

# Reentry of the Space Shuttle

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## Entry

The entry phase of flight begins approximately five minutes before entry interface, which occurs at an altitude of 400,000 feet. At EI minus five minutes, the orbiter is at an altitude of about 557,000 feet, traveling at 25,400 feet per second, and is approximately 4,400 nautical miles (5,063 statute miles) from the landing site. The goal of guidance, navigation and flight control software is to guide and control the orbiter from this state (in which aerodynamic forces are not yet felt) through the atmosphere to a precise landing on the designated runway. All of this must be accomplished without exceeding the thermal or structural limits of the orbiter.

The entry phase is divided into three separate phases because of the unique software requirements. Entry extends from EI minus five minutes to terminal area energy management interface at an altitude of approximately 83,000 feet, at a velocity of 2,500 feet per second, 52 nautical miles (59 statute miles) from the runway and within a few degrees of tangency with the nearest heading alignment cylinder in major mode 304.

TAEM extends to the approach and landing capture zone, defined as the point when the orbiter is on glide slope, on airspeed, and on runway centerline, which occurs below 10,000 feet and is the first part of major mode 305. The orbiter attains subsonic velocity at an altitude of approximately 49,000 feet about 22 nautical miles (25 statute miles) from the runway.

Approach and landing begins at the approach and landing capture zone, an altitude of 10,000 feet and Mach 0.9 and extends through the receipt of the weight-on-nose-gear signal after touchdown, which completes major mode 305.

The forward RCS jets are inhibited at entry interface.

At 400,000 feet, a pre-entry phase begins in which the orbiter is maneuvered to zero degrees roll and yaw (wings level) and a predetermined angle of attack for entry. The flight control system issues the commands to the roll, yaw and pitch RCS jets for rate damping in attitude hold for entry into the Earth's atmosphere until 0.176 g is sensed, which corresponds to a dynamic pressure of 10 pounds per square foot, approximately the point at which the aerosurfaces become active.

When the orbiter is in atmospheric flight, it is flown by varying the forces it generates while moving through the atmosphere, like any other aerodynamic vehicle. The forces are determined primarily by the speed and direction of the relative wind (the airstream as seen from the vehicle). The direction of the airstream is described by the difference between the direction that the vehicle is pointing (attitude) and the direction that it is moving (velocity). It may be broken into two components: angle of attack (vertical component) and sideslip angle (horizontal component).

To rotate the orbiter in the atmosphere, aerodynamic control surfaces are deflected into the airstream. The orbiter has seven aerodynamic control surfaces. Four of these are on the trailing edge of the wing (two per wing). They are called elevons because they combine the effects of elevators and ailerons on ordinary airplanes. Deflecting the elevons up or down causes the vehicle to pitch up or down. If the right elevons are deflected up and the left elevons are deflected down, the orbiter will roll to the right—that is, the right wing falls and the left wing rises. The fifth control surface is the body flap, located on the rear lower portion of the aft fuselage. It provides thermal protection for the three main engines during entry, and during atmospheric flight it provides pitch trim to reduce elevon deflections. The sixth and seventh control surfaces are the

rudder/speed brake panels, located on the aft portion of the vertical stabilizer. When both panels are deflected right or left, the spacecraft will yaw, moving the spacecraft's nose right or left, thus acting as a rudder. If the panels are opened at the trailing edge, aerodynamic drag force will increase, and the spacecraft will slow down. Thus, the open panels are called a speed brake.

On the flight deck display and control panel (panel F7 between the commander and pilot) are the surface position indicators, which display the position of each aerodynamic control surface.

The aft RCS jets maneuver the spacecraft until a dynamic pressure of 10 pounds per square foot is sensed; at this point, the orbiter's ailerons become effective, and the aft RCS roll jets are deactivated. At a dynamic pressure of 20 pounds per square foot, the orbiter's elevators become effective, and the aft RCS pitch jets are deactivated. The orbiter's speed brake is used below Mach 10 to induce a more positive downward elevator trim deflection. At Mach 3.5, the rudder become activated, and the aft RCS yaw jets are deactivated (approximately 45,000 feet).

Entry flight control is maintained with the aerojet DAP, which generates effector and RCS jet commands to control and stabilize the vehicle during its descent from orbit. The aerojet DAP is a three-axis rate command feedback control system that uses commands from guidance in automatic or from the flight crew's RHC in control stick steering. Depending on the type of command and the flight phase, these result in fire commands to the RCS or deflection commands to the aerosurfaces.

In the automatic mode, the orbiter is essentially a missile, and the flight crew monitors the instruments to verify that the vehicle is following the correct trajectory. The onboard computers execute the flight control laws (equations). If the vehicle diverges from the trajectory, the crew can take over at any time by switching to CSS. The orbiter can fly to a landing in the automatic mode (only landing gear extension and braking action on the runway are required by the flight crew). The autoland mode capability of the orbiter is used by the crew usually to a predetermined point in flying around the heading alignment cylinder. In flights to date, the crew has switched to CSS when the orbiter is subsonic. However, autoland provides information to the crew displays during the landing sequence.

The commander and pilot can select automatic or CSS flight control modes. The crew can select separate modes for pitch and roll and yaw (roll and yaw must be in the same mode). The body flap and speed brake have automatic and manual modes.

Automatic pitch provides automatic control in the pitch axis, and the automatic roll and yaw provides automatic control in the roll and yaw axes. During entry, the automatic mode uses the RCS jets until dynamic pressure permits the aerosurfaces to become effective; the aft RCS jets and spacecraft aerosurfaces are then used together until dynamic pressure becomes sufficient for aerosurface control only.

Control in the pitch axis is provided by the elevons, speed brake and body flap. The elevons provide control to guidance normal acceleration commands, control of pitch rate during slap-down (landing) for nose wheel load protection, and static load relief after slap-down for main landing gear wheel and tire load protection. The speed brake provides control to guidance surface deflection (open/close, increase/decrease velocity) command. The body flap provides control to null elevon deflection.

Control in the roll and yaw axes is provided by the elevons and rudder. The elevons provide control to guidance bank angle command during terminal area energy management and autoland and control to guidance wings-level command during flat turns, 5 feet above touchdown. The rudder provides yaw stabilization during TAEM and autoland and control to guidance yaw rate command during flat turn and subsequent phases.

When the orbiter is in the automatic pitch and roll and yaw modes, the crew's manual control stick steering commands are inhibited. In the CSS mode, the crew flies the orbiter by deflecting the RHC and rudder pedals. The flight control system interprets the RHC motions as rate commands in pitch, roll or yaw and controls the RCS jets and aerosurfaces. The larger the deflection, the larger the command. The flight control system compares these commands with inputs from rate gyros and accelerometers (what the vehicle is actually doing-motion sensors) and generates control signals to produce the desired rates. If the crew releases the RHC, it will return to center, and the orbiter will maintain its present attitude (zero rates). The rudder pedals position the rudder during atmospheric flight; however, in actual use, because flight control software performs automatic turn coordination, the rudder pedals are not used until the wings are leveled before touchdown.

The CSS mode is similar to the automatic mode except that the crew can issue three-axis commands, affecting the spacecraft's motion. These are augmented by the feedback from the same spacecraft motion sensors, except for the normal acceleration (velocity) accelerometer assemblies, to enhance control response and stability.

The commander's or pilot's RHC commands are processed by the GPCs in the CSS mode together with data from the motion sensors. The flight control module processes the flight control laws and provides commands to the flight control system, which positions the aerosurfaces in atmospheric flight.

Control in the roll and yaw axes is provided by the elevon and the rudder. The elevons augment the RHC control. The rudder interface between the roll and yaw channel automatically positions the rudder for coordinated turns. A rudder pedal transducer assembly is provided at the commander and pilot stations. The two rudder pedal assemblies are connected to their respective RPTAs. Because of the roll and yaw interface, rudder pedal use should not be required until just before touchdown. There is an artificial feel in the rudder pedal assemblies. The RPTA commands are processed by the GPCs, and the flight control module commands the flight control system to position the rudder.

In the CSS mode, the commander's and pilot's RHC trim switches, in conjunction with the trim enable/inhibit switch, activate or inhibit the RHC trim switch. When the RHC trim switch is positioned forward or aft, it adds a trim rate to the RHC pitch command; positioning it left or right adds a roll trim.

Manual control (CSS mode) in the pitch axis is provided by the elevons, speed brake and body flap. The elevons provide augmented control through the RHC pitch command. The speed brake can be switched to its manual mode at either the commander's or pilot's station by depressing a takeover switch on the speed brake/thrust controller handle. Manual speed brake control can be transferred from one station to the other by activating the takeover switch. When the SBTC is at its forward setting, the speed brake is closed. Rotating the handle aft, positions the speed brake at the desired position (open) and holds it. To regain automatic speed brake control, the push button must be depressed again. In the manual mode, speed brake commands are processed by the GPCs, and the flight control module commands the flight control system to position the speed brake and hold it at the desired position. The body flap can be switched to its manual mode at panel C3 by moving a toggle switch from auto/off to up or down for the desired body flap position. These are momentary switch positions; when released, the switch returns to off .

In the entry phase, the RCS commands roll, pitch and yaw. Lights on the commander's panel F6 are used to indicate the presence of an RCS command from the flight control system to the RCS jet selection logic; however, this does not indicate an actual RCS jet thrusting command. The minimum light-on duration is extended to allow the light to be seen even for minimum-impulse RCS jet thrusting commands. After the roll and pitch aft RCS jets are deactivated, the roll indicator lights are used to show that three or more yaw RCS jets have been requested. The pitch indicator lights are used to show elevon rate saturation.

During the entry subphase, the primary objective is to dissipate the tremendous amount of energy that the orbiter possesses when it enters the atmosphere so that it does not burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow), stays within structural limits, and arrives at the TAEM interface with the altitude and range to the runway necessary for a landing. This is accomplished by adjusting the orbiter's drag acceleration on its surface using bank commands relative to vehicle velocity. During TAEM, as the name implies, the goal is to manage the orbiter's energy while the orbiter travels along the heading alignment cylinder, which lines up the vehicle on the runway centerline. A HAC is an imaginary cone that, when projected on the Earth, lies tangent to the extended runway centerline.

Guidance performs different tasks during the entry, TAEM and approach and landing subphases. During the entry subphase, guidance attempts to keep the orbiter on a trajectory that provides protection against overheating, overdynamic pressure and excessive normal acceleration limits. To do this, it sends commands to flight control to guide the orbiter through a tight corridor limited on one side by altitude and velocity requirements for ranging (in order to make the runway) and orbiter control and on the other side by thermal constraints. Ranging is accomplished by adjusting drag acceleration to velocity so that the orbiter stays in that corridor. Drag acceleration can be adjusted primarily in two ways: by modifying the angle of attack, which changes the orbiter's cross-sectional area with respect to the airstream, or by adjusting the orbiter's bank angle, which affects lift and thus the orbiter's sink rate into denser atmosphere, which in turn affects drag. Using angle of attack as the primary means of controlling drag results in faster energy dissipation with a steeper trajectory but violates the thermal constraint on the orbiter's surfaces. For this reason, the orbiter's bank angle (roll control) is used as the primary method of controlling drag, and thus ranging, during this phase. Increasing the roll angle decreases the vertical component of lift, causing a higher sink rate. Increasing the roll rate raises the surface temperature of the orbiter, but not nearly as drastically as does an equal angle of attack command. The orbiter's angle of attack is kept at a high value (40 degrees) during most of this phase to protect the upper surfaces from extreme heat. It is modulated at certain times to "tweak" the system and is ramped down to a new value at the end of this phase for orbiter controllability. Using bank angle to adjust drag acceleration causes the orbiter to turn off course. Therefore, at times, the orbiter must be rolled back toward the runway. This is called a roll reversal and is commanded as a function of azimuth error from the runway. The ground track during this phase, then, results in a series of S-turns.

If the orbiter is low on energy (the current range-to-go is much greater than nominal at current velocity), entry guidance will command lower-than-nominal drag levels. If the orbiter has too much energy (the current range-to-go is much less than nominal at current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Roll angle is used to control cross range. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cylinder tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds an initialized-loaded number, the orbiter's roll angle is reversed.

Thus, descent rate and downranging are controlled by bank angles-the steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum-drag altitude is wings level. Cross range is controlled by bank reversals.

The entry thermal control phase is designed to keep the thermal protection system's bond line within design limits. A constant heating rate is maintained until the velocity is below 19,000 feet per second.

In the equilibrium glide phase, the orbiter effects a transition from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. Equilibrium glide is defined as flight in which the flight path angle, the angle between the local horizontal and the local velocity vector, remains constant. This flight regime provides the maximum downrange capability. It lasts until drag acceleration reaches 33 feet per second squared.

The constant drag phase begins at 33 feet per second squared. Angle of attack is initially 40 degrees, but it begins to ramp down until it reaches approximately 36 degrees by the end of this phase.

The transition phase is entered as the angle of attack continues to ramp down, reaching about 14 degrees at TAEM interface, with the vehicle at an altitude of some 83,000 feet, traveling 2,500 feet per second (Mach 2.5), and 52 nautical miles (59 statute miles) from the runway. At this point, control is transferred to TAEM guidance.

During these entry phases, the orbiter's roll commands keep the orbiter on the drag profile and control cross range.

TAEM guidance steers the orbiter to the nearest of two heading alignment cylinders, whose radii are approximately 18,000 feet and whose locations are tangent to and on either side of the runway centerline on the approach end. Normally, the software is set to fly the orbiter around the HAC on the opposite side of the extended runway centerline. This is called the overhead approach. If the orbiter is low on energy, it can be flagged to acquire the HAC on the same side of the runway. This is called the straight-in approach. In TAEM guidance, excess energy is dissipated by an S-turn, and the speed brake can be used to modify drag, lift-to-drag ratio and the flight path angle under high-energy conditions. This increases the ground track range as the orbiter turns away from the nearest HAC until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet at the nominal entry point. The orbiter can also be flown near the velocity for maximum lift over drag or wings level for the range stretch case, which moves the approach and landing guidance phase to the minimum entry point.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the nearest HAC and continues until it reaches way point 1. At way point 1, the TAEM heading alignment phase begins, in which the HAC is followed until landing runway alignment, plus or minus 20 degrees, is achieved. As the orbiter comes around the HAC, it should be lined up on the runway and at the proper flight path angle and airspeed to begin the steep glide slope to the runway.

In the TAEM prefinal phase, the orbiter leaves the HAC, pitches down to acquire the steep glide slope, increases airspeed and banks to acquire the runway centerline, continuing until it is on the runway centerline, on the outer glide slope and on airspeed.

The approach and landing guidance phase begins with the completion of the TAEM prefinal phase and ends when the orbiter comes to a complete stop on the runway. The approach and landing interface airspeed requirement at an altitude of 10,000 feet is approximately 290 knots, plus or minus 12 knots, equivalent airspeed, 6.9 nautical miles (7.9 statute miles) from touchdown.

Autoland guidance is initiated at this point to guide the orbiter to the minus 19- to 17-degree glide slope (which is more than seven times that of a commercial airliner's approach) aimed at a target approximately 0.86 nautical mile (1 statute mile) in front of the runway. The descent rate in the latter portion of TAEM and approach and landing is greater than 10,000 feet per minute (approximately 20 times higher than a commercial airliner's standard 3-degree instrument approach angle). The steep glide slope is tracked in azimuth and elevation, and the speed brake is positioned as required.

Approximately 1,750 feet above the ground, guidance sends commands to keep the orbiter tracking the runway centerline, and a preflare maneuver is started to position the orbiter on a shallow 1.5-degree glide slope in preparation for landing, with the speed brake positioned as required. At this point, the crew deploys the landing gear.

Final flare is begun at approximately 80 feet to reduce the sink rate of the vehicle to less than 9 feet per second. After the spacecraft crosses the runway threshold-way point 2 in the autoland mode-navigation uses the radar altimeter vertical component of position in the state vector for guidance and navigation computations from an altitude of 100 feet to touchdown. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 184 to 196 knots (211 to 225 mph). As the airspeed drops below 165 knots (189 mph), the orbiter begins derotation in preparation for nose gear slap-down.

The navigation system used from entry to landing consists of the IMUs and navigation aids (TACAN, air data system, microwave scan beam landing system and radar altimeter). The three IMUs maintain an inertial reference and provide delta velocities until MSBLS is acquired.

Navigation-derived air data-obtained after deployment of the two air data probes at approximately Mach 3-is needed from entry through landing as inputs to the guidance, flight control and crew display. TACAN provides range and bearing measurements and is available at approximately 145,000 feet, nominally accepting the data into the state vector before 130,000 feet. It is used until MSBLS acquisition, which provides range, azimuth and elevation commencing at approximately 18,000 feet. Radar altimeter data are available at approximately 9,000 feet.

TACAN acquisition and operation are completely automatic, but the crew has the necessary controls and displays to evaluate TACAN system performance and to take over if required. When the distance to the landing site is approximately 120 nautical miles (138 statute miles), TACAN begins interrogating six navigation region stations. As the spacecraft proceeds, the distances to the remaining stations and to the next-nearest station are computed, and the next-nearest station is selected automatically if the spacecraft is closer to it than it is to the previous locked-on station. Only one station is interrogated if the distance to the landing site is less than approximately 20 nautical miles (23 statute miles). Again, TACAN automatically switches from the last locked-on navigation region station to begin searching for the landing site station. TACAN azimuth and range are provided on the CRT displaying the horizontal situation. TACAN range and bearing cannot be used to produce a good estimate of the altitude position component, so navigation uses barometric altitude derived from the air data system probes.

MSBLS acquisition and operation are also completely automatic, and the flight crew can evaluate system performance and take over if necessary. MSBLS acquisition occurs at approximately 18,000 feet and about 8 nautical miles (9.2 statute miles) from the runway. The range and azimuth measurements are provided by a ground antenna located at the end of the runway and to the left of the runway centerline. Elevation measurements are given by a ground antenna to the left of the runway centerline, about 2,624 feet from the runway threshold.

During entry, the commander's and pilot's altitude director indicators become two-axis balls displaying body roll and pitch attitudes with respect to local vertical/local horizontal. These are generated in the attitude processor from IMU data. The roll and pitch error needles each display the body roll and pitch attitude error with respect to entry guidance commands by using the bank guidance error and the angle of attack error generated from the accelerometer assemblies. In atmospheric flight, the roll attitude error and the normal acceleration error are displayed by the roll and pitch error needles, respectively. The sideslip angle is displayed on the yaw error needle. The roll and pitch rate needles display stability roll and body rates by using stability roll rate, rate gyro rate and pitch rate. The yaw rate needle displays stability yaw rate. After main landing gear touchdown, the yaw error with respect to runway centerline and nose gear slap-down pitch rate error are displayed on the roll and pitch error needles. During rollout, the pitch error indicator indicates pitch error rate.

During entry, the commander's and pilot's horizontal situation indicators display a pictorial view of the spacecraft's location with respect to various navigation points. The navigation attitude processor provides the inputs to the HSI until the communications blackout is passed, at approximately 145,000 feet. TACAN is then acquired and accepted for HSI inputs at about 130,000 feet until MSBLS acquisition at approximately 18,000 feet some 8 nautical miles (9.2 statute miles) from the runway.

When the approach mode and MSBLS source are selected for the commander's and pilot's HSI, data from the MSBLS replaces TACAN data. MSBLS azimuth, elevation and range are used from acquisition until the runway threshold is reached, and azimuth and range are used to control rollout.

At an altitude of 9,000 feet, radar altimeter 1 or 2 can be selected to measure the nearest terrain within the beamwidth of the altimeters. This indication is given to the altitude/vertical velocity indicator radar, altitude and meter display from 5,000 feet to landing.

The left and right air data system probes are deployed by the flight crew at about Mach 3. This system senses air pressures related to orbiter movement through the atmosphere for updating the navigation state vector in altitude, guidance in steering and speed brake command calculations, flight control for control law computations, and for display on the alpha Mach indicators and altitude/vertical velocity indicators.

The AMIs display essential flight parameters relative to the spacecraft's travel in the air mass, such as angle of attack, acceleration, velocity and knots of equivalent airspeed. The source of data for the AMIs is determined by the position of the air data select switch. Before the deployment of the air data system probe, the AMIs receive inputs from the navigation attitude processor. When the air data probes are deployed, the left or right air data system provides the inputs to all AMIs except the acceleration indicator, which remains on the navigation attitude processor, and the radar altitude. Neither is operational until the orbiter descends to 5,000 feet.

The three rate gyro assemblies of the flight control system measure and supply output data proportional to the orbiter's attitude rates about its three body axes, while the three accelerometer assemblies measure and supply output data proportional to the orbiter's normal (vertical) and lateral (right and left) accelerations. These assemblies are incorporated into the flight control system for augmenting stability because of the orbiter's marginal stability in its pitch and yaw axes at subsonic speeds.

The three IMUs constitute an all-attitude stabilized platform that also measures and supplies output data proportional to the spacecraft's attitude (rotation) and acceleration (velocity). They augment the rate gyro assemblies and accelerometer assemblies.

The rate gyro assembly pitch rate (rotation) and the accelerometer assembly normal acceleration (velocity) are used to generate elevon (elevator) deflection commands. The rate gyro assembly yaw rate (rotation) and the accelerometer assembly lateral acceleration generate the rudder deflection required for directional stability. The rate gyro assembly roll rate (rotation) generates the elevon (aileron) deflection command required for lateral (roll) stability. The speed brake and body flap positions generate the elevon deflection required for trim near neutral to maximize roll effectiveness of the elevons.

In the entry phase, navigation software functions as it did during the deorbit phase (three state vectors corresponding to each IMU) except that additional external sensor data are sequentially incorporated. These data provide the accuracy necessary to bring the orbiter to a pinpoint landing and, to some extent, to maintain vehicle control. The TACAN system, which becomes available at about 156,000 feet, provides slant range and magnetic bearing to various fixed stations around the landing site. It is used until the orbiter is approximately 1,500 feet above the ground, at which point it is rendered ineffective by ground reflection. The air data system, which includes two transducer assemblies attached to a probe on the left side of the vehicle and two on the right side, provides pressures from which angle of attack, Mach number, equivalent airspeed, true airspeed, dynamic pressure, barometric altitude and altitude rate are computed. Only barometric altitude is used by navigation. The other parameters are used by guidance and flight control as well as for display to the flight crew. The probes are normally deployed around Mach 3. The MSBLS

precisely determines slant range, azimuth and elevation relative to the landing runway. For landing at runways with MSBLS ground stations, MSBLS data become available at 20,000 feet for processing by navigation.

One other tool used by navigation is a drag altitude software sensor, which uses a model of the atmosphere to correlate the drag acceleration measured by the IMUs to altitude. This measurement, then, is only as good as the atmospheric model on which it is based. The model is not perfect. However, it has been determined through testing and analysis that drag altitude data are important in keeping downrange and altitude errors bounded during the blackout portion of entry (from approximately 265,000 to 162,000 feet). During this time, the ground is unable to uplink state vector corrections to the orbiter, and TACAN data are not available because of the heat-generated ionization of the atmosphere around the vehicle.

Navigation also maintains a statistical estimate of the expected error in the state vector. This is called a covariance matrix and is propagated along with the state vector. When an external sensor, such as TACAN, becomes available to the navigation software, a check is made to see if the data lie within the current expected range of error. Flight crew controls are provided on an onboard CRT horizontal situation display to force the software to accept or inhibit the external sensor data whether or not the data lie within the expected range. Another control on the display may be selected to allow the software to use the external sensor data to update its state vector so long as the data lie within the expected range.

About five minutes before entry interface, the crew adjusts the software to major mode 304. During this mode, which lasts until TAEM interface, five CRTs become available sequentially and are used to monitor auto guidance and the orbiter trajectory compared to the planned entry profile. The five displays are identical except for the central plot, which shows the orbiter's velocity versus range or energy/weight versus range with a changing scale as the orbiter approaches the landing site. This plot also includes static background lines that allow the crew to monitor the orbiter's progression compared to planned entry profiles.

Once TAEM interface is reached, the software automatically makes a transition to major mode 305. The CRT vertical situation 1 display then becomes available. It includes a central plot of orbiter altitude with respect to range. This plot has three background lines that represent the nominal altitude versus range profile, a dynamic pressure limit in guidance profile and a maximum lift-over-drag profile. At 30,000 feet, the scale and title on the display change to vertical situation 2, and the display is used through landing. When the approach and landing interface conditions are met, a flashing A/L appears on the display.

Another prime CRT display used during entry is the horizontal situation. In addition to providing insight into and control over navigation parameters, this display gives the crew orbiter position and heading information once the orbiter is below 200,000 feet.

The entry trajectory, vertical situation and horizontal situation CRT displays, then, are used by the flight crew to monitor the GN&C; software. They can also be used by the crew to determine whether a manual takeover is required.