SPACE SHUTTLE CONTINGENCY PROCEDURES

PART 2 - ECAL/BDA

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 2

ECAL & BDA ABORT

Section 1

Source: NASA Contingency Aborts 21007/31007

Some east coast airfields and Bermuda NAS (BDA) can be used as an emergency landing site in case the Shuttle is forced to an immediate reentry following a 2 or 3 engine failure.

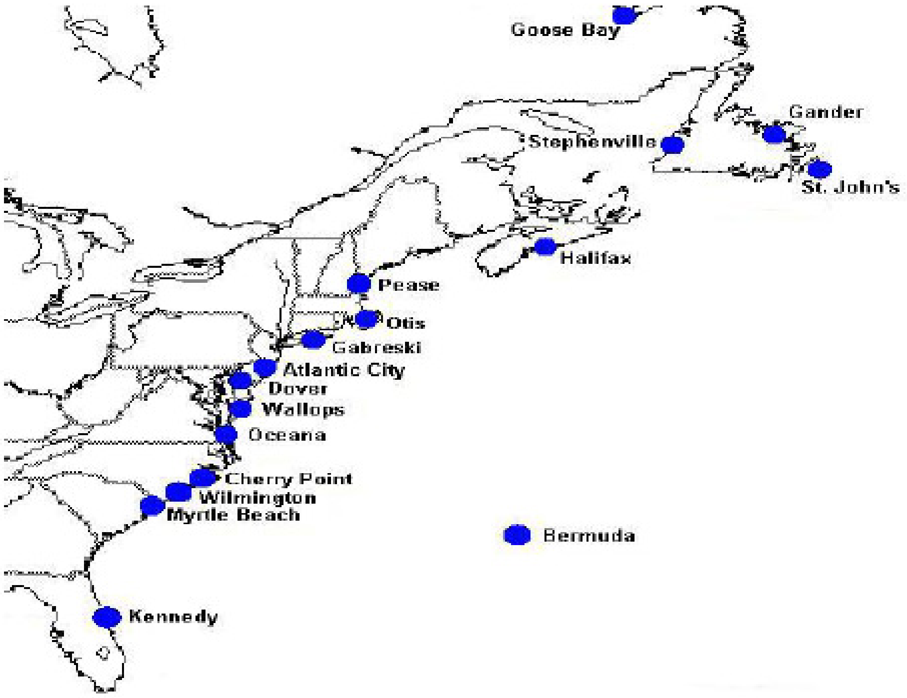

Fig.1 - ECAL/BDA landing sites map

BDA is used for low or med inclination launches (28° to 39°). For high inclination launches (51° to 57°) any of the east coast airfields in the figure above may be used (ECAL), depending on when the failure happens and the shuttle energy state at that stage.

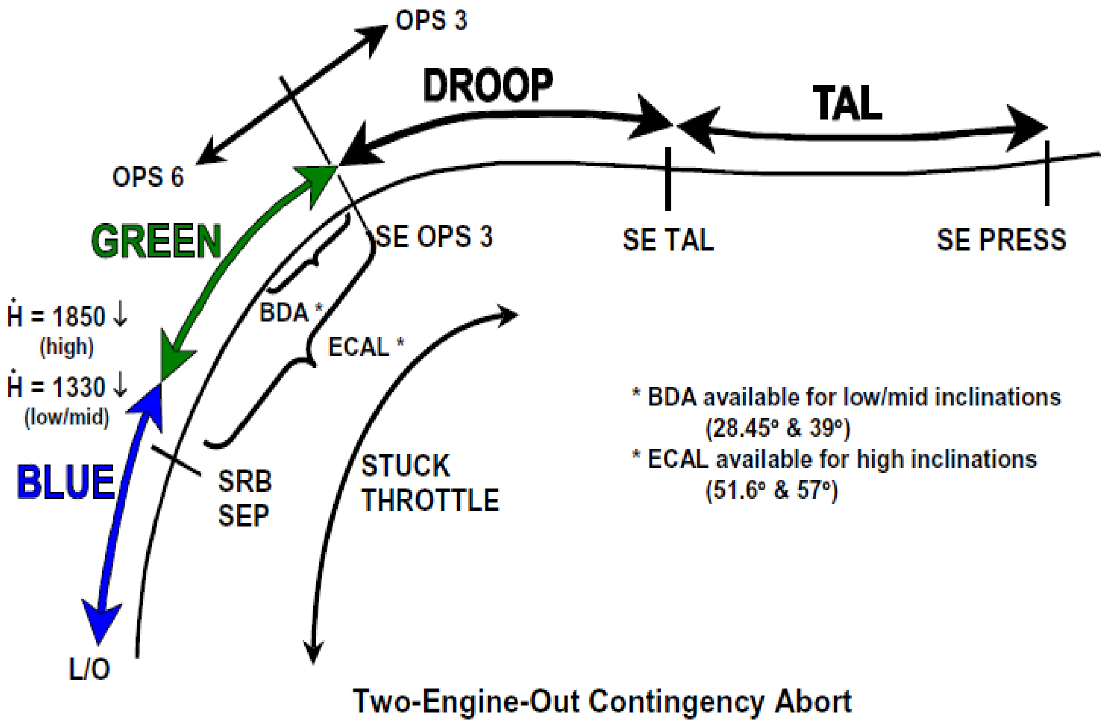

Fig.2 - Contingency profiles

The figure above illustrates what kind of abort (and related landing site) maybe selected during ascent.

Contingency Single-Engine Thrust Attitudes

In two-engine-out situations, contingency guidance will fly a single engine thrust attitude that will minimize the pullout severity post Main Engine Cutoff (MECO).

For **high H'** (vertical speed) (> +1850 fps for high or > +1330 fps for mid and low inclinations) low velocity profiles a more horizontal profile will be flown to minimize the pullout. A horizontal attitude will use the remaining thrust to increase the horizontal component of velocity and thus shallow the flight path angle.

For **low H'** (< +1850 fps for high or < +1330 fps for mid and low inclinations) high altitude profiles, a more vertical attitude is flown ("stand on the tail") in order to minimize the sink rate. In this case, the profile already has a larger horizontal than vertical velocity component. Hence, a vertical attitude is used to minimize the downward trend generated by loss of thrust.

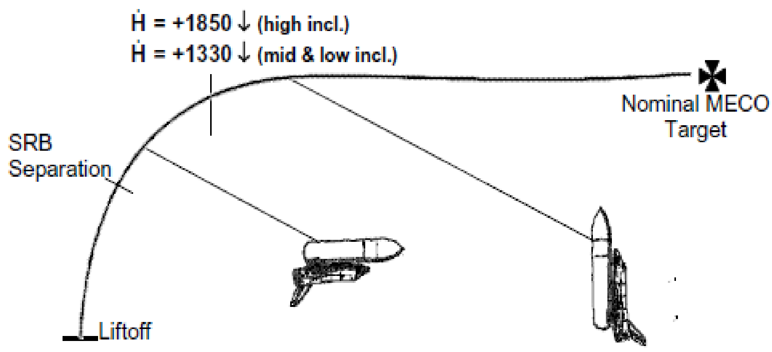

Fig.3 - Shuttle initial attitude after 2 Engine failure vs Vertical speed

Early in second stage, when first passing through H' = +1850/1330 fps, contingency guidance may require a “combined” maneuver which initially pitches horizontal to increase the horizontal velocity component, then pitches vertical to reduce the sink rate. By combining both aspects, the “combined” maneuver will more effectively reduce the entry pullout.

Basic Contingency ET SEP/Entry Sequence

In both two- and three-engine-out situations, contingency guidance will maneuver to a safe External Tank separation (ET SEP) and entry attitude as follows:

1. Dependent upon current trajectory conditions, one of six possible set-ups/maneuvers will be performed to prepare for ET separation.

2. MECO will be commanded (for two-engine-out situations).

3. Some contingency maneuvers (RTLS two-engine-out near Vrel = 0) will have an extended Mated Coast (still attached to the ET) to allow further alpha reduction with a brief Orbital Maneuvering System (OMS) burn during Mated Coast, which will reduce ET propellant slosh dynamics. The reduced alpha is required to improve ET separation dynamics.

4. A safe separation from the ET will be performed using the Fast SEP portion of the ET SEP sequence software once the appropriate attitude is achieved.

5. A -Z translation will be commanded in order to provide a safe separation distance from the ET.

6. Post ET SEP, the vehicle maneuvers to a predetermined alpha (AoA) for entry via the shortest path (**alpha recovery**). **The post ET SEP attitude is heads up, wings level, and flying a specific alpha with the nose pointed into the wind.**

7. A dump of OMS propellant through the Orbital Maneuvering Engines (OMEs) and Aft Reaction Control System (ARCS) jets is accomplished to decrease weight and improve the X c.g. for entry (if required)

2 EO ECAL/BDA "Yaw" Procedure

If a large yaw angle is displayed on ADI REF ball (and the HSI) on a two-engine-out Powered ECAL/BDA abort the required yaw maneuver shall be commenced.
For ECAL/BDA powered flight 2 EO contingency guidance will command an unguided 45° yaw toward either the East Coast or Bermuda. This maneuver reduces crossrange by turning the velocity vector more toward the landing site. However, most of the crossrange is still flown out later in thicker atmosphere during glided flight.
Once the EAS starts building greater than 4 kts, the vehicle will yaw back into the velocity vector in preparation for MECO and ET SEP.

IMPORTANT: If the yaw maneuver is observed, it is critical to enable Max throttles (109%) on the remaining engine (SPEC 51,ITEM 4) ASAP. This will not only improve steering toward the landing site, but will extend the powered flight time as long as possible until EAS builds up and MECO and ET SEP are required. For this reason, this procedural step is included in the 2 OUT procedure blocks prior to transitioning to the POWERED ECAL/BDA procedure.

Alpha Recovery

Post MECO and post ET SEP, guidance will target an alpha that is appropriate to the current Mach number. This is known as the Alpha Recovery phase. **During this phase expect Alpha between 20° and 58°.**

Nz Hold

In this phase guidance avoids exceeding the 470 kts EAS constraint during the entry pullout by managing the g-level and limiting it to max 3.9g. 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 is referred to as Nz Hold.

Alpha Transition

During the Nz hold phase the orbiter's descent rate can be quite high (much greater than -1000 fps). As the vehicle descends into the atmosphere, this descent rate quickly slows, becoming less negative. **When vertical speed is -320 fps and climbing, that is becoming less negative (H' = -320 >), the Nz Hold phase is complete and the Alpha Transition phase starts. Here, the vehicle flies a wings-level attitude and an alpha based on Mach number. 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.**

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. Post-pullout contingency abort profiles sometimes create a subsequent phugoid that require thermal, g, and EAS consideration. For ECAL and BDA aborts, contingency entry guidance will actively manage alpha within a specified range to control energy to the designated landing site.

Once the Alpha Transition phase is complete, the orbiter is ready to be positioned for either landing or bailout.

NOTE: bailout procedure is discussed later in this chapter

Mach-Alpha Schedule

After Nz Hold, contingency guidance will enter the alpha transition flight phase and fly a Mach-Alpha schedule. The M/Alpha profile (example below) insures a safe attitude in hypersonic and supersonic fight, and is usually good for subsonic flight.

M	>12	9	6	3	1
α	40	35	26	18	12

Fig.4 - Mach vs Angle of Attack (Alpha) flown during reentry.

Speedbrake/Body Flap

Both speedbrake and bodyflap are set prior to the Nz Hold phase because they may not move in the presence of high g's and aerodynamic loads. The speedbrake opens to generate a nose-up pitching moment, contributing to lateral-directional stability by causing elevons to move down into the relative wind. The bodyflap position reduces aero loads on the elevons.
If Mach is less than 3 upon transition to entry, then the crew should open the speedbrake manually to 65%. This gets the S/B open faster than leaving it in AUTO because the S/B will be needed as soon as possible.

POWERED ECAL/BDA Procedure

Initial checks are that maximum throttles have been selected and the vehicle is flying a modified “stand on the tail” with yaw procedure, Pitch = 60° and Yaw = 45°, and has rolled Heads Up.

For POWERED ECAL/BDA a rate SEP is required once EAS conditions are met (EAS > 10 kts and increasing). The vehicle will yaw back in plane to the Earth-Relative velocity vector bearing pointer on the HSI just prior at EAS > 4 kts. Once back in plane, the pitch rate is commanded. When at the target rate, MECO will be commanded on the remaining engine, followed by ET SEP 1 second later.

CSS is required for the alpha recovery phase post ET SEP. After 8 seconds of -Z translation while the pitch rate continues, Pitch CSS will be taken to achieve a 4 °/sec rate in reaching Alpha = 58°. **The concern is that if DAP pitches the nose below the horizon (after 8 sec) high dynamic pressure may saturate flight control and prevent the positive pitch rate required to reach Alpha = 58°**

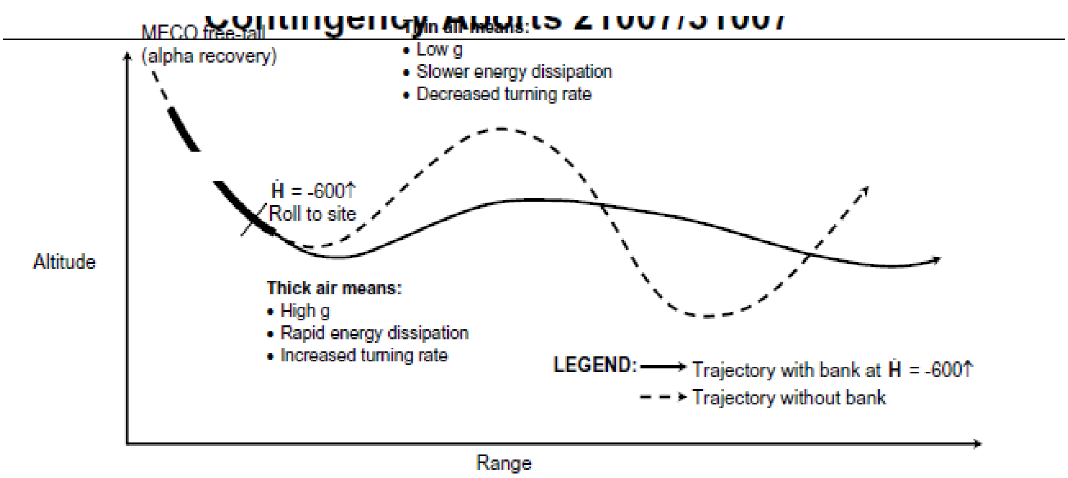

Fig.5 - The phugoid profile during reentry

The bank at **H**' = - 600 decreases the magnitude of the phugoid and allows the orbiter to sink into thicker air. While in thicker air g’s will increase, energy will be dissipated more rapidly, and an increased turning rate will be accommodated. So then, thicker air is a benefit for high DAz (Delta Azimuth) and/or high-energy situations.

However, for low energy situations, the bank maneuver is a detriment. Bank will be reduced in order to increase lift, find thinner air, lower g’s, and slow energy dissipation. Unfortunately, turning rate may also decrease to the point of allowing DeltaAz to increase too rapidly to manage.

ECAL/BDA Entry High Energy Control

After Nz hold, the ECAL/BDA Entry automation logic actively works to control energy.

The current state of energy over weight (E/W) is displayed on the VERT SIT E/W scale on the right-hand side. E/Wscale from high to low energy includes total range to the runway, including flying out the current heading error (deltaAz). **Although E/W may initially indicate low energy immediately after Nz Hold, the subsequent phugoid can easily increase ranging capability until the current E/W is nominal, or even high energy.**

If high energy is detected as indicated by E/W > STN on the VERT SIT display, then bank will be increased, if required, to a maximum of 70°.

1. The best single on-board cue for determining current ECAL/BDA energy state is the E/W Bug on VERT SIT. If the E/W Bug shows high energy above the S-turn (STN) mark, expect a 70° bank toward the site.

2. 70° bank will be held until deltaAz has crossed through 0° and increased to between 15° and 30° on the other side.

NOTE: Accepted DeltaAz heading error ramps from 30° at Mach 8 to 15° at Mach 3.2 since large heading errors in TAEM will lead to low-energy situations.

3. Once the heading error has reached its limit, bank will be reversed and return to the normal 2.2 X DeltaAZ value.

4. If the E/W Bug descends below the ECAL/BDA S-turn Termination line prior to reaching it's DeltaAz heading limit, guidance will also return to it's normal 2.2 X DeltaAZ banking technique.
During the 2nd and subsequent phugoids the roll commands are limited to protect g's and dynamic pressure. Thus it is common to see a smaller bank than the 70° high energy roll command or the normal 2.2 X DeltaAZ roll command.

ECAL/BDA Entry Energy Management - Alpha, Bank

ECAL/BDA Entry automation logic manages energy on entry by flying a bounded Mach-Alpha schedule and controlling bank as follows:

	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.6 - Use of bank for energy control depending on E/W state

Where the Mach-Alpha schedule is bounds Alpha by maximum and minimum limits as follows:

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°

Fig.7 - Max and Min Angles of attack vs Speed (Mach)

NOTE: Min Alpha is optimized to increase ranging capability, while protecting Vertical Tail Thermal Indicator (VTTI) limits.

Thus high and low energy is managed, including the following constraints:

1. If E/W > STN, bank = 70° until DeltaAZ increased to 15° to 30° heading error limit, then 2xDeltaAZ,

2. If low energy, Alpha may not decrease until deltaAZ <25°.

For high-energy cases, the angle of attack will be increased to maximize drag and kill off energy. Also, if high enough energy exists, the high-energy S-turn bank logic will be initiated. The angle of attack will also be reduced to protect for g's if necessary.

For low energy cases the angle of attack will be reduced to fly closer to the max L/D while still protecting VTTI limits. If large heading errors exist, the angle of attack will not be reduced further until the heading error is below 25°. It is better to keep the nose up and more g's on the vehicle to converge the heading error quicker. The quicker heading error is reduced, the less range that has to be flown.

ECAL/BDA TAEM transition

With the ECAL/BDA flag set to ENA (enabled) guidance will automatically transition to TAEM (MM 603) at **Mach 3.2.** At that point the ECAL/BDA and Contingency flags are set to OFF and TAEM guidance works exactly the same as a standard RTLS abort.

ECAL/BDA Entry Bailout Assessment

At 70k ft altitude, a Bailout assessment is made. Runway range is evaluated to ensure that range is NOT < 28 nm (for the high energy check) and range is NOT > 54 nm (for the low energy check).
Downmode from overhead (OVHD) to straight-in (STIN) HAC and/or use Nominal or Minimum Entry Point (NEP/MEP) as required.

If Range is < 28 NM or > 54 NM, then BAILOUT will be required.

BAILOUT

When it is determined that a bailout is necessary, the commander places the orbiter in a minimum-sink-rate attitude and engages the autopilot.

At 50.000 feet, the commander directs the crew to close and lock their visors and activate emergency oxygen.

At 40.000 feet, MS 3 (seated middeck in seat 5) vents the cabin via the pyro vent valve T-handle initiator.

At an altitude of 31.000 feet the cabin pressure is about equalized with the outside atmosphere.

Shortly thereafter, the commander directs MS3 to jettison the side hatch. As soon as the hatch is jettisoned, all crewmembers disconnect their oxygen and communication connections, and egress their seats.

MS3 deploys the egress pole by pulling the safing pin and arming pin and rotating the handle counterclockwise. Should the pole fail to deploy fully, the manual ratchet is used to manually extend the pole. The exit involves each crewmember attaching the lanyard hook assembly to the parachute harness and egressing through the side hatch opening.

It takes approximately 2 minutes for a maximum crew of eight to bailout. As each crewmember exits the orbiter, the force exerted by entering the windstream activates the automatic parachute sequence. Once the crewmember is off the pole and away from the orbiter (1.5 second delay), a pyrotechnic cutter separates the bridle and lanyard. The 18-inch pilot chute is deployed 1.5 seconds later, and immediately deploys the 4.5-foot drogue chute.

The drogue chute stabilizes the crewmember down to an altitude of 14,000 feet, then deploys the main canopy.

Prior to a water landing, the crewmember pulls the manual inflation tab for the life preserver unit.

Bailout is the only option in case the orbiter has not enough energy to reach an airfield as landing off the runway or ditching are considered not survivable by NASA and will lead anyway to loss of vehicle.

Section 2 - Orbiter simulation

NOTE: the aim of this tutorial is not only to show how to perform an ECAL/BDA 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.

Addons required:

- Latest "*Shuttle Fleet"* (currently 4.8R0) by David413

I strongly suggest to download and install the following addons for this simulation:

- "*NASA Shuttle Abort and Backup Landing Sites"* by ky

- "*Bermuda Island* "by Perseus

Abort to BDA

This scenario simulates a double engine failure 3 minutes and 50 seconds after liftoff on a low inclination orbit launch which will lead to an emergency reentry at Bermuda NAS (BDA).

Engine failure/Roll maneuver

At MET 3' and 50" engines n.2 and n.3 will fail; cues for engine failure will be the Engine out warning horn and loss of Engine n.2 and 3 thrust indication on the MPS panel of GPC OPS6 MFD. Also your acceleration values on the SRF MFD will drop dramatically.

At this stage the orbiter is flying head down and the horizontal component of velocity is much greater then the vertical component (V/S is lower then 450 m/s) therefore a huge orbiter attitude change is required (see Fig.3 in section 1). After silencing the Engine Fail Aural Warning (press **ESC**) increase your Pitch to 90° (which in this case means pitch down since the shuttle is on a head down orientation) to put the orbiter on a "stand on the tail" attitude.

As you reach target pitch you now need to roll the orbiter 180° in order to set it on a head up attitude with the nose pointing towards the Velocity Vector (VV).

Fig.8 - SSME n. 2 and 3 failed at T+3' 50"

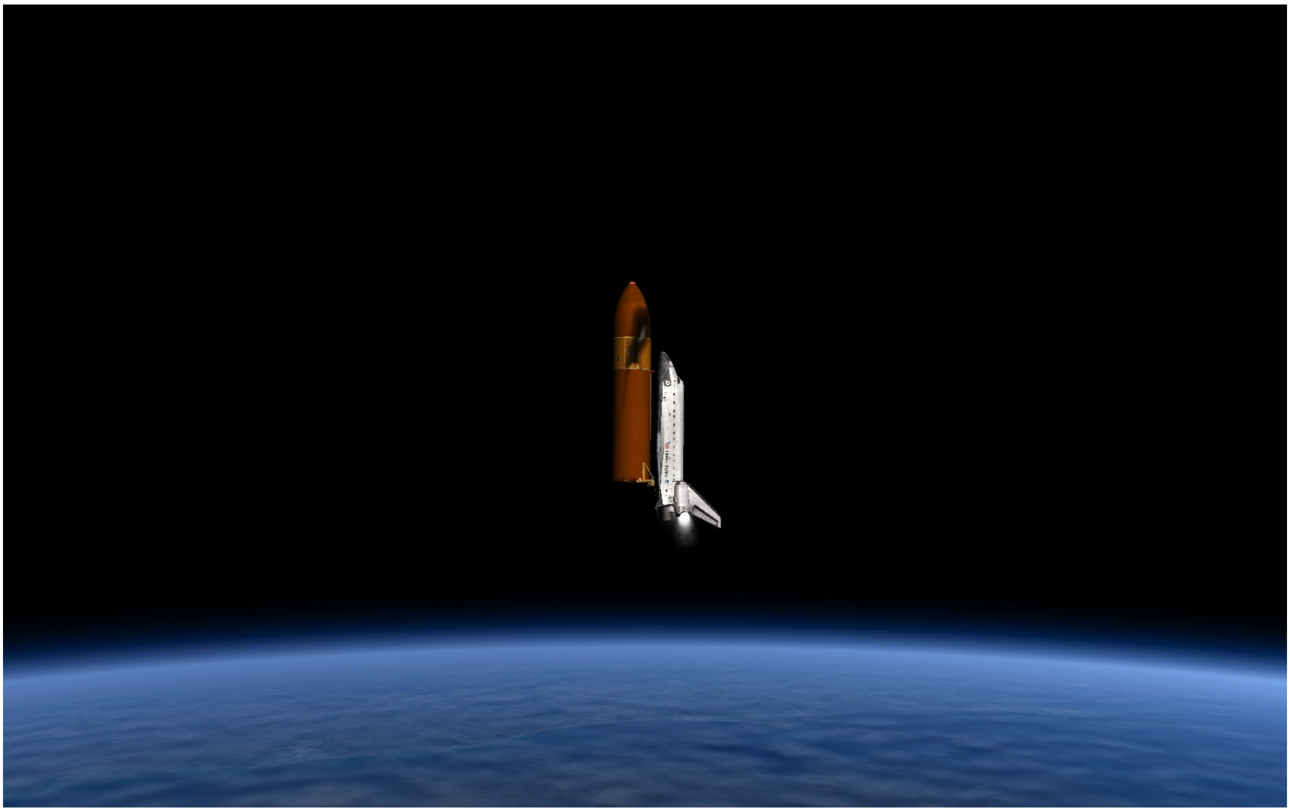
Fig.9 - Immediately after engine failure the shuttle is positioned tail down (facing the earth)

This is the most delicate and difficult maneuver of the whole contengency procedure: proper timing, correct RCS inputs and instruments crosscheck are essential.

First of all, in order to turn towards the VV with the proper head up attitude **DO NOT bank the shuttle by using roll commands as, with one engine remaining and the ET still mated to the shuttle, roll maneuvers are very limited and can easily lead to LOC (loss of control).**

Use combined YAW and PITCH inputs instead. As you yaw, the shuttle will actually start rolling into the desired direction while pitch will tend to decrease. Now, **it is very important not to reduce Pitch below 60° for two reasons: 1)by keeping a relatively high Pitch the shuttle will more easily and quickly yaw towards the VV. 2)This will also prevent unwanted over-roll during the maneuver which will lead to LOC.**

When approaching the VV stop pitching up and continue yawing until wings level (the pitch will drop down around +30°) See Fig.11 for a pictorial view of this step. Don't rush or exagerate with RCS inputs or you may loose control.

Timing is also important: after the SSME failure start pitching for 90° immediately but don't rush. Monitor your V/S (which will be decreasing). A good reference is to reach you "stand on the tail" attitude when V/S approaches +100m/s and then commence the roll maneuver.

The roll maneuver doesn't need to be rushed either. It should take 40-50 seconds to reach your desired attitude (wings level, around 30°pitch up and HDG 070°(VV) with a descent rate between -100 and -150 m/s).

Fig.10 - After pitching up (tail facing earth) orbiter is rolled head up and turned towards the VV

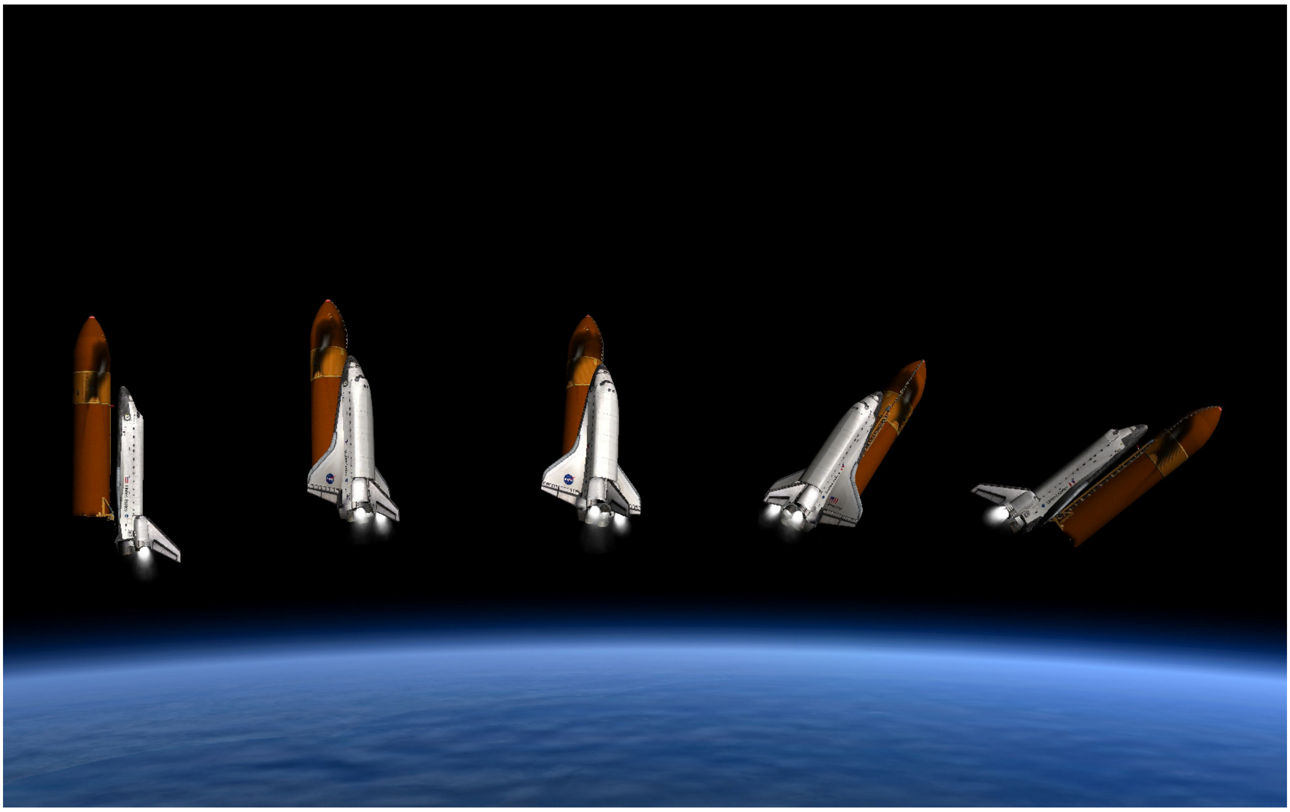

Fig.11 - The roll-pitch maneuver sequence.

The next step now is to lower your Pitch to almost 0°, perform MECO and separate from the ET. Again timing is essential at this stage since your descent rate will increase incredibly fast as you free-fall back into the atmosphere. <u>Your goal is to safely separate from ET and do it before your altitude loss gets too high.</u>

NOTE: at MECO your V/S should not exceed **-200 m/s**. If you see it is greater and increasing, immediately kill rotation, shutdown the engine (press*) and perform an "emergency ET separation". If you keep the shuttle mated to the ET longer you will end up loosing too much altitude and will never make it to the landing site (in real life emergency ET SEP is also performed to avoid dynamic pressure on the ET exceeding limits and causing structural failure and hull loss).

MECO and ET SEP

Pitch down to 0° and cutoff the engine (press *). Right after MECO the shuttle should be wings level, pitch near 0° with a positive Alpha (AoA) and nose pointing towards the VV. Verify this conditions are met **before** ET jettison as this will prevent collision between ET and the shuttle after separation.

Perform ET separation (press **J**), immediately select RCS traslation and fire the RCS (-Z thrust) to move the shuttle away from the ET.

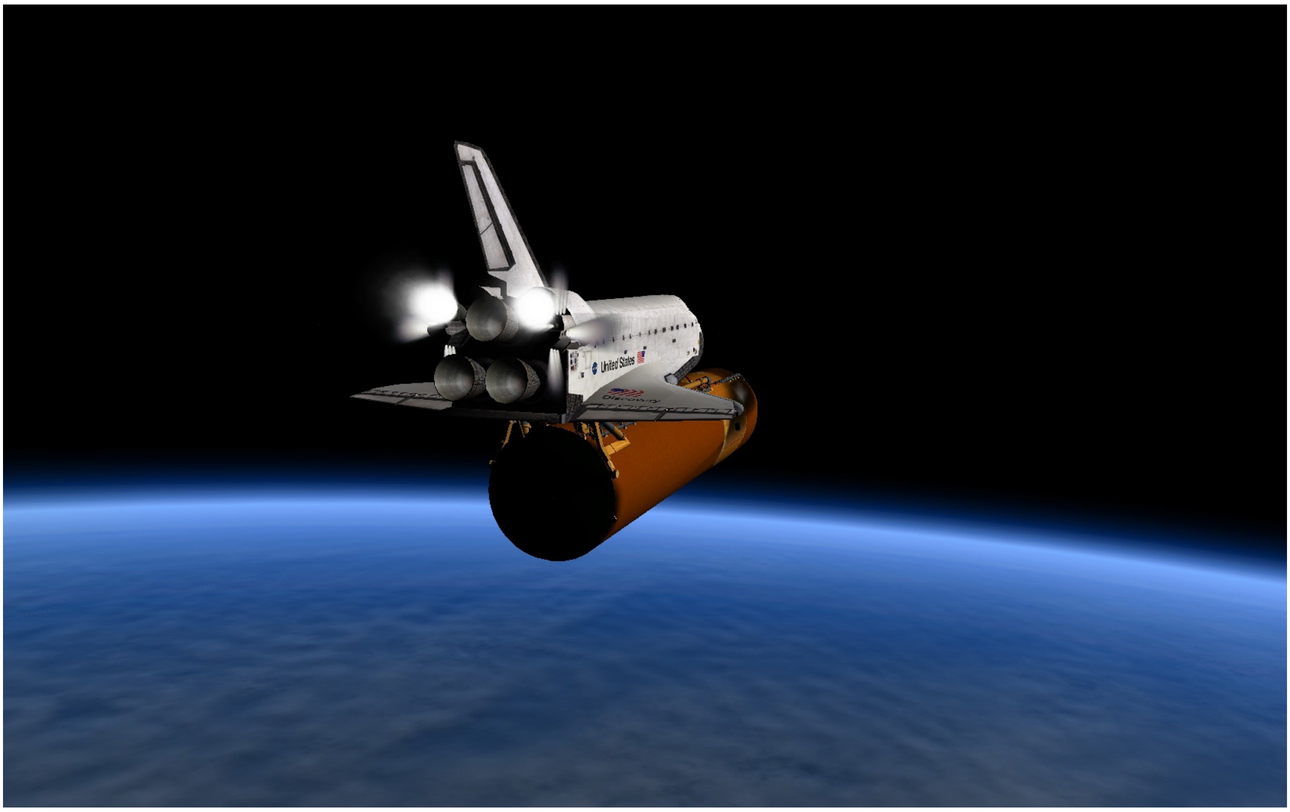
Fig.12 - MECO


Fig.13 - ET separation

Alpha Recovery

Use traslation thrust for not more then 5 seconds then reselect Rotation and Pitch up to around 55° AoA (Angle of Attack) to achieve the Alpha recovery attitude (the actual range varies between 20° and 58° depending on Mach number). **You need to be quick as your descent rate is now very high and increasing fast (can easily exceed 800 m/s!).**

Fig.14 - Alpha recovery. Note the steep descent on the Ascent MFD graph

Once you've reached the desired Alpha trim the shuttle full up (press **Canc** until trim scale reaches the upper limit). I find this very useful to keep the desired AoA later as you descend through denser air.

NOTE: Engaging the Shuttle DAP won't work, you'll have to manage your attitude manually.

Remember to close the umbelical doors (**CTRL+J**).

Nz Hold

As you descend towards thicker atmosphere check your acceleration on SRF MFD and keep it around **2,5g** (25m/s2) by slightly adjusting (lowering) your pitch. You are now in the Nz Hold phase.

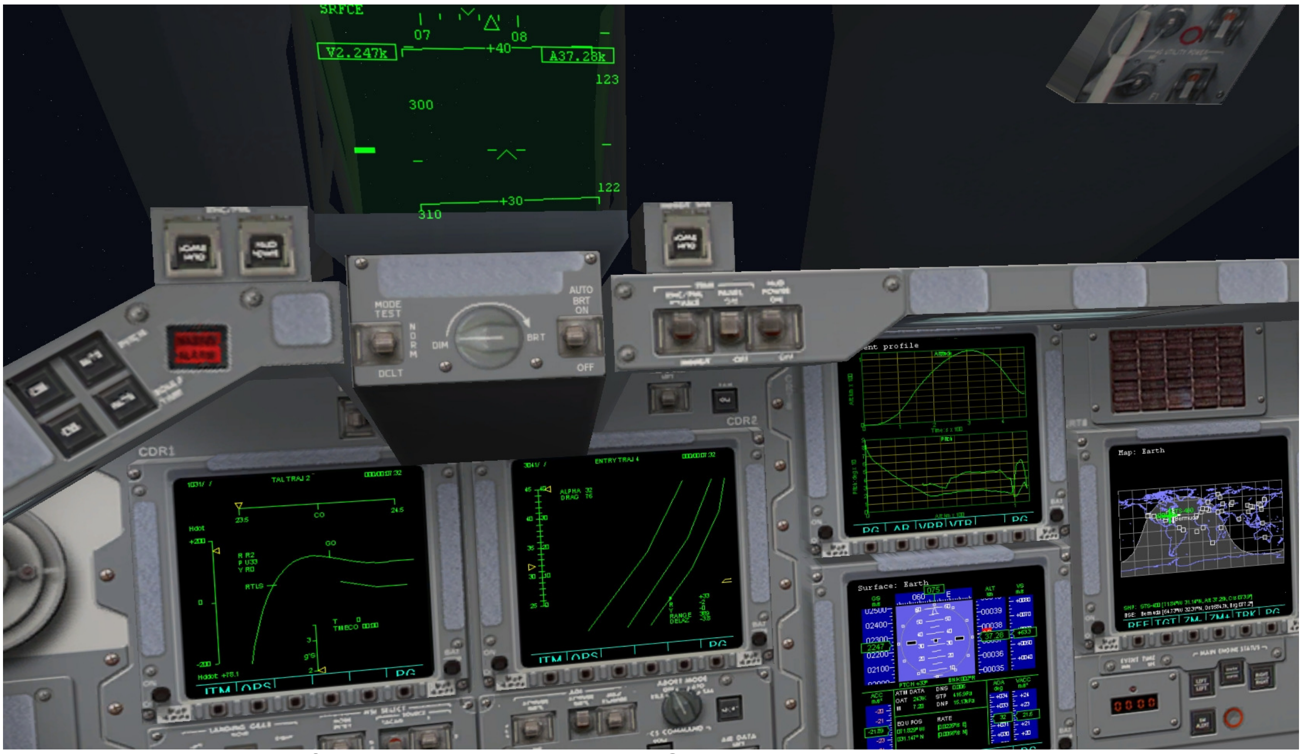

Fig.15 - Nz Hold phase. Check the Acc value on the SRF MFD within limits (target is 25m/s2) Alpha is lowered accordingly

As you continue your descent the aerodynamic effects will increase, therefore the Shuttle V/S will start progressively decreasing and eventually come to zero (see Fig.15 above).
If you've done everything properly at this point you should find yourself at the lowest altitude of 35Km, 400NM from BDA travelling at Mach 6.5 This is the beginning of what is called phugoid and the orbiter will now begin climbing again. You should reach around 50Km altitude, approximately 300NM from BDA at Mach5 and start descending again until reaching 30Km altitude around 250NM from BDA before commencing a second climb that should bring you to 45Km altitude less then 200NM from the landing site at Mach 3.5.

Instruments setup

Your primary instrument will be SRFMFD where you can monitor your ALT, SPD, V/S, ACC , DNP and AoA values.

During this phase I also use GPCMFD OPS4 (selecting BDA as landing site*) and OPS3: at this stage I will use OPS3 only to check my drag/Alpha values and my distance from BDA since during the phugoid maneuver the energy state symbol won't be reliable; climbs and descents will bring the shuttle above and below the nominal profile, so disregard that information (see Section1 page 8). You can also switch on AscentMFD; this won't give you any useful information but a nice pictorial view of the shuttle vertical trajectory and the phugoid maneuver .
Other useful MFD's are MAP where you can check your lateral track and distance from BDA and Aerobrake MFD which can help you verify and mange your reentry profile.

***NOTE:** BDA will <u>not</u> appear in your Orbiter Base Folder (Config/Earth/Base) unless you've installed *"NASA Shuttle Abort and Backup Landing Sites*" so you won't see it on your MAPMFD. Also if you are using *"Bermuda Islands"* by Perseus you need to change the values in the GPCMFD landing site table to match with the actual Runway position/orientation.


Fig.16 - Second phugoid. Orbiter around 140kfeet and 200NM from BDA

NOTE: Altitude, distances and speeds may vary depending on how your initial pitch-roll maneuver, MECO, ET SEP and Alpha recovery were performed (remember your initial altitude loss is dramatic and may vary a lot depending on how long you've been mated to the ET after engine failure). If you run the attached secenario it is very unlikely you'll end up high on energy towards BDA while it will be easy to find yourself low if you don't manage everything properly. The double engine failure 3' and 50" after liftoff (giving you enough energy to reach BDA but very little margin) was deliberately chosen to make the scenario more challenging.

Adjust your AoA according to the **Mach/Alpha schedule**, and, if high on energy (very unlikely) bank up to 70° (S-Turn) to help loosing altitude and increasing track miles. Also use speedbrake if needed.

NOTE: Pitch changes may be achieved by trimming the shuttle instead of using continuous joystick or keyboard inputs. I find it easier and it works pretty well.

While you manage your pitch to achieve the desired AoA, bank as necessary to steer the shuttle towards BDA. Check your DELAZ value on GPC MFD OPS4 and also your target heading bug on the HUD (after selecting BDA on your MAP MFD). You should be almost aligned with BDA, therefore very little banking is required.

When your speed approaches Mach 5 , deploy the air data probes (**CTRL+5**) so that you'll have your altitude (feet) and speed (kts) readings available on the HUD.

Now you're back on a normal continuous descent towards your landing site. Full use of GPC OPS3 and OPS4 is now recommended. Just before reaching TAEM you should be around Mach 3.5 at an altitude of 120.000 feet and approximately 120 NM form BDA.

If your values are lower then these and you see the shuttle symbol on GPC OPS3 below your minimum energy profile then it's a good time to "downmode" : to do that either choose a different RWY for approach (RWY11) or MEP on GPCOPS4 (select ITEM7) that will give you less track miles to fly on the HAC, or even select a straight in approach instead of an overhead (ITEM6).

If none of these corrections work, that means you do NOT have sufficient energy to reach the field and land; your only option now is to get as close as possible to Bermuda and prepare for "bailout" (as ditching is not an option according to NASA studies).

Bailout procedure will be discussed later in this section.

TAEM

From now on your reentry will be like any other normal one except that you should reach TAEM at a higher than standard speed (Mach 3.2 is target).

Your goal now is to perform a nice overhead approach for RWY29 at BDA. If you haven't done it yet, select GPC OPS3 and OPS4 on your MFD's. You should be now on nominal energy profile (OPS3) and tracking towards the HAC for RWY29 (OPS4 SPEC50 display).

Fig.17 - TAEM. Note the phugoid profile performed by the Orbiter on the Ascent MFD

If you are high on energy use speedbrake to reduce your speed and bank (roll) to reduce your altitude.

Autospeedbrake maybe selected (by pressing **CTRL+;**) but I found it will lead the orbiter to reach the HAC too low on energy therefore I recommend using it only once on the HAC.

NOTE: As you change speedbrake position in order to keep nominal speed (300kts) remember to trim (press **Canc**/**Ins**). This is bacause deploying the speedbrake will cause a pitchdown moment that has to be compensated by trimming up (and vice-versa).

Keep yourself slightly high on energy until reaching the HAC; if you are too low on energy, remember you can always downmode.

Fig.18 - TAEM - Bermuda island on the background

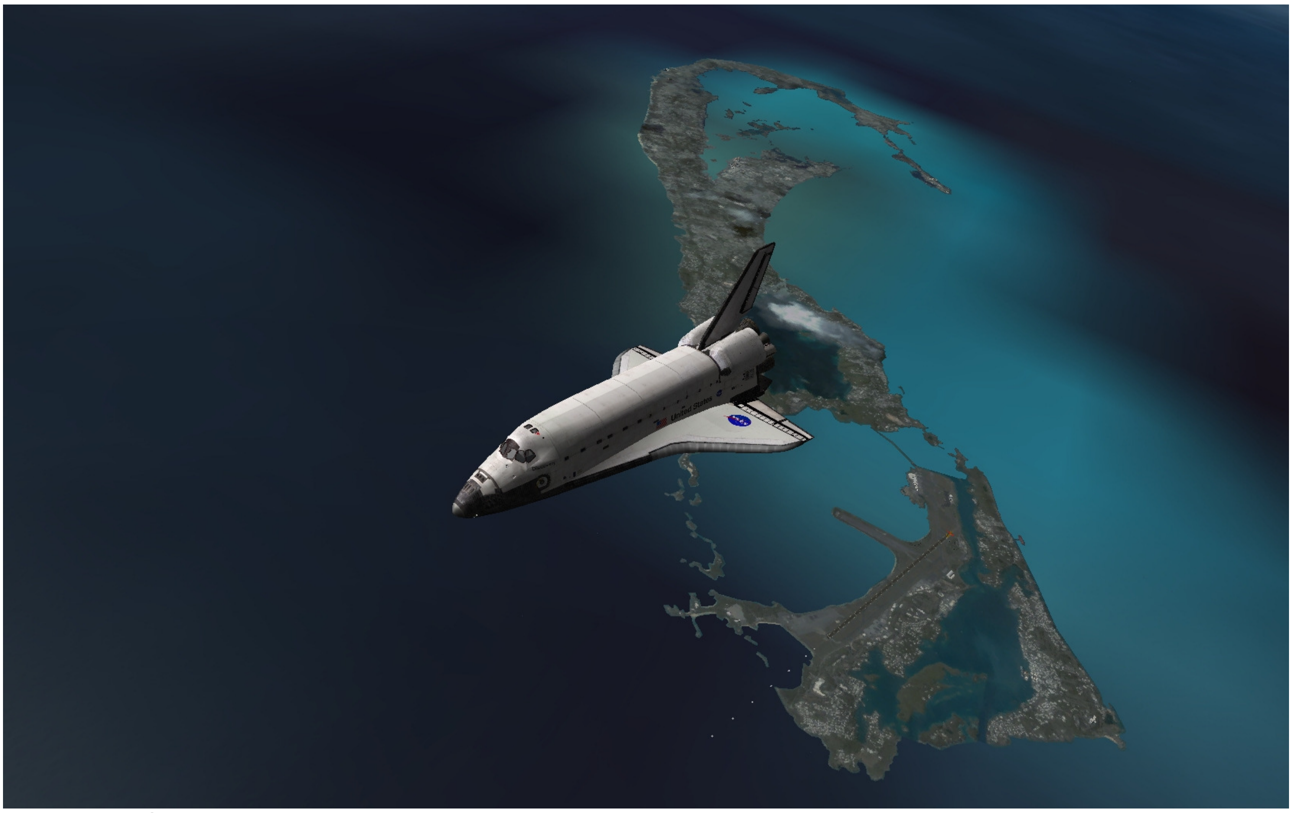

Fig.19 - HAC nominal entry point

Fig.20 - "On at the 90" - The shuttle during the HAC turn 90° from final approach course at 20.000'

Approach and landing

Your task now is to keep yourself on the correct vertical and lateral profile during the HAC turn and use the speedbrake to maintain your approach speed < 300kts.
Once on final RWY29 your glidepath should be around -20° (OGS), speed 300 kts until reaching the preflare altitude (1800') where you will start pitching up gently to reduce your rate of descent and intercept the inner glideslope (IGS)

Fig.21 - Final OGS RWY 29

Passing 5000 feet arm the landing gear (**CTRL+G** and verify "GR" appears on the HUD) so that it will be automatically deployed at 300 feet AGL.

At 1800' start gently pitching up for the pre-flare maneuver. A good reference is reaching 0° pitch as you pass through 500' radio altitude.

At 300' the gear should be deployed (max speed 315 kts!). Aim to cross the RWY threshold at 20-30' and perform final flare till reaching around 10° pitch (check your velocity vector on the HUD and put it just below the horizon line in order to almost kill your descent rate).

A good cue for correct flare is the **40-30-20 rule**: at 40'/240kts, 30'/ 230kts, 20'/220kts (this is a training issue for real Shuttle pilots and I found it works pretty well also with Shuttle Fleet in Orbiter)

As your descent rate reaches almost zero, keep present attitude until main gear touchdown (max speed 225 kts, min 185 kts!). Do not aim for your touchdown point but for your speed instead (**200** kts); remember you're flying a very heavy glider at this point with a lot of drag a very little margin ; the minimum touchdown speed is 185 kts and in real life the shuttle will stall (and slam into the Runway) at 165 kt

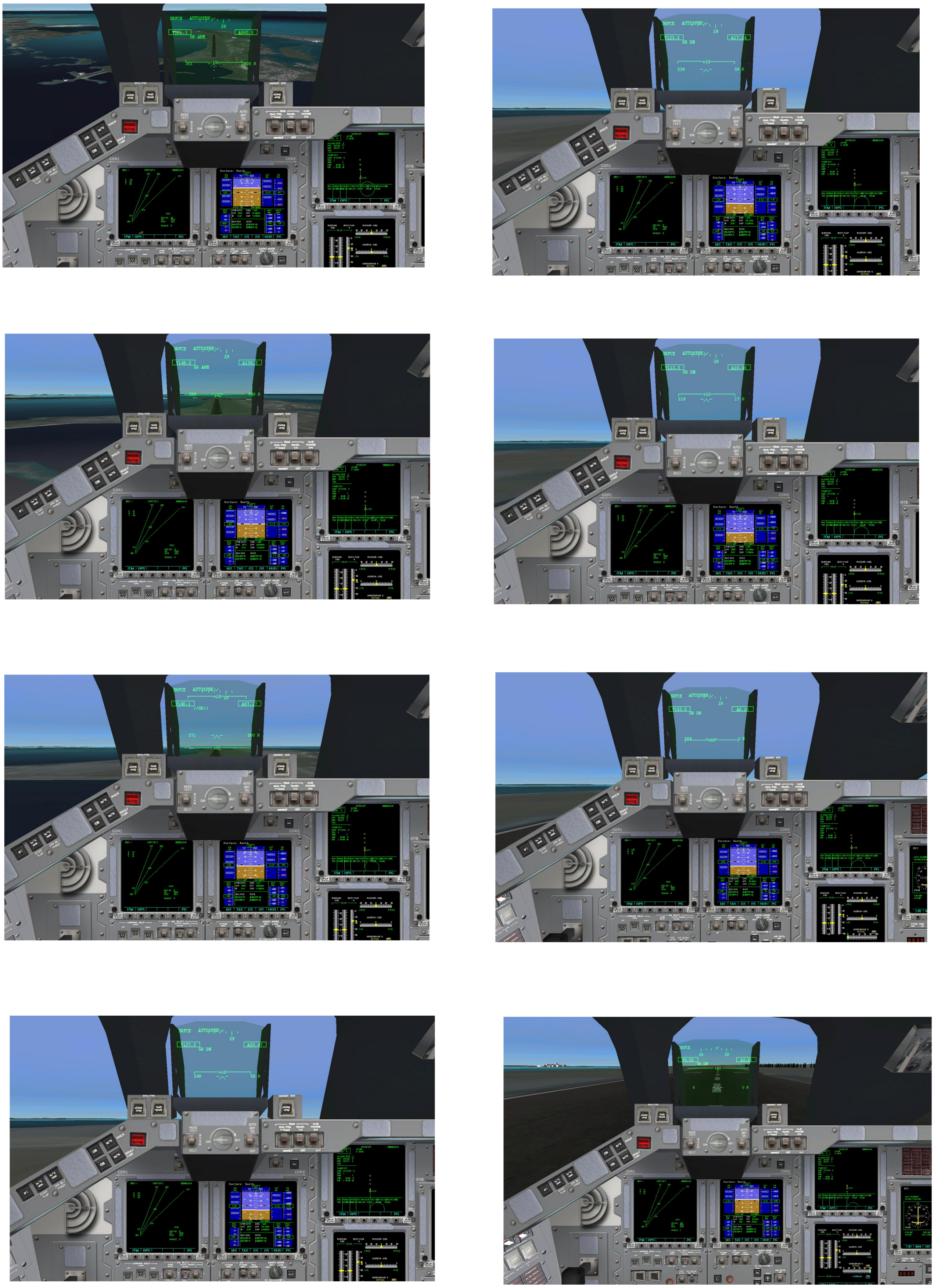

Fig.22 - Up/down and left /right the final to touchdown sequence - Note the HUD info displayed

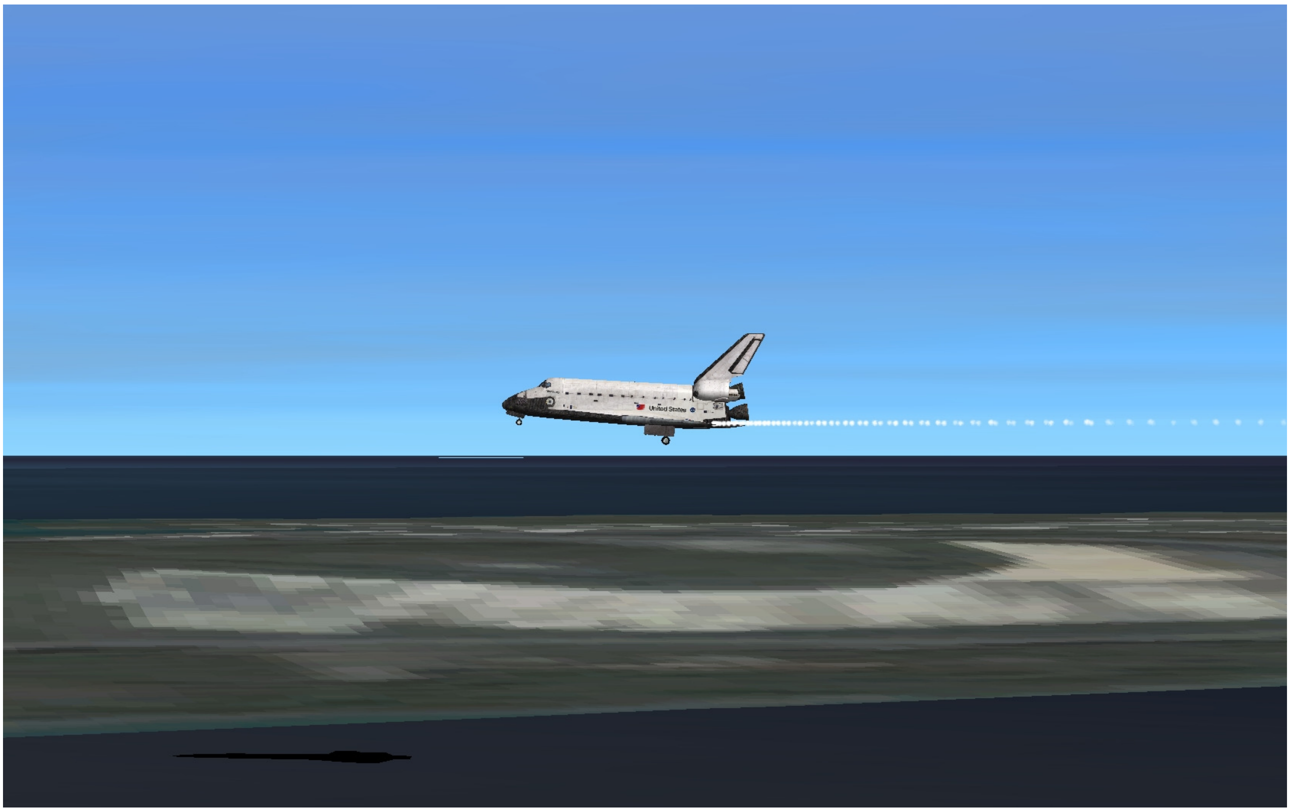

Fig.23 - Gear down approaching the Runway threshold

At main landing gear touchdown the speedbrake will go full open and the drag chute will be deployed (all done automatically in Orbiter).
As your speed reaches 180 kts start derotation (slowly pitch down) and gently lower the nose gear (target nose gear touchdown speed is 145 kts)

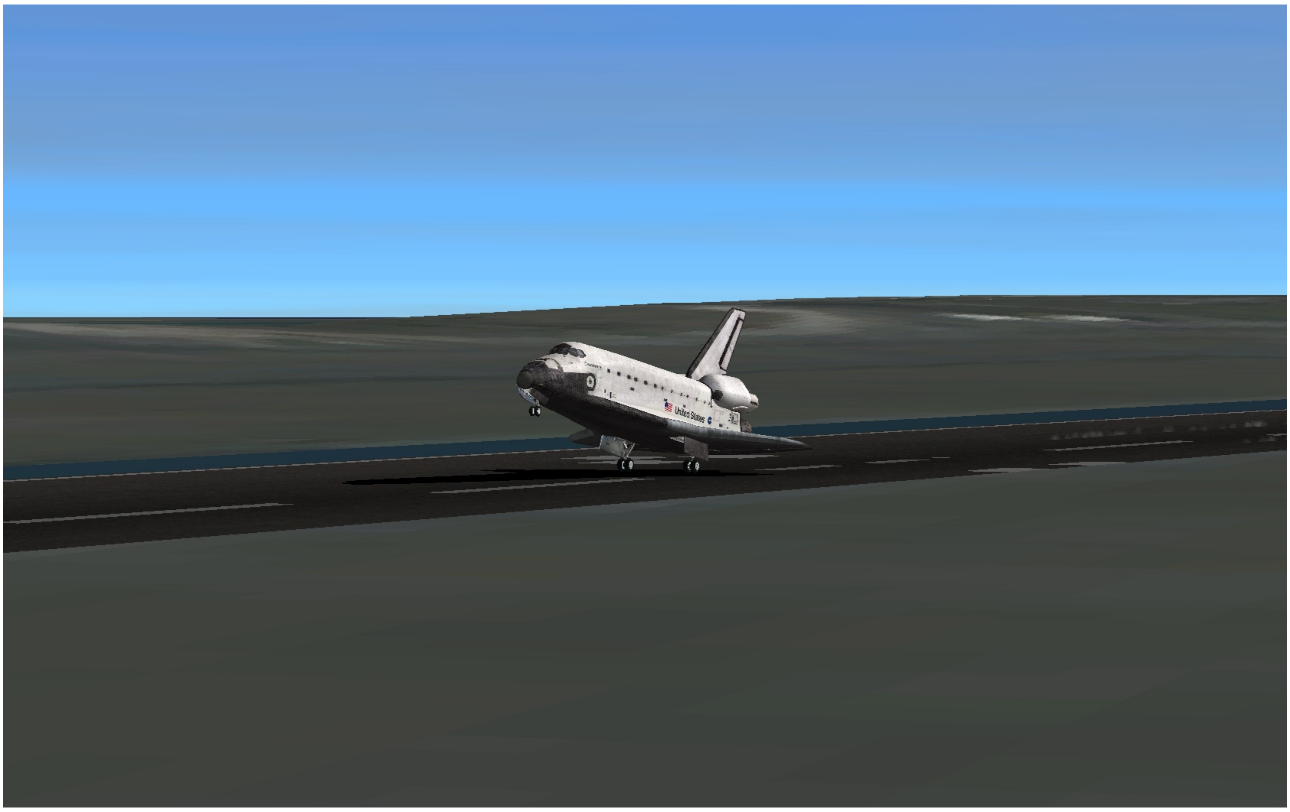

Fig.17 - Touchdown

Keep the shuttle on the centerline using rudder and nosewheel steering inputs and when reaching 140 kts start braking gently (**; and .**) until wheelstop.

Fig.18 - Rollout

That's it. You've made it safely back to earth and more important (almost) "by the books"!

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.

Appendix 2

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	170 kts (t.down allowed speed range is185-205 kts)
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:	2/3m/sec (240/210klbs-gear damage/collapse if fabove)
Max Landing pitch	12° (tailstrike will occur at 14,5°)
Landing gear down/lock	15 secs after deployment (usually 5 secs before t.down)

Appendix 3

QRH Checklists

Shuttle Fleet 4.8
Quick Reference Handbook

ECAL/BDA Reentry Checklist

Condition: 2 MPS failed during second stage ascent
H' < 600 m/s high incl
H' < 450 m/s low incl

1 RCS..Pitch 90°

2 Roll Maneuver...Start

Yaw and Pitch as necessary to roll towards VV

Maintain Pitch > 60°

3 Rollout..Maintain wings level

! If H' reaches -200 m/s immediately press KILLROT and go to step 5

4 Pitch to 0°..MECO

5 V/S < -200 m/s...ET SEP

6 -Z traslation...Engage RCS for 5 seconds

7 ET umbelical Doors...Close

Continued on next page

8 Alpha Recovery..Pitch to Alpha 60°

Trim..Full Up

ACC..Pitch for -25 m/s

Do not exceed -38 m/s (3.9g)

9 NzHold...Reduce Alpha to maintain -25 m/s

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

11 Trim...adjust for target Alpha

M	>12	9	6	3	1
α	40	35	26	18	12

12 Mach 5...Deploy Air data Probes

13 TAEM..Check profile/Energy state

Altitude...85000 feet

Range..60 NM

IAS...Mach 3.2

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

! If Range is outside limits Go to the BAILOUT checklist

15 < Mach 1...CSS

16 Autospeedbrake..ON

Continued on next page

17 2000'...Arm LND GEAR

18 1800'...Preflare

19 300'...LND GEAR DOWN

20 Touchdown ....Speedbrake full open

21 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

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