JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 30, No. 5, September–October 1993

21st Century Space Transportation System Design Approach: HL-20 Personnel Launch System

Howard W. Stone* and William M. Piland†
NASA Langley Research Center, Hampton, Virginia 23681

This article provides an introduction to and overview of the research that was conducted on the HL-20 lifting body and is documented in several articles in this issue of the *Journal of Spacecraft and Rockets*. The concept has been defined as an option for a personnel launch system (PLS) that is intended to carry six to eight Space Station Freedom crew persons. In this role the HL-20 will complement the Space Shuttle operation and ensure the ability to transport people to and from Earth orbit after the year 2000. The research covers a broad range of disciplines, including aerodynamics, aerodynamic heating and thermal protection systems, structural design, subsystem definition, trajectory and guidance system development for entry and abort, production and operations, and human factors. This article also presents the lifting-body heritage, design features of the concept, and HL-20/PLS mission requirements.

Introduction

FOR the past several years, the National Aeronautics and Space Administration (NASA) has been studying personnel launch system (PLS) concepts for carrying personnel to and from the Space Station Freedom. The approach is to launch a reusable PLS spacecraft on an existing or new expendable launch vehicle. The PLS would provide assured human access to space and complement Space Shuttle operations after the year 2000. The NASA Langley Research Center (LaRC) and several major airframe companies have been developing a lifting-body concept called the HL-20 (see Fig. 1) for this mission and other potential missions, including orbital rescue, orbital sortie, and satellite servicing.

The assessment of the viability of the HL-20 as a PLS option has produced an extensive database and provides an approach for developing and assessing safe, efficient, and cost-effective future space transportation concepts. This study has covered a wide range of technology disciplines and the methodology, and the results are the focus of a series of articles in this issue of the *Journal of Spacecraft and Rockets*.

This article gives an introduction to the HL-20 PLS concept and provides an overview of the research that is documented in the series of articles. The lifting-body research and testing heritage, lifting-body advantages, design features of the HL-20 concept, and PLS mission are described. The research areas discussed specifically are: aerodynamics, aerodynamic heating and thermal protection system (TPS) design, entry and landing flying qualities, launch vehicles, ascent abort, spacecraft production and operations, subsystems, structural design, and human factors.

Lifting-Body Heritage

Lifting-body concepts were proposed for transporting people to and from space in the late 1950s. LaRC developed a lifting-body concept called the HL-10 that could carry 12 people and be launched on a Saturn 1B booster with about 15,000 lb of payload to service an orbiting space station. The HL-10 design approach is discussed in Ref. 1. The NASA Ames Research Center developed the M2-F2 lifting-body concept for this mission whereas the U.S. Air Force developed the X-24 lifting-body concept for military-oriented missions. Each of these configurations was the subject of extensive research and wind-tunnel testing. Large-scale piloted prototypes of each were built and flight-tested at subsonic to supersonic speeds at the NASA Dryden Flight Research Facility.

The primary goals of these early lifting-body research programs included the definition of concepts that would be reusable and have minimal operational refurbishment requirements, low entry accelerations, fixed geometries, runway landing capability, and a minimum of a once-per-day return capability to the United States from orbits of interest. Specific vehicle goals were the achievement of a lift to drag ratio (L/D) greater than 1 at hypersonic speeds, high trim-lift coefficient at hypersonic speeds, L/D greater than 4 at subsonic speeds, high volumetric efficiency, static stability and controllability at all speeds, and of course, compatibility with projected launch vehicles.

A HL-10 flight test vehicle shown in Fig. 2 was built and delivered in January 1966 by the Northrop Corporation.[1] The vehicle was initially tested in the Ames Research Center full-scale wind tunnel and the first flight test at the Dryden Flight Research Facility occurred in December 1966. The vehicle was air-launched with a single pilot from a B-52 aircraft many times during the subse-

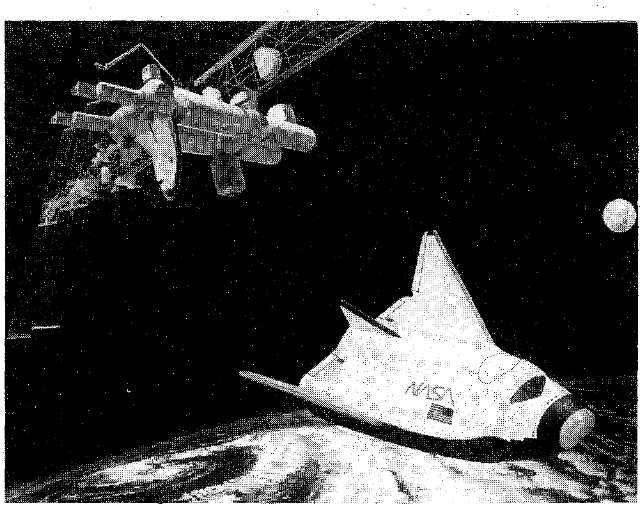

Fig. 1 HL-20 personnel launch system.

Received Dec. 10, 1992; revision received Feb. 15, 1993; accepted for publication Feb. 17, 1993.

*Aerospace Engineer, Space Systems Division.
†Chief, Space Systems Division. Associate Fellow AIAA.

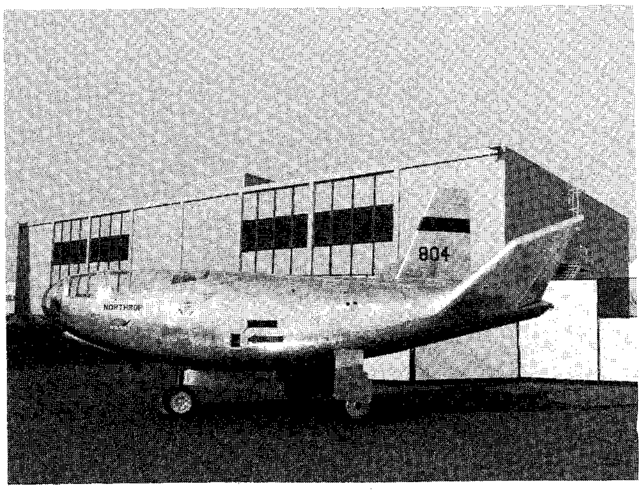

Fig. 2 HL-10 flight vehicle.

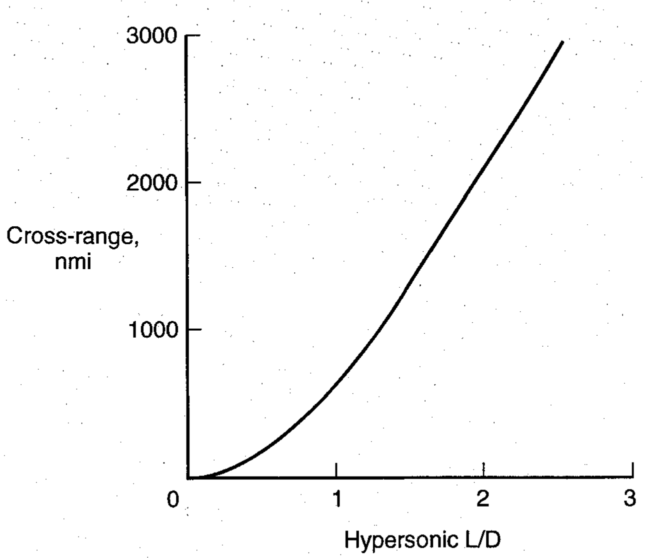

Fig. 3 Variation of entry crossrange with hypersonic *L/D*.

quent years. It was found that the vehicle had good flying qualities with a maximum subsonic L/D of about 4.25. The major result of the flight test program was to demonstrate that a lifting-body shape could have good flying qualities and safely achieve an unpowered landing (as with subsequent landings of the Shuttle orbiter). As the Space Shuttle system was conceived in the later 1960s, the requirement for a large payload bay and heavy propulsion systems in the aft end made a wing-body vehicle, rather than a lifting body, more appropriate for the orbiter.

Also in the early 1960s, according to Ref. 2, the Soviet Union began development of a lifting-body concept later known as the Lapot space plane in response to the United States development of the Dyna-Soar reconnaissance space plane. The Lapot configuration, which was apparently based on a late 1930s design by Dr. Eugene Sanger, had folding wings or fins. During entry, the wings were folded up in a lifting-body configuration and for landing, the fins were folded down, providing a delta wing planform. This delta wing planform was also required since the configuration was test-flown using conventional jet engines and a runway liftoff. In the 1980s, a small-scale model of this concept was flown to orbit to test TPS materials for the Soviet Shuttle, the Buran. In these tests, the configuration was called the BOR-4 and launched on a SL-8, Kosmos booster. The test flights ended with the vehicle landing by parachute in the water. The HL-20 aerodynamic shape has evolved from early lifting-body work in the United States, with particular attention given to several aerodynamic features of the BOR-4 design.

During the period of the 1970s and early 1980s most United States space transportation research and development focused on the Space Shuttle, and as a result, much more attention was given to the design of wing-body concepts than lifting-body configurations. Now that a permanently manned Space Station is envisioned by the United States, the need for a simple, rugged, relatively inexpensive passenger carrier is evident, and the volumetrically efficient, runway landing, lifting body is again under consideration.

Advantages of the Lifting Body

The effects of hypersonic L/D on entry crossrange to either side of the orbital ground track are illustrated in Fig. 3. Lifting-body shapes that have a hypersonic L/D of 1.0 to 1.4 provide a crossrange capability of 700 to over 1000 n.mi. The advantages of higher crossrange is illustrated in Fig. 4, where the Space Station Freedom ground track (orbit at 28.5-deg inclination) and the landing coverage provided by an HL-20 lifting body with a hypersonic L/D of 1.4 and crossrange of approximately 1100 n.mi. are depicted. For a 24-h period, the global area available for landing is illustrated by the overlap of the orbital ground track plus crossrange for a 24-h period. Landing opportunities are offered by complete global coverage for a latitude variation of +46 deg to −46 deg for an L/D of 1.4. (See Fig. 4b.) Figure 5 shows that as the crossrange increases, the number of day/night landing opportunities at the two prime Shuttle-landing sites [Kennedy Space Center (KSC) and Edwards Air Force Base] increases dramatically. A crossrange of 1000 n.mi. provides six daily landing opportunities at KSC and five daily opportunities at Edwards. (The Space Shuttle has demonstrated that runway landings at night are safely achievable.) Also, the figure shows that the wait time in orbit between a series of landing opportunities at these sites decreases with crossrange. For a lifting body with a hypersonic L/D of 1.4,

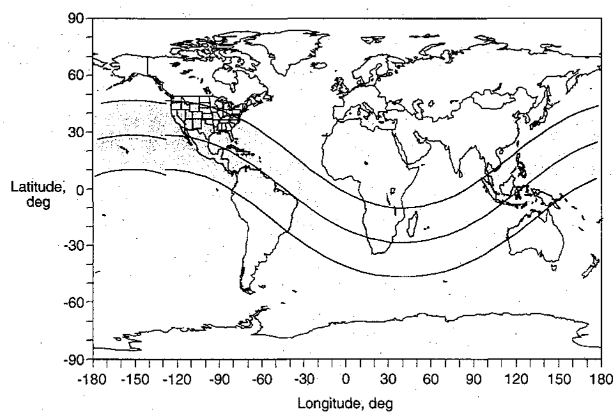

Fig. 4a Space Station Freedom ground-track and HL-20 lifting-body entry crossrange.

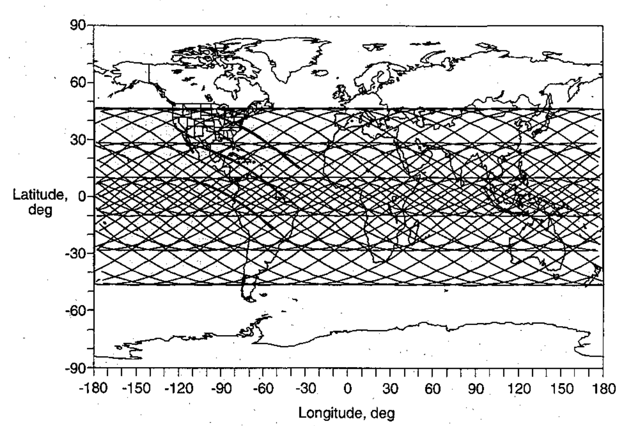

Fig. 4b HL-20 lifting-body 24-h landing site accessibility.

the wait time between landings at KSC in a 24-h period will be 14 to 15 h. This is because the landing opportunities are sequential since KSC is at the highest latitude the station orbit reaches. It should be noted that with the current HL-20 aerodynamic design, landings are possible at any runway of 10,000-ft length that lies within its crossrange coverage. Horizontal runway landings provide for simple recovery operations and minimal refurbishment of reusable vehicles.

Another advantage of a hypersonic L/D greater than 1.0 is the decrease in the accelerations to which the crew is subjected during entry. Low-entry accelerations are very desirable in the routine transport of deconditioned or possibly sick or injured personnel from space. Entry accelerations experienced by the HL-20 with moderate hypersonic L/D will be about 1.5 g's.

When a lifting spacecraft is used in conjunction with an expendable launch booster and mounted on "top of the stack," the spacecraft-induced loads that are imposed on the booster structure and the control requirements on the booster engine gimbal system during launch become an issue. The lifting-body concept is a good compromise. Although it has sufficient lift to land on a runway, the booster launch loads have been found to be within the load and control capability of current and future ELVs.

The lifting-body shape tends to minimize the surface area requiring TPS, while providing the hypersonic L/D and potential for runway landings. This is an operational benefit since TPS acreage can be a maintenance driver. The current HL-20 design has also provided a convenient arrangement for subsystem accessibility and crew comfort and safety. A study objective was to consider manufacturing and operations early in the design process to minimize development and life-cycle cost. The centerline of the 30-ft vehicle is a 76-in.-diam cylinder that can be used very effectively as a habitable pressure vessel. The region outside this pressure vessel and within the vehicle outer mold lines is adequate volume for the required subsystems. By using removable panels on the upper surface of the vehicle, this volume is readily accessible to technicians working outside the vehicle during operational turnaround and in the manufacturing process.

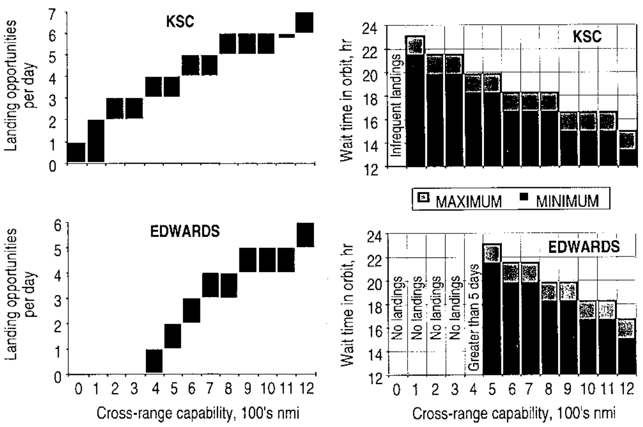

Fig. 5 Landing opportunities from Space Station Freedom.

	PLS	Sabreliner Series 60	Learjet 25
Crew + passengers	2 + 8	2 + 10	2 + 8
Cabin Dimensions			
Length	25 ft	20.5 ft	20.5 ft
Width	6.3 ft	5.2 ft	5.9 ft
Height	5.5 ft	5.6 ft	4.3 ft
Volume	580 ft^3	500 ft^3	450 ft^3
Volume/person	58 ft^3	42 ft^3	45 ft^3

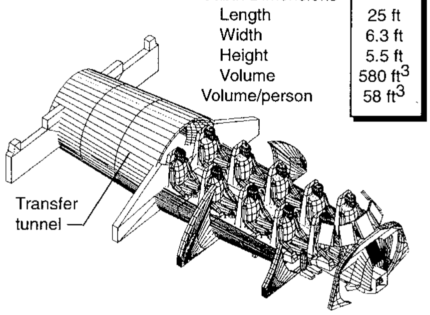

Fig. 6 HL-20 cabin/crew accommodations.

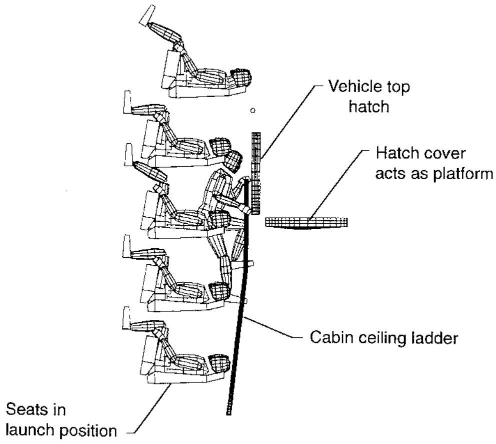

Fig. 7 HL-20 PLS on-pad emergency egress.

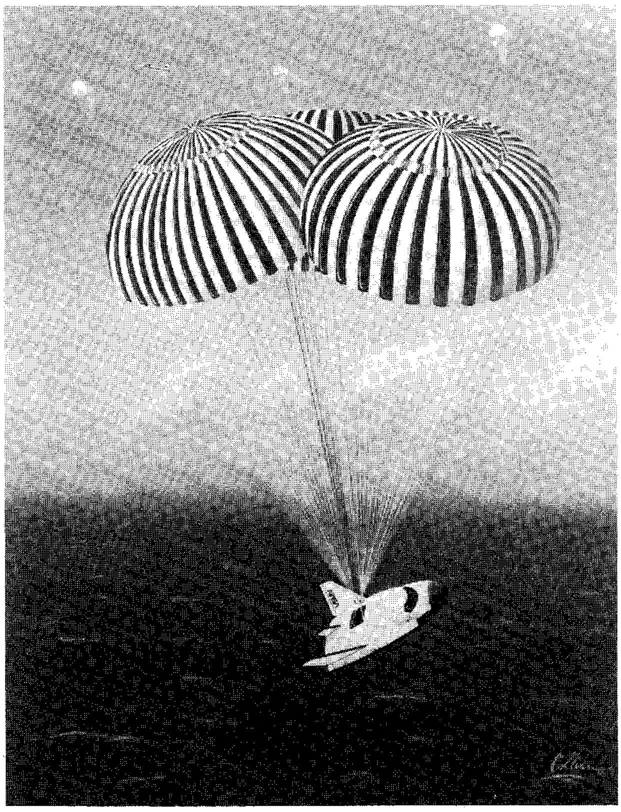

Fig. 8 HL-20 PLS abort landing.

Mission and Guidelines

The PLS guidelines were established with a view toward satisfying the primary requirement of the Space Station Freedom crew rotation and defining other missions in which human accessibility to space would be required. The delivery of the PLS would be on an expendable launch vehicle such as the Titan III or NLS. Since the initial design of the Space Station Freedom included a crew of eight astronauts, accommodations for eight passengers were included in the HL-20 design. This was the baseline for LaRC studies and the Rockwell concept development. The passenger accommodations for the later Lockheed study were changed to six since the Space Station requirements were reduced. A piloted and automated entry and runway landing capability was also a requirement. The system was required to have a fail operational/fail safe capability in all flight critical systems like the Shuttle. The PLS

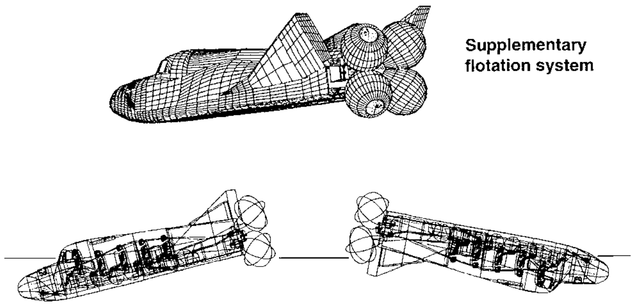

Fig. 9 HL-20 PLS flotation concept.

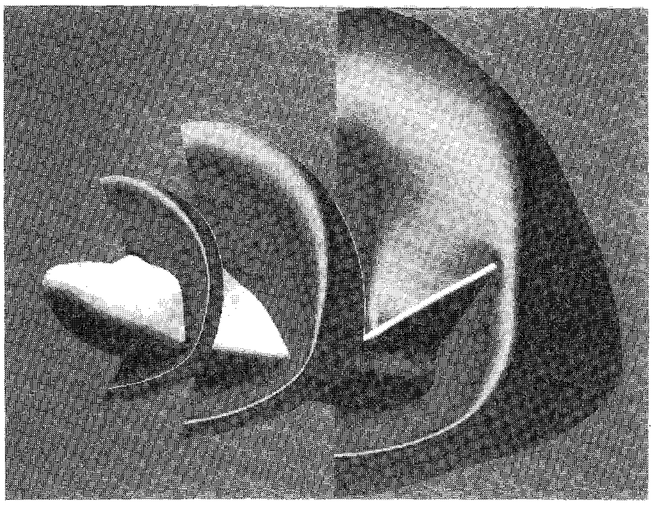

Fig. 10: Mach number contours: $M_\infty = 10$, $\alpha = 25$ deg, $\gamma = 1.4$.

cabin will be designed for a normal atmosphere of 14.7 psia with enough gas supply for one repressurization. Current technology is used extensively to reduce the risk associated with vehicle development, and a design to provide ease of maintenance was required to minimize life-cycle costs.

In the PLS operations scenario, the vehicle is processed separately from the launch vehicle and towed to the launch pad where the two are mated. The launch and entry constraints due to weather must be minimized. Intact abort capability must be provided in all mission phases, including off the pad. Following a successful launch, the PLS will rendezvous and dock or be berthed with the Space Station Freedom and, upon completion of its mission, will enter the atmosphere, land on a runway, and be processed for reuse. An on-orbit propulsion system is provided for 1100 fps of on-orbit maneuvers, including rendezvous, docking, and deorbit. The Space Station crew rotation mission is expected to require a total of 72 h to complete. Other missions have been briefly examined. For example, a satellite-servicing capability is described in Ref. 3.

HL-20 PLS Features

Specific program requirements for which the HL-20 PLS was designed focus on the important crew safety aspects of the configuration. Emphasis has been given in the HL-20 design to launch abort capability and the protection of crew during vehicle recovery. Other program requirements focus on low-cost manufacturing and minimizing life-cycle costs by ensuring simple operations, maintainability, and high utilization of the vehicle. The HL-20 PLS was designed to satisfy these requirements by incorporating key operational features early in the design process. Details of these features are included in the following discussion.

The HL-20 sized for the Space Station mission and 10-person complement (eight passengers plus a crew of two) is approximately 28 ft long and 15 ft wide at the base, with a 22.5-ft span between the tips of the fins. The landed weight is estimated to be 21,000 to 24,000 lb depending on crew size. The launch weight including an adapter and escape system is estimated to be 32,000 lb for a Titan III for an 8-person complement.

HL-20 PLS crew accommodations are illustrated in Fig. 6. Shown are the volumetric aspects of the configuration, where the HL-20 cabin including the cockpit area and transfer tunnel provides 58 ft^3 per person for a crew of two and eight passengers. This is about the same per person volume provided by the 12-man HL-10 concept studied in the 1960s. Fifty-eight ft^3 per person would appear to be adequate when compared to that available in typical business-type aircraft. As shown in Fig. 6, the Saberliner and Lear Jet have 42 and 45 ft^3 per person, respectively.

On-the-pad emergencies are accommodated in two ways. The first is illustrated in Fig 7. When sufficient warning of a pending emergency is provided, the crew can egress from the vehicle and move away from the launch complex in an orderly fashion. In the vertical position atop the launch vehicle, the crew is provided an emergency egress system that consists of a ladder and ample room to systematically exit through a hatch located on top of the HL-20. In the event of a more serious, immediate emergency on the launch pad, the launch escape system separates the HL-20 from the launch vehicle and launch complex. The abort rockets located on the adapter between the HL-20 and launch vehicle will rapidly accelerate the spacecraft to a distance where the HL-20 would experience no more than a 10-psi overpressure, yet not be exposed to

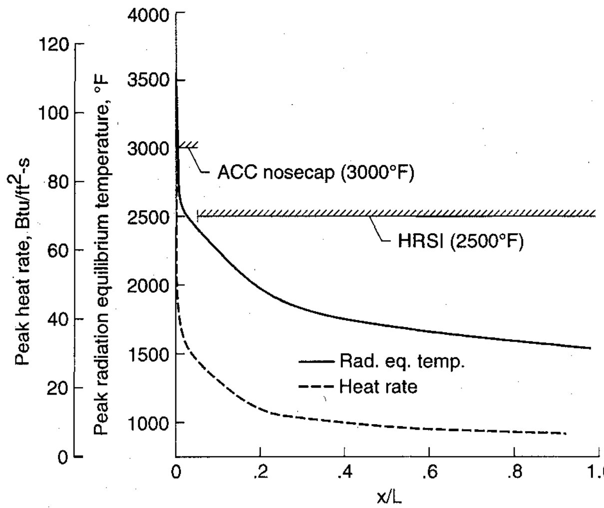

Fig. 11 HL-20 PLS windward centerline peak heating distribution/material requirements. $\varepsilon = 0.85$; transition $Re_\theta/M_e = 335$.

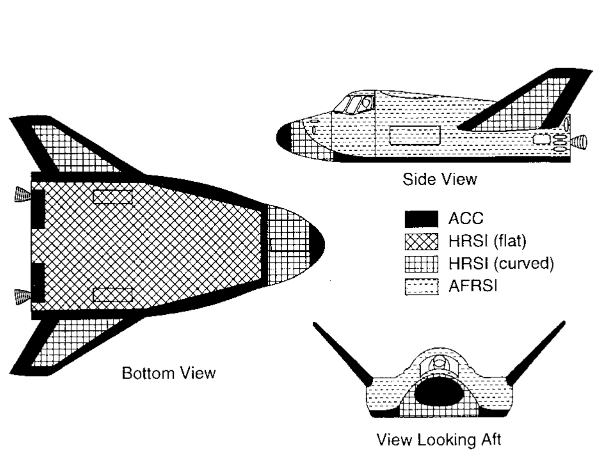

Fig. 12 HL-20 PLS thermal protection system.

greater than 8 g's of acceleration during the abort maneuver. This system requires a minimum of 2- to 3-s warning that a major emergency situation is pending because of acceleration limitations. For abort off the pad and during the first 65 s of the ascent, the HL-20 can return to the launch site (RTLS) for a runway landing. After this time and prior to 430 s into the ascent, following launch escape, parachutes would be deployed, and the vehicle would land in the water.[4] A parachute system concept based on the Apollo recovery system is illustrated in Fig. 8.

The design process for the HL-20 PLS included concern for water landing loads and dynamics. Once again, the HL-10 archived data proved useful. The HL-10 had been drop-tested at the Langley Research Center to better understand the dynamics of water landing.[5] These data were used to design a flotation concept for the HL-20 that is illustrated in Fig. 9. In addition to the hatch on top of the HL-20, a second hatch is located at the rear of the vehicle for docking with Space Station Freedom. Since the HL-10 data showed that a configuration of this type would float upside down and right side up, a supplementary inflatable bag flotation system will be required to ensure that the aft hatch remains unsubmerged, thus assuring safe egress from the vehicle after water touchdown.

HL-20 Design Status

The following discussion briefly gives the background and results of the LaRC and contractor studies in all the discipline areas. These areas are discussed in much more detail in 14 other articles in this special issue.

Aerodynamics, Aeroheating, and Flight Controls

Extensive wind-tunnel testing of the HL-20 has been performed to cover the flight speed range (Mach numbers 0.1 to 20) and assess configuration variations and improvements. Force and moment tests were conducted in air at Mach numbers from 0.3 to 10.4 (Ref. 6). Damping tests were also conducted at low subsonic speeds in the Langley full-scale wind tunnel. Additional force and moment tests were conducted in carbon tetrafluoride (CF-4) at Mach 6 and in helium at Mach 20. The test results indicate the vehicle has a trimmed maximum hypersonic L/D of about 1.4. At subsonic speeds the vehicle has longitudinal trim at close to maximum L/D, with an elevon deflection of −15 deg and a subsonic (or landing) L/D of about 4.2. Substantial improvements in subsonic L/D were achieved by the substitution of airfoil cross sections for initially flat plate fins. Data shows that the low-speed and hypersonic aerodynamic characteristics are similar to the HL-10 data. Furthermore, in the transonic regime, the HL-20 demonstrates aerodynamic characteristics very similar to that of the HL-10. Although both concepts are statically stable and controllable through the speed range, they encounter difficulties in the Mach number range of 1.5 to 2.0. Without aerodynamic control deflections in this Mach number range, the vehicles tend to trim at a small negative angle of attack. Some aerodynamic redesign such as increasing the aerodynamic surface size is warranted to help increase the trim angle-of-attack range.

The HL-20 PLS study has included complementary computational fluid dynamics (CFD) studies for understanding the complex three-dimensional flow about the HL-20 lifting body.[7] These studies have provided important flowfield information such as that illustrated in Fig. 10. Shown are Mach number contours for a flight condition of Mach 10 and an angle of attack of 25 deg.

The predicted peak hypersonic aerodynamic heating rates and radiation equilibrium temperature along the windward centerline are presented in Fig. 11. This peak temperature is estimated to lie within the state-of-the-art of the Shuttle TPS. The Shuttle-type reusable TPS tiles can be used on a large part of the windward surface, and advanced carbon-carbon (ACC) is only needed for the nose region and leading edges of the wing. The methodology for estimating the aerodynamic heating and comparisons with wind-tunnel and CFD results are presented in Ref. 8.

Another feature of the HL-20 PLS that has a bearing on ground turnaround man-hour requirements is the TPS design that is illustrated in Fig. 12. While current Shuttle-type TPS technology is used, since the HL-20 is substantially smaller (approximately 1/10th of the overall size of the Space Shuttle orbiter), the number of high-temperature reusable surface insulation (HRSI) thermal protection tiles required is drastically reduced. For example, on the Shuttle orbiter over 27,000 individual tiles are required and cover 50% of the orbiter surface. By comparison, the 10-person HL-20 PLS requires only 1000 of these reusable tiles, which cover only about 29% of the surface. The remainder of the surface is covered by advanced flexible reusable surface insulation blanket material and ACC on the nosecap and leading edges. Another simplifying feature of the HL-20 PLS concept is that 70% of the tiles are similar since the bottom is flat, and large numbers of identical tiles can be used. In the case of the Shuttle orbiter, only 13% of the HRSI tiles are similar. Fewer tiles and the large number of similar tiles result in less TPS maintenance time required for the HL-20 PLS.

The results of wind-tunnel testing and CFD analyses form the basis of a total entry aerodynamic database and six-degree-of-free-

Fig. 13 Landing simulator cockpit.

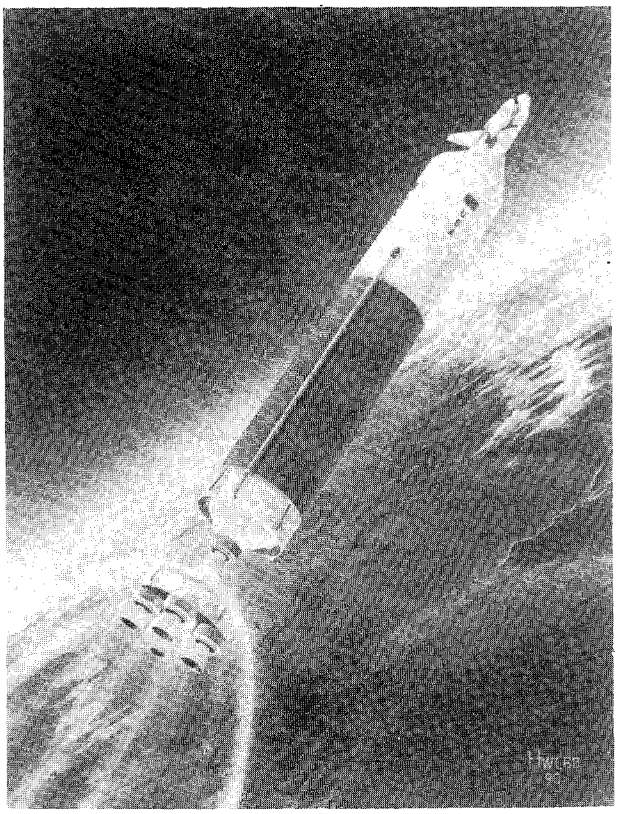

Fig. 14 HL-20/NLS launch configuration.

dom HL-20 entry simulations have been developed.[9] An entry guidance and control system was developed and simulations with nominal and off-nominal entry conditions (including flightpath offsets, off-nominal atmospheric density profiles, and winds) have been performed. These simulations showed that autopilot touchdowns will occur within 800 ft of the nominal longitudinal touchdown point with minimal lateral offset. Vertical velocity at main gear touchdown is less than 5 fps. These results also emphasize the need for some aerodynamic redesign due to the low-trim angle of attack in the supersonic speed range.

Pilot-in-the-loop simulations of the HL-20 landing have been conducted[10] using an aircraft cockpit that was modified for purposes of the HL-20 studies (Fig. 13). A full-scene generator provides a realistic view of the approach and landing through the cockpit window. A heads-up display (HUD) has also been integrated into the scene generation. The simulation is nominally initiated at a Mach number of about 0.6 and an altitude of 15,000 ft. The simulation has been flown by a number of pilots with varying degrees of experience, including one pilot who flew both the HL-10 and M2-F2 lifting bodies in the 1960s. Also, several astronauts who have landed the Space Shuttle orbiter have flown the simulator. Current simulation results show that the configuration is easily landed and similar to the Shuttle orbiter system. Landing qualities in moderate crosswinds are also very acceptable. Typically, a Cooper-Harper rating of 2 (level 1 flying qualities) is awarded the simulation by the test pilots. Reference 10 describes a parametric study where landing L/D was varied and pilot ratings were analyzed. The results showed that for L/D's above 3.8, level 1 handling qualities could be expected. The current HL-20 configuration has a subsonic L/D of 4.2.

In addition to the piloted landing simulations, an autoland system for the HL-20 was designed. Simulation studies of the autoland system indicate acceptable touchdown performance in the presence of gust, shear, and steady-state winds.[11] Touchdown sink rate and speed are well within stated requirements and performance is best on a Shuttle-like trajectory. Acceptable terminal area energy-management performance is available using a Shuttle-like heading alignment cone. The capability for landing in at least 25-kn crosswinds has been demonstrated. Sufficient pitch attitude margin to prevent tail scrape and sufficient control power for nose wheel letdown are available.

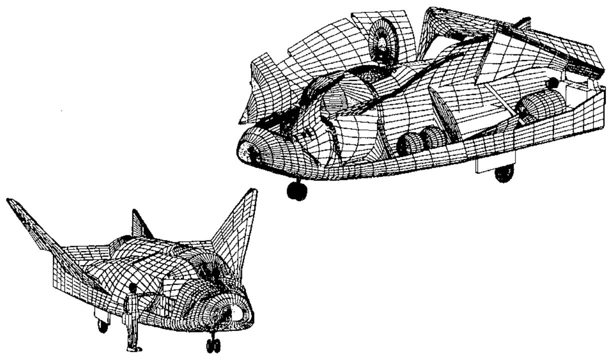

Fig. 15 HL-20 design for maintainability.

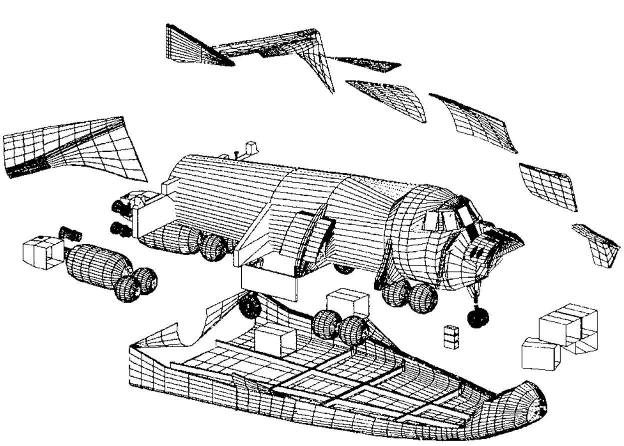

Fig. 16 HL-20 design for manufacturability.

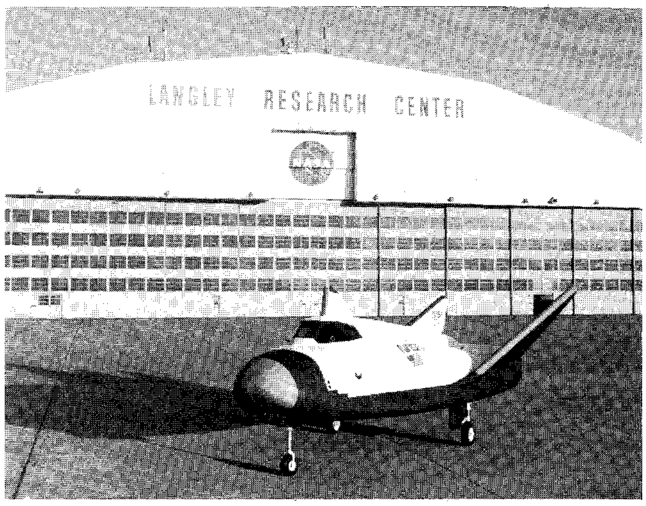

Fig. 17 HL-20 full-scale research model.

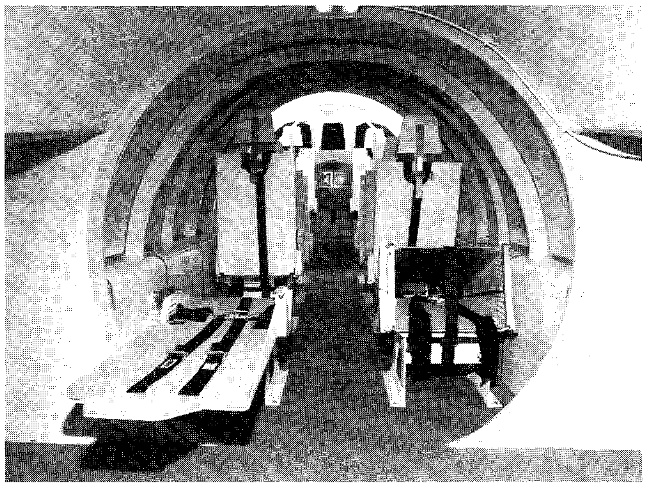

Fig. 18 HL-20 full-scale research model interior.

Launch Vehicles and Launch Escape

Several launch vehicle options have been considered for the HL-20. These include a Titan III that has sufficient lift capability for the HL-20 PLS to a Space Station orbit and national launch system (NLS) type of booster concept that is illustrated in Fig. 14. The capability and features of these boosters are described in Refs. 12 and 13.

If the launch vehicle experiences critical failure at any point during the ascent phase, the HL-20 is designed to escape and protect the crew and passengers. Optimization techniques have been used to develop maneuvers to return to the launch site runway during off-the-pad and early ascent aborts. If the abort occurs during the first 65 s, the HL-20 with its lifting capability can return to the launch site and execute a runway landing. During the latter part of the ascent, transatlantic runway landing sites are within range of the HL-20. In the intermediate portion of the ascent, water landing would be required. The trajectories and maneuvers for a Titan III booster are described in Ref. 4.

HL-20 Production and Operations

The overall design of the HL-20 PLS concept has incorporated lessons learned from the operation of the Space Shuttle. Vehicle subsystems are located close to the exterior of the vehicle and removable panels, as illustrated in Fig. 15, are provided for easy access to these subsystems for quick vehicle maintenance and turnaround. A technician requiring access to a particular subsystem merely removes a panel for access without having to remove other subsystem elements.

Overall, HL-20 PLS vehicle processing is expected to be substantially less than for the Space Shuttle orbiter. A detailed analysis by Langley and Rockwell[14] has shown that by designing maintainability and quick turnaround features into the HL-20 PLS concept, and by reducing or eliminating the systems that are time-consuming on the Shuttle orbiter (i.e., no main engines, fewer tiles, no hydraulics, etc.), the HL-20 PLS can be turned around in less than 1/10th the total number of man-hours required for the Shuttle orbiter. These results, including the flight or mission operations and the ground operation techniques, are presented in Ref. 14.

Another cost-saving feature of the HL-20 PLS is a design that allows for the ease of production. As shown in Fig. 16, the vehicle layout promotes manufacturing access and assembly and most systems are designed for external installation. A separate heat shield, as shown in Fig. 16, permits easy inspection of the system and late manufacturing installation and subsystem access from the bottom of the vehicle while it is being manufactured. The detachable, separate heat shield could permit easy replacement if required. This design for manufacturing and operations was a product of the Rockwell International effort on the PLS team.[15]

After the initial vehicle design was completed, the Lockheed Advanced Development Company, working with Martin Marietta Astronautics Group and the Lockheed Missile and Space Company, reviewed the design and evaluated the concept for development in a "skunk works" process.[16] The objective was to examine whether cost and schedule reductions in the development were possible. In this development approach, a prototype vehicle will be built and flown prior to production.

HL-20 Subsystems

As part of the definition of the concept and maintenance approach, the HL-20 subsystems were defined in detail.[17] Subsystem selection relied heavily on past experience both in manufacturing and maintenance, and all subsystem components were required to have a current technology readiness. Whereas the Rockwell subsystem selection was focused on operations efficiency, the Lockheed selection reflected the requirements for the rapid skunk works prototype production schedule.

The structural design has been the subject of a finite-element panel analysis.[18] The effects of the critical loading conditions that occur throughout the mission were examined. These conditions include ascent, the abort from the pad axial acceleration and overpressure conditions, a hard landing, aerodynamic maneuver, and the internal pressure in the cabin in space. The structure is sized to withstand each of these loading conditions. The resulting structural sizing (the physical dimensions for each element) is used to estimate the total structural weight.

HL-20 Human Factors

Students at North Carolina State University and North Carolina Agriculture and Technical State University built a full-scale research model of the HL-20 PLS for the Langley Research Center. A photograph of the model is shown in Fig. 17. The model is 28.25 ft long, constructed of a fiberglass shell, and is capable of being mounted horizontally as shown or vertically for studies simulating the HL-20 atop a launch vehicle. The interior of the model is shown in Fig. 18 where accommodations for a crew of two and eight passengers are provided. Studies using the full-scale model have included the assessment of some aspects of human-machine interface and human accommodation capability of this concept in both the horizontal and vertical positions.[19] Studies of emergency and routine ingress and egress from the vehicle in the horizontal and vertical positions have been conducted for a range of male and female human subjects with physical sizes from the 5 to 95th percentile. Measurements of time criticality and acceptability of the egress procedures have shown that the vehicle can be evacuated in an orderly fashion in less than 30 s in both orientations. Additional research using the full-scale model to study pilot visibility for a range of pilot seating positions has shown that some additional downward viewing capability over the nose is desirable and can be accommodated by nose contour modifications without sacrificing aerodynamic performance.

Conclusions

Early lifting-body studies and research provided a wealth of data on the utilization of these concepts for the future transport of people to and from space. Research at the Langley Research Center focused on the HL-10 configuration and the establishment of an extensive database on vehicle aerodynamic and aerothermodynamic characteristics. A flight research program demonstrated that a safe, unpowered landing of the concept was possible, and this work was instrumental in the development of the Space Shuttle that executes an unpowered runway landing. In recent years the evolution of lifting-body technology has resulted in concepts with considerable viability for near-term application for assured human access to space. The HL-20 PLS concept described here has been shown to be a viable approach to providing low-cost access to space. The HL-20 would provide much flexibility for routine access to and from space with its high crossrange capability, low entry acceleration, and the capability of precision runway landing. Two studies by major airframe companies and NASA have shown that the HL-20 vehicle could be built with current technology materials and systems and potentially at low manufacturing costs. In addition, the concept as designed provides adequate crew accommodations, crew safety (including on-the-pad abort), an improved maintainability and operability concept for reduced operations costs, and the capability of being launched on a number of expendable launch vehicles.

Of particular importance is the value of the depth in technical definition resulting from this research program. Recent recommendations of the Vice President's Space Policy Advisory Board[20] support the need for near-term development of a PLS to be launched on the also recommended "Spacelifter" launch vehicle. The HL-20 research team has provided a PLS option with enhanced crew safety and mission flexibility and one that may be developed with minimum risk and assurance of low development and life-cycle costs.

References

[1]Stone, H. W., and Piland, W. M., "The Personnel Launch System," *SAE 1991 Transactions*, Vol. 100, Pt. 2, Sept. 1992; see also SAE Paper 911970.

[2]Newkirk, D., "Soviet Space Planes," *Spaceflight*, Vol. 32, Oct. 1990, pp. 350–355.

[3]Talay, T. A., and Stone, H. W., "The Personnel Launch System—A Lifting Body Approach," IAF Paper 91-202, Oct. 1991.

[4]Naftel, J. C., and Talay, T. A., "Ascent Abort Capability for the HL-20," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 628–634.

[5]Stubbs, S. M., "Landing Characteristics of a Dynamic Model of the HL-10 Manned Lifting Entry Vehicle," NASA TN D-3570, Nov. 1966.

[6]Ware, G. M., and Cruz, C. I., "Aerodynamic Characteristics of the HL-20," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 529–536.

[7]Weilmuenster, K. J., and Greene, F. A., "HL-20 CFD Analysis," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 558–566.

[8]Wurster, K. E., and Stone, H. W., "Aerodynamic Heating Environment Definition/Thermal Protection System Selection for the HL-20," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 549–557.

[9]Powell, R. W., "Six-Degree-of-Freedom Guidance and Control Entry Analysis of the HL-20," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 537–542.

[10]Jackson, E. B., Rivers, R. A., and Bailey, M. L., "Effect of Lift-to-Drag Ratio in Pilot Rating of the HL-20 Landing Task," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 543–548.

[11]Jackson, E. B., Ragsdale, W. A., and Powell, R. W., "Utilization of Simulation Tools in the HL-20 Conceptual Design Process," AIAA Paper 91-2955, Aug. 1991.

[12]Benson, S. W., Beaver, B. A., Edelman, A. L., and Sholes, E. H., "Titan III Feasibility for HL-20 Prototype Missions," *Journal of Spacecraft and Rockets*, Vol. 30, No. 5, 1993, pp. 615–621.

[13]Duffy, J. B., Lehner, J. W., and Pannell, B., "Evaluation of the National Launch System as a Booster for the HL-20," *Journal of Spacecraft and*

Rockets, Vol. 30, No. 5, 1993, pp. 622–627.

[14]Morris, W. D., White, N. H., and Caldwell, R. G., "HL-20 Operations and Support Requirements for the Personnel Launch System Mission," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 597–605.

[15]Ehrlich, C., "HL-20 Concept: Design Rationale and Approach," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 573–581.

[16]Urie, D. M., Floreck, P. A., McMorris, J., and Elvin, J. D., "Design for Effective Development and Prototyping of the HL-20," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 582–589.

[17]Stone, H. W., and MacConochie, I. O., "HL-20 Subsystem Design," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 590–596.

[18]Bush, L. B., Robinson, J. C., and Wahls, D. M., "Preliminary Structural Evaluation and Design of the HL-20," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 567–572.

[19]Willshire, K. F., Simonsen, L. C., and Willshire, W. L., "Human Factors Evaluation of the HL-20 Full-Scale Model," *Journal of Spacecraft and Rockets,* Vol. 30, No. 5, 1993, pp. 606–614.

[20]Aldridge, E. C., Jr., "The Future of the U. S. Space Launch Capability, A Task Group Report," Vice President's Space Policy Advisory Board, ANSER, Arlington, VA, Nov. 1992.