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# Ascent Abort Capability for the HL-20

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**The HL-20 has been designed with the capability for rescue of the crew during all phases of powered ascent from on the launch pad until orbital injection. A launch-escape system, consisting of solid rocket motors located on the adapter between the HL-20 and the launch vehicle, provides the thrust that propels the HL-20 to a safe distance from a malfunctioning launch vehicle. After these launch-escape motors have burned out, the adapter is jettisoned and the HL-20 executes one of four abort modes. In three abort modes—return-to-launch-site, transatlantic-abort-landing, and abort-to-orbit—not only is the crew rescued, but the HL-20 is recovered intact. In the ocean-landing-by-parachute abort mode, which occurs in between the return-to-launch-site and the transatlantic-abort-landing modes, the crew is rescued, but the HL-20 would likely sustain damage from the ocean landing. This paper describes the launch-escape system and the four abort modes for an ascent on a Titan III launch vehicle.**

## Nomenclature

$A$ = acceleration, $g$
$A_n$ = normal-axis acceleration, $g$
$AZ$ = heading angle (measured clockwise from north), deg
$h$ = altitude, ft
$I_{sp_v}$ = vacuum specific impulse, s
$\dot{Q}$ = heating rate (based on a 1-ft radius sphere), Btu/ft$^2$-s
$\bar{q}$ = dynamic pressure, psf
$T$ = time, s
$V$ = relative velocity, ft/s
$\alpha$ = angle of attack, deg
$\phi$ = roll angle, deg
$\gamma$ = flight-path angle, deg

## Introduction

ALL vehicles that transport people to space must be designed in such a way as to give the crew the best possible chance for survival in the event of a launch-vehicle malfunction at a minimum cost in terms of weight, volume, and complexity. Past, present, and proposed space transportation systems include a scheme for saving the crew in the event of a launch-vehicle malfunction.

Mercury and Apollo spacecraft were designed with a launch-escape tower containing a solid rocket motor (SRM) that would pull the manned capsule away from the launch vehicle in an abort situation from prelaunch to staging.[1] During a nominal ascent the launch-escape tower was discarded soon after staging. If an abort was necessary during the remainder of the ascent, the capsule would separate from the launch vehicle using small thrusters and proceed to an ocean landing by parachute or to an abort to orbit. Gemini was designed with ejection seats instead of a launch-escape tower for aborts during the early part of ascent.[1] After the Gemini reached trajectory conditions outside of the ejection seat envelope, the retrograde or orbit attitude maneuvering system rockets would separate the spacecraft from the launch vehicle in an abort situation.

The Space Shuttle has intact abort capability throughout ascent with the shutdown of one main engine and partial abort capability with the shutdown of two or three main engines.[2] If main engines are shut down while the solid rocket boosters are thrusting, the Orbiter and external tank must remain attached to the solid rocket boosters until they are normally staged and an abort maneuver can be initiated. In the event a single main engine requires shutdown, the Orbiter can perform an intact abort throughout ascent by one of three modes depending on the time of abort initiation, including a return-to-launch-site (RTLS), a transatlantic-abort-landing (TAL), or an abort-to-orbit (ATO). With the loss of two or three main engines, the Orbiter can execute these same abort modes during certain time spans. There are times, however, where if more than one main engine is shutdown, the Orbiter cannot RTLS or TAL, but must glide to an ocean landing. The Orbiter is not expected to survive a water landing. Therefore, as the Orbiter is gliding toward the ocean, the crew would bail out[3] of the Orbiter's side hatch starting at approximately 20,000-ft altitude.

The design of the Hermes Space Vehicle,[4] which was planned for launch on an Ariane 5, includes ejection seats that can be used to Mach 3. If an abort is necessary between Mach 3 and staging of the Ariane's SRMs, the Hermes must remain attached to the launch vehicle until the SRMs are normally staged. In aborts that occur between SRM staging and the time when TAL sites are within range, the Hermes separates from the Ariane 5 using a separation abort motor and glides down

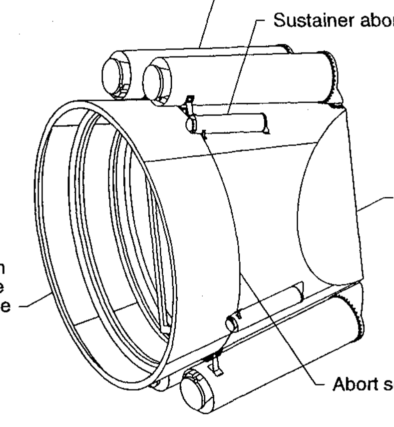


**Fig. 1 HL-20/Titan III adapter with abort solid rocket motors.**

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to an altitude where the ejection seats can be used. The crew parachutes to the ocean for recovery, and the Hermes is lost at sea. The Hermes has TAL and ATO capability during the last phase of ascent with recovery of both crew and vehicle.

The HL-20 has been designed with a launch-escape system that is similar to the Mercury and Apollo systems. The main difference is that the launch-escape solid rocket motors are attached to the adapter that connects the HL-20 to the launch vehicle (Fig. 1). In the event of an abort, the connection between the adapter and the launch vehicle is severed, and the motors thrust the HL-20 away from the launch vehicle, whereas the Mercury and Apollo capsules were pulled away from their launch vehicles by a tractor rocket system. Once the launch-escape solid rocket motors stop thrusting, the adapter and motors are jettisoned from the rear of the HL-20, and one of four abort modes is initiated. These abort modes include RTLS with a runway landing, ocean-landing-by-parachute, TAL, and ATO.

Within this paper, the design of the HL-20 launch-escape system and the details of the four abort modes are described. The reference ascent trajectory used in this analysis is for a Titan III launch vehicle.[5] The analysis methods used in this analysis, however, are applicable to other candidate launch vehicles such as the National Launch System.[6] Launch-vehicle failure modes and their methods and systems for detection are not discussed in this paper. In this analysis, the assumption is made that a need for abort has been detected, and the HL-20 must separate immediately from its launch vehicle.

## HL-20 Description

The HL-20 is described in detail in Ref. 7. The aerodynamic characteristics of the HL-20 are presented in Ref. 8. Pitch rates in this analysis were limited to 5 deg/s and roll rates were limited to 10 deg/s. The structural analysis for the HL-20 is presented in Ref. 9. The HL-20 is designed to accommodate a 10 psi overpressure from an exploding booster, an axial-axis acceleration of 8 $g$ during the abort motor burn, and a one-time normal-axis acceleration of 4 $g$ which occurs during certain RTLS and TAL abort trajectories. During some of the aborts to the ocean, the normal-axis acceleration can approach 6.5 $g$. Further structural analysis will be required to determine the impact on the HL-20 from this increase in normal-axis acceleration above the design limit.

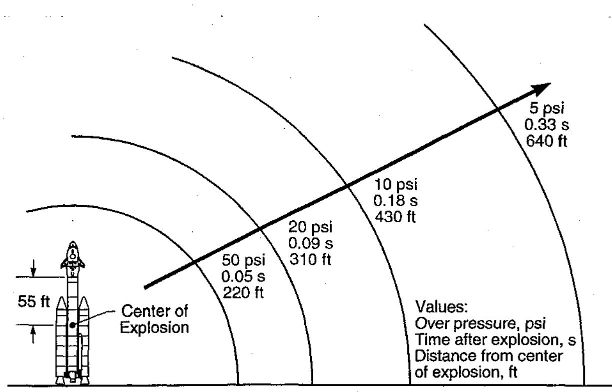


Fig. 2 Fully fueled Titan III explosion overpressures.

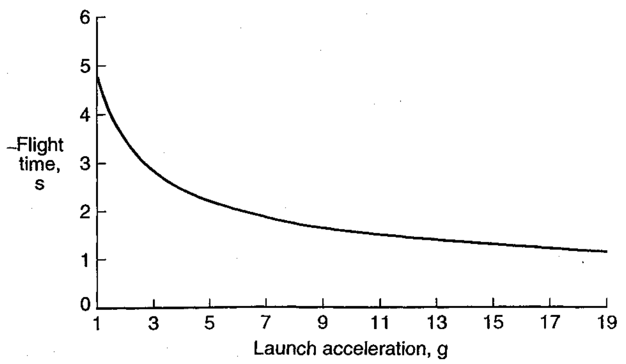


Fig. 3 Flight time to 10-psi overpressure boundary.

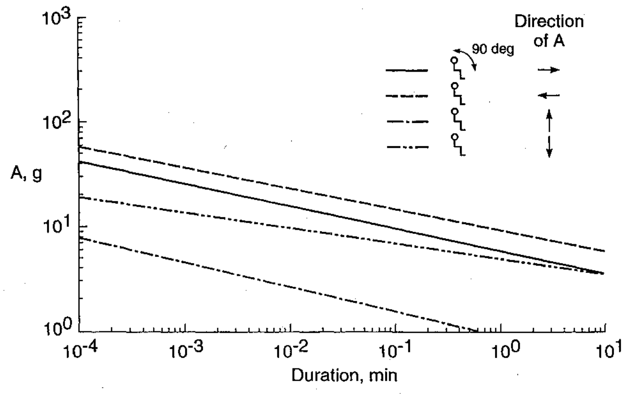


Fig. 4 Human acceleration limits.

Table 1 HL-20 weights used in abort study

| | |
|---|---|
| Entry, lb | 22,932 |
| OMS propellant, lb | 2,948 |
| Launch escape system, lb | 6,028 |
| Adapter, lb | 2,553 |
| Abort weight, lb | 34,461 |

Table 2 Engine characteristics

| | Thrust, lb | $I_{sp_v}$, s | Burn time, s |
|---|---|---|---|
| Primary abort SRMs | 248,800 | 256.7 | 3.5 |
| Sustainer abort SRMs | 33,000 | 256.7 | 12.0 |
| OMS | 1,740 | 278.0 | 471.0 |

## Launch-Escape System Design

The abort condition that sizes the launch-escape system is a return-to-launch site that is initiated while the HL-20 is on the launch pad. If an explosion is imminent, the HL-20 must be removed immediately from the launch vehicle to a safe distance by applying thrust. The design of the launch-escape system is based on four factors: the acceleration imposed on the crew by the thrust of the abort SRMs; the overpressures imposed on the HL-20 by the launch-vehicle explosion shock wave; the orientation of the launch pad relative to the RTLS runway; and the weight of the combined HL-20 and launch-escape system.

A fully fueled Titan III is estimated to have a TNT equivalency of 111.5 tons based on the analysis method described in Ref. 10. The resulting shock-wave pattern from an explosion is shown in Fig. 2. As previously mentioned, the HL-20 has been designed to withstand a 10-psi overpressure. Therefore, the HL-20 must reach a distance about 430 ft from the center of the explosion in order to survive intact. The flight time required to reach this boundary for a range of launch-escape accelerations is shown in Fig. 3. The flight time decreases significantly as launch acceleration increases up to 8 $g$. The flight time decreases at a much slower rate for levels above 8 $g$. The crew is prone and facing up on the launch pad. In this orientation, an acceleration of 8 $g$ is acceptable for up to 12 s (Fig. 4).[10] A thrust level that provides a maximum 8-$g$ acceleration was selected for the primary abort SRMs, and a burn

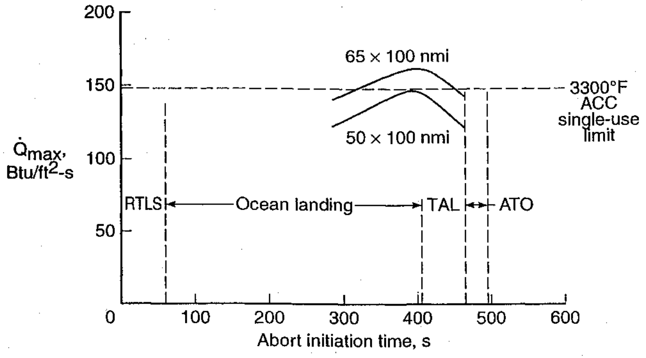


Fig. 5 Maximum reference heating rates for abort maneuvers.

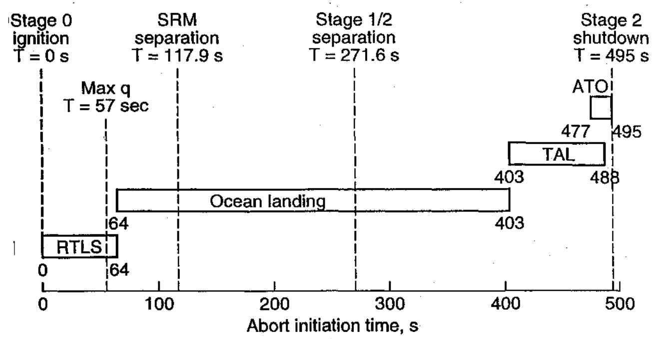


Fig. 7 HL-20/Titan III abort modes.

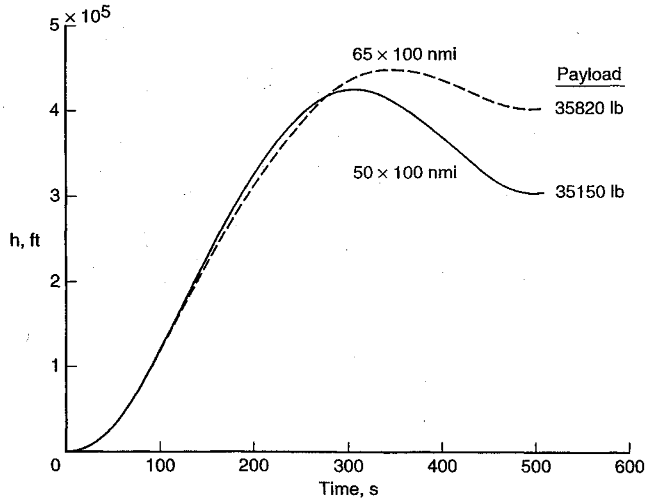


Fig. 6 HL-20/Titan III ascent profiles.

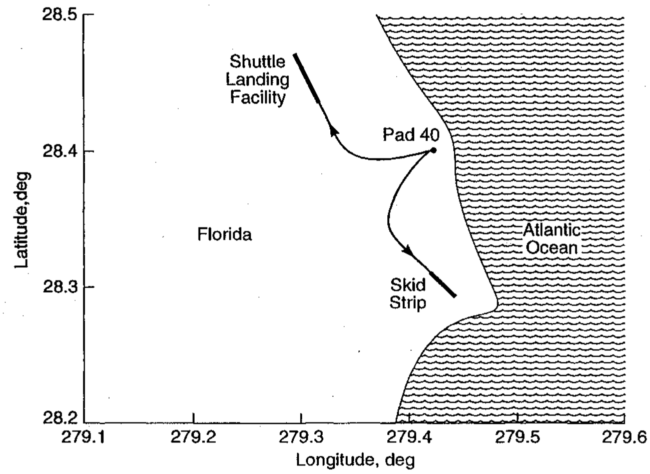


Fig. 8 Groundtracks for on-the-pad abort maneuvers (altitude and velocity profiles).

duration of 3.5 s, which is well below the 12-s limit, was chosen because of weight considerations. The flight time to the 10-psi overpressure boundary at this thrust level is 1.8 s. The shock wave reaches this same location in 0.18 s. Therefore the launch-escape system must be activated approximately 1.6 s before an explosion occurs.

In addition to the primary abort SRMs, the launch-escape system has an additional set of SRMs that supply a thrust level of approximately 1 *g* with a burn duration of 12 s. These sustainer SRMs enable the HL-20 to reach an energy state which is sufficient to reach the Shuttle Landing Facility runway from an abort initiated on the launch pad. This maneuver is detailed in the RTLS abort section.

Tables 1 and 2 summarize the weight and propulsion characteristics of the launch-escape system and the HL-20. The thrust levels in Table 2 are the total thrust from the four primary abort SRMs, the four sustainer abort SRMs, and the two orbital maneuvering system (OMS) engines. The OMS engines have a gimbal capability of ±15 deg. The primary and sustainer abort SRMs have thrust vector control and can pitch the HL-20 up to 15 deg.

## Nominal Ascent Trajectory

The nominal launch trajectory for the delivery of an HL-20 to orbit on a Titan III was defined by the abort analysis. The Titan III optimally injects its payload into an orbit with a perigee higher than 80 n.mi., but an orbital injection perigee above 50 n.mi. is not acceptable for the HL-20 because of the peak heating experienced during some abort maneuvers.

If the target orbit has a 65-n.mi. perigee, some of the abort entry trajectories would subject the HL-20 to temperatures (Fig. 5) that exceed the single-use limit of the advanced carbon-carbon heat shield used on the nose and wing leading edges.[11] Initial orbits with perigees higher than 65 n.mi. would have even higher peak heating. If the orbital insertion perigee is reduced to 50 n.mi., the single-use limit of the material is no longer violated during any of the abort trajectories.

Thus, the nominal launch trajectory including a 50 n.mi. by 100 n.mi. injection point was selected to limit abort entry heating. Although the payload capability is diminished with the lower injection point (Fig. 6), a 700-lb payload margin remains above the combined weight of the HL-20, adapter, and launch-escape system.

## Launch Abort Modes

A minimum of four launch abort modes are required during an HL-20 launch on a Titan III launch vehicle. They include RTLS to a runway landing, ocean-landing-by-parachute, TAL, and ATO. Figure 7 shows the time span for each of the abort modes. In the ocean abort mode, which covers 70% of ascent, the crew is rescued, but the HL-20 sustains damage. Both the crew and vehicle are recovered in the other three abort modes, which cover the remaining 30% of ascent.

All of the abort trajectories were modeled with the three-degree-of-freedom version of the Program to Optimize Simulated Trajectories.[12] The initial conditions for each abort trajectory were taken from the nominal ascent trajectory previously shown. Launch is assumed to occur from Titan Pad 40 at Cape Canaveral. All runways used for the RTLS and the TAL trajectories are a minimum of 10,000 ft long and are currently available for use.

The results of this abort study depend on the location of the assumed launch pad and runways, as well as the current HL-20 and Titan III configurations. Changes in the HL-20 configuration, Titan III configuration, or launch pad and runway locations could alter the beginning and ending times of the four abort modes. However, the methodology of this study would remain valid. Following is a description of the four abort modes that were determined with the assumptions previously described.

**Return-to-Launch Site**

Depending on the nature of the emergency on the launch pad, the crew can either egress the HL-20 on the pad if time permits or fire the launch-escape system with the HL-20 executing an RTLS to a runway. Reference 13 details the crew egress procedures on the launch pad. For an RTLS abort from the pad, trajectories to the Shuttle Landing Facility and the Air Force Skid Strip were modeled to determine which runway could be reached with a minimum sustainer SRM burn time. The Shuttle Landing Facility has a heading angle of 330 deg (measured clockwise from north) and is 6.0 n.mi. from pad 40. The Skid Strip has a heading angle of 130.7 deg and is 5.4 n.mi. from pad 40. On the launch pad, the Titan III has a heading angle of 110 deg, and the HL-20 is positioned on top of the launch vehicle with its underside oriented toward the ocean. The abort sequence begins with the primary abort SRMs and the sustainer SRMs firing in series. The adapter is jettisoned at completion of the SRM firings, and the HL-20 has a heading angle of 290 deg and a flight-path angle of 77 deg. Figure 8 shows the groundtrack to each runway. The distance to the Shuttle Landing Facility is 0.6 n.mi. further than the Skid Strip, but the required turning angle to the Shuttle Landing Facility is 120 deg less than the Skid Strip. To reach the Skid Strip, a 14.25-s sustainer burn was required. An abort to the Shuttle Landing Facility required a 12.0-s sustainer burn. Therefore, the Shuttle Landing Facility was chosen as the landing site for RTLS aborts from the pad to minimize the weight of the launch-escape system.

The altitude, velocity, and control parameter profiles of the abort trajectory from the launch pad to the Shuttle Landing Facility is shown in more detail in Fig. 9. The maximum altitude reached by the HL-20 is 14,000 ft. The maximum velocity reached by the HL-20 is 700 ft/s and occurs when the primary abort SRMs have completed their burn. Since the HL-20 is pitched away from the ocean by the abort SRMs, its initial roll angle is 180 deg. Soon after the adapter is jettisoned, the HL-20 rolls to 0 deg and then later rolls to 50 deg during the final turn to the runway heading angle. The end conditions for this RTLS trajectory are an altitude of 2000 ft, a flight-path angle of − 19 deg, a dynamic pressure of 300 psf, and a distance to the runway threshold of 10,725 ft. These conditions match the nominal conditions for the flare and touchdown on the runway as described in Ref. 14.

Prior to 20 s in the nominal ascent trajectory, the HL-20 must abort to the Shuttle Landing Facility. At 20 s, the HL-20 has begun to move downrange and can no longer reach the Shuttle Landing Facility for an RTLS abort. From 20–64 s, the HL-20 can abort to the Skid Strip, which has a heading angle of 310.7 deg when approached from the ocean. The groundtracks for these trajectories are shown in Fig. 10. For aborts initiated after 64 s, the HL-20 does not have sufficient energy for RTLS to the Skid Strip.

The OMS engines were not used during any of the RTLS trajectories because their thrust level at low altitudes is uncertain. With a full OMS propellant load, the HL-20 center of gravity is located at 57.5% of its body length, and at low Mach numbers, the HL-20 can be trimmed at this center of gravity position with the control surfaces.

**Ocean-Landing-by-Parachute**

For aborts initiated between 64 s and when the nearest TAL site is within range at 403 s, the HL-20 must land in the ocean

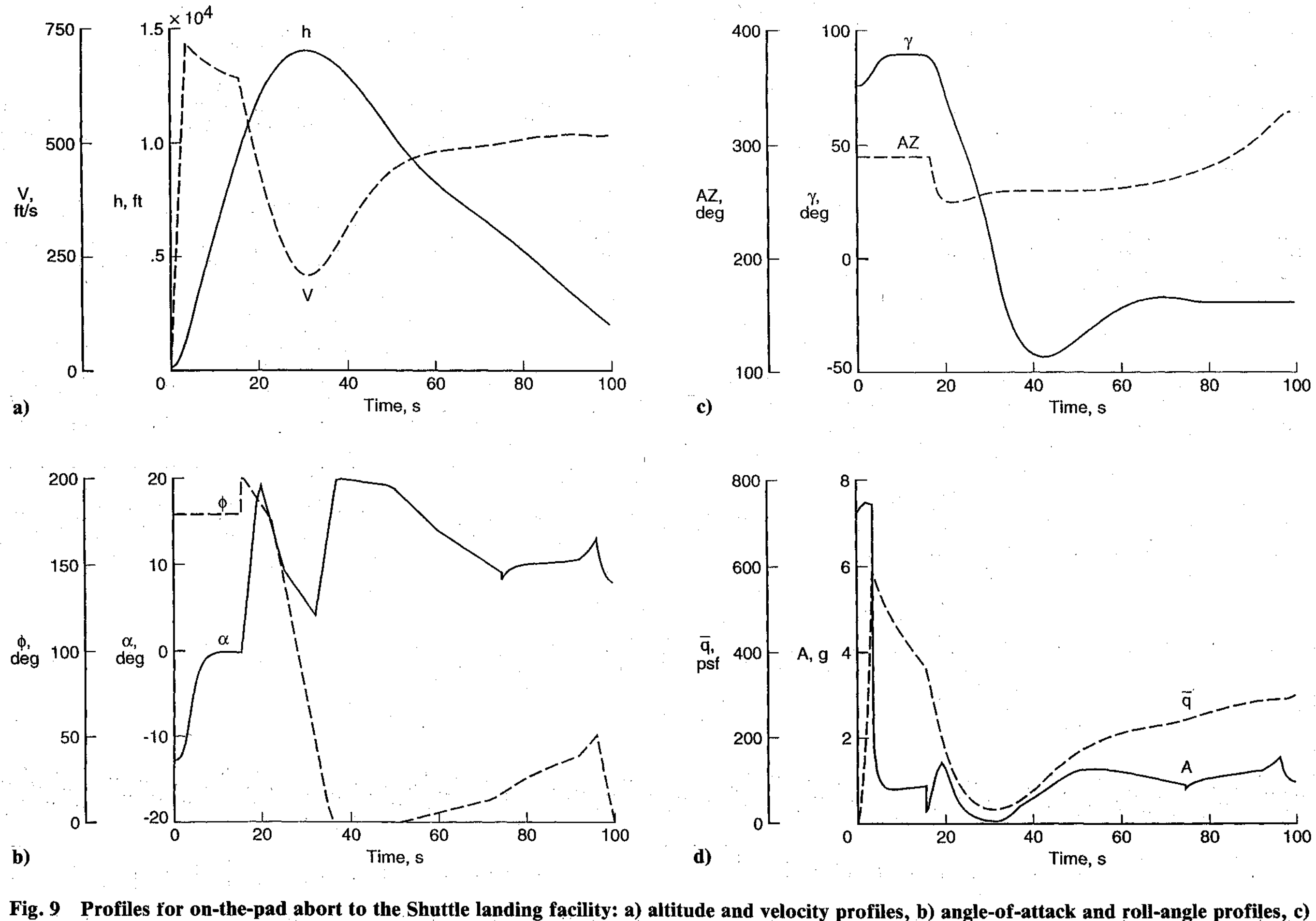


**Fig. 9 Profiles for on-the-pad abort to the Shuttle landing facility: a) altitude and velocity profiles, b) angle-of-attack and roll-angle profiles, c) flight-path angle and heading angle profiles, and d) acceleration and dynamic pressure profiles.**

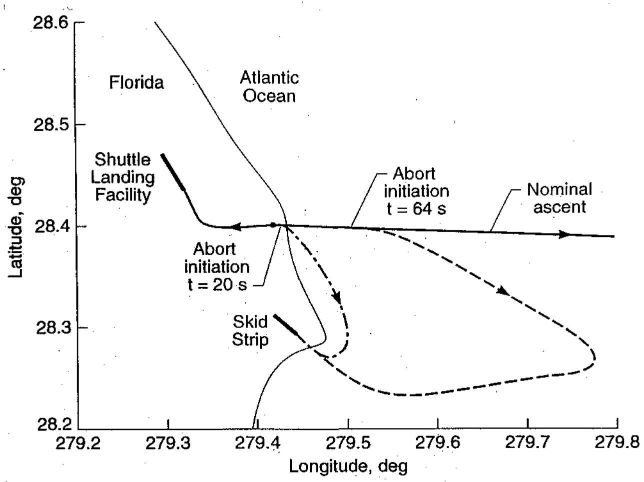


Fig. 10 RTLS groundtracks to the Shuttle landing facility and skid strip.

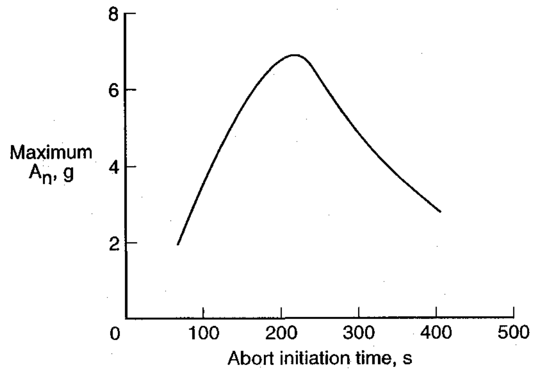


Fig. 11 Maximum normal acceleration at pullout for aborts to the ocean.

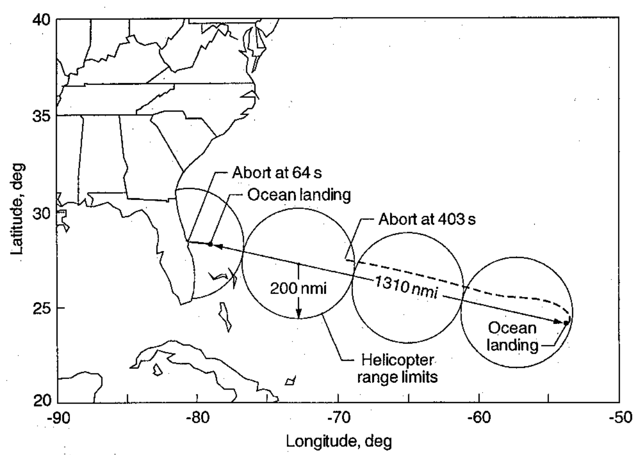


Fig. 12 Sea recovering sites for ocean landing aborts.

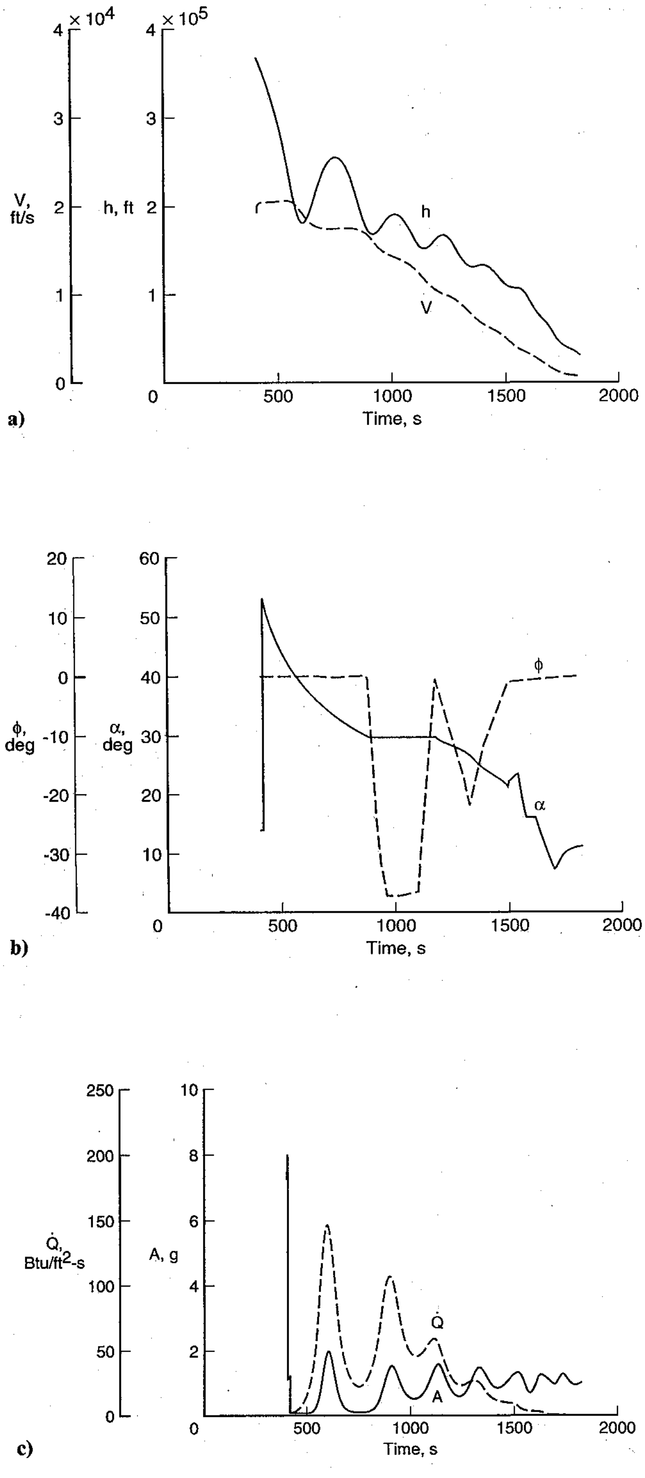


Fig. 13 Profiles for TAL to Amilcar Cabral initiated at 403 s: a) altitude and velocity profiles, b) angle-of-attack and roll-angle profiles, and c) acceleration and heating-rate profiles.

Table 3 TAL sites

| | Geodetic latitude, deg | Longitude, deg | Elevation, ft | Runway length, ft |
|---|---|---|---|---|
| Amilcar Cabral, Cape Verde Islands | 16.73 N | 22.93 W | 174 | 10,728 |
| Banjul, Gambia | 13.33 N | 16.65 W | 95 | 11,800 |
| Roberts Field, Liberia | 6.23 N | 10.37 E | 27 | 11,000 |

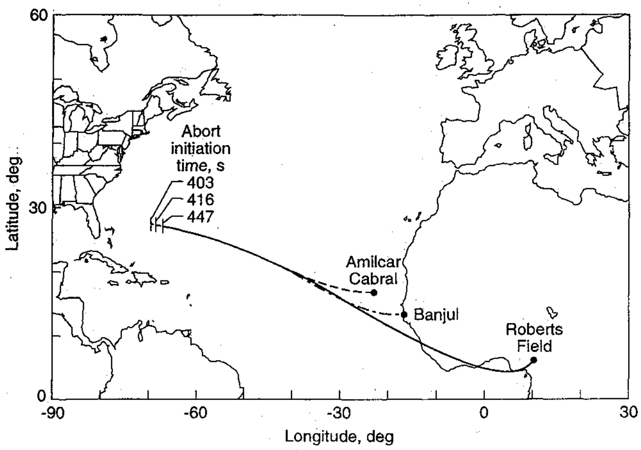


**Fig. 14 Earliest TAL opportunity groundtracks.**

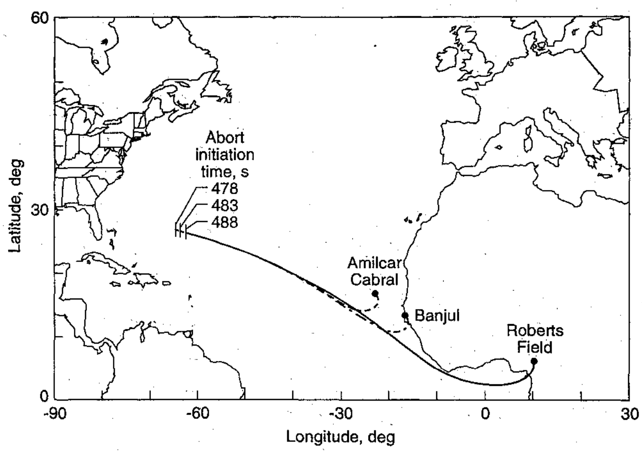


**Fig. 15 Latest TAL opportunity groundtracks.**

by parachute. During each of the ocean-landing-by-parachute aborts, the parachute deployment procedure is initiated when the HL-20 glides to 23,000-ft altitude. The HL-20 parachute system, which is similar to the Apollo parachute system, and the loads experienced by the HL-20 at water impact are described in Ref. 7.

At abort initiation, the primary and sustainer SRMs are fired, and the adapter is jettisoned. The OMS engines must be fired immediately until the OMS propellant is depleted so the center of gravity will shift to the nominal entry position of 55.5%. At the high Mach numbers experienced during the ocean-landing-by-parachute aborts, the HL-20 cannot be trimmed with the control surfaces for an OMS loaded entry condition.

Most of the aborts to the ocean subject the HL-20 to high normal accelerations. At abort initiation, the HL-20 has a high flight-path angle and will have a steep re-entry angle after the HL-20 reaches its maximum altitude. The pullout maneuver during these abort re-entry maneuvers are much more severe than a nominal entry maneuver. The peak normal accelerations at pullout for a range of abort initiation times is shown in Fig. 11. The worst case occurs during an abort initiated at 220 s. The duration of the high normal accelerations ($A_n > 2.5\,g$) for this case is approximately 40 s.

Figure 12 shows the groundtracks for the abort trajectories initiated at 64 and 403 s. The locations where the HL-20 parachutes to the ocean at the completion of these two aborts is separated by 1310 n.mi.. Aborts that are initiated between 64 and 403 s will parachute to the ocean within this range. Helicopters currently used for sea search and rescue operate within a range of 200 n.mi. The coverage of the entire ocean landing area would require a minimum of three ship-based helicopters and one land-based helicopter. The center of the circles on Fig. 12 represent the nominal locations of these helicopters during a launch.

#### Transatlantic-Abort-Landing

For the TAL analysis, three Space Shuttle abort landing sites are chosen. The characteristics of the three landing sites are shown in Table 3. Banjul is currently the primary Shuttle TAL landing site. Amilcar Cabral and Roberts Field are Shuttle emergency landing sites. For each TAL trajectory in this analysis, the end condition was an altitude of 30,000 ft above the runway location. From an altitude of 30,000 ft to runway touchdown, the HL-20 would follow the nominal approach and landing that is described in Ref. 14.

The first TAL opportunity occurs at 403 s after launch when the HL-20 has sufficient range to reach Amilcar Cabral with the firing of the abort SRMs. This abort trajectory is shown in Fig. 13 and is similar to a nominal entry trajectory. The groundtrack for this earliest abort capability to Amilcar Cabral as well as the other two TAL sites are shown in Fig. 14.

For the latest TAL abort time to each of the three landing sites, only the OMS engines are fired at abort initiation. In the later part of ascent, the launch-vehicle explosive potential is sufficiently low to allow a separation of the HL-20 from the launch-vehicle using only the OMS engines, assuming shutdown of the launch vehicle thrust. The groundtracks for the latest abort opportunities to each of the three TAL sites are shown in Fig. 15. The final time that an abort to Amilcar Cabral can be initiated (478 s) occurs after the first ATO capability is available (477 s), as will be shown in the next section. Therefore Amilcar Cabral is the only TAL site required. The other two TAL sites could be used as backup sites to Amilcar Cabral.

#### Abort-to-Orbit

For this study, the minimum acceptable orbit for an ATO was set as the nominal injection orbit (50 n.mi. by 100 n.mi.). At 477 s after launch, the HL-20 can reach the nominal injection orbit with the firing of the primary and sustainer abort SRMs. After 490 s, only the sustainer abort SRM is required to attain this orbit. Nominal shutdown of the launch vehicle occurs at 495 s after launch.

## Summary

Complete ascent abort capability for the HL-20 has been demonstrated. If a launch-vehicle problem occurs, the HL-20 is removed to a safe distance by launch-escape system solid rocket motors. Four abort modes have been described including, return-to-launch-site with a runway landing, ocean-landing-by-parachute, transatlantic-abort-landing, and abort-to-orbit. Two landing sites are required for the return-to-launch-site mode, and one landing site is required for the transatlantic-abort-landing mode. The crew is saved throughout the ascent, and the vehicle is recovered intact in all but the ocean landing mode. The ascent trajectory of the current Titan III was modified so that the heating constraint of the HL-20 was not exceeded during the abort trajectories. The maximum normal acceleration for some of the aborts to the ocean was greater than acceptable limits and will require further study to determine the impact on HL-20 structural design.

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