Performance Assessment of a Space Station Rescue and Personnel/Logistics Vehicle

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A study has been conducted to assess the ascent, abort, and entry capability of a vehicle that can be configured for rescue of a space station crew or ferry of personnel and supplies to and from a space station. The space station rescue vehicles (SSRV), each of which have a capacity of eight crewmen, would be delivered to the space station in the payload bay of a Space Shuttle Orbiter and remain parked until needed. The design of the SSRV allows it to be reconfigured as a space station personnel/logistics vehicle (SSPLV) with a capacity of four crewmen and 1000 lb of supplies when delivered to orbit on a Titan III launch vehicle. The nominal ascent trajectory for the SSPLV/Titan III as well as an analysis of the various ascent abort modes from launch to orbital injection are presented in this paper. Entry trajectories were simulated to various landing sites each with runways longer than 10,000 ft. This study demonstrated that five landing sites would provide a landing opportunity from every orbit of a space station in a 220-n.mi. circular orbit inclined 28.5 deg. The frequency of daylight landing opportunities was also determined.

Nomenclature

A	= sensed acceleration, g (gravitational constant, $g = 32.2$ ft/s^2
He	= helium
h	= altitude, ft
MMH	= monomethyl hydrazine
N_2	= nitrogen
N_2O_4	= nitrogen tetroxide
O_2	= oxygen
$\dot{Q}$	= heat rate, Btu/ft^2-s
$\dot{Q}_{max}$	= maximum heat rate, Btu/ft^2-s
$\bar{q}$	= dynamic pressure, psf
T	= thrust, lb
V	= velocity, ft/s
α	= angle of attack, deg
γ	= flight-path angle, deg
ϕ	= bank angle, deg

Introduction

WITH the development of a permanently manned space station underway, the need to provide some type of a rescue capability for the space station crew has become an important issue. Certain mechanical or medical emergencies would require an immediate evacuation of the crew from the space station and a return to Earth. If the Space Shuttle were not available for rescue, the space station crew would be stranded. Therefore, it would be desirable to have a vehicle attached to the space station that would provide an assured crew return capability.

Studies at the NASA Johnson Space Center and NASA Langley Research Center have concentrated on two potential configurations, a capsule and a lifting body. The lifting body offers lower entry accelerations and higher cross ranges than the capsule. These lower accelerations could be important in a medical emergency, and the higher cross range would provide mission flexibility. The rescue vehicle discussed in this paper was designed with a lifting body shape that can fit in the payload bay of a Shuttle Orbiter and seat eight crewmen.

An additional use for the crew rescue vehicle evolved as this study progressed. In a space transportation architecture, avoiding single-point failures is desirable. When the space station becomes operational, the only manned access currently expected is the Space Shuttle. An alternative would be a reconfigured rescue vehicle that could also provide access to and from the space station for crewmen and supplies. Delivered to orbit on an expendable launch vehicle, such as a Titan III, a manned access to space independent of the Shuttle would exist.

Configuration Details

The space station rescue vehicle (SSRV) is shown in detail in Fig. 1. The vehicle is 24.56 ft long and has a wing span of 20.90 ft. The wings can pivot to a stowed position so that the vehicle can be carried in the payload bay of a Shuttle Orbiter. The vehicle has a gross weight of 15,000 lb and has two rocket engines, each producing 870 lb of vacuum thrust for the orbital maneuvers necessary for deorbit. The SSRV has reaction control system (RCS) thrusters, each producing 25 lb of vacuum thrust for undocking and attitude control. Storable propellant systems are used since the vehicle could remain docked to the space station for long periods of time before use or refurbishment.

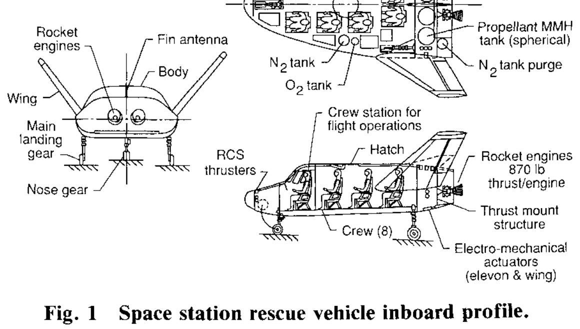

Fig. 1 Space station rescue vehicle inboard profile.

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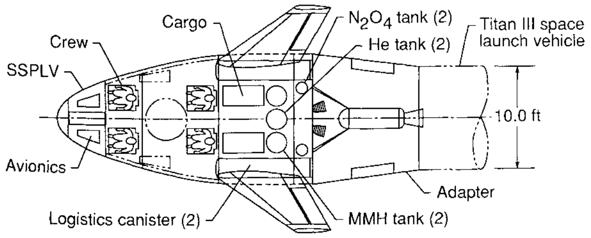

Fig. 2 Space station personnel/logistics vehicle.

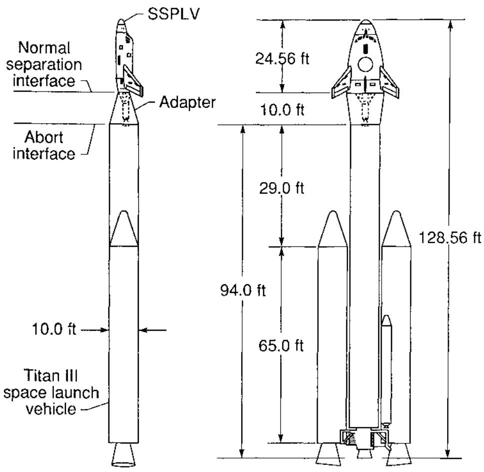

Fig. 3 SSPLV/Titan III launch configuration.

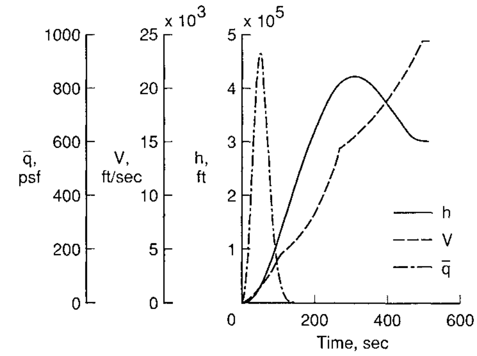

Fig. 4 Dynamic pressure, velocity, and altitude ascent profiles for SSPLV/Titan III.

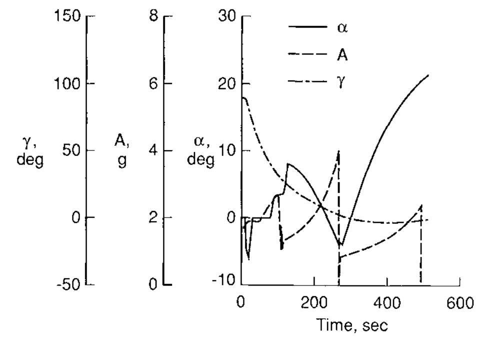

Fig. 5 Flight-path-angle, acceleration, and angle-of-attack ascent profiles for SSPLV/Titan III.

With some modifications, the SSRV can be transformed into a space station personnel/logistics vehicle (SSPLV) to ferry crewmen and supplies to and from the space station. The configuration shown in Fig. 2 can carry four crewmen and 1000 lb of supplies and has a gross weight of 15,755 lb. With the addition of an escape rocket system and a launch vehicle adapter to the rear of the SSPLV, the weight increases to 24,582 lb. The Titan III launch vehicle (Fig. 3) currently has the capability to deliver a 35,088-lb payload to a 50 by 100 n.mi. orbit. The margin between the Titan III payload capability and the weight of the SSPLV with the adapter and escape motor is 10,500 lb. The Titan III would have to be man-rated before it could carry the SSPLV to orbit, which would result in a reduction in some of the payload margin.

The Titan III consists of two solid rocket motors (SRM) and two core stages. The system weight when fully loaded is 1.50 Mlb. The SRM's and the first-stage core engine fire in parallel with a combined sea level thrust at liftoff of 2.51 Mlb, thus giving a thrust-to-weight ratio of 1.67 at liftoff. The engine on the core second stage is rated at 104,000 lb vacuum thrust.

Ascent Analysis

The trajectories shown in this paper were modeled using the three-degree-of-freedom version of the Program to Optimize Simulated Trajectories (POST).[1] This is a well-documented program available to the public. Figures 4 and 5 are the ascent profiles for the SSPLV/Titan III. The vehicle is launched from the Kennedy Space Center (KSC) and, after 510 s, inserts into a 50 by 100 n.mi. orbit, inclined 28.5 deg. During ascent, the maximum dynamic pressure is 950 psf, and the maximum acceleration is approximately 4 *g*. The boosters are staged at 116 s, and the core first stage is jettisoned at 269 s.

After insertion into orbit, the SSPLV separates from the Titan III core second stage and uses its own orbit maneuver engines to rendezvous with the space station, which is assumed to be in a 220-n.mi. circular orbit with an inclination of 28.5 deg. Using a Hohmann transfer, two engine firings are required for the change from the injected orbit to the space station orbit. The RCS thrusters are then used for the docking maneuvers.

Abort Analysis

Five abort modes for the SSPLV/Titan III were studied (see Fig. 6). Included are the on-the-pad launch escape, return-to-launch-site (RTLS), ocean landing by parachute, transatlantic abort landing (TAL), and abort-to-orbit (ATO).

On-the-Pad Aborts

When the SSPLV is sitting on top of the Titan III on the launch pad, it is in proximity to a large quantity of highly volatile and explosive liquid and solid fuel. If an explosion occurs, the crew must be removed immediately from the launch vehicle to a safe distance by applying thrust to the SSPLV. To do this requires consideration of four factors: the acceleration imposed on the crew during abort, the overpressures imposed on the SSPLV by the explosion shock wave, the weight of the abort SRM system, and the range requirement for an ocean landing.

The Titan III SRM's and two core stages were estimated to have a combined TNT equivalency[2] of 111.5 tons. The resulting shock-wave history from an explosion is shown in Fig. 7. The SSPLV has been designed to withstand 10-psi overpressure. Therefore, the SSPLV must reach a distance of 433 ft from the center of the explosion to prevent exceeding the 10-psi limit. The warning time required to reach 433 ft is shown in Fig. 8 for different abort SRM accelerations, assuming that the launch escape system (LES) requires 0.5 s to be activated. The maximum acceleration provided by the abort solid is determined by human acceleration tolerances[2] (see Fig. 9). Since the crewmen are facing up on the pad, a 1-s interval of about 8–9 *g* acceleration is acceptable. Figure 10 shows the thrust history for the abort SRM and the resulting accelerations sensed by the crewmen. After 1 s of 8 *g*, the thrust of the SRM ramps down to 0 in the next 2.5 s. Therefore, with the 8-*g* abort SRM chosen, a 2-s advance warning is necessary for a safe on-the-pad abort in the case of an explosion (see Fig. 8). The chosen abort SRM system weighs 4740 lb.

The complete on-the-pad launch escape sequence[3] is shown in Fig. 11. A pitch motor is fired along with the abort SRM to give the SSPLV an initial pitchover of 14 deg so that horizontal ranging occurs and an ocean landing can take place. At the maximum altitude attained, the SSPLV rolls 180 deg to a heads-up orientation to deploy the drogue chutes. The adapter is jettisoned just before the main chutes begin the deployment sequence at 26 s. During the next 10 s, the main chutes are deployed in stages to limit shock loads. The SSPLV impacts the ocean, tail down, at 30 ft/s over 3000 ft downrange from the launch pad at approximately 86 s after abort initiation.

Return-to-Launch-Site

If an abort occurs between 30–60 s after launch, the SSPLV has the capability to execute an RTLS abort (see Fig. 12). Figure 13 shows the RTLS maneuver initiated at 30 s after liftoff. After the abort SRM fires, the SSPLV rolls 180 deg and loops back to the launch site. The altitude at the launch site is just under 10,000 ft. From there the SSPLV glides to a wheeled, horizontal landing at a launch site runway. In an RTLS initiated at 60 s, the SSPLV also rolls to 180 deg and slowly unbanks until it is headed back to the launch site. Again, the SSPLV reaches the launch site at approximately 10,000-ft altitude. If an RTLS is attempted beyond 60 s, the SSPLV cannot reach the launch site with an adequate altitude margin. For each RTLS trajectory, the acceleration during the banked turn was limited to 3 g.

Ocean Landing Aborts

Two ocean landing abort windows were found to be required. The first window occurs between launch and 30 s into ascent when the RTLS aborts first become possible. The second window starts when the RTLS aborts are no longer possible at 60 s and ends when the TAL aborts can take place starting at 450 s. If an abort situation occurs within one of these two windows, the abort SRM is fired, the SSPLV glides until the parachutes are opened, and an ocean landing takes place.

The SSPLV's thermal protection system (TPS) is designed to withstand heating rates up to 110 Btu/ft^2-s. Figure 14 summarizes the maximum heat rates that the SSPLV would experi-

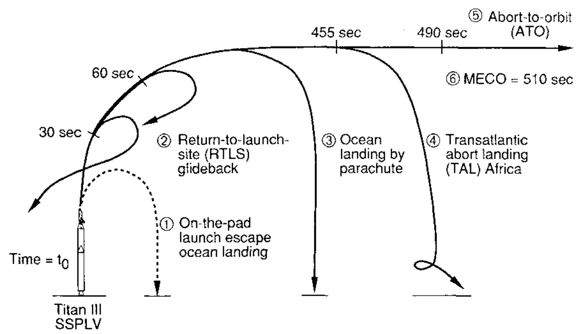

Fig. 6 SSPLV/Titan III abort modes.

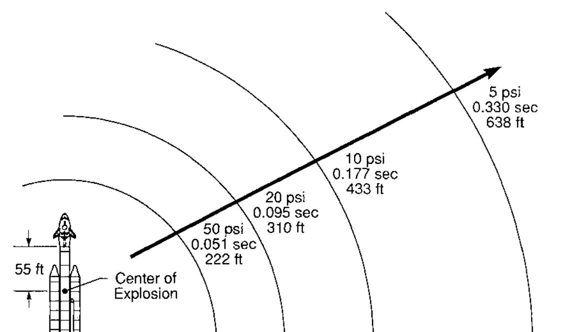

Fig. 7 Titan III on-the-pad explosion overpressures.

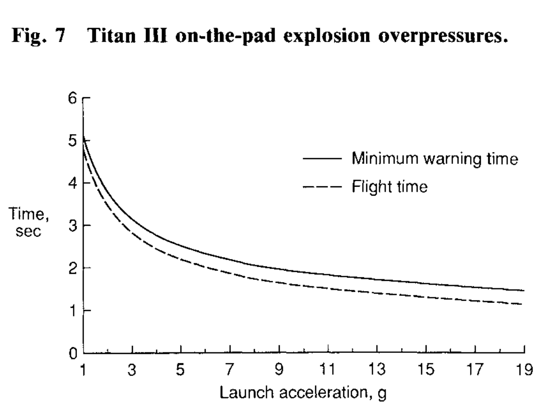

Fig. 8 Warning time requirements for on-the-pad launch escape.

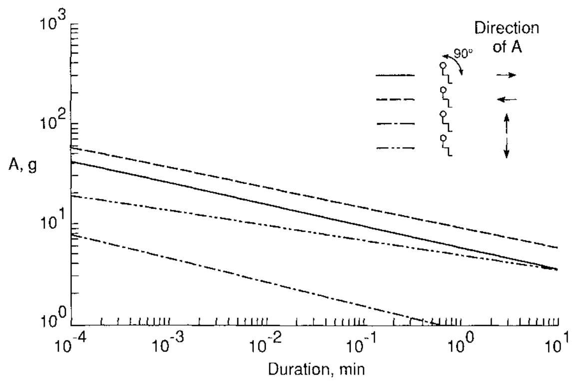

Fig. 9 Human acceleration limits.

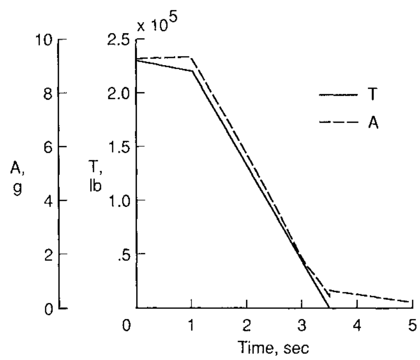

Fig. 10 On-the-pad abort thrust and acceleration profiles.

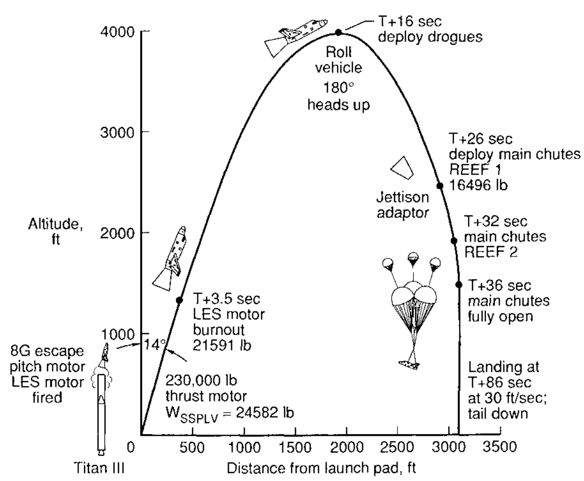

Fig. 11 On-the-pad launch escape sequence.

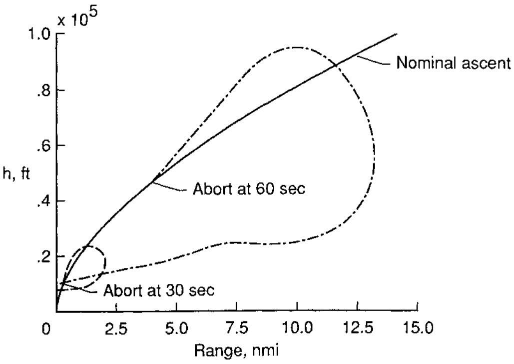

Fig. 12 SSPLV return-to-launch-site trajectories.

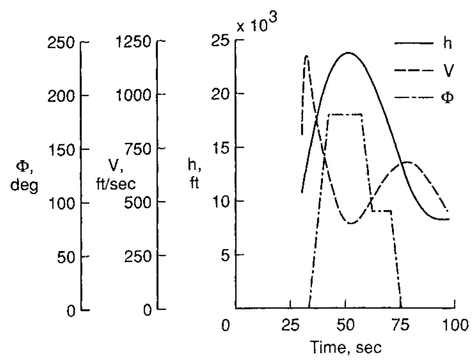

Fig. 13 SSPLV RTLS at 30 s.

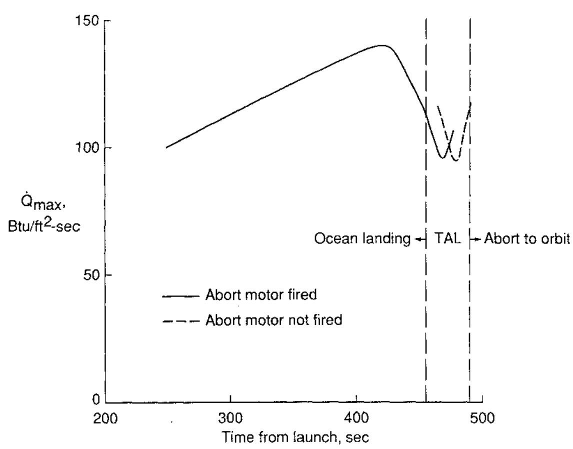

Fig. 14 Maximum heat rate for abort trajectories.

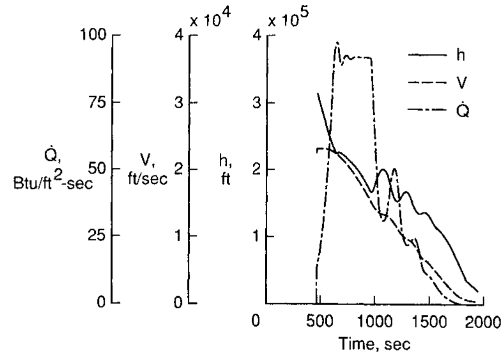

Fig. 15 Heat rate, velocity, and altitude profiles to transatlantic abort landing to Dakar.

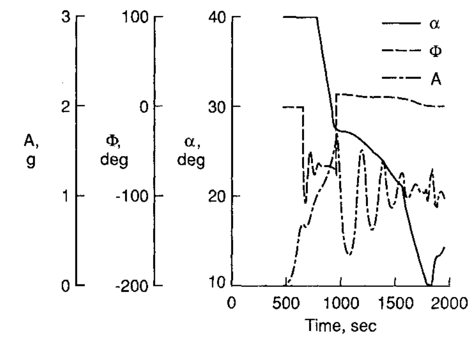

Fig. 16 Acceleration, bank-angle, and angle-of-attack profiles for transatlantic abort landing to Dakar.

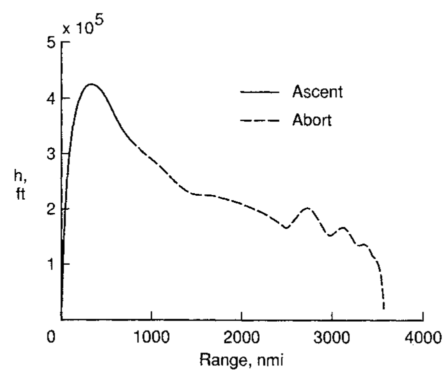

Fig. 17 Ascent and transatlantic abort landing profiles.

ence depending on the time of abort initiation. During the ocean landing aborts, between 300–450 s, the maximum heat rates are above the design limits. Damage to the TPS would result, but the vehicle would survive.

TAL

At 450 s after launch, the SSPLV has reached the point where a TAL abort to Dakar is possible following the firing of the abort SRM. Between 470 s and the end of the TAL abort window at 490 s, reduced maximum heat rates occur if the abort SRM is not fired (Fig. 14). Figures 15 and 16 are the profiles for the TAL abort initiated at 465 s. Bank angle modulation is used to hold a constant heat rate of 90 Btu/ft^2-s. The vehicle follows the angle-of-attack profile for trimmed conditions. The SSPLV reaches Dakar with a margin of a 20,000-ft altitude, which would be used for the approach and landing maneuvers. Figure 17 shows the altitude vs range profile for the ascent and TAL.

Abort-to-Orbit

If the SSPLV experiences an abort situation between 490 s and nominal second-stage main engine cutoff (MECO) at 510 s, firing the abort SRM will put the vehicle in an operational orbit.

Entry Analysis

All of the entry trajectories were modeled from a space station orbit (220-n.mi. circular, inclined 28.5 deg) to a landing site with a final altitude of 20,000 ft, which is assumed to be ample altitude margin for the terminal area maneuvers. The hypersonic lift-to-drag ratio for the SSRV and SSPLV is approximately 1.8.

All-Orbit Landing Capabilities

Numerous entries were analyzed to demonstrate the capability of the SSRV and SSPLV to land at a minimum of one of five designated landing sites on every orbit. Each of the sites has a runway length $\geq 10{,}000$ ft. This minimum runway length was chosen because the vehicle would be unpowered and have an automatic (no pilot) landing system. Other sites would also be acceptable, but a minimum of five are required to provide a landing opportunity from every orbit of the space station. The automatic landing requirement was imposed because of the potential for a deconditioned crew or the unavailability of a pilot.

The five landing sites include Kennedy Space Center in Florida, Edwards Air Force Base in California, Hickam Air Force Base in Hawaii, Guam, and Dakar. Every 16th orbit, the space station approximately repeats its groundtracks (Fig. 18). Therefore, landing opportunities only needed to be determined for 15 consecutive orbits of the space station. During some of the orbits, as shown in Table 1, two landing opportunities exist, whereas all other orbits have one landing opportunity. The trajectory profiles for the entry into KSC from the first orbit are shown in Figs. 19 and 20. The nominal entry trajectories are similar to the TAL abort trajectories. A constant heat-rate profile is flown during a segment of each entry by modulating the bank angle. Figure 21 demonstrates the groundtrack of space station orbit no. 4 and the accompanying entry into Edwards Air Force Base.

Table 1 SSPLV/SSRV landing opportunities

Orbit	Landing site	Max heat rate, Btu/ft^2-s	Total heat load, Btu/ft^2	Max cross range (final), n.mi.	Max accel, g
1	KSC	92.81	103,051	374 (170)	1.32
1	Edwards	93.21	101,026	504 (412)	1.30
2	KSC	92.77	98,320	613 (572)	1.40
2	Edwards	92.81	102,114	497 (417)	1.31
3	Edwards	92.80	104,906	682 (682)	1.30
4	Hawaii	92.43	109,686	351 (309)	1.30
5	Hawaii	92.74	98,472	145 (53)	1.41
6	Hawaii	92.74	99,502	680 (623)	1.40
7	Guam	92.76	97,666	641 (595)	1.40
8	Guam	92.13	111,814	211 (68)	1.30
9	Guam	92.72	101,447	596 (596)	1.31
10	Dakar	92.73	106,479	317 (11)	1.30
11	Dakar	92.49	112,217	509 (509)	1.30
12	Dakar	93.70	111,701	792 (792)	1.30
13	KSC	92.41	107,659	654 (585)	1.30
14	KSC	92.48	107,577	177 (177)	1.30
15	KSC	93.77	108,190	269 (8)	1.39
15	Edwards	93.18	104,772	732 (662)	1.31

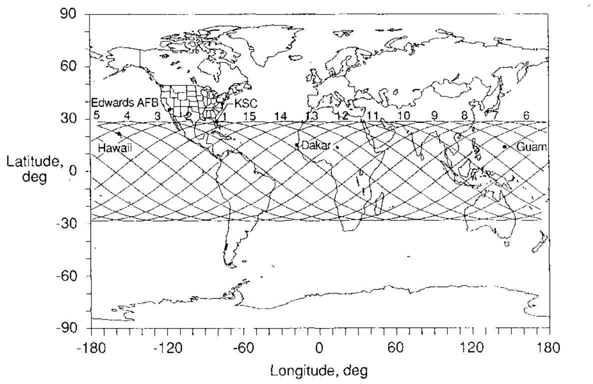

Fig. 18 Groundtrack of space station in 220 n.mi. circular orbit, inclined 28.5 deg.

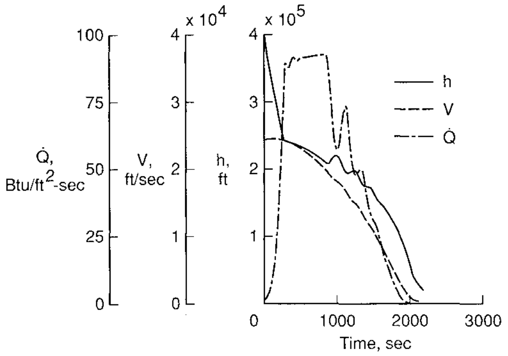

Fig. 19 Heat rate, velocity, and altitude entry profiles into KSC from orbit no. 1.

Daylight Landing Opportunities

Although the baseline SSRV and SSPLV were capable of all-orbit landing, a study was conducted to examine conditions where only daylight landings were allowed. Four landing sites were chosen for this study including KSC as the primary north latitude site, with Hawaii as a backup site, and Darwin, Aus-

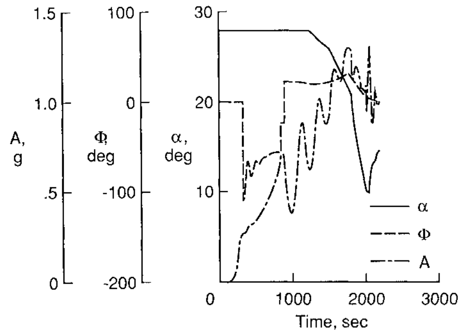

Fig. 20 Acceleration, bank-angle, and angle-of-attack entry profiles into KSC from orbit no. 1.

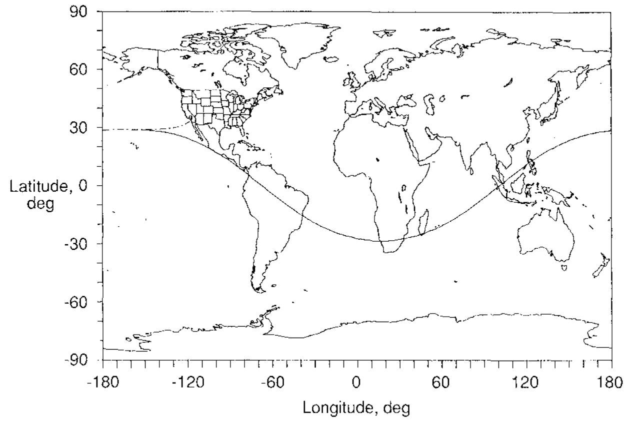

Fig. 21 Entry into Edwards from orbit no. 4.

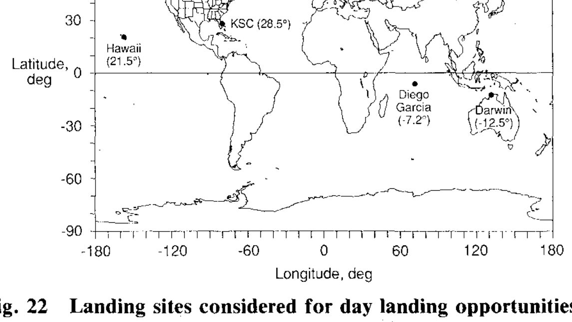

Fig. 22 Landing sites considered for day landing opportunities.

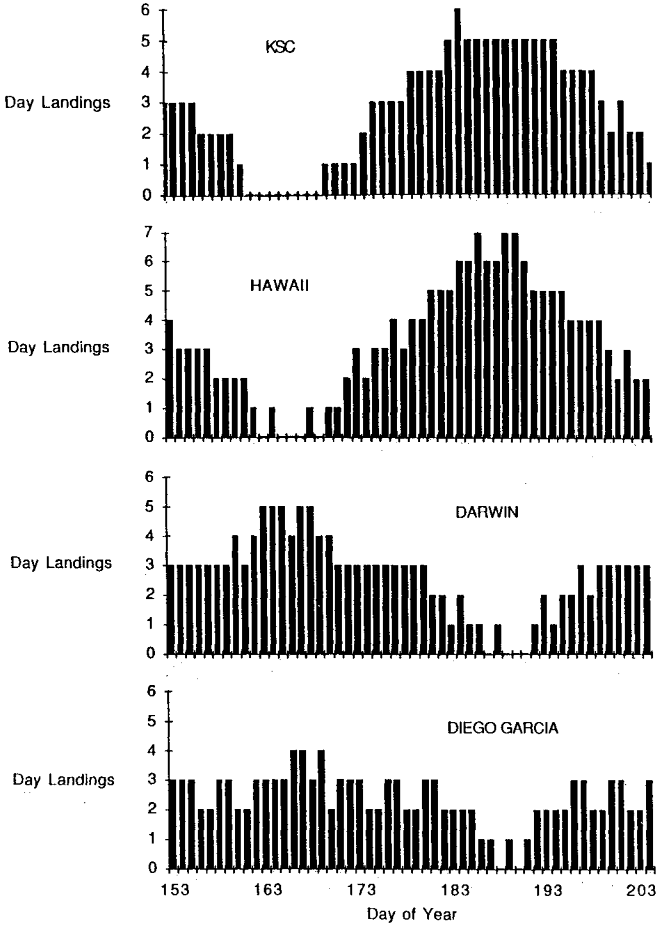

Fig. 23 Day landing opportunities for 50 days starting June 1.

tralia, as the primary south latitude site, with Diega Garcia as a backup site (see Fig. 22). The backup site would be used in case of weather problems at the primary landing site. The criterion chosen for daylight was 1 h before sunrise to 2 h before sunset to allow lighted conditions in which recovery crews could operate. To study the effect of season on the number of daylight landing opportunities, two cases of 50 consecutive days were chosen for study. The starting dates of the two cases are June 1 (see Fig. 23) and December 1.

Each backup landing site has landing opportunities in phase with its primary site. The south latitude sites are a necessary complement to the north latitude landing sites. When the north latitude sites are in darkness, the south latitude sites are at their peaks of day landing opportunities and vice versa. The combined number of landing opportunities for the north and south sites is at least six each day for both cases. Since the two cases studied demonstrated little seasonal effect, the number of day landing opportunities during the remainder of the year will be of the same order.

Conclusions

A study has been conducted to assess the ascent, abort, and entry of a lifting vehicle configured for a space station rescue vehicle (SSRV) and a space station personnel/logistics vehicle (SSPLV). The SSPSLV can be delivered to orbit on a Titan III launch vehicle and has abort capabaility throughout ascent. The SSRV and SSPLV can enter and land at one or two of five landing sites on every space station orbit. Also, the vehicle has at least six daylight landing opportunities at the two primary landing sites each day of the year.

Acknowledgments

The space station rescue and personnel/logistics vehicle study was a team effort. This paper represents the performance assessment completed by the three authors. Parallel efforts in the areas of weights, sizing, aerodynamics, operations, and heating were of equal importance. Particularly significant were the contributions of Ian O. MacConochie, Christopher I. Cruz, W. Douglas Morris, Kathryn E. Wurster, Anne C. Costa, and Patrick A. Troutman.

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[3]West, R. B., "Apollo Experience Report—Earth Landing Systems," NASA TN D-7437, Nov. 1973.