSS: MAN THROT
 Man MECO
√P_c = 104% (2 eng)/69% (3 eng)
√DUMP

UNCONVERGED GUIDANCE TABLE

ENG OUT	OUTBOUND INITIAL θ	PITCHAROUND at % (8°/sec)	FLYBACK INITIAL θ
Liftoff	60°	44%	64°
:30	56°	47%	63°
1:00	57°	47%	63°
:30	56°	48%	62°
2:00	49°	51%	61°
:30	42°	51%	52°
3:00	38°	52%	50°
:30	34°	53%	48°
4:00	Last RTLS	52%	46°

√P_c at PPA + 20 sec
 * If P_c = 104% (2 eng): *
 * G51 MAX THROT – ITEM 4 (*) *

Pitchdn: √P_c → 67%

- - - - - - MECO - - - - - - MECO - - - - - -
KEAS = 77 √SPDBK → 81%
 √ET DOORS – Closed and latched (MECO +1:30)
 √ET SEP, SRB SEP – AUTO
 Adjust seat
 √TACANS, INCORPORATE

 * If KSC TACAN Fail: *
 * TACAN Ch 073X (OMN), ITEM 5 EXEC *

G51   √AIR DATA, INCORPORATE
MM603   HYD MPS/TVC ISOL VLV (three) – CL
 (hold 5 sec) √tb – CL
H = 85K   MLS (three) – ON
 If Rwy 33(15): MLS CH (three) – 6(8)
 I/O RESET
M = 2.7   R HUD PWR   – ON
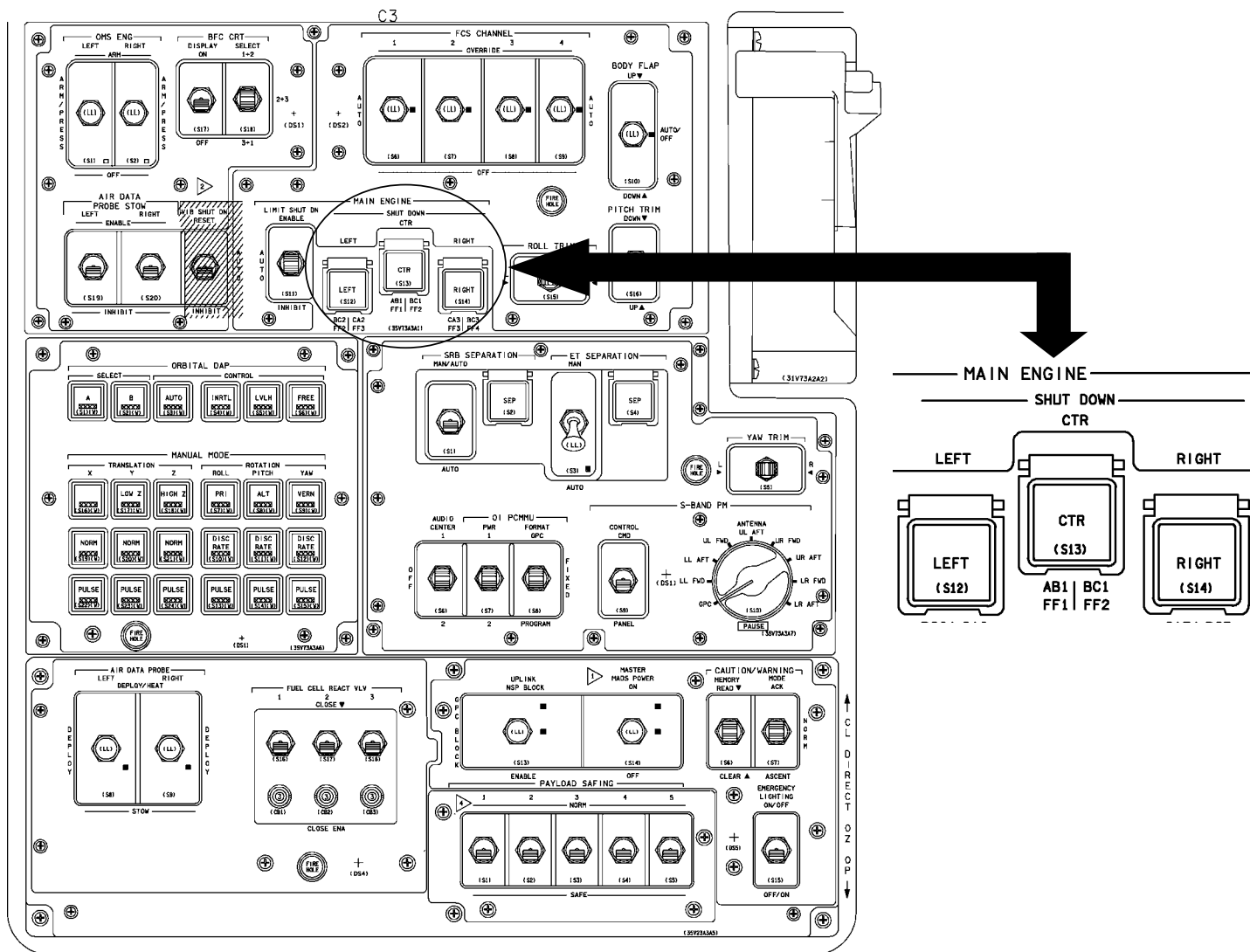M < 1.0   √R FLT CNTLR PWR – ON
 Lock Inertia Reels
M = 0.7   √LG EXTEND ISOL VLV – OP
H = 10K   √BDY FLP – TRAIL
 LES Visors – Down
POST LANDING: ENT, POST LDG

TAL

FB 2-13   ASC/116/FIN

usa007151_766r1.tif

Figure 6-6. RTLS CDR cue card   **Figure 6-7. RTLS PLT cue card**

Figure 6-8. Panel C3

6.4.4   Fuel Dissipation Guidance

If the RTLS abort is declared early in the flight, some fuel wasting is necessary, so the fuel dissipation task takes control of guidance. When first activated, this task computes a pitch angle (theta) to perform the fuel wasting. This theta is chosen primarily to minimize any loss of altitude while still heading the shuttle away from the runway; theta is calculated using the Earth-relative velocity saved by the SSME-out safing task. From then on, this theta remains virtually constant, and every cycle, the guidance equations compute the optimum time to pitcharound.

The fuel dissipation task works by assuming an immediate pitcharound. From this assumption, software predicts the trajectory of PPA and flyback phases to compute the shuttle mass at MECO. This burnout mass is then compared to the desired 2 percent ET propellant remaining. If the predicted mass is less than the desired mass, then the pitcharound is initiated immediately. If the predicted mass is still greater than the desired mass, then further fuel wasting is necessary. The difference in mass between computed and desired is then used to compute how much more fuel must be wasted. This is then used to compute TMECO.

The crew needs to know two important things to fly the fuel dissipation phase in CSS: the proper theta angle to fly during wasting and when to turn around. The engine-out time that was noted earlier is used to determine these parameters. Using the engine-out time in conjunction with the table on the RTLS PLT cue card (Figure 6-7), the outbound initial theta can be determined. The crew then maneuvers the shuttle to that theta angle in CSS. Normally, little or no additional maneuvering is required until pitcharound.

Additional information about fuel dissipation guidance can be found in the Ascent Guidance and Flight Control Workbook.

6.4.5   Powered Pitch Around

When the fuel dissipation phase is complete, PEG 5 begins to fly to the RTLS MECO target. Since the shuttle is still thrusting away from the runway, the orbiter must first turn around. This turn is called PPA and changes the shuttle attitude from heads-down going away from the launch site to heads-up pointing toward the launch site. It is important to remember that even though the shuttle pitches around toward the launch site, it is still moving away.

PPA is a fairly dramatic maneuver in shuttle terms. The flight control software is programmed to fly the pitcharound at a pitch rate of 10 deg/sec. This rate is kept high in order to prevent the shuttle from gaining too much altitude while passing through the vertical.

The PPA also sets a flag denoting flyback phase. This flag is normally set when the PPA is commanded and is used to reconfigure guidance for the flyback phase. If the crew has selected CSS, then there are software checks to detect when the crew initiates PPA to properly mode the guidance algorithms. A crew-initiated turnaround is

said to be in progress when CSS has been selected and the shuttle passes through vertical and begins to thrust back toward the runway.

In the "√ Guidance Status" procedure is a reminder that if guidance does not converge (GUID 'INHB' on the RTLS TRAJ), the crew should select CSS and manual throttle control and pitch around manually at the right time. The crew can determine the proper time for a manual PPA by consulting the RTLS cue card in the same way that the initial outbound theta was determined. The actual propellant remaining is displayed on the RTLS TRAJ display. When the actual PRPLT level decreases to the PPA PRPLT level, pitcharound should be performed at 10 deg/sec. This PPA PRPLT value cannot be reliably used to predict the AUTO time of PPA.

6.4.6   Flyback

As soon as the fuel dissipation task decides that the orbiter has wasted enough fuel, it sets a flag that initiates the flyback phase. Technically speaking, PPA is part of the flyback phase even though we have talked about it separately. The flyback phase is that part of powered RTLS when the orbiter is pointing back toward the runway, steering to achieve the proper MECO targets so that it can then glide to a safe landing.

During the flyback phase, unlike the fuel dissipation phase, the outputs of PEG 5 are used to compute orbiter steering and throttle commands instead of merely acting as a predictor. These steering and throttle commands direct the shuttle to fly along the trajectory computed by guidance. Each guidance cycle results in a new set of steering and throttle commands that are better than the old set. The actual commands should not change much from cycle to cycle, but the accuracy of PEG 5 predictions will improve as MECO approaches.

As the shuttle gets close to MECO, the computation of new steering and throttle commands is no longer appropriate since the updated commands would not have time to materially affect the MECO conditions. This could lead to ridiculously large attitude excursions as guidance and flight control attempt to make large corrections close to MECO. To prevent this from happening, part of PEG 5 is always calculating the time remaining until PPD. When this time is less than an I-loaded value (currently 6 seconds), a flag is set that initiates fine countdown. This procedure locks out further attempts to correct the final MECO conditions, thus the flyback phase terminates.

6.4.7   Powered Pitchdown

Once the fine countdown phase is initiated, PRTLS guidance has virtually completed its task. The only thing to be done is to pick the MECO time. PEG 5 predicts the time that MECO should occur, which is still many seconds in the future, and then fixes this time. Once set, the MECO time does not change even if subsequent events make this time less than optimum.

In order to satisfy the altitude and flightpath angle constraints on the MECO state, the shuttle has a positive angle of attack of about 30° as MECO approaches. However, to safely separate the ET from the orbiter, an angle of attack of -2° is required. The

transition between these two widely differing angles of attack is a big PD maneuver (Figure 6-9), usually called Powered Pitchdown (PPD).

A leisurely maneuver to -2° of alpha (angle of attack) would result in a sink rate larger than desired. This could cause overheating or overstressing of the vehicle. To prevent this, the PPD maneuver is performed at high rates (~8 deg/sec) at literally the last instant. Only a few seconds are allowed at the conclusion of the maneuver for establishing stable conditions before the MECO timer expires. Normally, before MECO, the SSMEs are throttled back to 67 percent. This is done to reduce the impact of the PPD maneuver on the trajectory.
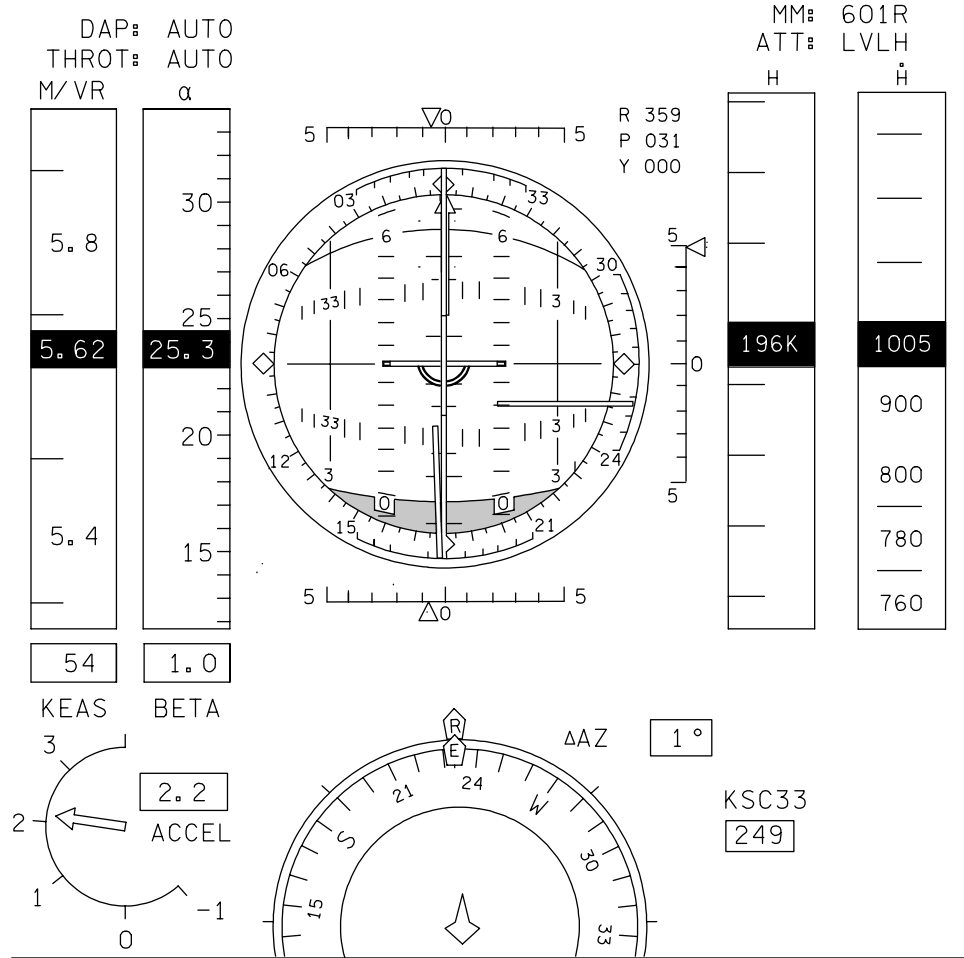
For a three-engine RTLS, this throttle-back is not possible because the three engines are already throttled back to 69 percent. Pitching down at the same time with three engines takes just as long, and glide range is increasing 50 percent faster. This could result in MECO occurring before completion of the PPD maneuver. To correct for this, a three-engine RTLS is commanded to PD earlier to allow more time to complete the pitch maneuver before MECO.

6.4.8   Main Engine Cutoff and External Tank Separation

Once the shuttle vehicle has stabilized at -2° angle of attack (see Figure 6-10), the next event is MECO. The time for MECO has already been fixed so the shuttle simply holds alpha = -2° until the MECO timer expires. The shuttle then enters a phase called mated coast.

Mated coast is the time after MECO but before ET SEP, The shuttle engines can no longer be used for attitude control since they are shut down. The aerodynamic surfaces are not yet effective enough because of the thin atmosphere. This means the entire burden of attitude control falls on the RCS jets during mated coast.

If all goes well at MECO, the shuttle should be stable and in the proper attitude. If this is so, then few jet firings are required. For off-nominal MECOs, the shuttle might be well out of attitude or rotating at relatively high rates. The RCS jets then have to fire to establish and maintain the proper attitude.

DAP: AUTO
THROT: AUTO

MM: 601R
ATT: LVLH

M/VR   α

R 359
P 031
Y 000

5.8

30

5.62   25.3

25

5.4

20

15

54   1.0

KEAS   BETA

H   Ḣ

5

196K   1005

900

800

780

760

0

5

3

2.2

2

ACCEL

1

0   -1

ΔAZ   1°

KSC33
249

FLIGHT INSTRUMENT MENU

| P1* | UP | A/E PFD | ORBIT PFD | DATA BUS | MEDS MSG RST | MEDS MSG ACK | FC3 |
| S2 | | | | | | | AUT |

00715117.PNL:8

Figure 6-9. Composite ADI/HSI during PPD
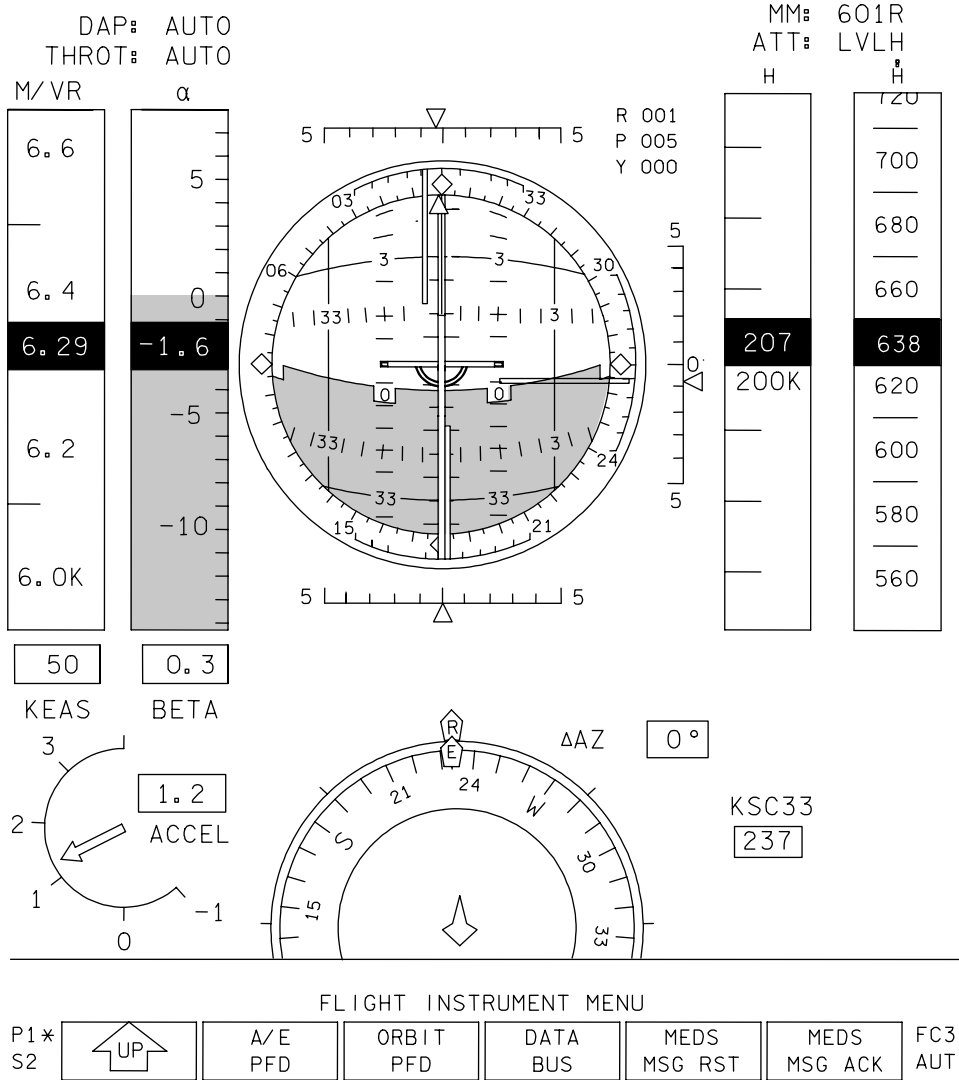
Figure 6-10. Composite ADI/HSI at MECO

During the mated coast phase, the orbiter and ET are being prepared for SEP. Valves are closed, umbilicals are retracted, and electrical connections are deadfaced. These activities normally take about 16 seconds to perform. If the orbiter attitude and body axis rates are within limits the vehicle is configured for ET SEP.

An ET SEP inhibit suspends the separation sequence to provide more time for the shuttle to get to the proper pitch rate. If the pitch rate parameter remains out of limits after 6 seconds, the ET SEP occurs anyway. Otherwise, the dynamic pressure would continue to increase until a safe separation would not be possible regardless of the shuttle attitude.

Also, the AUTO SEP INH can be overridden by the crew simply by placing the ET SEP SWITCH on panel C3 to the MAN position and depressing the ET SEP PB. See Figure 6-11 for the location of the ET SEP switch and pushbutton. This procedure is seldom done on an RTLS because the ET SEP INH is automatically overridden after 6 seconds.
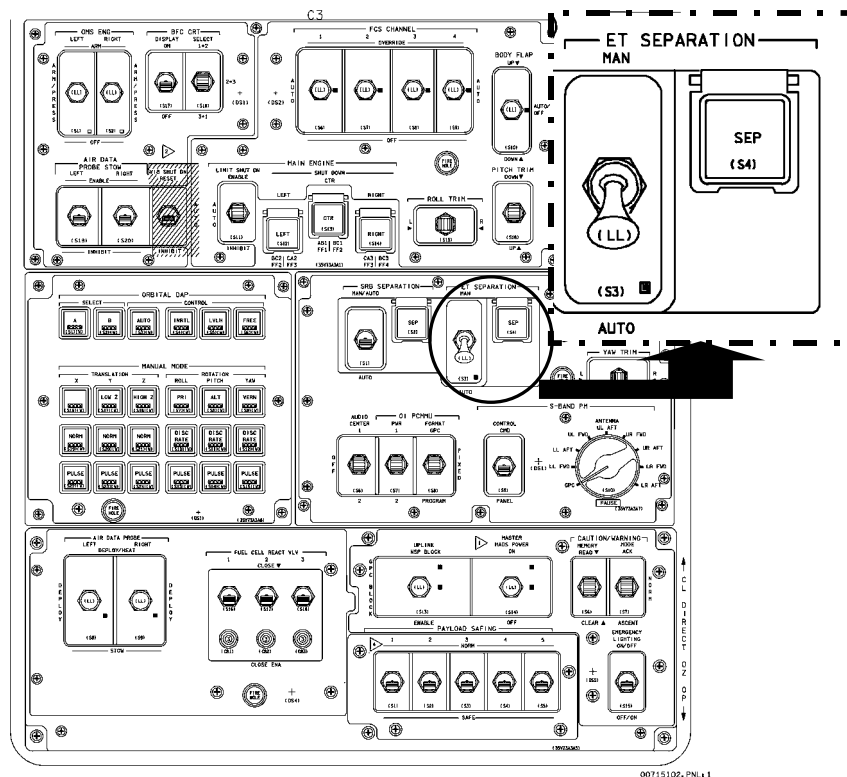
Figure 6-11. ET SEP switches

When the ET SEP sequence decides, or is directed, to continue with the separation, the actual separation commands are issued to the Master Events Controllers (MECs). These devices fire the explosive bolts that disconnect the three attach points between the orbiter and the ET. At this point, the orbiter and ET are separated.

With the orbiter now disconnected from the ET, it is important that the orbiter get away from the ET. For a normal separation in the proper attitude, the aerodynamics of the

two bodies cause the ET to "peel" off underneath the orbiter much like a belly tank being dropped from a fighter airplane. This process is too slow and unpredictable to be relied upon, especially since the ET SEP attitude might not be perfect. To establish a greater separation rate, RCS jets are used.

As soon as the separation commands are issued, a flag is set to tell the shuttle autopilot that separation has occurred. The autopilot, called the Digital Auto Pilot (DAP), changes modes to perform a combination maneuver to pitch up while translating away from the ET. This maneuver is accomplished by turning on all the orbiter downfiring RCS jets. With four forward downfiring jets and six aft downfiring jets, you might well wonder how a pitchup results. That is because the forward RCS jets have a much longer moment arm resulting in about twice the pitch effectiveness of the aft downfiring jets. The net result of these 10 RCS jets is a simultaneous translation and rotation, which carries the orbiter up and away from the tank.

Should any pitch or roll correction be necessary during this separation maneuver, it is performed by momentarily turning off some of the jets firing for the separation maneuver. This is done so that at no time is it necessary to fire any upfiring RCS jets, which might decrease the separation rate.

The downfiring jets performing the separation continue to fire until the proper criteria for moding to MM 602 are satisfied. These criteria are that at least 10 seconds have passed since separation occurred and that the shuttle has achieved at least a 10° angle of attack. Upon transition to MM 602, the powered phase of RTLS is said to have ended and GRTLS begins.

If the MECO and ET SEP portions of PRTLS are flown in CSS, it is important that the shuttle already be in the proper attitude pre-MECO. With the shuttle in the proper attitude (α = -2°), the PLT shuts down the remaining SSMEs using the SSME shutdown PBs.

Once the engines have been shut down, the CDR should maintain the same -2° alpha and 0° beta while the ET SEP sequence configures the orbiter and ET for separation. In order to maintain the proper -2° of alpha, the CDR has to hold in a small negative pitch rate. This is because the shuttle is now ballistic and its sink rate is increasing due to gravitational acceleration. This causes alpha to become more positive, which is undesirable for ET SEP.

When ET SEP occurs about 16 seconds after MECO, the -Z translation maneuver also occurs automatically, even in CSS. This translation maneuver can be terminated by moving the Translational Hand Controller (THC) out of detent in any axis. However, if this is done, a manual -Z maneuver must be accomplished to ensure a safe separation. This manual -Z maneuver does not provide the proper pitchup rate to recover alpha post-SEP; therefore, this pitchup rate should be provided through RHC inputs.

It is generally preferable to allow the RTLS DAP to perform its simultaneous -Z and pitchup maneuver automatically rather than to perform these maneuvers manually.

Additional information on RTLS MECO and ET SEP can be found in ASC G&C 21002.

6.5 GLIDING RTLS

6.5.1 Glide Range and Energy

After MECO, the shuttle has a certain amount of energy that determines how far and how long it can glide. This amount of energy is a function of the speed and altitude of the shuttle. The initial energy state, determined by the speed and altitude at the time the SSMEs are shut down, decreases continually during GRTLS, reaching zero at orbiter wheels stop.

The horizontal distance or range that the shuttle can glide with a given amount of energy is determined by the vehicle's lift and drag characteristics. These lift and drag characteristics are usually summarized as a ratio of Lift to Drag (L/D). The L/D of the shuttle can be varied by changing the shuttle basic flight parameters, such as angle of attack (alpha), or by moving aerodynamic control surfaces, which affect drag and/or lift.

For example, L/D varies with angle of attack as well as sideslip angle (beta) and bank angle. L/D also varies with the position of the elevons, body flap, speedbrake, and rudder. Some of these controls, such as the rudder, have very little effect on the shuttle L/D, while others, such as the speedbrake, exist primarily to alter L/D. The speedbrake simply alters drag without affecting lift, thereby decreasing the L/D ratio.

The flight condition of the orbiter can be adjusted to maximize the L/D ratio. This state, referred to as MAX L OVER D, determines the maximum glide range of the orbiter for a given amount of energy.

In practice, it is not a good idea to plan on flying at maximum L/D. An extra headwind or unplanned drag results in insufficient range to make the runway. To avoid this, the MECO energy state is planned to be comfortably more than the minimum necessary. The nominal amount of excess energy can be easily dissipated during GRTLS. Should the shuttle arrive at MECO with less than the planned amount, it is said to be low on energy. This usually means that there is enough energy to make the runway, but less than planned. If the shuttle is extremely low on energy, such that the planned runway cannot be reached, then the shuttle has to downmode.

Downmoding is doing something other than what was planned because it takes less energy to do so. An example of downmoding is changing the path to the runway from an overhead turn approach to a straight-in approach. It is also sometimes possible to change the targeted runway to one that requires a shorter approach.

It is also possible that the shuttle might have more energy at MECO than was planned on. This might not appear to be a problem since energy can always be dissipated but never increased. The problem is that if the shuttle is too high on energy it could conceivably go by the runway and not be able to land. The shuttle has a very limited turning capability and cannot just orbit above the field waiting to slow down to landing speed. This problem is avoided, if possible, by dissipating excess energy relatively early in the GRTLS profile so that the energy state is as normal as possible when the shuttle approaches the runway.

The role of GRTLS guidance is to manage the shuttle energy state to maximize the chances of a safe landing. The techniques that guidance uses to manage energy are given at the end of this section.
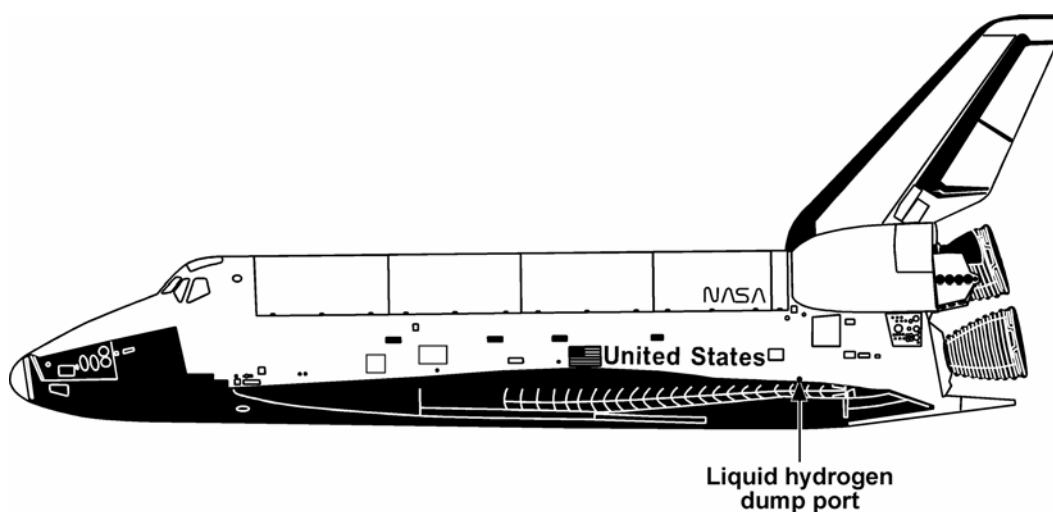
6.5.2   Post MECO Dumps

After MECO and ET SEP, there are still thousands of pounds of liquid oxygen (LO$_2$) and liquid hydrogen (LH$_2$) trapped onboard the orbiter in the various pipes of the MPS system. The LO$_2$ is heavier (more dense) and thus affects the c.g. more, but the real hazard is the LH$_2$. If the hydrogen is not dumped, it will eventually vent through a relief valve, presenting a potential fire hazard.

To eliminate as much of the hydrogen (and oxygen) as possible, a post-MECO MPS dump is performed. This dump starts immediately after the beginning of MM 602. Because of the limited time available to dump these propellants during an RTLS, the LO$_2$ and LH$_2$ dumps are performed simultaneously.

The LO$_2$ dump is performed by opening the Main Oxidizer Valves (MOVs) in the three SSMEs and dumping through the engines. The dump is not a pressurized dump. Little liquid is actually expelled because of the position of the engine nozzles and the direction of the aerodynamic forces on the vehicle. The engine nozzles are, in effect, uphill on the feedlines where the LO$_2$ is trapped.

Because of the dangers associated with LH$_2$, the LH$_2$ dump is performed with special plumbing called the RTLS dump line. This line, which exits portside aft of the vehicle, is designed to provide for the maximum dump under the accelerations experienced during GRTLS. To further ensure the best possible LH$_2$ dump, the hydrogen manifold is pressurized with helium to force the LH$_2$ overboard as quickly as possible. The position of the LH$_2$ dump line is shown in Figure 6-12.


Liquid hydrogen
dump port

usa007151_029.cnv

Figure 6-12. Liquid hydrogen dump port

There is also a provision in the software for a post-MECO dump of RCS propellant through the RCS jets to help move the c.g. For details of this dump time, please refer to Section 1 and Figure 1-9, which shows the RTLS/TAL Abort Dump section of the Ascent Flip Book.

6.5.3   GRTLS Display

The primary display for the early portion of GRTLS is Vertical (VERT) Situation (SIT) 1, which is the OPS display in MM602. This display, shown in Figure 6-13, is primarily a plot of altitude versus range to go.
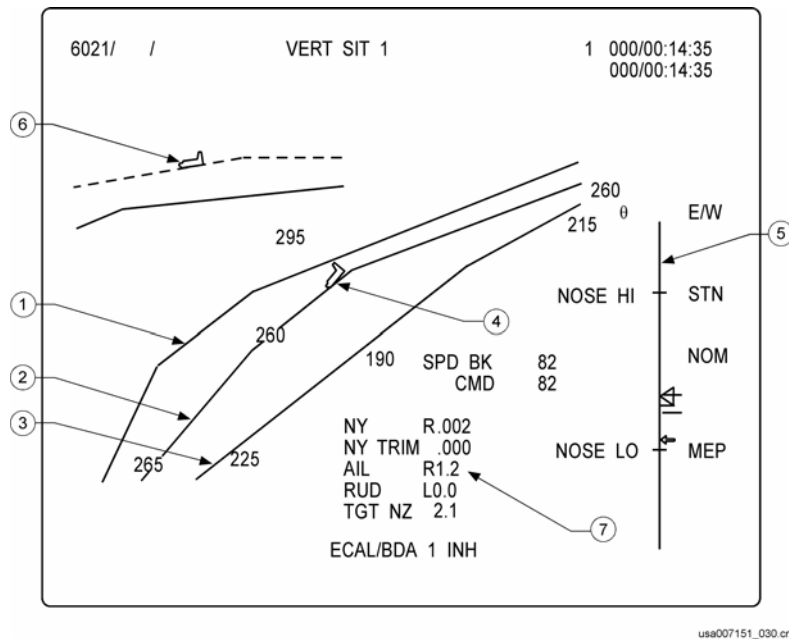
Figure 6-13. VERT SIT 1 display

The three lines ① , ②, and ③ running from the upper right to the lower left, depict representative trajectories; ② is the nominal trajectory. The leftmost line ① is the $\bar{q}$ limit line; if to the left of this line you will not make the runway even flying at max $\bar{q}$. The rightmost line ③ is the maximum L/D line; if to the right of this line you will not make the runway even flying at max L/D. Therefore, the $\bar{q}$ limit line and the maximum L/D line bound the range of acceptable trajectories.

The shuttle position on this plot is represented by a shuttle symbol ④, which is rotated to represent the altitude dissipation rate (sink rate). During TAEM (OPS 603), the shuttle symbol will move down the screen from right to left.

Note: Shuttle symbol appears only at one location on the display at a time.

The three representative trajectories are labeled with Knots Equivalent Airspeeds (KEASs), which are airspeeds that need to be flown to stay on the trajectory at that point.

To the right of the display is a scale of the shuttle pitch angle (θ) and energy state in terms of Energy Over Weight (E/W) ⑤. The pitch angle is displayed only at lower airspeeds and the NOSE HI and NOSE LO limits are commonly referred to as the theta limits. These theta limits are used to maintain an acceptable flight condition if air data is not available to the flight control system below Mach 2.

The E/W scale displays the current energy state of the shuttle as a triangle on the tape. This triangle, or bug, flashes if the energy level is above the S-Turn (STN) limit or below the Minimum Entry Point (MEP) level. These limits are displayed by STN and MEP on the E/W scale. The minimum energy required for an overhead approach is displayed as "⬅" An energy state below the "⬅" would require a straight-in approach.

In the upper left-hand corner of the display ⑥ is an alpha transition display. During the alpha transition portion of GRTLS, the shuttle symbol appears in this portion of the display, which represents an alpha versus Mach profile. The nominal command profile is represented by the dashed fine, and the solid line is the $\bar{q}$ limit line for alpha transition and should not be crossed. The shuttle symbol flashes if a limit is violated.

In the lower center of the display ⑦ is a readout of actual and commanded speedbrake position, Lateral Acceleration (Ny), Lateral Acceleration Trim (Ny TRIM), Aileron Trim (AIL TRIM), Rudder Trim (RUD TRIM), and finally, the Target (TGT) Normal Acceleration (Nz). TGT Nz is the guidance-computed normal acceleration to be maintained during the Nz hold phase of GRTLS. Nz hold is discussed in Section 6.5.6

The BFS version of this display (Figure 6-14) has a few features not found on the PASS. To the left of the screen ① is a readout of the BFS-computed attitude errors.

usa007151_031.cnv
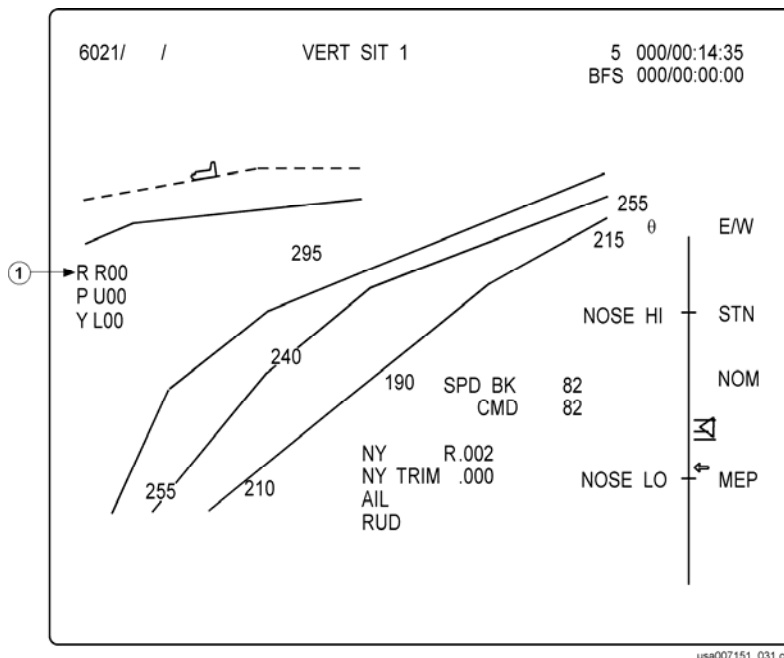
Figure 6-14. BFS VERT SIT 1

At lower altitudes (< 30,000 ft) PASS VERT SIT 1 is replaced by PASS VERT SIT 2 (Figure 6-15). Except for the different scaling of altitudes and range-to-go, the second display is very similar to the first and requires little additional explanation. The one addition ① is a flashing Approach and Landing (A/L), which appears when Terminal Area Energy Management (TAEM) guidance is terminated, and A/L is initiated
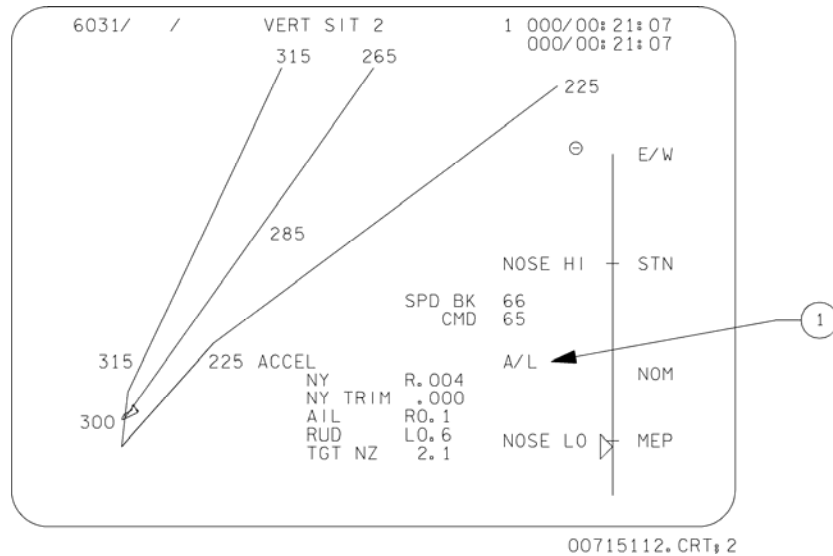
Figure 6-15. PASS VERT SIT 2 display

The entry displays we have discussed up to now convey mostly vertically referenced information (that is, altitude versus range or altitude versus velocity). Another display is used to view the horizontal component of the trajectory. This display is SPEC 50, the Horizontal (HORIZ SIT) display that is shown in Figure 6-16. The lower portion of the HORIZ SIT display presents navigational information and is covered in greater detail in the Navaids 21002 training manual (USA006055). The major feature of this display, however, is a map showing the location of the runway and the HAC in relation to the shuttle current position.
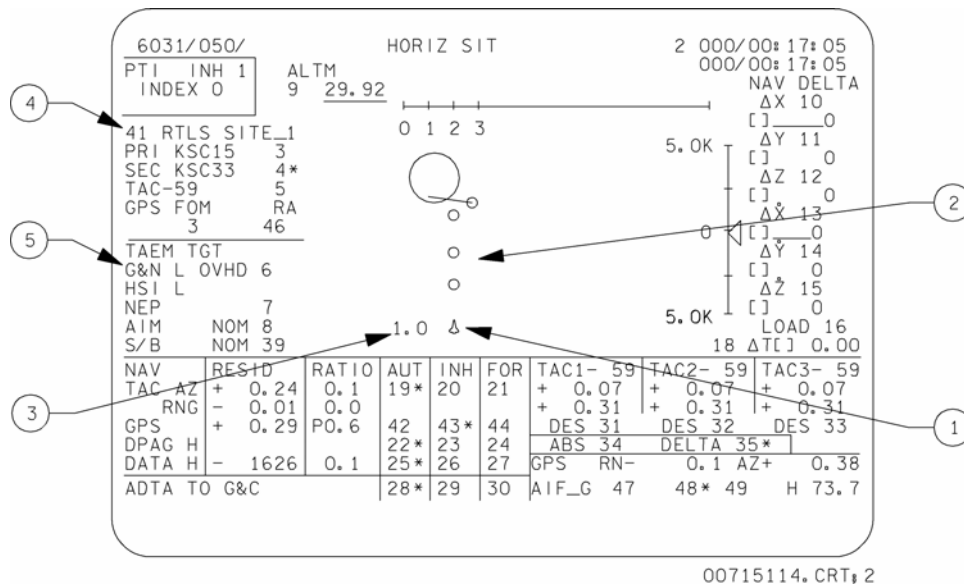
Figure 6-16. HORIZ SIT display

The shuttle symbol ① is always plotted at the bottom as shown, while the shuttle's future position is shown by the three predictors ② at 20, 40, and 60 seconds in the future. These predictors allow the shuttle to be flown to and around the HAC. Next to the shuttle is the shuttle's load factor (Nz for GRTLS) in g's ③.

On the left side of the screen is additional data that is relevant to GRTLS ④. Item 41 allows for the selection of various landing sites and/or runway combinations. The selected runway is the one used for guidance computations and is the one shown in the central portion of this display.

Also displayed ⑤ is the TAEM targeting status. This portion shows whether TAEM guidance is targeted for an overhead or straight-in approach to the right or left HAC and whether the shuttle is using the Nominal Energy Point (NEP) or MEP. It also displays whether the shuttle is using the NOM or Close In (CLSE) aim point. Finally, the speedbrake can be set for a NOM or Short Field Setting (SHORT). The status of any of these TAEM downmode options (including runway) can be changed through the appropriate item number. TAEM targeting is more completely described in the Entry, TAEM and Approach/Landing Guidance Workbook.

The BFS HORIZ SIT display does differ slightly from its PASS counterpart. However, for the purpose of GRTLS, these two displays are the same. Therefore, the PASS and BFS HORIZ SIT displays shall be treated as identical. Figure 6-17, BFS HORIZ SIT display, is included as a reference.

```
6031/050          HORIZ SIT              5 000/00:17:04
            ALTM                    BFS 000/00:00:00
            9  29.92                        NAV DELTA
                                             ΔX 10
                                         [+]_____0
                                             ΔY 11
41 RTLS SITE_1                           [+]      0
PRI KSC15    3                               ΔZ 12
SEC KSC33    4*                          [+]      0
TAC-59       5                               ΔX̊ 13
                                         [+]_____0
TAEM TGT                                     ΔY̊ 14
G&N L OVHD 6                             [+]      0
HSI L                                        ΔZ̊ 15
NEP        7                             [+]      0
AIM    NOM 8                                  LOAD 16
                  PASS/BFS SV XFER 17   18 ΔT[+] 0.00
NAV  | RESID | RATIO | AUT | INH | FOR | TAC1- 59 | TAC2- 59 | TAC3- 59
TAC AZ + 0.21 | 0.1 | 19*| 20 | 21 | +231.63 | +231.63 | +231.63
   RNG - 0.01 | 0.0 |    |    |    | + 27.26 | + 27.26 | + 27.26
GPS  + 0.30 | 0.1 | 42 | 43*| 44 | DES 31 | DES 32 | DES 33
DPAG H      |     | 22*| 23 | 24 |         GPS
DATA H - 1767 | 0.1 | 25*| 26 | 27 |    AZ   +231.57
ADTA TO G&C       | 28*| 29 | 30 |    RNG    27.64
```

Figure 6-17. BFS HORIZ SIT display

6.5.4   GRTLS Guidance

As discussed in the previous section, the one fundamental task of guidance during GRTLS is to arrive at the runway with the right amount of energy to complete a safe landing. To manage the energy state while providing satisfactory flight conditions, GRTLS guidance can be divided into the following sections:

- Alpha recovery phase
- Alpha transition phase
- GRTLS TAEM phase
- Nz hold phase
- S-turn phase

The first three of these phases are designed to provide the transition from an exo-atmospheric ballistic trajectory to hypersonic gliding flight. S-turn and TAEM are where most of the energy management takes place. We will discuss each of these phases in order.

6.5.5   Alpha Recovery

The orbiter, when we left it, was at a 10° angle of attack immediately after ET SEP. Because of the constraints on ET SEP, the orbiter was in a dive and just beginning to pull up. In order to provide the proper transition to stable level flight, it is necessary to pull out relatively quickly before the aerodynamic forces build up to uncontrollable levels. To accomplish this phase, the shuttle is maneuvered into a high angle of attack as soon as possible. That is why this phase is called the alpha recovery phase.

Immediately when the shuttle transitions to MM 602, the ET SEP translation maneuver is stopped. Control of the shuttle is then taken over by the new DAP called the aerojet DAP. This marks the first time on an RTLS that the aerodynamic control surfaces (elevons and rudder) of the shuttle are used for vehicle control. These controls are not

very effective at first because of the low atmospheric density. At first, the aerosurfaces are supplemented with the RCS jets. Using the RCS jets and the elevons in tandem, the aerojet DAP begins to pitch the orbiter up at 2 deg/sec. This action continues until the shuttle reaches a 50° angle of attack. The shuttle then maintains 50° for the duration of the alpha recovery phase.

As the orbiter falls further into the atmosphere, the increasing dynamic pressure will cause more and more lift to be generated by the wings of the shuttle. This lift produces an acceleration along the Z-axis called the Nz acceleration (normal to the Z-axis). The 50° alpha is held until the Nz acceleration reaches about 1.8g (~53 ft/s2).

During this period of increasing dynamic pressure, several other events are taking place. The aerosurfaces are becoming increasingly effective, so fewer RCS jet firings are required. For roll maneuvers, the RCS jets are no longer used after a $\bar{q}$ of 10 psf, while the pitch jets are turned off after 40 psf. Because of the reduced effectiveness of the rudder at high angles of attack, RCS firings for yaw control are required down to Mach 1.

After about 1.8g, the DAP begins to reduce the angle of attack to hold the target Nz. The target Nz that is calculated is usually about 2.2g. It is shown on PASS VERT SIT 1 and 2 next to TGT Nz. The 2.2g is comfortably below the design limit of 2.5g and provides adequate normal force for the pullout maneuver. This change in angle of attack marks the transition to the Nz hold phase.

The CSS procedures for the post-ET SEP and alpha recovery timeframe are on the lower portion of the RTLS CDR and PLT cue cards (Figure 6-6 and Figure 6-7). The CSS and AUTO actions are similar; in other words, increase the alpha to 50°, maintain this alpha until Nz ~ 1.8g, and then reduce alpha to hold Nz around 2.2g. At this time, the PLT should verify that the automatic ET umbilical door is closing and that the speedbrake is set to 80 percent.

6.5.6   Nz Hold Phase

As the shuttle enters Nz hold phase, the DAP decreases alpha to maintain the calculated target Nz, usually 2.2g. The angle of attack continues to be decreased until the shuttle's rate of descent is less than 250 ft/sec. At this time, the pullout is essentially complete and the transition to stable flight begins.

As in AUTO, the CSS procedure for Nz hold is to decrease alpha to maintain 2.2g until the descent rate is less than 250 ft/sec. At that time, the alpha transition phase is initiated.

6.5.7   Alpha Transition

After the termination of the Nz hold phase, the angle of attack is changed to conform to the predetermined alpha profile. This profile, which is a function of the shuttle velocity,

is designed to provide the best vehicle control until active ranging begins in the TAEM phase.

Also during alpha transition, the shuttle turns toward the runway unless there is considerable excess energy, in which case the shuttle deliberately turns away from the runway. This turn away from the runway is called an S-turn and is designed to dissipate excess energy by flying a longer path to the runway. Normally, an S-turn would not be executed until TAEM, but for extremely high energy cases, an early S-turn can be initiated while still in alpha transition.

The alpha transition phase is maintained until the GRTLS TAEM phase begins.

Flying the alpha transition phase in CSS can be done either by following the alpha transition display in the upper-left portion of VERT SIT 1 or by referring to the entry alpha cue card (Figure 6-18). Although AUTO can initiate S-turns in alpha transition, there are no procedures to manually initiate S-turns during this phase. Ranging in CSS is done primarily by exercising Optional TAEM Targeting (OTT) options. OTT is more completely described in the Entry, TAEM and Approach/Landing Guidance Workbook.

ENTRY ALPHA

VR	αref	R	H	Href	Rref
25	40	4396	400		
24	HI 40 LO	2623	246	-46	L79
23	43 40 37	2166	238	-63	69
22	43 40 37	1809	232	-82	62
21	43 40 37	1534	225	-103	59
20	43 40 37	1309	219	-119	58
19	43 40 37	1130	212	-141	58
18	43 40 37	988	205	-162	59
17	43 40 37	869	198	-180	60
16	43 40 37	767	192	-191	61

KSC 15

MAX L/D	
M	α
3	17
2	15
1	12

ASC-14b/116/A,E/A

(116 OCFR1 CY)

HOOK VELCRO

HOOK VELCRO

HOOK VELCRO

15	43 40 37	685	186	-203	63
14	43 40 37	612	180	-127	61
13	43 40 37	544	177	-137	58
12	43 40 37	481	173	-153	56
11	42 39 36	424	167	-195	R54
10	41 38 35	372	164	-174	49
9	39 36 33	322	157	-209	46
8	37 34 31	274	149	-242	43
7	33 30 27	227	140	-271	42
6	30 27 24	183	128	-275	L42
5	26 23 20	143	117	-273	40
4	23 20 18	105	103	-264	42
3	19 16 15	74	89	-248	R35
2.5	14	60	82	-273	
2	12	49	75	-282	
1.5	9	37	64	-331	
1	8	28	50	-263	

Figure 6-18. Entry alpha cue card

6.5.8   S-Turn Phase

The S-turn phase is actually part of the alpha transition phase, but it is explained separately for simplicity. If an S-turn is required, the shuttle is directed to turn away from the runway, thereby increasing the distance to be flown. During the S-turn, both the energy state and the shuttle heading are constantly monitored. If the S-turn succeeds in dissipating the excess energy, the S-turn will be ended and the shuttle will turn toward the HAC.

6.5.9   GRTLS TAEM

The portion of GRTLS that controls the fine tuning of the orbiter energy state for landing is called TAEM. GRTLS TAEM, which starts at Mach 3.2 , is essentially identical to normal entry TAEM, which is discussed in great detail in the Entry, TAEM & Approach/Landing Guidance workbook. An overview of TAEM is provided here for completeness.

TAEM guidance is divided into four phases. The four phases are

- S-turn

- Acquisition

- Heading alignment

- Prefinal

In order for TAEM guidance to function, it must know the accurate distance the shuttle must fly before it can land (range-to-go). It is not enough to know the straight-line distance from the shuttle to the runway. This is obvious when considering that the shuttle must approach the runway at the proper speed and direction. Therefore, the turn(s) necessary to get the shuttle lined up for landing must be taken into account.

To model these turns, the shuttle computers project the HAC. This HAC is an imaginary cone in space that is located approximately 7 nm from the end of the runway. The projection of this cone at any altitude is a circle that describes a turn the shuttle must make to get lined up with the runway. By approaching the HAC on a tangent and then turning on the HAC, the shuttle will complete the HAC lined up with the runway centerline.

The shuttle range-to-go can be accurately computed by summing the distance to the HAC, the distance around the HAC, and the distance from the HAC to the runway (Figure 6-19). In order to manage the range-to-go so that the shuttle can fly to the runway, TAEM guidance will fly an altitude versus range profile.

For each runway there are four possible HACs, two on each side of the runway centerline (overhead and straight-in). The shuttle is normally targeted for the overhead HAC, which has a turn angle greater than 180 degrees. The straight-in HAC has a turn

angle less than 180 degrees. It can also be seen that the overhead HAC requires more energy. Therefore, the selection of these HACs is partly a function of energy. For example, Figure 6-19 shows a right-hand turn into an overhead HAC, commonly called a right overhead. The straight-in HAC will not improve the energy situation, if the HAC turn angle is near 180 degrees. In addition, each HAC has a nominal (NEP) and minimum (MEP) entry point. The difference is that the MEP HAC is approximately 3 nm closer to the runway. By selecting the MEP HAC, the shuttle will fly the HAC closer to the runway, thus requiring less energy to make the runway. The shuttle is normally targeted for the NEP HAC. Selection of the MEP HAC will not improve the energy situation if the HAC turn angle is near zero or 360 degrees.
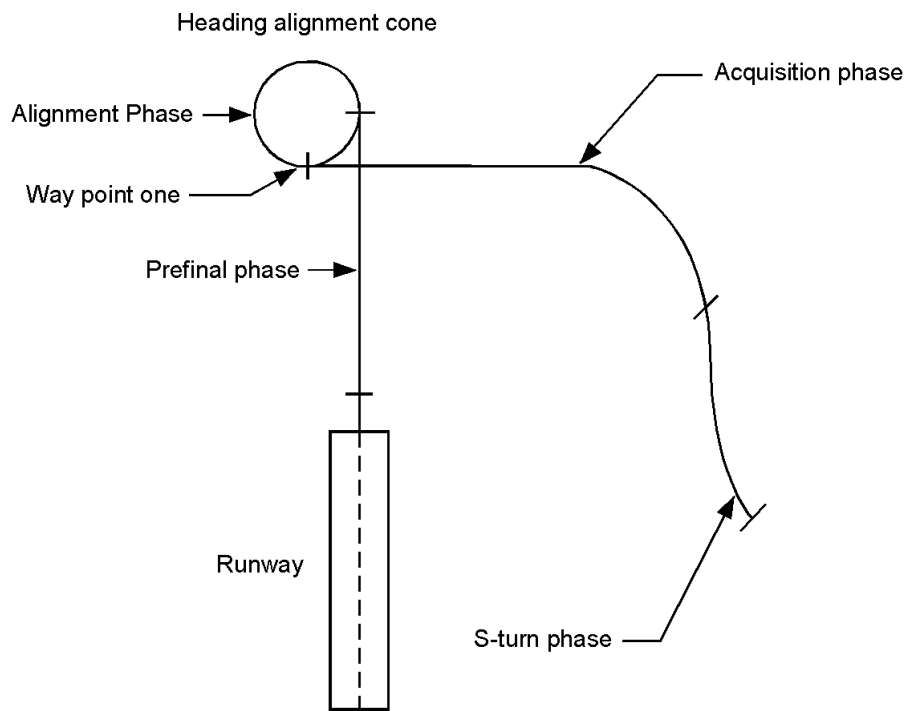
usa007151_016.cnv

Figure 6-19. TAEM phases

For low-energy situations, TAEM guidance will increase the N_Z command; as a result, flight control will pitch the vehicle up thus lowering the descent rate (Hdot). By doing so, the potential energy (i.e., altitude) will not decrease as fast, thus getting the shuttle back to nominal energy. For extremely low-energy cases, TAEM guidance will request a change to the straight-in HAC or to the MEP HAC, or both.

For high-energy situations, TAEM guidance will decrease the N_Z command; as a result, flight control will pitch the vehicle down thus increasing the Hdot. By doing so, the potential energy will decrease, thus getting the shuttle back to nominal energy. For extremely high energy cases, TAEM guidance will initiate an S-turn in order to increase the range to fly to the runway.

a. S-turn phase

While the S-turn phase of GRTLS guidance is actually a subset of the alpha transition phase, the S-turn phase of TAEM guidance is a separate phase altogether.

If the shuttle energy is too large to be dissipated with lower alphas, the TAEM guidance algorithm will mode into the S-turn phase. During this phase the shuttle will turn away from the runway in order to increase the required range to go. Once the shuttle energy has been sufficiently reduced, TAEM guidance will transition to the acquisition phase, and the shuttle will turn toward the HAC.

b. Acquisition phase

When the velocity is less than Mach 3.2, guidance will mode directly from the alpha transition phase of GRTLS guidance to the acquisition phase of TAEM guidance. During the acquisition phase, a course is computed which causes the shuttle to arrive at the HAC on a course tangent to the HAC.

c. Heading alignment phase

Once on the HAC, the shuttle will stay on the HAC until final lineup with the runway is achieved.

d. Prefinal phase

This phase is entered when either range-to-go to the runway or the altitude is less than an I-loaded value. After lining up on the runway, the shuttle rolls out of the turn and begins diving toward an aimpoint just short of the runway threshold. This dive is done to increase airspeed for the landing. Prefinal phase continues until the shuttle enters the approach and landing phase. The approach and landing phase on an RTLS is the same for nominal end-of-mission flights and is described in the Entry, TAEM & Approach/Landing Guidance workbook.

This concludes the main text of the workbook, please review the appendices for supplemental information.

If this workbook has been completed as part of a formal training syllabus, the reader is reminded to complete and submit the evaluation form at the end of this document.

6.6   QUESTIONS

1.   What is negative return?

2.   In what ways does BFS control differ from PASS?

3.   Why must the shuttle waste fuel after an RTLS abort is declared?

4.   Describe the primary and the backup means of selecting an RTLS abort.

5.   True or false. Most of the information on the RTLS TRAJ display shows the output of PEG 5 guidance so the crew can fly manually.

6.   How can a crewmember tell whether guidance is converged or not?

7.   True or false. When an engine fails, the crew need only note the time that the failure occurred in order to determine the proper abort.

8.   Describe the primary reason for performing an OMS dump during RTLS.

9.   True or false. During an RTLS, the shuttle should always fly along one of the lines drawn on the RTLS TRAJ display.

10. For a three-engine RTLS, PPD occurs_____.

     a.   Earlier than a two-engine RTLS

     b.   Later than a two-engine RTLS

     c.   At the same time as a two-engine RTLS

11. True or False. After MECO, the shuttle glide range begins increasing because of the pull of gravity.

12. Describe the maneuvers the shuttle must perform immediately after ET SEP.

13. True or False. RCS jets are used in controlling the vehicle down to Mach 1.

14. Describe the purpose of each of the following phases of TAEM: S-turn, acquisition, and heading alignment.

APPENDIX A   ACRONYMS AND ABBREVIATIONS

A/L	Approach and Landing
ACLS	Augmented Contingency Landing Site
ADI	Attitude Direction Indicator
AIL TRIM	Aileron Trim
AME	Abort Maneuver Evaluator
AOA	Abort-Once-Around
AOA-S	AOA-shallow
APU	Auxiliary Power Unit
ARD	Abort Region Determinator
ATO	Abort-to-Orbit
BEN	Ben Guerir, Morocco
BFS	Backup Flight Software
BYD	Banjul, Gambia
c.g.	center of gravity
CDR	Commander
CLSE	Close In
CO	Cutoff
CRT	Cathode-Ray Tube
CSS	Control Stick Steering
CUR	Current
ΔVTOT	total ΔV required for an OMS maneuver
DAP	Digital Auto Pilot
DPS	Data Processing System
E/W	Energy Over Weight
EDW	Edwards Air Force Base
EI	Entry Interface
ELS	Emergency Landing Site
ENA	Enable
EOM	End-of-Mission
ET	External Tank
FDO	Flight Dynamics Officer
GPC	General Purpose Computer
GPO	Guidance and Procedures Officer
GRTLS	Gliding Return to Launch Site
GUID	Guidance
HA	Height of Apogee
HAC	Heading Alignment Cone
HORIZ	Horizontal

HP	Height of Perigee
HT	altitude of target
HYD	Hydraulics
ID	Identification
INH	Inhibit
ISOL	Isolation
KEAS	Knots Equivalent Airspeed
KSC	Kennedy Space Center
L/D	Lift to Drag
LH$_2$	liquid hydrogen
LO$_2$	liquid oxygen
MCC	Mission Control Center
MEC	Master Events Controller
MECO	Main Engine Cutoff
MEP	Minimum Entry Point
MET	Mission Elapsed Time
MM	Major Mode
MNVR	Maneuver
MOV	Main Oxidizer Valve
MPS	Main Propulsion System
MRN	Moron Air Base, Spain
NEP	Nominal Entry Point
nm	Nautical Miles
NOM	Nominal
NOR	Northrup Flight Strip
Ny	Lateral Acceleration
Ny TRIM	Lateral Acceleration Trim
Nz	Normal Acceleration
OMS	Orbital Maneuvering System
OPS	Operational Sequence
OTT	Optional TAEM Targeting
P	Pitch
PASS	Primary Avionics Software System
PBI	Pushbutton Indicator
PD	Pitchdown
PEG	Powered Explicit Guidance
PLT	Pilot
PPA	Powered Pitcharound
PPD	Powered Pitchdown

PRPLT	Propellant
PRTLS	Powered Return to Launch Site
R	Roll
RCS	Reaction Control System
REI	Range from Entry Interface
RHC	Rotational Hand Controller
RTHU	Roll to Heads Up
RTLS	Return to Launch Site
RUD TRIM	Rudder Trim
SBTC	Speedbrake/Thrust Controller
SEP	Separation
SHORT	Short Field Speedbrake Setting
SIT	Situation
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STN	S-Turn
TAEM	Terminal Area Energy Management
TAL	Transoceanic Abort Landing
TFF	Time of Free Fall
TGO	Time to Go, time left on OMS burn
TGT	Target
TIG	Time of Ignition
TMECO	MECO Time
TRAJ	Trajectory
TTA	Time to Apogee
TTC	Time to Circularization
TTG	Time to Go
TTP	Time to Perigee
VERT	Vertical
VGOX	velocity to go in X direction
VGOY	velocity to go in Y direction
VGOZ	velocity to go in Z direction
V_I	Inertial Velocity
Y	Yaw
ZZA	Zaragoza Air Base, Spain

APPENDIX B   ANSWERS

Answers to Section 1

1. The difference between a standard insertion and a direct insertion is that a standard insertion has both an OMS-1 and an OMS-2 burn, and a direct insertion only has an OMS-2 burn.

2. A MECO velocity that is less than the target velocity is called an <u>underspeed</u>.

3. The four types of intact aborts are ATO, AOA, TAL, and RTLS.

4. The typical orbit for an ATO is 105 nm circular.

5. The consequences of an AOA-shallow are that the vehicle is exposed to a longer period of atmospheric heating and to less predictable aerodynamic drag forces.

6. The primary means to select an ATO or TAL is by turning the abort rotary switch to the desired position and then pushing the abort pushbutton.

    The backup means of selecting an ATO or TAL abort is by performing an ITEM 1 EXEC or ITEM 2 EXEC, respectively, on SPEC 51 and then performing an ITEM 3 EXEC.

Answers to Section 2

1. During powered flight, the three types of cues normally available to provide the crew with information about abort mode boundaries are voice calls from the MCC, velocity boundaries on the NO COMM BOUNDARIES cue card, and the RTLS and GO tick marks on the TRAJ display (Negative Return and Press to ATO, respectively).

2. MCC voice calls are defined as follows

    (a) Two-Engine TAL – Earliest point at which a TAL could be achieved with only two good main engines.

    (b) Negative Return – Last opportunity to achieve an RTLS.

    (c) Press to ATO – Earliest point at which at least an ATO could be achieved with only two good main engines, with an OMS dump.

    (d) Single-Engine OPS 3 – The first point after which, for two engine failures, the crew will abort downrange using OPS 3 (Droop procedure) software. Prior to this point, the loss of two engines requires a contingency abort using OPS 6 software.

    (e) Press to MECO – Earliest point at which an orbit could be achieved with only two good main engines and no OMS dump.

    (f) Single-Engine TAL – Earliest point at which a TAL could be achieved with only one good main engine.

    (g) Single-Engine Press – Earliest point at which at least an AOA could be achieved with only one good main engine.

3. The boundaries listed on the NO COMM MODE BOUNDARIES cue card are defined as follows:

    (a) NEG TAL – Last opportunity to achieve a pre-MECO TAL to this site.

    (b) LAST PRE MECO TAL - Last opportunity to select a pre-MECO TAL.

    (c) LAST TAL - Last opportunity to achieve a post-MECO TAL to this site.

4. RTLS on the TRAJ display indicates the last point at which an RTLS abort should be selected. This tick mark usually corresponds to the Negative Return call from MCC.

    GO on the TRAJ display indicates the earliest point at which a main engine could fail and an AOA could still be accomplished. This tick mark usually corresponds to the Press to ATO or the Press to MECO call from MCC.

5. The systems failures that require an abort pre-MECO are

    (a) OMS helium or propellant tank failures

(b) APU/HYD failures

(c) A cabin leak

(d) Loss of cryogenics

(e) Freon loop failures

(f) Main bus failures

(g) A crack in the thermal window pane

6. The OMS 1/2 TGTING cue card is used to determine the type of abort required in the case of a MECO underspeed.

7. The OMS 2 TARGETING cue card is used to determine the type of abort required for various system failures.

Answers to Section 3

1. The three software functions that can aid ascent performance and are consequences of ATO selection during powered flight are switching to the ATO MECO targets, enabling variable IY steering, and initiating an OMS/RCS dump.

2. The major difference between the nominal MECO target and the ATO MECO target is that the altitude for the target would be lower than the altitude for the nominal target.

3. If the planned inclination for your flight is 57°, and the I-loaded minimum inclination is 32°, the inclination that results if an ATO is selected because a main engine had failed is as follows:

    (a) Very early, when the current IY vector represents an inclination of 28°, the resultant inclination is 32°. The vehicle continues steering to the minimum inclination.

    (b) Later, when the current IY vector represents an inclination of 40°, the resultant inclination is 40°. The vehicle no longer steers toward the target inclination.

    (c) Near MECO, when the current IY vector represents an inclination of 57°, the resultant inclination is 57°. The target inclination has already been achieved.

4. Two reasons for performing an abort OMS dump during powered flight are to control the c.g. of the vehicle and to reduce overall weight in order to improve performance in powered flight.

5. A software timer, which uses an I-loaded dump duration, normally stops an ATO OMS dump.

6. During an ATO OMS dump, OMS propellant may be dumped through both the OMS engines and RCS jets, all of which are burning at the same time.

7. To select an ATO before MECO, turn the abort rotary switch to ATO and push the abort pushbutton.

8. If the abort rotary switch does not work, select an ATO before MECO by calling up SPEC 51 and typing in ITEM 2 EXEC (selects ATO) and ITEM 3 EXEC (initiates the abort).

Answers to Section 4

1. The OMS 1/2 TGTING cue card is used to help determine abort targets for underspeed situations.

2. CUR HA and CUR HP are the most important parameters on the MNVR display for use in determining the target in an underspeed situation.

3. Using the MNVR display, OMS 1/2 TGTING cue card, and OMS TARGETS, the following are true

    (a) Since CUR HA + HP is equal to 83, you can determine from the OMS 1/2 TGTING cue card that an OMS-1 burn is required. Remember, also, that anything to the left of the bold vertical line (HA = 95) requires an OMS-1 burn.

    (b) By following the vertical line up from HA + HP = 83 until it intersects with 40 percent OMS quantity, you can determine that target set 1 must be selected (ATO/MIN HP).

    (c) The required TTA can be found on the OMS TARGETS – W/OMS 1 cue card (TTA = 2:00). The TTA can also be determined from the top of the OMS 1/2 TGTING chart. MECO underspeeds between 25.3 and 25.8k ft/sec require the OMS-1 TIG at a TTA of 2:00 minutes. Also note that MECO underspeeds between 25.1 and 25.3k ft/sec require the OMS-1 TIG at MECO + 2:00 minutes, which is worst case.

    (d) Since current TTA = 17:02, the TIG should be targeted for 15:02 minutes from the current MET. Add 15:02 to the current MET of 10:24, and you will get a TIG of 25:26 MET.

    (e) For this target set, the ΔV range expected for this burn is 130 - 875 ft/sec. To get the range of ΔV, look at the actual burn parameters from the target set on the OMS TARGETS cue card.

    (f) For an ATO abort, target set 1 comes up loaded automatically with a TIG of MECO + 2:00 minutes.

4. ATO or AOA targets can be selected manually using the ABORT TGT item on the MNVR display. To select the targets, the crew performs an ITEM 35 + (desired ID) EXEC. Individual target parameters can also be manually entered or changed by keyboard entries (Items 10 through 17 on the MNVR display).

Answers to Section 5

1. For ISS missions Le Tube (FMI), Zaragoza (ZZA), Moron (MRN), and Ben Guerir (BEN) are the available TAL sites.

2. The SE OPS 3 (109) boundary represents the earliest point at which OPS 3 software is used to execute an abort with only one engine running.

3. The crew can execute the abort by selecting TAL on the abort rotary switch and pushing the pushbutton on panel F6 (preferred method). A TAL may also be declared using SPEC 51 with an ITEM 1 EXEC to select TAL and an ITEM 3 EXEC to initiate the abort.

4. The following confirming cues are available for the crew to determine that a TAL has been selected in the onboard software.

   (a) The ASCENT TRAJ display is replaced by the TAL TRAJ display on both the primary avionics software system (PASS) and the BFS machines.

   (b) SPEC 50 shows a TAL site at ITEM 41.

5. Variable IY steering is designed to achieve a MECO target that is within a 500 n. mi. cross range of the landing site.

6. In a normal TAL sequence, once TAL software is on board, an OPS 301 PRO (PASS and BFS) is performed to proceed to OPS 3. The software scrolls to OPS 304.

7. The post-MECO OMS dump is executed on a TAL to do the following:

   (a) Provide additional velocity away from the ET.

   (b) Provide additional velocity that helps to lessen wing leading edge temperature on the vehicle (in low-energy cases).

   (c) Protect the landing weight constraint of the OMS tanks.

   (d) Aid in overall vehicle c.g. management.

   (e) Reduce orbiter gross weight for landing.

8. Prelaunch, a TAL site change is required if the primary TAL site has weather that is out of limits or has a navigation aid failure.

Answers to Section 6

1. Negative return is the point after which an RTLS can no longer be performed.

2. The differences in BFS control to that of PASS are that BFS supports only Automatic (AUTO) flight control pre-MECO and only CSS post-MECO; PASS supports AUTO and CSS in all flight control regimes.

3. The shuttle must waste fuel after an RTLS abort is declared to ensure that no more than 2 percent propellant remains at MECO. To prevent collisions between the shuttle and the ET, separation is planned to occur at 2 percent propellant remaining.

4. The primary and the backup means of selecting an RTLS abort are as follows:

    (a) Primary - Use the ABORT rotary switch on panel F6 to select RTLS. The ABORT PBI, also on F6, is then depressed.

    (b) Backup - Type "OPS 601 PRO" into any PASS keyboard.

5. False. Most of the information the RTLS TRAJ displays is based solely on navigation data. Therefore, if PEG 5 fails, the crew can still use the RTLS TRAJ to manually fly the vehicle.

6. A crewmember determines whether guidance is converged or not in several ways. If guidance is unconverged, the ADI error needles will be stowed out of sight and GUID INHB will appear pre-PPA on the PASS RTLS TRAJ display.

7. False. The velocity of the vehicle at the time an engine fails is used to determine the type of abort required. The time an engine fails is used to determine initial outbound theta and PPA cues if in CSS.

8. The primary reason for performing an OMS dump during RTLS is to burn off the unnecessary OMS prop, which will move the c.g. forward, improving the vehicle control post-MECO. Also, the OMS dump is necessary in order to protect the landing weight constraint of the OMS tanks.

9. False. During an RTLS, the shuttle should not always fly along one of the lines drawn on the RTLS TRAJ display. The lines drawn on the RTLS TRAJ display represent guidelines and are not absolute boundaries.

10. (a) For a three-engine RTLS, PPD occurs earlier than a two-engine RTLS in order to complete the maneuver before MECO.

11. False. The shuttle glide range is at its maximum at MECO and decreases thereafter.

12. After ET SEP, the shuttle must pitch up to an alpha of 50° to pull out while simultaneously translating away from the ET.

13. True. The RCS yaw jets are used down to Mach 1 because the shuttle flies at high alphas that tend to blank the rudder.

14. The TAEM phases are used as follows:

    (a) S-turn - Used to dissipate excess energy by flying a longer route to the runway.

    (b) Acquisition - Used to line up on and approach the HAC.

    (c) Heading alignment - Used to fly around the HAC and line up on the runway.

APPENDIX C
TRAINING MATERIALS EVALUATION

Please answer the following questions regarding the lesson you just completed. Your feedback will allow us to produce more effective training materials. When completed, mail to: Manager, DT34.

TITLE/CODE OF LESSON: **Intact Ascent Aborts Workbook 21002**

SIZE OF AUDIENCE/CLASS:

1.   How well did this lesson meet its purpose?
For each statement below, mark one box on the scale:

Strongly Disagree ———— Strongly Agree

a.   *The lesson objectives are clearly stated.* ☐ ☐ ☐ ☐ ☐ ☐
b.   *The lesson objectives are clearly defined.* ☐ ☐ ☐ ☐ ☐ ☐
c.   *The lesson effectively teaches skills and information.* ☐ ☐ ☐ ☐ ☐ ☐
d.   *The lesson meets its purpose and objectives.* ☐ ☐ ☐ ☐ ☐ ☐

2.   How satisfying is the content of this lesson?
For each statement below, mark one box on the scale:

Strongly Disagree ———— Strongly Agree

a.   *The information is structured in a logical flow.* ☐ ☐ ☐ ☐ ☐ ☐
b.   *The content is clear.* ☐ ☐ ☐ ☐ ☐ ☐
c.   *The content is complete.* ☐ ☐ ☐ ☐ ☐ ☐
d.   *The level of detail is correct for this information.* ☐ ☐ ☐ ☐ ☐ ☐
e.   *The amount of information is effective.* ☐ ☐ ☐ ☐ ☐ ☐
f.   *The graphics contribute to my understanding.* ☐ ☐ ☐ ☐ ☐ ☐

3.   How appealing was the presentation of this lesson?
For each statement below, mark one box on the scale:

Strongly Disagree ———— Strongly Agree

a.   *The overall presentation is appealing.* ☐ ☐ ☐ ☐ ☐ ☐
b.   *The visuals chosen are appropriate for the lesson.* ☐ ☐ ☐ ☐ ☐ ☐
c.   *The visuals make the information more interesting.* ☐ ☐ ☐ ☐ ☐ ☐
d.   *The graphics are legibly reproduced.* ☐ ☐ ☐ ☐ ☐ ☐
e.   *The audio/visual or print quality is good.* ☐ ☐ ☐ ☐ ☐ ☐

4.   How valuable is this information?
For each statement below, mark one box on the scale:

Strongly Disagree ———— Strongly Agree

a.   *The lesson teaches skills and information I need.* ☐ ☐ ☐ ☐ ☐ ☐
b.   *The lesson meets my expectations.* ☐ ☐ ☐ ☐ ☐ ☐
c.   *This information is useful for later reference.* ☐ ☐ ☐ ☐ ☐ ☐
d.   *I would recommend this lesson to others.* ☐ ☐ ☐ ☐ ☐ ☐

PLEASE WRITE YOUR COMMENTS/QUESTIONS ON THE BACK OF THIS FORM.
EXPLAIN ANY NEGATIVE ANSWERS IN SPECIFIC TERMS.
THANK YOU IN ADVANCE FOR YOUR ASSISTANCE!