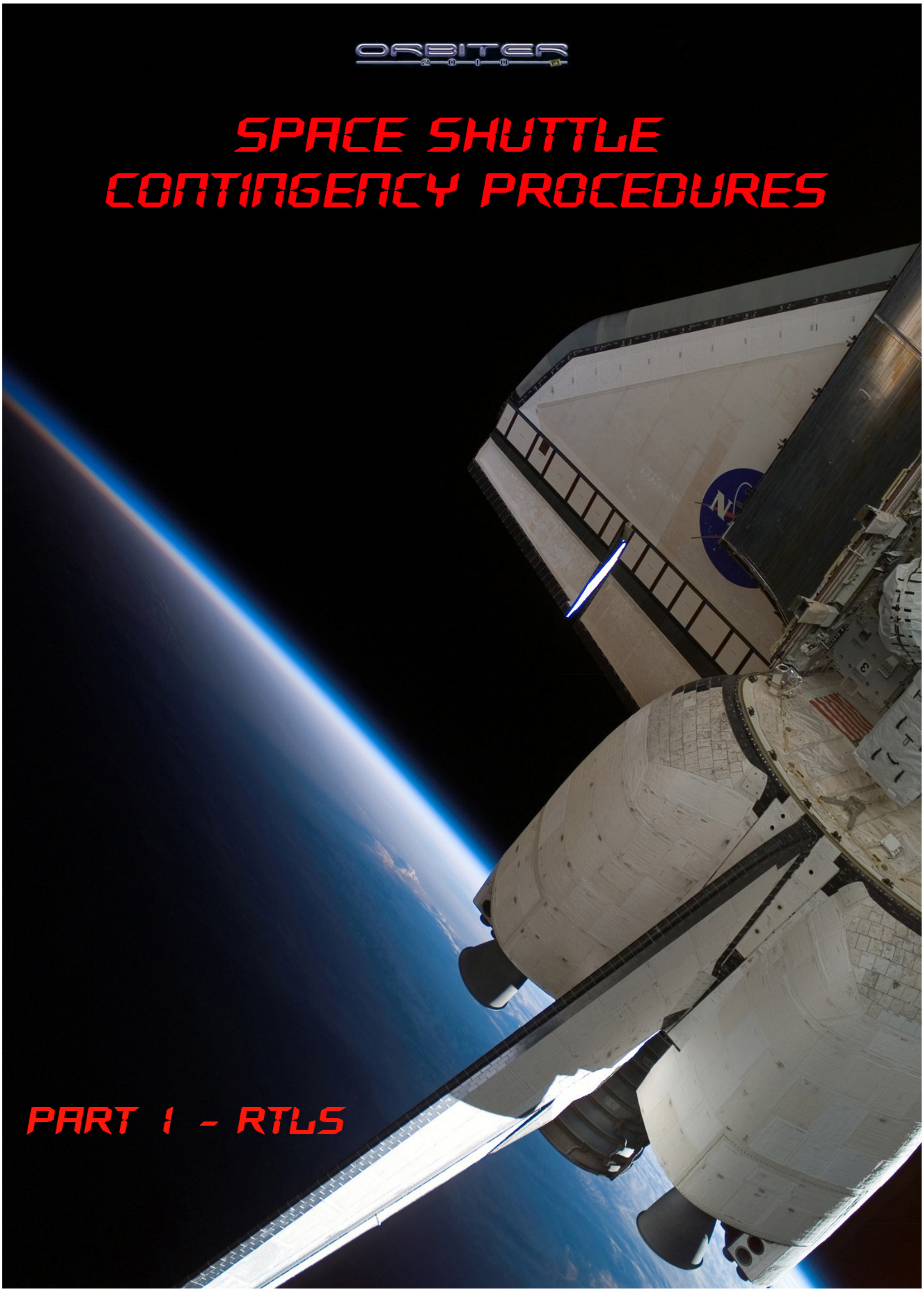
SPACE SHUTTLE CONTINGENCY PROCEDURES



PART 1 - RTLS

SPACE SHUTTLE CONTINGENCY PROCEDURES

Orbiter 2010-P1

Introduction

This document reassembles some of the contingency aborts that the Space Shuttle could have faced during its 30 years of service. Each one of the abort procedures has a dedicated Part which covers the following : NASA procedure - Orbiter simulation tutorial - Appendixes with additional data, Checklists and cuecards. An Orbiter scenario file has also been attached to each contingency tutorial.

NOTE: all scenarios require David413 Shuttle FleetV4.8 to be installed; some of them will need additional addons which will be listed in the relative tutorial section.

The first purpose of this document is to explain in details how things work (or should work) when something goes wrong abord the Space Shuttle and what are the procedures that NASA set up and used during Astronauts simulator training sessions. The second one is giving a guidance on how to "play them with Orbiter".

It is important to stress the point that some of the contents explained in the tutorial are simply the result of multiple " trials and errors" experienced while running the specific scenarios in Orbiter. In other words they worked out well for me (and in most cases the data collected from these scenarios were quite close to the NASA official ones) but this does not mean I have done everything properly. Comments and suggestions are always encouraged and very welcome!

Part 1

RTLS

Section 1

Source: NASA Intact Ascent Aborts Workbook
NASA Contingency Aborts Manual
NASA Shuttle Crew Operations Manual

What is an RTLS

RTLS stays for **Return To the Launch Site** and is the most dangerous and complex Shuttle contingency procedure. It is performed when the Shuttle is unable to reach orbit after launch due to either performance (single or multiple engine failures/shutdown) or critical system failures that require an immediate landing. In such cases the only option for the crew is to fly back towards the launch site (in certain circumstances a different landing site maybe selected such as Bermuda or a US East Coast Airfield (discussed in Part 2).
An RTLS abort has never occurred during the Space Shuttle Program's 135 flights, therefore the actual outcome of such a maneuver in terms of success is questionable.

A real RTLS simulation was initially planned for STS-1 but NASA decided to drop this option as it was considered far too dangerous.

RTLS boundaries

RTLS may be required for either performance problems (1, 2 or 3 engines out) or system failures (such APU's, 2 main Buses, Cabin pressure leak, fuel Leak, cracked window pan, etc).
For systems failures, an RTLS abort is delayed until Liftoff + 3m 40s (referred to as 3+40). By aborting at 3m 40s, ground controllers have more time to determine whether to abort RTLS or TAL (Trans Atlantic Landing).

RTLS boundaries are from launch to the "NEGATIVE RETURN" MCC callout (at which point the Shuttle distance from the launch site and downrange velocity are too high to permit a reentry).

RTLS is selected for any engine failure occurring up to the “2 ENG TAL” boundary (beyond this point the shuttle will be able to reach an alternate field cross the Atlantic ocean with two engines operating).

In case of single engine failure, if that happens within the first 4 minutes of flight (T+4) the Shuttle will not be able to reach orbit, therefore an RTLS (or a TAL) will be the available options.

If it happens during the first 2 and half minutes it cannot even perform a TAL, therefore an RTLS is called.

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) +2m 30s (referred to as 2+30). For example, if an engine fails during first stage, the RTLS abort is delayed until 2m 30s.

This is made to allow time for SRB separation 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 2m 30s anyway. The result is that the RTLS abort is always delayed until at least 2m 30s. If an engine fails after 2m 30s, but before a TAL is possible, the RTLS abort is performed immediately.

The RTLS maneuver can be divided into different phases:

Lofting (fuel dissipation)

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.**
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 (Powered Pitch Around) and turn back toward the launch site.

Powered Pitch Around

The turn to reverse course is called Powered Pitch-Around (PPA), and the timing of PPA is critically important.

The Shuttle pitches down to approximately 55-60° towards the landing Site. This usually happens when fuel remaining is about 50% (depending on when the engine failed). the PPA is performed at 10°/sec to prevent the orbiter from gaining too much altitude while passing through the vertical

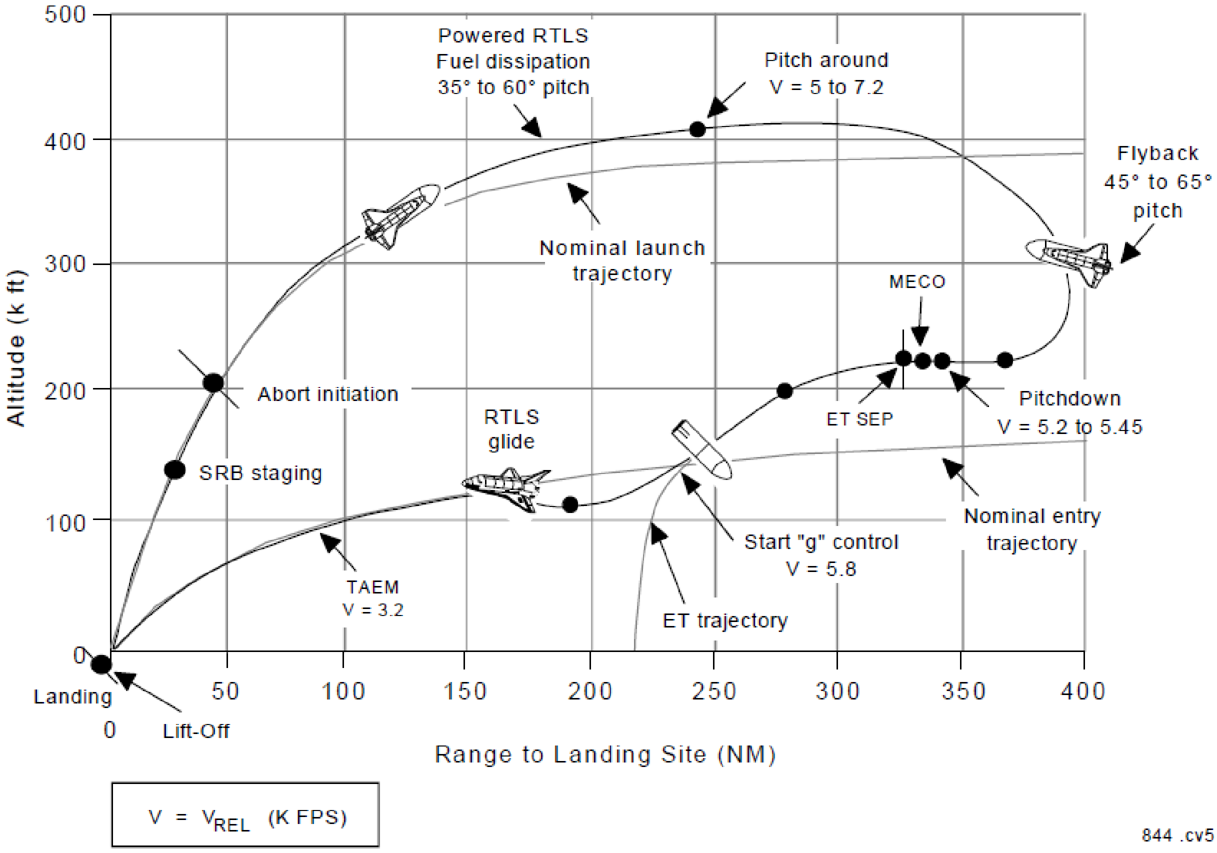


Fig.1 - Typical RTLS profile

Manual flight (CSS)

In case manual control is necessary, the crew needs to know two important things to fly the fuel dissipation phase in CSS: 1) the proper Theta angle (Pitch) to fly during wasting and when to turn around. 2)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 3), the outbound initial Pitch can be determined. The crew then maneuvers the shuttle to that Pitch value in CSS. Normally, little or no additional maneuvering is required until PPA.

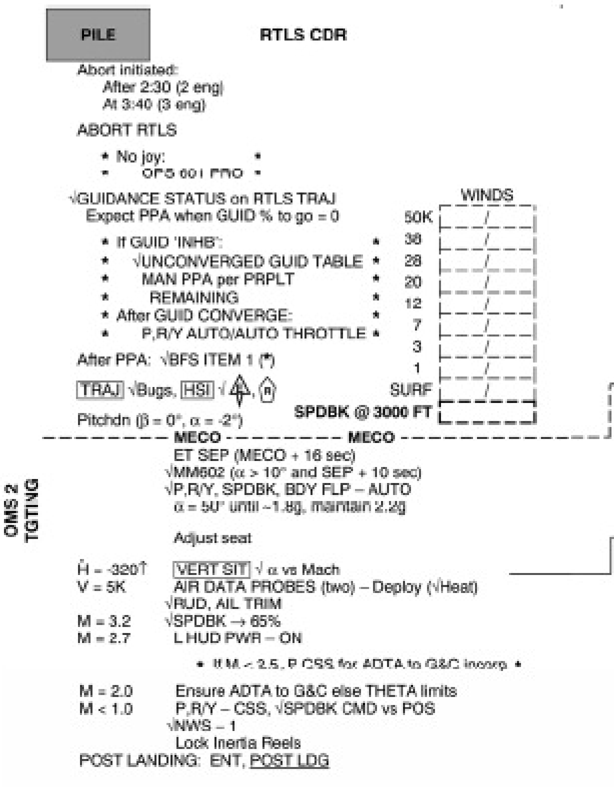


Fig.2 - RTLS CDR cue card

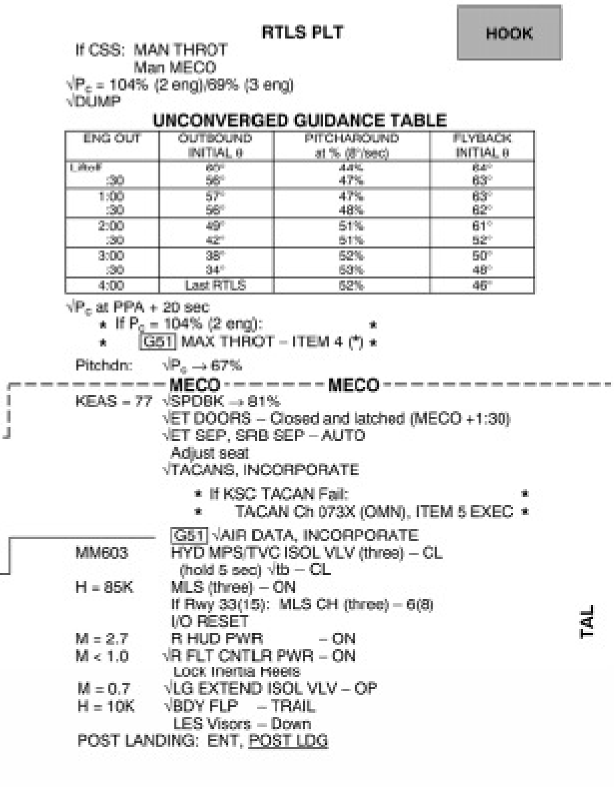


Fig.3 - RTLS PLT cue card

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. 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.

Powered Pitchdown

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 pitchdown maneuver, called Powered Pitchdown (PPD).

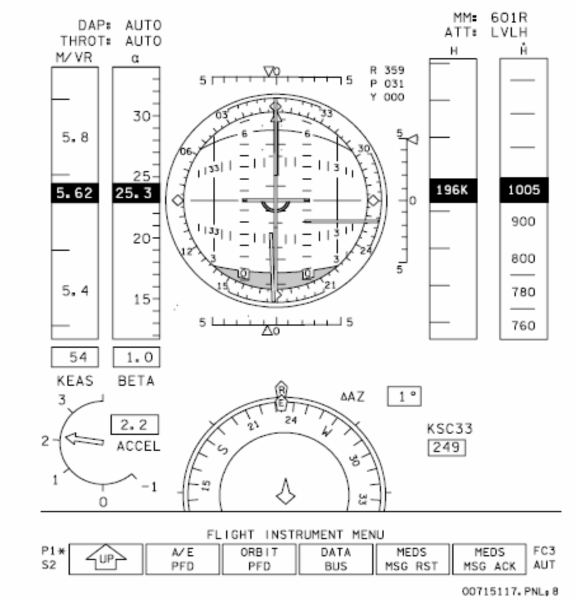


Figure 6-9. Composite ADI/HSI during PPD

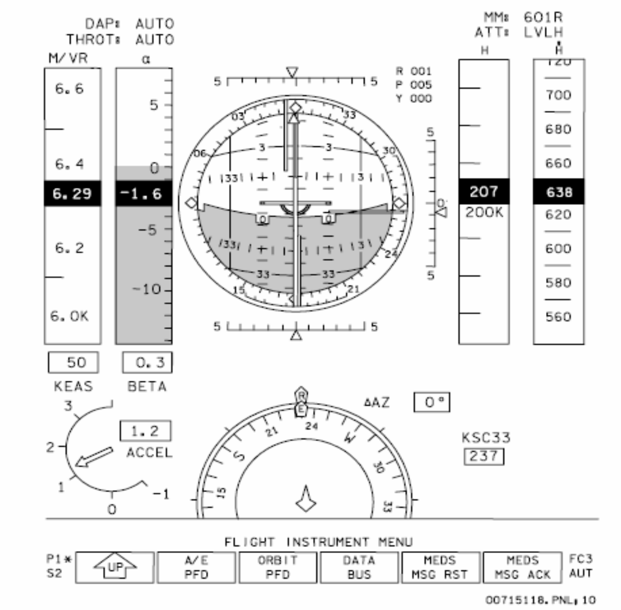


Figure 6-10. Composite ADI/HSI at MECO

Safe ET SEP is a function of Alpha and q-bar (dynamic pressure). As the shuttle descends, q-bar increases and **ET SEP must be performed prior to 10 psf. At pressures above 10 psf, the ET may recontact the orbiter. Between 2 and 10 psf, the shuttle must be at a small negative (about -2°) angle of attack to ensure successful separation.**

As soon as the separation commands are issued and separation has occurred the Digital Auto Pilot (DAP) performs 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.The result is a simultaneous translation and rotation,which carries the orbiter up and away from the tank. **After ET SEP the orbiter angle of attack (Alpha) is +10°.**

With the shuttle in the proper attitude (α = -2°), the PLT shuts down the remaining SSMEs using the SSME shutdown pushbuttons. 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.

Gliding RTLS

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:

1) Alpha recovery phase

2) Nz hold phase

3) Alpha transition phase

4) S-turn phase

5) GRTLS TAEM phase

The first three of these phases are designed to provide the transition from an exoatmospheric ballistic trajectory to hypersonic gliding flight. S-turn and TAEM are where most of the energy management takes place.

Alpha recovery phase

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 up 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. 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). 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.**

Nz hold phase

The pullout must be managed by controlling g's or acceleration normal to the Z-axis (Nz) and Equivalent Airspeed (EAS). Nz is decreased by reducing Alpha. However, reducing Alpha will also increase the EAS. Thus guidance will select a target Nz g-level to balance the trade between Nz and EAS constraints and the vehicle gradually pitches down accordingly to hold that g-level. This change in angle of attack marks the transition to the Nz hold phase **The Angle of Attack continues to be decreased until the shuttle's rate of descent is less than 250 ft/sec (- 80 m/sec).**

Procedurally Nz Hold is considered complete once Nz is less than 2 g. At that time, the alpha transition phase is initiated.

Fig.4 - The H' value (-2183 fps) shows how fast the orbiter is descending during NzHold phase.

Alpha Transition

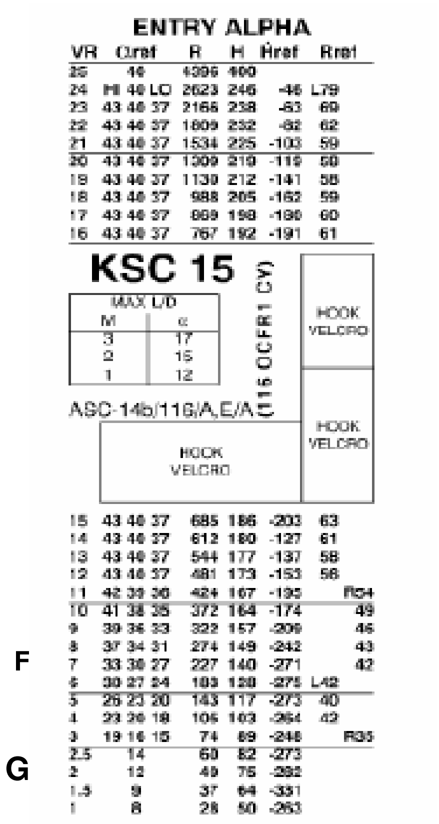
The objective of the Alpha Transition phase is to protect thermal, g, and EAS constraints as the vehicle comes in contact with the thicker atmosphere.

After the termination of the Nz hold phase, the Angle of Attack is changed to conform to the predetermined Alpha profile (the vehicle flies a wings-level attitude and an Alpha based on Mach number). 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.

It is not uncommon for the vehicle to actually gain altitude (**H'** goes positive) during this Alpha Transition phase**.** **This is known as a phugoid.**

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 5).



M	>12	9	6	3	1
α	40	35	26	18	12

α max	50°	50°	50°	50°	32°	17.5°
Mach	>14	>11	>6	5	4	3.2
α min	31°	27°	24°	21.5°	19°	17°

	Low g (< 2.5 g)	High g (≥ 2.5 g)
High Energy	Increase α (max per schedule) Bank = 2 x ΔAz (70° max) or, if E/W ≥ STN, bank = 70°	Decrease α to hold 2.5 g Bank = 2 x ΔAz (70°) max or, if E/W ≥ STN, bank = 70°
Low Energy	Decrease α (min per schedule) Bank = 2 x ΔAz (70° max)	Decrease α (min per schedule) Bank = 2 x ΔAz (70° max)

Fig.5 - Entry Alpha Cuecards and Bank vs Energy state and Delta Azimuth figures.

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. An overview of TAEM is provided here for completeness.

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

1) S-turn

2) Acquisition

3) Heading alignment

4) Prefinal

S-turn phase

If the shuttle energy is too large to be dissipated with lower alphas, the TAEM guidance 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.

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.

Heading alignment phase

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

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.

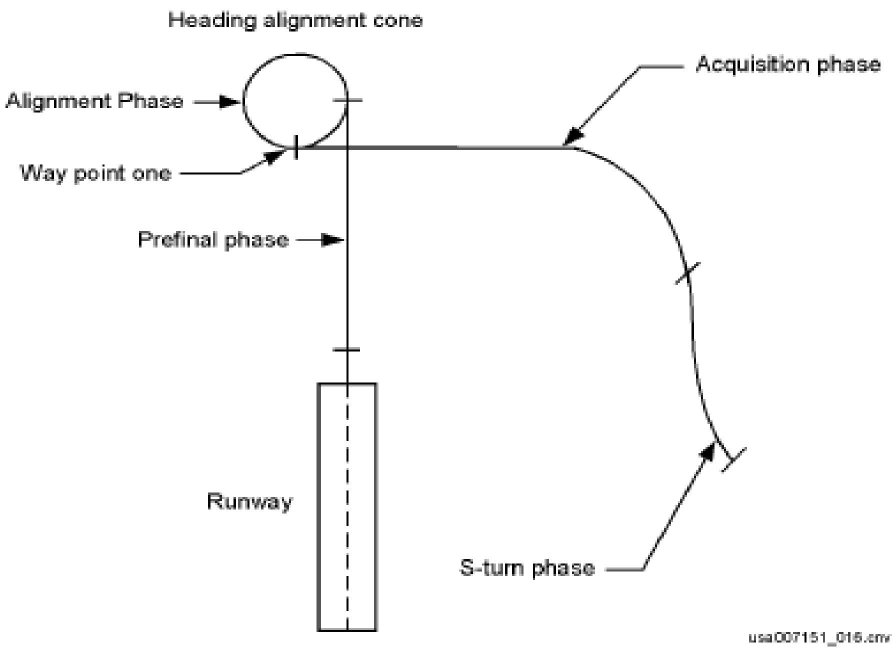


Fig.6 - TAEM phases

Section 2 - Orbiter simulation

NOTE: the aim of this tutorial is not only to show how to perform an RTLS abort with Orbiter but (keeping in mind the obvious differences and limitations of this sim compared to real life) how close to the official NASA procedures and numbers we can simulate a Shuttle contingency abort.

The scenario will see Discovery suffering a single SSME failure 30 seconds after liftoff.
After cancelling the Engine failure aural warning (**Esc**) take manual control of the Shuttle and continue first stage ascent following the nominal profile on GPC MFD OPS1. You will notice that the 2 good engines will automatically throttle up to the max thrust of 109% (GPC MFD OPS6).

Fig.7 - Engine n.1 failed 30" after liftoff. Thrust on the good engines is automatically set at 109%. The Orbiter keeps flying the normal ascent profile while "*Abort RTLS 2+30*" is invoked by MCC. This means no action will be required until that time after SRB separation.

Lofting

After SRB separation, the lofting/fuel dissipation phase starts. Fly an initial pitch attitude of 40° until MET 3 minutes and then start increasing Pitch to about 55° and hold it. Monitor your ApA on SRF MFD (your target is 120Km) and your Vertical Speed which is now decreasing until reading about 100 m/s at MET 6 minutes just before PPA maneuver is initiated. If you see on SRF MFD that your ApA will exceed 120Km reduce your Pitch (and V/S) accordingly.

Refer to the RTLS 1 ENG.OUT CUECARD in Section 3 which gives you the desired values checked every 30 seconds during the flight.

Monitor fuel! This is very important as timing for PPA is based on fuel quantity (in order to perform MECO at the right time with only 2% remaining in the ET).

As you approach 6 minutes and 30sec after liftoff you should have half fuel remaining (look at your fuel quantity gauge on the top left corner of the screen) and approaching 120Km altitude at 250 NM from KSC with a speed of 2100 m/s.

NOTE: this will put you quite farer away from KSC then you should be according to NASA, but I preferred to loft a little bit longer and have the correct fuel consumption later on at MECO then anticipating the PPA at the nominal distance and then reach MECO with too much fuel (I guess the fuel consumption rate of the Shuttle Fleet is not quite the same as the real Shuttle one)

PPA

Pitch the Shuttle down and point the nose back towards the Florida east coast. Maintain initially 65° nose up.

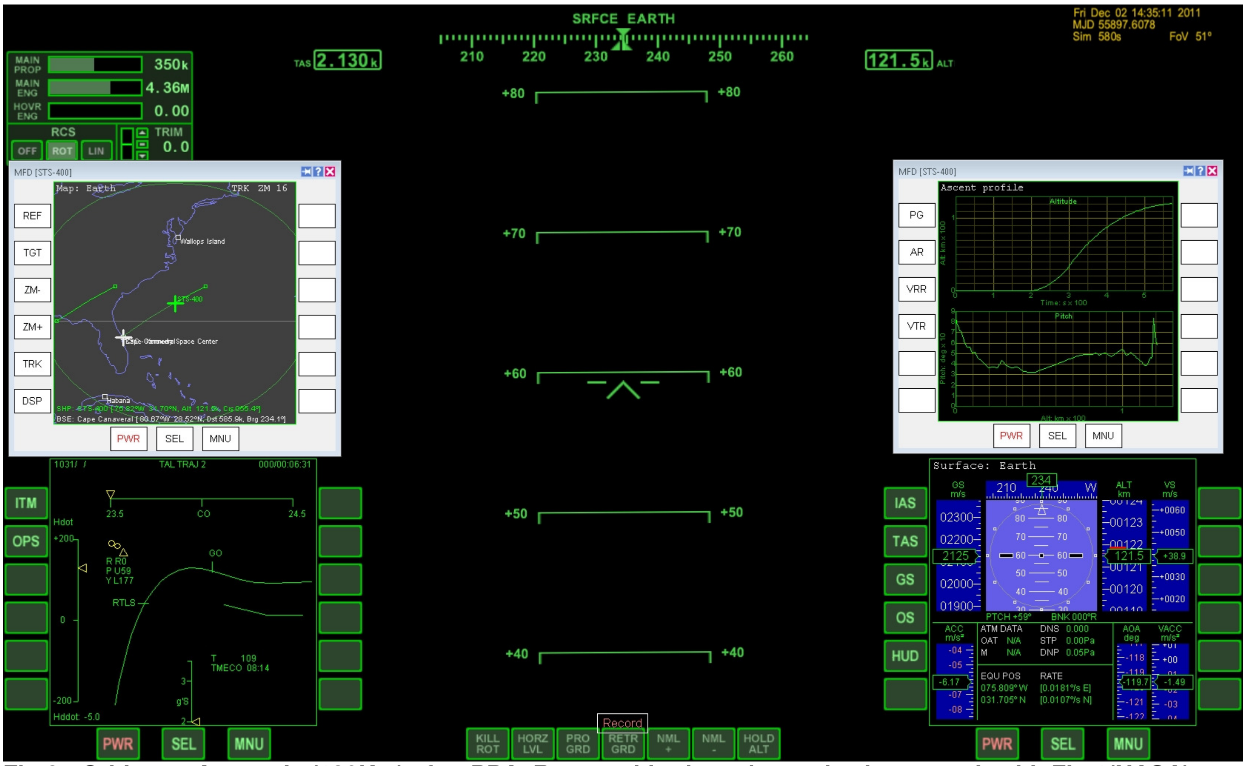


Fig.8 - Orbiter at Apoapsis (120Km) after PPA. Range, altitude and speed values match with Fig.1(NASA)

As your engines thrust back towards the landing site your speed will start decreasing and the shuttle will commence descending. This is probably the most difficult part of the procedure since if you lose altitude too rapidly you'll be too low on energy to reach KSC
and your dynamic pressure will exceed structural limits. On the other hand if you keep your rate too shallow you will end up at MECO too high on energy.

Again refer to the CUECARD in section 3 for target values.

One tip is to always maintain your V/S less then -200 m/s. As a rule of thumb reducing your Pitch by 5° every 30 seconds should keep you on target profile.
Your Vrel will eventually reach zero and start increasing towards the landing site; at this point the shuttle will tend to drop down a lot. Keep monitoring V/S and modulate Pitch as necessary to stay within -200 m/s.

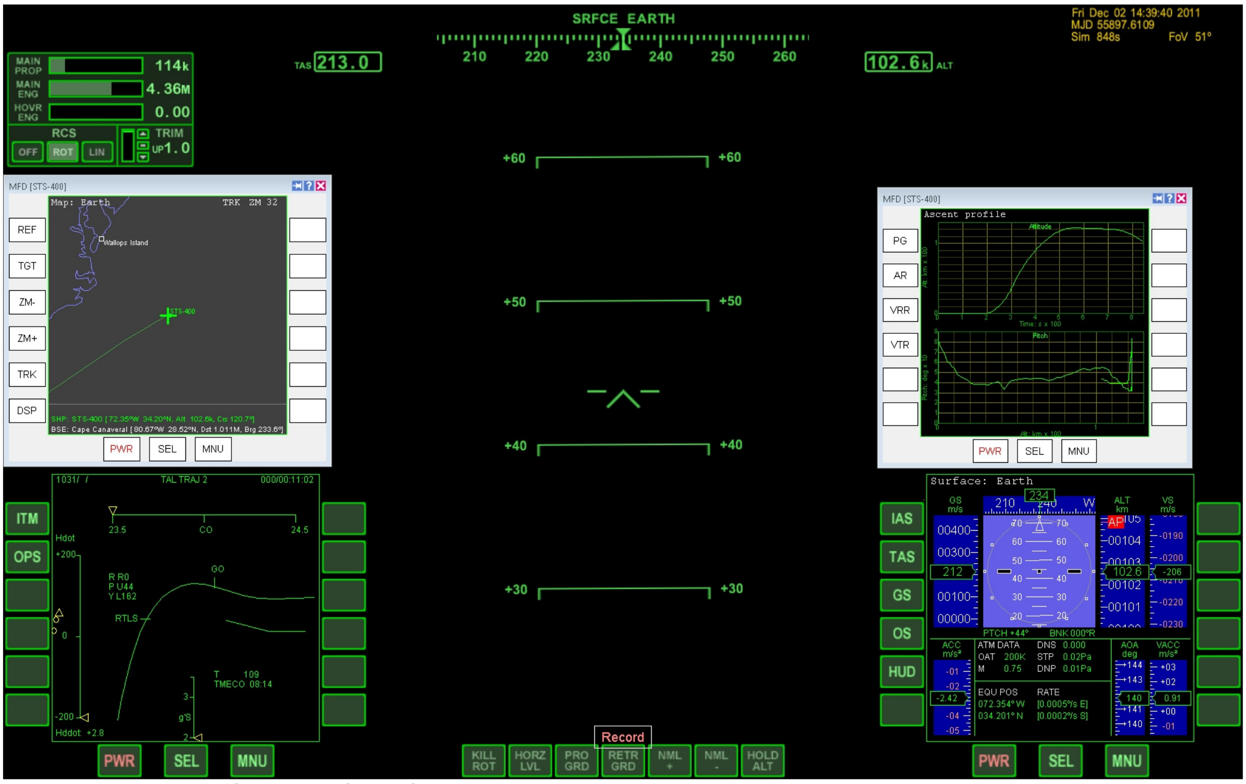


Fig.9 - VRel zero. Check V/S on SRFMFD

Your ACC value will also start to increase. As soon as it approaches the 2.5g target (25m/s) reduce engine thrust or you will exceed the max limit of 3.9g (40m/s).

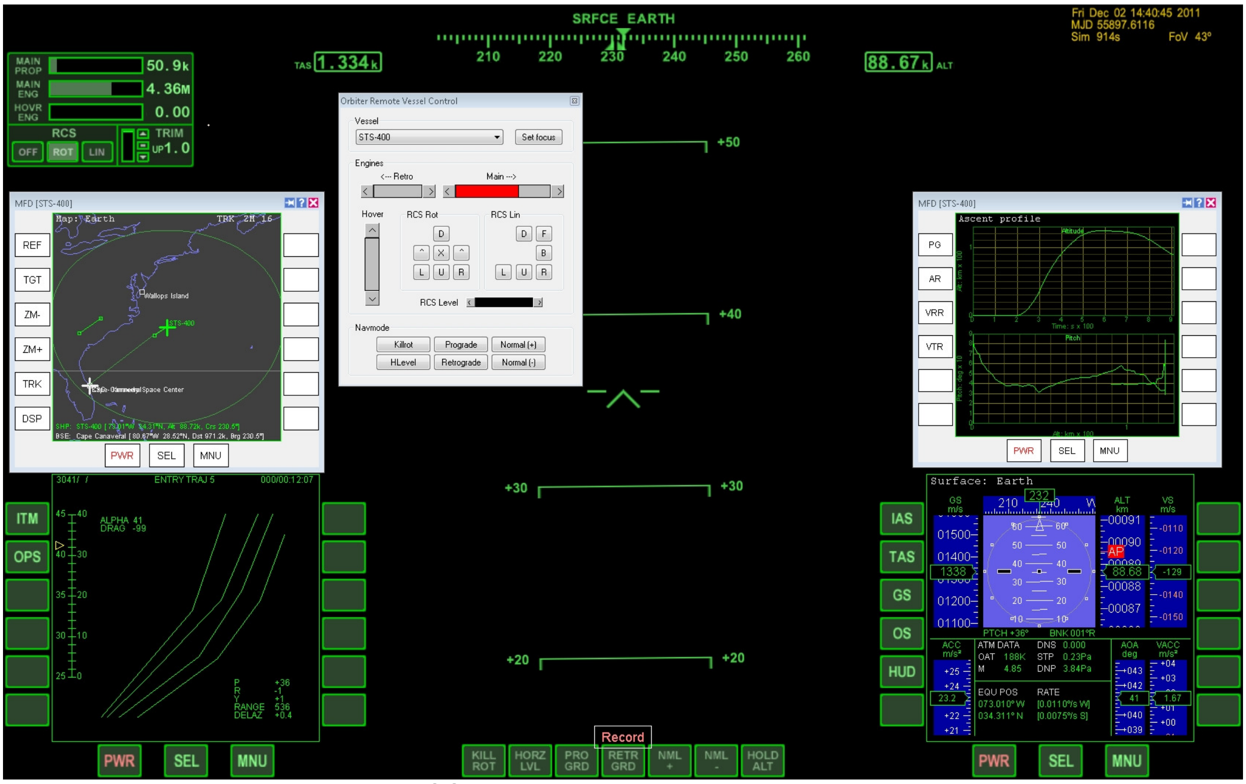


Fig.10 - Thrust reduced to keep ACC 2,5g

PPD - MECO - ET SEP

Approximately 13 minutes after liftoff your fuel should be almost depleted as you travel towards KSC at a distance of 400 NM. Prepare for MECO and ET SEP by pitching down the shuttle to 0° (you should still have a positive Angle of Attack which will permit safe ET separation).

As your fuel level reaches around 10 cutoff the engines (press *****) Check on SRFMFD your Dynamic pressure is within limits (between 100 and 500 Pa) and separate from the external tank (press **J**). As soon as the tank separates select traslation and fire the RCS (-Z thrust) to get the shuttle away from the tank.

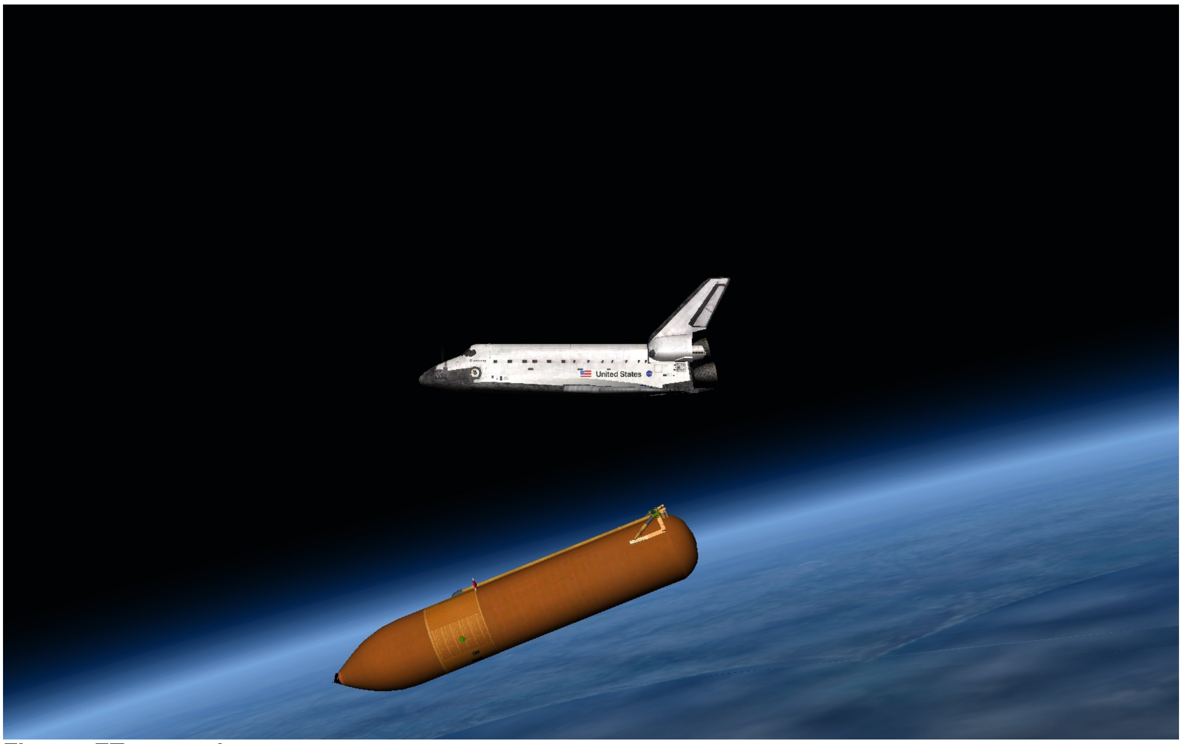


Fig.11 - ET separation

Alpha Recovery - NzHold - Alpha Transition

The shuttle is now on a quick dive therefore it is essential to immediately perform the Alpha recovery pitching up to 50°. Now this not easy as the Shuttle will tend to pitch down quite a lot.

What I do is setting the elevons trim full up and keep the joystick in the max pitch up position.

Maintain this attitude and keep ACC below 2.5g (25m/s) then as your speed decreases just follow the Mach/Alpha cuecard and your acceleration should stay below limits.

Fig.12 - Alpha recovery: note AoA around 50° and Acc increasing

At the Alpha recovery phase your V/S was very high (easily more then 600 m/s). Now it will have reduced quite a lot and will revert to positive rate during the Alpha transition phase. You should reach the lowest altitude of approximately 35Km at around 250 NM from KSC and then the shuttle at this point will climb again to about 40Km.

Fig.13 - Orbiter 200NM from KSC during Nz Hold phase: AoA is decreasing to keep 2.2g max.

The orbiter is now performing what is called phugoid (as described in Section 1 page 8)
and will resume a nominal reentry profile at a distance from KSC of about 130 NM.

Fig.14 - Orbiter back to nominal reentry profile 130NM from landing site and 35 Km Alt.

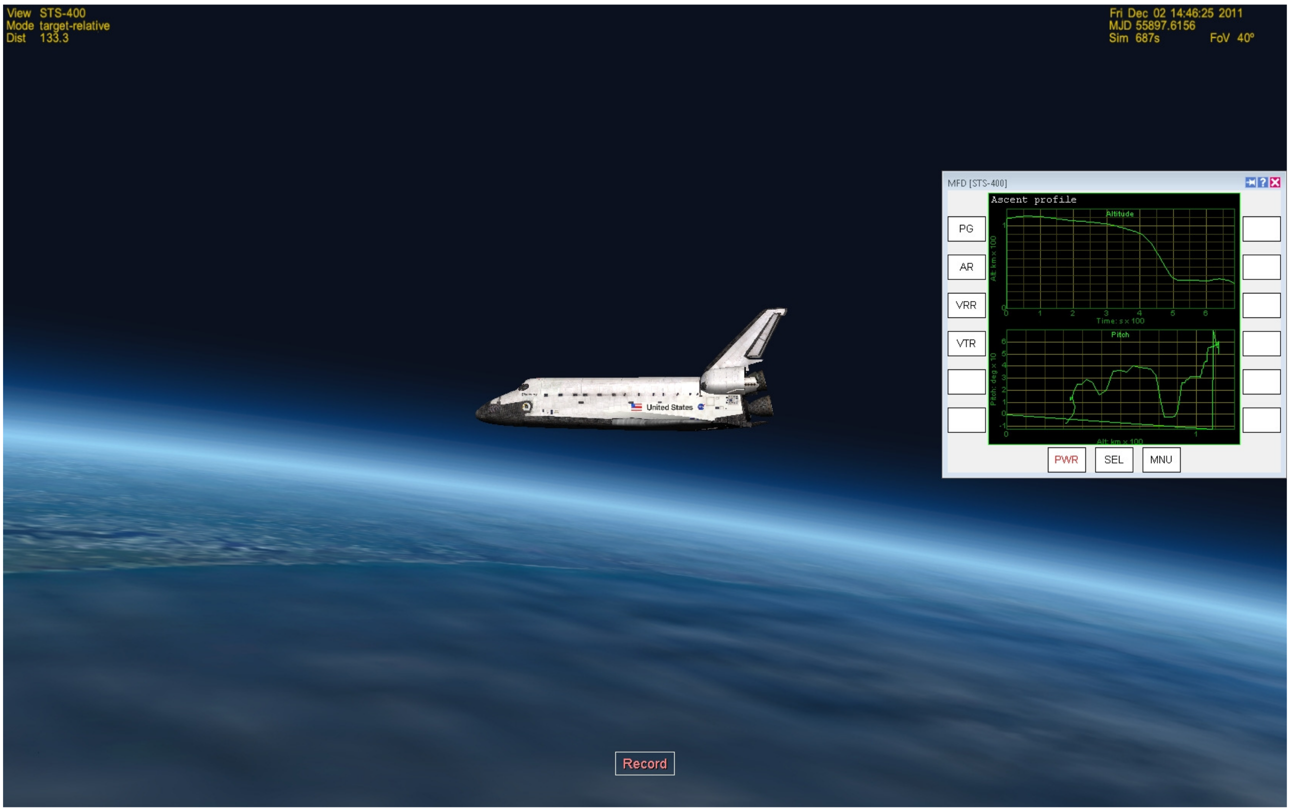


Fig.15 - Note the Altitude graph on the upper side of the Ascent MFD. From PPA, Flyback where the orbiter looses much of the Alt, then MECO where minimum Alt is reached, followed by Alpha recovery, Nz hold and Alpha transition Phase where the curve steepens again after catching the nominal descent path.

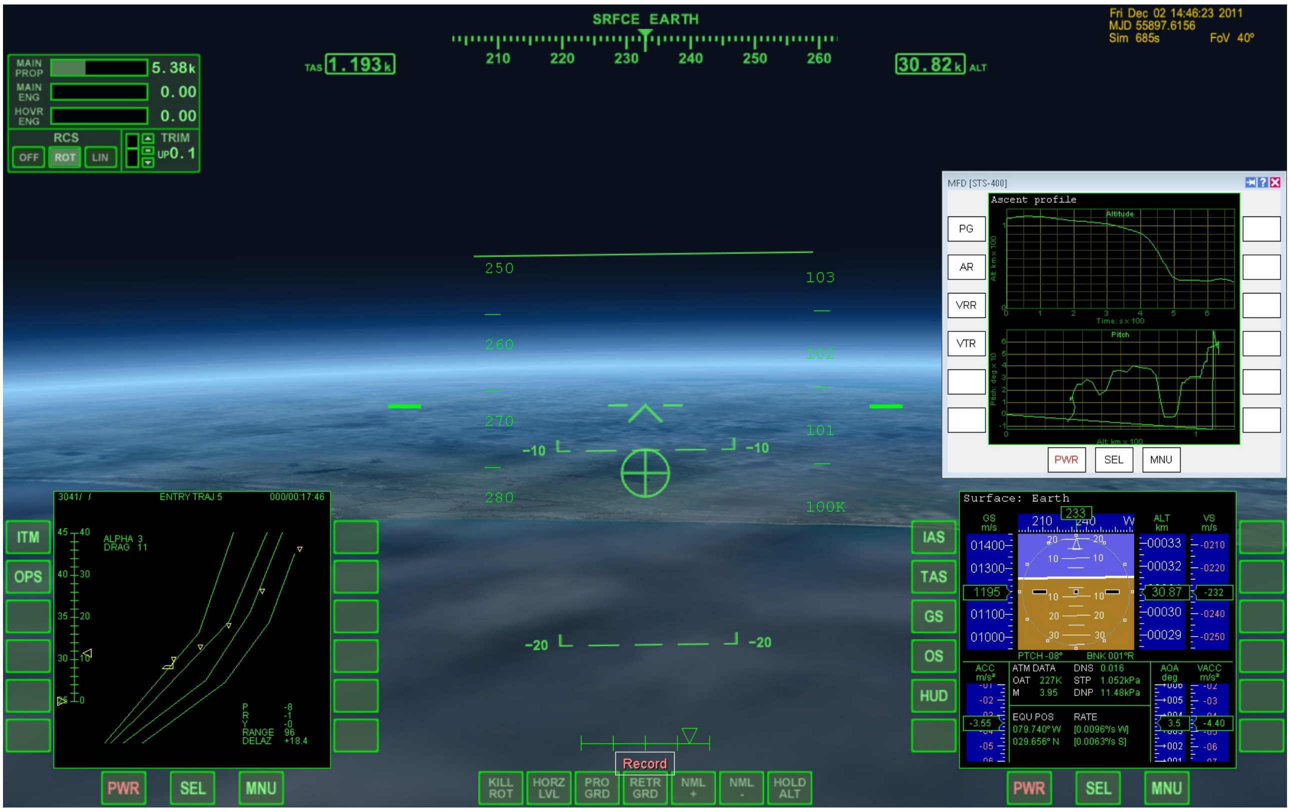


Fig.16 - The same phase seen from inside the Flight deck

Below Mach 5 deploy the Air data probes (**CTRL+5**) so that your speed and altitude tapes will appear on the HUD. At this point as you reach TAEM you only need two MFD's to guide you to land. Turn on GPC MFD OPS3 and OPS4, select the Runway you intend to land on and follow the GPC guidance.

NOTE: a detailed description on how to perform TAEM and Approach and land phase can be found in Part 2 (ECAL/BDA ABORTS).

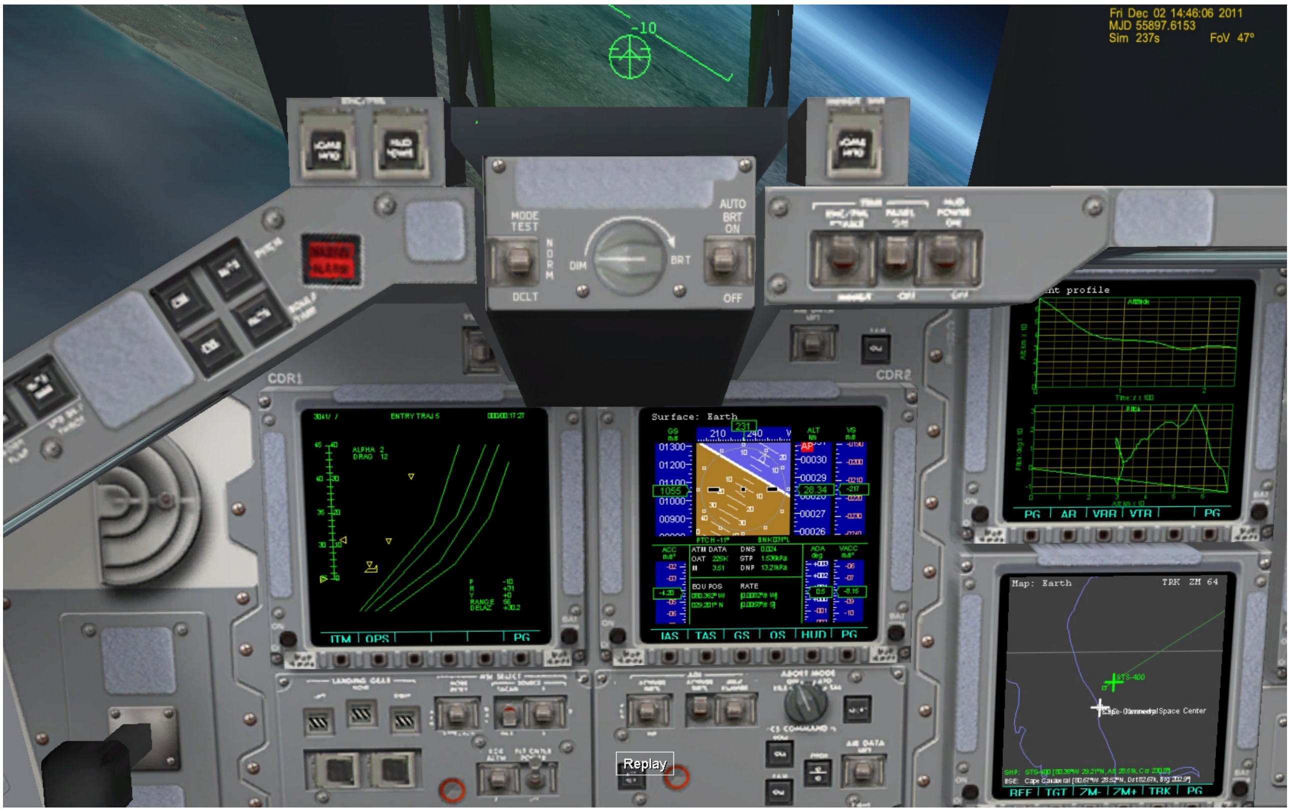


Fig.17 - TAEM at Mach 3.5 and 85000 feet Alt about 60NM from KSC.

Fig.18 - Orbiter about to become subsonic and approaching the HAC.

Fig.19 - Discovery 30' over the threshold RWY33 at KSC.

Section 3 - Appendixes

Appendix 1

Black zones

These are regions along the ascent trajectory that may not be survivable.

Black zones exist when:

1) Exceeding 470 Knots Equivalent Airspeed (KEAS) (750 psf **q**) during entry
NOTE: 470 kts is a known engineering constraint. The FCS is certified to 333 kts. However, a Loss of Control (LOC) will probably not occur unless the EAS is in excess of 470 kts.

2) Exceeding 4.2 g during entry
NOTE: 4.2 g is based on an engineering analysis for the OMS pod sheer limit (when 75% full). Also Nz Hold software for contingency aborts will attempt to hold a maximum of 3.9 g.

3) Three engines fail during first stage
For most or all of first stage, the three-engine-out contingency maneuver may not be survivable due to structural failure at the ET/SRB attach points. In addition, the alpha and/or dynamic pressure profile will lead to adverse conditions at staging, which would lead poor separation dynamics outside the contingency limit resulting in an LOC.

4) Experiencing high q during mated coast
LOC can occur during mated coast when high **q** aerodynamics exceed RCS control authority.

5) Min subsonic EAS is 185 kts
That is also the minimum touchdown speed in case of very low energy approaches. The aerodynamic stall speed is 165 kts.

Nominal values / limitations

Phase	Range(NM)	ALT(Feet)	Speed	G/S	V/S(m/sec)
HAC(270°)	20	25000	M0.8		
HAC(90°)	15	20000	290		
Final(OGS)	7	12000	290	-19°	65
Speedbrake reposit.		3000	290-310		
Preflare (IGS)		2000	290-310		4
Gear Down		300	290-310		
Final flare		100	250		1
Rwy threshold		20-50	230-240		
Main Gear t.down (1500'/2500')			190-200	(Pitch 8-10°)	
Derotation			175-185		
Nose Gear t.down /Drag Chute			160		
Braking			140		

Max pullout, g's in OPS 6	3.9
Max pullout, g's in OPS 3	3.5
Max EAS	470 kts
Max certified EAS	333 kts

Min subsonic EAS	185 kts
Stall speed kts)	170 kts (t.down allowed speed range is185-205
Max Landing gear deploy speeed:	315kts/M.95 (gear damage if above)
Max Tyre speed:	Main gear 225kt / Nosegear 215kts (tyre damage/ blowout if above)
Max V/S at T.down: damage/collapse	2/3m/sec (240/210klbs-gear if fabove)
Max Landing pitch	12° (tailstrike will occur at 14,5°)
Landing gear down/lock before	15 secs after deployment (usually 5 secs t.down)

QRH Checklists

Shuttle Fleet 4.8
Quick Reference Handbook

1 ENG. OUT RTLS Checklist

Condition: 1 SSME failed during first stage ascent

1 **SSME FAIL...Disengage DAP**

Continue first stage nominal ascent

2 **SRB sep...Pitch45°**

! Expect high pitch down momentum just before SRB SEP

3 **T+3'...Pitch 50°**

4 **Target ApA.. ..120 Km**

5 **Fuel <50%...Start PPA**

Pitch..Set70°

Pitch rate..10°/s

! If V/S > 0 reduce Pitch until V/S = 0

Follow RTLS 1 E. OUT CUECARD

6 **V/S Max... ....-200 m/s**

Continued on next pag

8 V/S Max at Vrel zero....................-100 m/s

9 PPD....................Pitch 0°

Target Alpha....................-2°

10 Mach> 10....................MECO

11 DNP 100 - 500 Pa....................ET SE

12 -Z traslation....................Engage RCS

13 ET SEP + 10sec....................Alpha > 10°

14 ET umbelical Doors....................Close

15 Alpha Recovery....................Pullup to Alpha 50° (2°/sec)

Trim....................Full Up

ACC....................Pitch for 25 m/s

16 Nz Phase....................Reduce Alpha until V/S -80 m/s

16 Alpha Transition (H'<-100 m/s)..............Follow Mach/Alpha schedule

17 Trim....................adjust for target Alpha

M	>12	9	6	3	1
α	40	35	26	18	12

18 Mach 5....................Deploy Air data Probes

19 TAEM....................Check profile/Energy state

Altitude....................85000 feet

Range....................60 NM

IAS....................Mach 3.2

20 Altitude 70000 feet....................Check Range 30 - 60 NM

! If Range is outside limit Go to the BAILOUT Checklist

21 < Mach 1....................CSS

22 Autospeedbrake....................ON

23 2000'....................Arm LND GEAR

24 1800'....................Preflare

25 300'....................LND GEAR DOWN

26 Touchdown ....Speedbrake full open

27 Drag chute....................Deploy

Bailout Checklist

Condition: orbiter too high or too low on energy to reach the landing site

1 **50.000'...Close and lock visors**

2 **Emergency O_2...Activate**

3 **IAS...185-195 kts**

4 **40.000'...Depressurize Cabin (MS3)**

5 **30.000'.....................Jettison side hatch/Deploy escape pole (MS3)**

5 **20.000'...................................Pitch-Roll zero/Engage DAP LVLHLD**

6 **Transmit Position, Speed, Hdg**

7 **Bailout**

Note: **It takes approximately 2 minutes for a max crew of eight to bailout**

Appendix 4

RTLS cuecard

RTLS 1 ENG. OUT CUECARD

MET	PITCH°	ALPHA°	ACC m/s2	ACC g	ALT Km	ALT Kfeet	RANGE km	RANGENM	SPD m/sec	Mach	V/S	FUEL	NOTES
2	40>				50>		85		1600			600	
3	50				80		175	95	1800		450	550	
03:30	50				90		210		1800		400	510	
04:00	55		2,5		100		270	145	1900		300	500	
04:30	50		3,5		110		320		2000		250	450	
05:00	40		4,7		115		370	200	2100		200	430	
05:30	35		5,7		120		430		2200		120	400	
06:00	35		6		123		500	270	2400		50	390	
06:30: PPA	pitch to 70		3,8		125		580		2600		0	350	Apoapsis
07:00	70		-5		123		650	350	2500		0	330	
07:30	65		-6		122		730		2400		0	300	
08:00	60		-7,5		122		800	430	2100		-20	270	
08:30	55		-9,8		121		850		1900		-50	250	
09:00	45		-10,5		120		900	490	1600		-50	220	
09:30	40		-12		119		950		1300		-100	200	
10:00	40		-13		115		980	530	950		-150	150	
10:30	40		-13		110		1000		550		-200	130	
11:00	40		3,3		100		1000	540	230		-200	100	Vrel 0
11:30	40	50	4		100		1000		500		-200	70	
12:00	38	45	21		90		980	520	1100	4	-150	50	
12:30	30	32	27		85		950		1800	7,5	-100	25	
PPD	25	30	20		80		850	450	2700	10	-150	10	
MECO	0	10	0		75		820		2800	10	-250		when M>10
13:30 ET SEP	pitch UP	to 50	0		78		800	430	2800	10	-300		
14:00 Alpha Recovery	40	50	1		65		700		2800	9,5	-550		
14:30	25	40	-10	-1	45		630	350	2750	8,5	-600		
15:00 NzHold	20	25	-18	-2	35		550		2300	7,5	-100		
15:30 Alpha Transition	25	20	-7,5		38		500	270	2000	6	150		altitude gain
16:00	20	15	-3,2		41	135	450		1800	5,7	50		
16:30	20	22	-4		40	130	380	200	1700	5,5	-100		
17:00 GRTLS					37	120	340		1600	5	-150		
17:30	10	15	-5		33	110	300	160	1500	5	-100		
18:00	10	8	-4		33	110	250		1300	4,5	0		
18:30	10	10	-3		33	110	200	110	1200	4	0		
19:00	5	8	-4		32		170		1150	3,8	-50		
19:30	3	7	-3		30	100	150	80	1100	3,5	-100		
20:00 TAEM	-3	5	-4,5		27	90	110	60	970	3,2	-130		
20:30	-3	6	-6,5		23	75	80	45	800	2,7	-100		
21:00	1	5				68	60	35		2	-50		
21:30	0	5				63	45	25		1,8	-50		HAC acquisition

Appendix 5

Acronyms and abbreviations

ACLS....................................... Augmented Contingency Landing Site
AFCS....................................... Autopilot Flight Control System
A/L..Approach and Landing
α (Alpha)/AoA............................Angle of Attack
ACC...Acceleration
ACQ...Acquisition
ADI..Attitude display Indicator
AGL...Above Ground Level
AOA..Abort Once Around
ApA...Apoapsis
APU..Auxiliary Power Unit
ATO................................... .....Abort To Orbit
ATT...Attitude
β (Beta).....................................Roll angle
BFS...Backup Flight Software
C.G...Center of Gravity
CDR..Commander
CRT..Cathode Ray Tube
CSS..Control Stick Steering
DAP..Digital Autopilot
ΔAz (DelAz)..............................Delta Azimuth
DME..Distance Measuring Equipment
DNP/q bar.................................Dynamic Pressure
DPS..Data Processing System
EAS..Equivalent Airspeed
ECAL..East Coast Atlantic Landing

EDW.....................................Edwards Air Force Base
EI..Entry Interface
ELS.......................................Emergency Landing Site
ET...External tank
ET SEP................................External Tank Separation
E/W......................................Energy to Weight
E/Q...................................... Energy to Weight ratio
FPS.......................................Feet per Second
g...Acceleration Unit (9,8 m/s)
γ(Gamma).............................Yaw angle
GNC......................................Guidance and Navigation and Fligth Control Computer
GPC......................................General Purpose Comupter
GRTLS..................................Glide Return To Launch Site
GS..Groundspeed
H...Altitude
H' (hdot)................................Vertical Velocity
H'' (hddot).............................Vertical Acceleration
HA....................................... Height of Apogee
HAC......................................Heading Alignment Cone
HDG......................................Heading
HSI.......................................Horizontal Situation Indicator
HP.. Height of Perigee
HUD......................................Head Up Display
KAS.......................................Calibrated Airspeed
Km..Kilometer
KSC.......................................Kennedy Space Center
KTS.......................................Knots
IAS.......................................Indicated Airspeed
IGS.......................................Inner Glideslope
L/D.......................................Lift to Drag
LH_2.. liquid hydrogen
LO_2.. liquid oxygen
M..Mach
MCC....................................Missio Control Center

MECO................................Main Engine Cutoff
MEP...................................Minimum Energy Point
MET.................................. Mission Elapsed Time
MFD...................................Multifunction Display
MGTD................................Main gear Touchdown
MPS...................................Main Propulsion System
mps....................................Meters per second
NEP...................................Nominal Entry Point
NM.....................................Nautical Miles
Nz......................................Normal Acceleration
Ny......................................Lateral Acceleration
OGS..................................Outer Glideslope
OMS..................................Orbiter Maneuvering System
OVHD................................Overhead
Pa......................................Pascal
PeA....................................Periapsis
PLS....................................Primary Landing Site
PLT....................................Pilot
PPA...................................Powered Pitch Around
PPD...................................Powered Pitch Down
PRTLS.............................. Powered Return to Launch Site
PSI.....................................Pounds per Square Inch
PSF....................................Pounds per Square Foot
QRH...................................Quick Reference Handbook
RA......................................Radio Altimeter
RCS...................................Reaction Control System
RHC...................................Rotational Hand Control
RTHU.................................Roll to Heads Up
RTLS.................................Return To the Launch Site
RWY..................................Runway
SB......................................Speedbrake
SPI.....................................Surface Position Indicator
SRB...................................Solid Rocket Booster
SSME................................Space Shuttle Main Engine

STIN..................................Straight In

TAS...................................True Airspeed

TAEM................................Terminal Area Energy Management

TAL...................................Transoceanic Abort landing

T/D....................................Touchdown

θ(Theta)..............................Pitch angle

TMECO............................ MECO Time

TRAJ...................................Trajectory

V..Velocity

V_I.. Inertial Velocity

Vrel.....................................Relative Velocity

V/S......................................Vertical Speed

VSD....................................Vertical Situation Display

VV.......................................Velocity Vector

WOW...................................Weight on Wheels

WT.......................................Weight