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HL-20 Subsystem Design

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The NASA Langley Research Center has been developing a lifting-body configuration called the HL-20 for potential application as a personnel launch system orbiter that will provide the crew changeout at the Space Station Freedom. The objectives have been to provide an alternate manned access to space with a more cost-effective, efficient, reliable, and safer system for the routine transportation of people to low Earth orbit. The detailed study of this concept includes the subsystem design, flight software sizing, and mass properties that are discussed in this paper. The goals were to develop a subsystem complement to maximize operational efficiency with minimum development costs while using current technology. The subsystem selection and trade studies were made by a combination of NASA Langley Research Center, Rockwell International Space Systems Division, and Lockheed Advanced Development Company personnel. The results showed that current technology components will provide the required performance and operational effectiveness. Many of the selected components have Shuttle flight histories or considerable development heritage from other programs that will help minimize development costs. The sequential study of this concept by two major contractors with different perspectives resulted in similar subsystem selections and gave credibility to the concept approach.

Introduction

NASA has been examining vehicle concepts to complement the Space Shuttle system to provide the crew changeout at the Space Station Freedom and other potential missions. The key objectives were to provide an alternate manned access to space facilities and a more cost-effective, operationally efficient, reliable, and safer system for routine transportation of people to low Earth orbit. This system has been referred to as the personnel launch system (PLS). It consists of a manned spacecraft or orbiter that would be launched by an expendable booster stage.

The Langley Research Center has been developing a lifting-body configuration called the HL-20 for potential application as a PLS orbiter. This concept has been the subject of a detailed study and the results of this study are presented in this special issue in several individual articles.[1-6] This article describes the design guidelines, subsystems, and flight software. The objective in the design and selection of the individual subsystem components was to minimize development and operations costs, while providing a safe system with high utilization potential. The subsystem selection and trade studies have been made by a combination of Langley Research Center, Rockwell International Space Systems Division, and Lockheed Advanced Development Company personnel. The Rockwell concurrent engineering design team and approach are discussed in Ref. 7, and the resulting Rockwell study data are presented in Ref. 8. The Lockheed approach, known as the "Skunk Works" approach, is discussed in Ref. 9.

Spacecraft Subsystems

The HL-20 subsystems selection guidelines focused on ease of maintenance and near-term technology. The basic vehicle design approach was to make the systems requiring routine maintenance readily accessible. To accomplish this, many of the subsystem components were located outside the crew-cabin pressure vessel under removable panels. Operation in the vacuum of space was therefore required. It was necessary for the components to have large design margins to minimize in-service failures. This maximized safety and minimized unscheduled maintenance actions. Each component was required to have sufficient testing or service history to predict degradation and life expectancy. Also, component built-in test capability was required to maintain a continuous history and system status throughout its lifetime. The systems were required to have sufficient redundancy to be fail operational/fail safe since people will be onboard. Whenever possible, operational systems or enhanced versions of current systems were selected to minimize cost and risk. If a new system design appeared to offer significant maintenance benefit, it was acceptable if the technology had reached the demonstration-in-a-flight environment stage by 1992 (the technology readiness date). In some instances, heavier or lower performing systems or approaches were selected to improve operability. This approach resulted in efficient ground operations with minimum technical risk at the lowest life-cycle cost.

Early in the study, the space station personnel requirements were for eight persons plus two PLS crew persons, for a total of 10 onboard. This was the crew size used in the Rockwell study. The passenger and subsystem layout for the Rockwell concept is shown in Fig. 1. Later, the space station requirements were reduced, and the crew size used in the Lockheed study was a total of eight persons onboard.

The Lockheed approach is to have an accelerated development schedule leading to a prototype vehicle. This drives the subsystem and material selection to current or near-term concepts that can be delivered in several months.

In this article, both configurations are carried as baseline concepts. Table 1 offers a summary of the selected subsystems for each configuration.

Aerosurface Actuators

Based on the Shuttle experience, the central hydraulic system with lines running to the various actuators was avoided due to high maintenance requirements. Preliminary sizing re-

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sulted in a 2- to 5-hp range for the actuators, and the maximum surface rate requirements as derived from landing and entry simulation studies were 20 deg/s. Both electromechanical and electrohydrostatic actuators were examined for application to the HL-20. Electrohydrostatic actuators were attractive because the failure modes are the typical hydraulic modes and multiple pumps could be used for redundancy. Electromechanical actuators can be summed for redundancy, but the failed unit must be isolated with a brake or clutch. Another approach was to use motors with multiple windings. As many as four windings have been utilized in a samarium-cobalt permanent magnet brushless dc motor. Either permanent magnet or induction motors are required for this application. The current baseline is multiple motor electromechanical actuators with built-in test electronics for fault diagnosis and health monitoring that is being demonstrated in an advanced development program.

Landing Gear

Since the HL-20 weighed less than 25,000 lb at landing, several fighter landing gears were potentially applicable (both the F-5 and F-16 are designed for this weight). The landing gear requirements included a maximum sink rate of 10 fps with a nominal sink rate less than 5 fps, landing speed of less than 230 kt (nominal 200 kt), 6-deg crab angle at touchdown, and 20 deg/s maximum rotation rate for nose slapdown. The gear is nominally deployed late in the approach phase since the vehicle deceleration after flare is critical. Therefore, the gear will have to deploy and lock very quickly. The number of landings for the gear is expected to be less than 200 based on the current mission model. The standard down and aft deploying main gear will result in a turnover angle of 50 to 55 deg, which is near the maximum design limit. An F-16 gear that deploys outward will further reduce the angle. The current baseline is the down and aft deploying gear with an electric-motor-driven deployment and a pyrotechnic gravity-forced drop backup mode. (A modified F-5E gear was the Lockheed selection.) Electric actuators are used for nose wheel steering and braking on all gears. It is expected that the gear as modified for the HL-20 will be tested on a suitable aircraft prior to any HL-20 flight testing.

Orbital Maneuvering System/Reaction Control System

The onboard propulsion orbital maneuvering system (OMS) was sized for 1100-fps of on-orbit velocity change for orbit circularization, rendezvous and docking, deorbit, and other orbital change maneuvers. The reaction control system (RCS) sizing was based on the Space Shuttle on-orbit and entry requirements and was required for use in the proximity of the space station without contamination of the local environment or equipment. Propellant tank sizing included a 15% margin for off-nominal performance and 25% for ullage. The propulsion system architecture was configured to have fail operational/fail safe capability for crew safety. The required thrust levels for the HL-20 are 1200 lbf total for the OMS and 80 lbf per engine for the RCS. Several propellant combinations were examined in this study to determine which would have the least maintenance burden without having to develop new hardware.

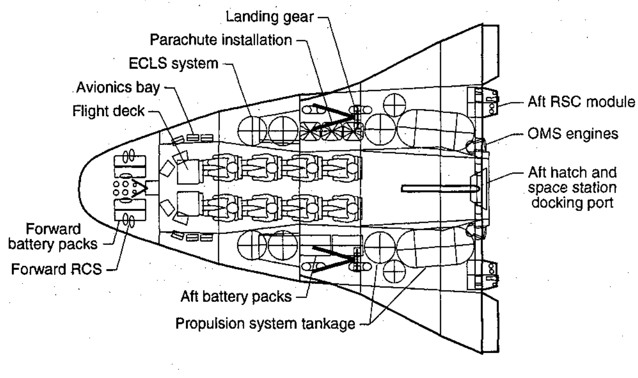

Fig. 1 Subsystem layout.

Table 1 Baseline subsystem selections

Subsystem	Rockwell baseline	Lockheed baseline
Aerosurface actuators	EMA	Same
Landing gear	Figher-type	F-5E modified
OMS/RCS	$JP4/H_2O_2$	MMH/N_2O_4
Avionics		
Processing system	ASCM/MDM	Same
GN&C	GPS/INS	Same
Communications	Telemetry, voice, air traffic control	Same
Vehicle health monitoring	Dual redundant processors	Vehicle management system
Software lines of code	290 k	206 k
ECLS	RCRS	Lithium/hydroxide
Personnel accommodations	Seats/ladder; no head or galley	Same
Power supply	Silver/zinc batteries	Same
Power distribution	28 Vdc	Same
Thermal control	Heat sink	Same
Adapter	Large (ALS)/heavy	Small (Titan III)/light
LES	Six solid boosters	Four solid boosters

One combination that was evaluated was the Shuttle Orbiter bipropellant system using monomethyl hydrazine (MMH) and nitrogen tetroxide (N_2O_4). The Shuttle Orbiter primary RCS engines were used for the HL-20 OMS (two engines), and the Shuttle Orbiter vernier RCS engines for the HL-20 primary RCS. This approach was selected by the Lockheed team since it is an off-the-shelf proven system with established operational procedures.

A monopropellant hydrazine concept was also examined. In this system, the hydrazine is passed through a catalytic bed that initiates a combustion reaction. The catalytic thrusters were used for both OMS and RCS at the 300- and 80-lbf thrust level per engine. This system has fewer parts than the bipropellant system previously described, but the significantly lower rocket efficiency increases the fuel requirement and total system weight by over 1000 lb. Another concern with this system is the degradation of the catalytic bed with use. The total thrust time required for the PLS mission has not been demonstrated. This system has never been used on a manned spacecraft and would, therefore, require man-rating.

The third propellant combination examined was a JP4/hydrogen peroxide (H_2O_2) concept. H_2O_2 has been used in several applications as a monopropellant since the products of combustion, water and oxygen, are noncontaminating. The monopropellant H_2O_2 could be used for both primary and vernier RCS, whereas JP4 and H_2O_2 could be employed for the OMS. The architecture to achieve fail operational/fail safe capability is shown in Fig. 2. This system would require the development and man-rating of new engines.

The last combination examined was a liquid methane or liquid hydrogen/liquid oxygen concept. The all-cryogenic system is the most efficient of all the concepts studied and results in the lightest propellant weight. However, the low density of liquid hydrogen requires more volume than available onboard the vehicle. The methane/oxygen approach has roughly the same weight and volume as the MMH/N_2O_4 system. A short-pulse RCS system using liquid cryogenics has never been developed and could be a significant developmental challenge. Gaseous cryogenic engines have been developed and test-fired but never flown. A gas generator system would be required for operation in this mode since there is insufficient volume to carry the required amount of gaseous oxygen onboard.

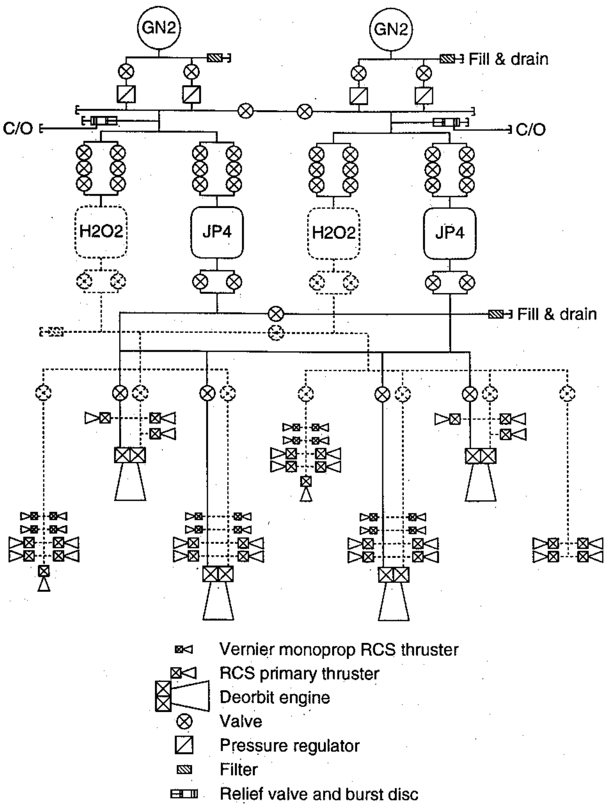

Fig. 2 OMS/RCS architecture.

The Rockwell study team concluded that the cryogenic system is the least attractive at this point due to complexity, development, qualification, and volume requirements for this vehicle. The MMH systems are current technology, but MMH is toxic, which requires serial operations. Therefore, even though the JP4/H_2O_2 system would require a new development, Rockwell selected it as their baseline.

Avionics

The avionics system components must be current technology, but it is highly desired to use proven components with a significant service history. Also, as new technology matures, the system design should be such that the new technology can be incorporated. Rockwell examined the feasibility of using a current integrated commercial aircraft system for the HL-20. An entire suitable system was not found, and the present baseline is a buildup of components from several on-going programs. The assessment of the avionics system included fault-tolerant processing; guidance, navigation, and control (GN&C); displays and controls; communications; health monitoring; and flight software.

Processing System

The on-board processing system must be highly reliable and redundant since it is a flight critical system in a vehicle carrying people. The Space Shuttle is totally dependent on its processing system and a fail operational/fail safe architecture has provided a successful design. Several architectures were examined for fault-tolerant processing for the HL-20. An architecture based on the advanced information processing system (AIPS) philosophy developed by the Charles Stark Draper Laboratory for NASA was examined. This architecture consists of a centralized AIPS fault-tolerant processor (FTP)[10] with triply redundant MIL-STD-1553B data buses for the input/output links to the subsystems. The FTP itself is a set of triply redundant processors operated synchronously with identical software and hardware fault-detection capability. This approach was developed for an entry research vehicle (ERV) that was studied[10] previously by the NASA Langley Research Center. The FTP is currently being developed for the engine-controller function on the NASA space transportation main engine for the National Launch System (NLS) Program.[11]

Another architecture examined in this study made use of multiplexer/demultiplexers (MDM) in the forward and aft avionics compartments with a space-rated central triplex processor (see Fig. 3). This is the space station approach. The processors studied included the space station standard data processor and the advanced spaceborne computer module (ASCM) that is being developed for the U.S. Air Force. Since this hardware is to be space qualified by October of 1993, these components have been selected as the baseline for both the Rockwell and Lockheed HL-20 concepts. The ASCM components are scheduled to have an 18-month delivery capability after an order is received.

Guidance, Navigation, and Control

The guidance, navigation, and control avionics system consists of the forward and aft RCS drivers and OMS interface, launch-escape system thrust vector controllers, and aerodynamic surface and landing gear actuator controllers. It also includes cockpit displays and controls, an integrated inertial navigation system, horizon sensor, star tracker, microwave landing system, radar altimeter, air-data system, and rendezvous/docking sensors. Several of these devices are baselined to be very similar to their Shuttle Orbiter counterparts. These include the OMS/RCS drivers, star tracker, and radar altimeter. The current baseline air-data system is a Shuttle-type system; however, a flush mounted system should be given further consideration for simplicity and an expanded envelope of usefulness. The launch-escape system thrust-vector-control electronics will depend on the type and number of rocket motors selected. (This will be discussed further in the abort/adapter systems section.) Nevertheless, the interface to the GN&C system should be similar to the Shuttle OMS interface. The aerodynamic surface and landing gear brake and nose wheel steering controllers will be designed for electromechanical actuators instead of hydraulic actuators as used on the Shuttle.

The inertial navigation system that will be used on the HL-20 is expected to be an integrated laser inertial system coupled with a global positioning system (GPS) receiver to provide a highly reliable and accurate navigation state. This system is being developed commercially and has been the focus of several aircraft flight experiments. Initial designs were flight-tested in 1986 and directed toward airline applica-

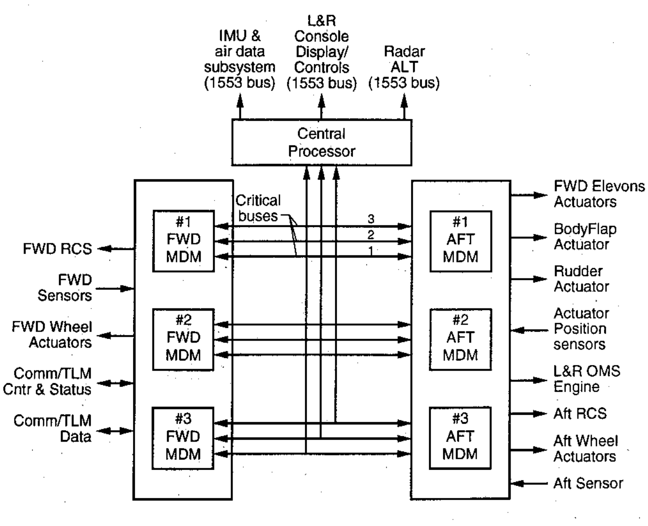

Fig. 3 HL-20 avionics block diagram.

tions.[12] Later studies demonstrated the applicability of the approach to manned re-entry vehicles when using a horizon sensor attitude alignment.[13] Fault tolerance designs have been developed using a strapdown ring-laser gyro hexad configuration.[14] This design provides fail operational/fail safe redundancy for both long-duration and manned space missions. A commercial aircraft package that includes an air-data system and sensors for flight control is expected to be in production by the mid-1990s. Recent flight tests using an integrated system[15] on the Langley Research Center 737-100 aircraft have shown that when inertial and barometric altitude data are included in the navigation system, the integrated approach can be used for an autoland system without relying on a microwave system or other landing aid. In this system, data from a landing-site GPS receiver were required to provide the aircraft with the landing-site position using the available satellites to eliminate any satellite availability and ionospheric effects on the GPS range data. The star tracker or horizon sensor would be required to provide on-orbit alignment for the inertial system.

The cockpit displays make use of the current state-of-the-art systems. The "glass cockpit" approach uses modern flat-panel technology and selectable formats. A display format approach and potential display requirements are available from the motion base landing simulations.[16] The simulation has also shown the desirability of having a heads-up display.

Since the HL-20 is designed for routine missions to the space station and the orbital parameters and geometry will remain somewhat constant, an automatic rendezvous and docking capability should be feasible. This would require suitable sensors and appropriate software. Since there would be knowledge of the relative orbits of the two vehicles, only line-of-sight sensors for proximity operations would be required. Lasers and very short-wavelength radar systems are the leading candidates for the sensors, and both are existing technologies that would have to be adapted for this role.

Communications

The HL-20 communication requirements are somewhat less than those for the Shuttle since the mission complexity is much less, but many of the components could be modern versions of the Shuttle components. The HL-20 requirements include voice and telemetry downlink and uplink with the ground, voice and telemetry communications with the space station, air traffic control link with landing sites, an emergency transponder, and a crash recorder. If mission requirements are changed to include extravehicular activity (EVA), then appropriate links will be required. Also if significant onboard or EVA activities are required, then a video downlink could be required. Both these systems are called for in the baseline systems, but are not required for the design reference mission.

Vehicle Health Monitoring

The HL-20 incorporates a health-monitoring or vehicle management system that provides for onboard vehicle checkout and health status/fault data recording. This system also provides the necessary caution and warning functions for the vehicle and crew. The vehicle systems must be designed with integrated diagnostics and system performance sensors. Additionally, a data recording and both inflight and ground-based analysis capability must be provided. The commercial aircraft industry is moving toward a central maintenance computer approach that has an onboard display unit and either a telemetry downlink or datalink to a ground computer at the maintenance facility. The Rockwell approach for the HL-20 has dual redundant health-monitoring processors with access to the main central processor system for status messages and alarms. Expert systems in the health-monitoring processors assess fault and wear data that will be saved on optical disks for later downlink and postflight analysis. The Lockheed baseline incorporates an overall vehicle management system with a vehicle monitoring subsystem. The main technology challenges in the development and implementation of these systems are the high false alarm, cannot duplicate faults, and retest "OK" rates that occur in many current systems.

Software

A flight software lines-of-code estimate for the HL-20 was made using a bottoms-up approach. This approach was first used in the mid-1980s, when an ERV GN&C and processing system was defined by the C. S. Draper Laboratory in a task for the Langley Research Center. The Space Shuttle backup flight system (BFS) was examined by function to determine applicability to the ERV system. Some functions were deleted and new functions added as needed to the BFS to estimate the total number of bits required to size the ERV onboard computers. When the HL-20 was envisioned for use as an assured crew return vehicle (ACRV), Langley used this process to estimate the lines of code to determine software cost. The Johnson Space Center also contracted with the Draper Laboratory to perform this type of estimate for other ACRV configurations. This technique has now been used for the HL-20 PLS mission. About 170 software functions were examined for use in the HL-20 PLS and modified for hardware changes, and about 20 other functions were added to account for new capability such as health-monitoring, autodocking, etc. Since the Space Shuttle system was coded in a higher-order-language, the HL-20 software estimate was converted to Ada lines of code. The prediction by this method is 290-k lines of Ada code. Rockwell estimated approximately the same number using a Shuttle comparability approach and Lockheed estimated 206-k lines of Ada code.

Environmental Control and Life Support

The environmental control and life support (ECLS) system is designed to provide fresh air and cooling for the 72-h mission, and sufficient oxygen and nitrogen are stored for at least one cabin repressurization. The cabin atmosphere throughout the mission must be compatible with the space station, which will have an atmospheric pressure of 14.7 psi and normal nitrogen/oxygen balance. The design is based on the Shuttle system, in which 1) contaminants are removed from a fan-driven cabin airflow, 2) a water loop is used to transport heat, and 3) a flash evaporator is used to reject the excess heat overboard. Since the mission is intended to be no longer than 72 h, there does not appear to be a need for a Shuttle-type space radiator. Rockwell utilized the newer systems that are being developed for the Shuttle extended-duration orbiter that would require the least maintenance. The chosen approach is a new Shuttle regenerable CO_2 removal system using solid amine beds. Heat rejection in the Rockwell concept is dependent entirely on a flash evaporator. Lockheed added an ammonia boiler for atmospheric heat rejection which is the Shuttle approach, and chose the standard Shuttle lithium/hydroxide canister system for CO_2 removal.

Personnel Accommodations

In the cylindrical cabin, the seats are positioned two abreast with an aisle between them. This approach provides the maximum potential for mobility in the cabin, but the aft two rows of seats are crew-height-limited because of the proximity of the cabin side wall. The seats are configured to accommodate the height range from the 95% American male to the 5% oriental female, that is, 6 ft, 3 in. to 4 ft, 10 in. The height limitation is discussed in detail in Ref. 17. The seats will be required to be repositioned from straight up for ascent to reclined for entry. Current design is to recline the seat backs at 16 deg for entry. The entry accelerations sensed by the HL-20 will be relatively small (less than 1.5 g). It may be desirable, however, to increase the reclining angle to position the heart and head of the returning deconditioned crew in a more horizontal plane. This position will help keep the blood from draining from the head, which would cause crew persons to blackout during and after landing. Another potential feature

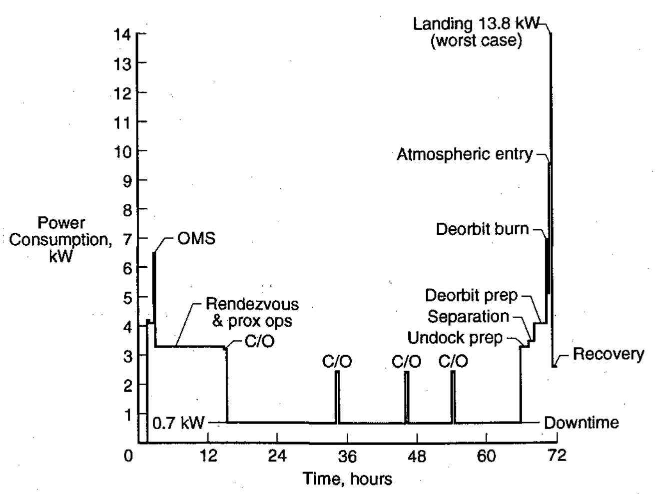

Fig. 4 PLS mission power history timeline.

will be the ability to totally recline the seat for the sick or injured. In this situation, it may also be desirable to be able to easily disconnect the upper portion of the seat from the pedestal and use it as a litter for removing the sick or injured from the vehicle. Since the seats will be occupied while the vehicle is in the vertical position for ascent, the seat backs must be designed to carry the full weight of the heaviest crew member falling onto the seat back. The design loads should be the same as those of the Shuttle seats. This includes up to 20 gs longitudinally and 10 gs vertically for crash loads. The Rockwell concept calls for five rows of two seats, whereas the Lockheed concept specifies four rows of two seats.

Since the vehicle is being designed to be a basic transporter and not a live-in flying laboratory, it does not have crew quarters with galley and lavatory facilities. Any meals required during the mission would be simple packaged meals, and flight crew diapers would probably be used. The new Shuttle head design appears to fit the vehicle when the last row of seats is removed from the eight-passenger configuration. The cabin is sized for crew members wearing either lightweight flight suits or partial-pressure suits. If partial-pressure suits are worn for launch, the crew would be expected to remove them once the vehicle reaches a phasing orbit.

An internal ladder is required for ingress and egress from the 36-in.-diam ceiling hatch on the pad. This ladder is expected to be integral with the ceiling area of the cylindrical crew cabin. The use of the ladder is discussed in Ref. 17. The aft portion of the cabin is a conical section that tapers to the aft hatch size. The tunnel area can be used as an airlock if a hatch is placed at the front of the tunnel. This provision does not appear to be required for the role of a space station people transporter, but may be required for other missions. The aft hatch is designed to be the hard docking port with the space station node. An adapter on the node will be required to taper from the space station hatch size to the 42-in. aft-hatch diameter of the HL-20.

Power Supply and Distribution

Figure 4 shows an estimate of the power history timeline for the 72-h PLS mission. This timeline assumes worst-case requirements, including a 15-h launch, phasing, rendezvous, and docking sequence; several vehicle checkout operations prior to return; and 5 h for undocking, deorbit, entry, and landing. Also, while the PLS is docked with the space station, the crew is assumed to be onboard the station and only thermal control system functions are occurring on the PLS vehicle. The peak load of 14 kW occurs at landing when all aerodynamic surfaces are active, the landing gear is being deployed, and other electronics are in use.

The user power requirements for the HL-20 PLS dictate a low-voltage supply, except for aerosurface actuators. The baseline is a 28-Vdc system connected to three cross-strapped power buses running the length of the vehicle. Internally redundant converters are connected to these buses to provide 270-Vdc power for the actuators. Several potential power sources, including chemical batteries and fuel cells, were examined for the HL-20 PLS. Rockwell found that a fuel cell system would be heavy for the nominal 72-h mission and fuel cells are historically maintenance-intensive. Therefore, following a duty-cycle analysis of the power users, Rockwell selected silver-zinc battery packs with fail operational/fail safe redundancy. The concept was considered to be the least costly and easiest to maintain. The silver zinc batteries are rechargeable, but they would have to be removed from the vehicle for charging. An 80% charge must remain in the battery to be rechargeable. The total power load estimate of 112 kW-h would require about 3000 lb of batteries. These batteries would be configured in eight packs; six are required for the mission and two are for redundancy. Four packs are located in the nose and four in a side bay on the vehicle center of gravity. Lockheed also chose the silver-zinc approach after much study as described in Ref. 9.

Thermal Control

Cold plates with fluid heat-transport loops for the avionics components have been a manufacturing and maintenance difficulty in past programs. Since many of the avionics components are smaller and require less power than their predecessors, Rockwell proposed using passive cooling for these components. The design approach is to mount these components on the aluminum pressure vessel wall near the ECLS cooling water lines and absorb the generated heat through the structure. This approach is employed in the unpressurized compartments of several modern aircraft. A simplified analysis showed that the approach would be feasible if we assume that the components can operate at higher than usual temperatures, which several vendors say is acceptable. A proposed test of the approach is described in Ref. 7.

Abort/Adapter System

An expendable element in the HL-20 PLS configuration is the conical-adapter section that carries the ascent thrust loads from the booster to the spacecraft. The design and manufacturing aspects of this adapter concept are discussed in Ref. 9. It also contains the launch-escape system (LES). If a failure is

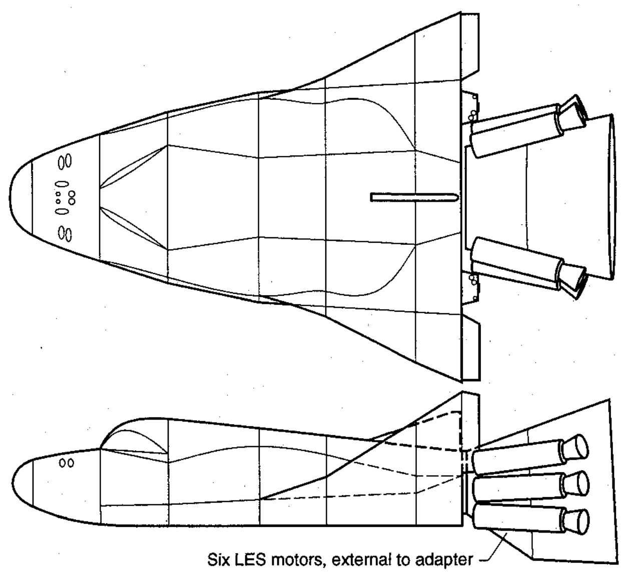

Fig. 5 PLS escape motors.

imminent in the booster system, the LES is designed to propel the HL-20 away from any potential explosion or out-of-control element. An acceleration of about 8 g, which is approximately the maximum passengers can tolerate, will allow the HL-20 to move almost 500 ft from an exploding booster in about 3 s. For the estimated explosive potential of a Titan booster with solid-rocket motor strap-ons or the liquid hydrogen/liquid oxygen NLS booster, this distance will reduce the overpressure to about 10 psi, which is a structural design load case for the HL-20. Just over a 2-s warning of the impending explosion is required.

The LES consists of multiple solid-rocket motors attached to the outside surface of the adapter with nozzle gimbal capability for steering. The Rockwell concept[8] has six motors, shown in Fig. 5, that are 18 in. in diameter and 7.5 ft long. They produce 41 klb of thrust, each for 4 s. The Lockheed concept[9] has four solid-rocket motors that are 7.25 ft long and 20 in. in diameter. These motors produce almost 250 klb of thrust for just under 4 s. The thrust vector control system provides a nozzle slew rate of up to 25 deg/s. The propellant for both concepts is the Shuttle solid rocket booster, separation motor grain.

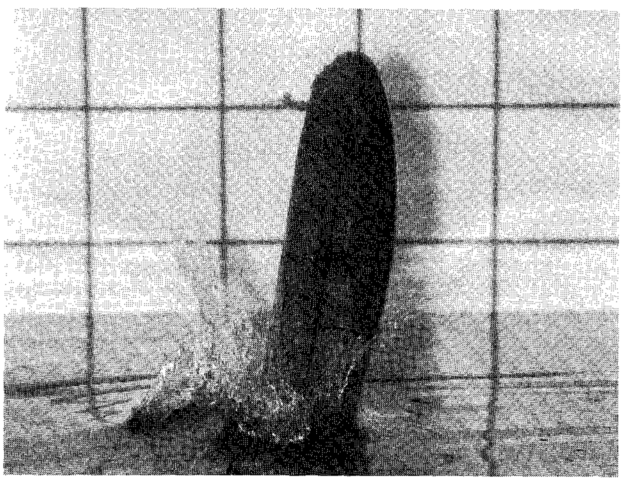

Fig. 6 HL-10 water entry tests.

Table 2 Mass properties

Component	Rockwell Weight, lb		Lockheed Weight, lb	
Wing group	1869		1782	
Center fin	69		69	
Body group	3502		3502	
Thermal protection	2124		2166	
Landing gear	1161		927	
Propulsion	1366		976	
Prime power	2880		2695	
Electrical conversion and distribution	1226		1170	
Actuators	172		268	
Avionics	1337		978	
ECLS	2070		1618	
Crew accommodations	1434		1180	
Recovery and auxiliary	1961		1839	
HL-20 dry weight	21,173		19,170	
Personnel and provisions	2415		1953	
Fluids and residuals	727		318	
HL-20 landed weight	24,315		21,441	
Consumables	5038		4045	
HL-20 launch weight	29,353		25,486	
Adapter/LES	10,348	(Titan IV)	6699	(Titan III)
HL-20/adapter launch weight	39,701		32,185	

The abort analysis presented in Ref. 4 shows that two smaller sustainer motors are also needed to abort to a runway from the pad. This entire launch-escape system will be separated at booster burnout in a nominal mission.

The launch-escape system also requires a parachute system for water landing for much of the trajectory.[4] Both baseline concepts have three Apollo-type ringsail parachutes sized for a 30-fps vertical velocity at splashdown. The concept uses the Apollo approach of deploying drogue chutes followed by a mortar-fired pilot chute for each main chute. Each main chute is about 120 ft in diameter and there is redundancy such that if one chute fails to deploy, the splashdown velocity will be less than 40 fps. The chutes would be housed under panels on the upper surface of the vehicle near the center of gravity. When chute deployment is required, the panels would be pyro-separated, and the chute risers would be pulled from under the TPS blankets on the vehicle upper surface. The riser attachment would be configured so that the vehicle enters the water tail first, with the vehicle centerline about 85 deg above the horizontal. This entry attitude was shown in HL-10 tests in the 1960s to minimize the entry-g accelerations on the crew. The entry deceleration for the HL-10 with a sink rate of 40 fps and water entry angle of 85 deg (see Fig. 6) was 3 g initially and 5 g when the vehicle surfaced and splashed down on its belly according to Ref. 18. Since the HL-20 has two stable floating positions in the normal horizontal upright attitude and inverted, a flotation system is needed to raise the aft hatch above the water line to assure that at least one hatch is accessible for egress.

Mass Properties

The mass properties of both configurations are given in Table 2. Although the vehicles have identical exterior geometry, the Lockheed configuration has accommodations for eight persons onboard and the original Rockwell configuration has accommodations for 10 persons. Other weight differences can be attributed to the selection of different subsystem components or different designs. The subsystem weights have a weight margin that is dependent on system maturity and ranges from 5 to 40%. The composite margin for the dry weight is 18.5%.

Subsystem Qualification Testing

The subsystems will be subjected to varying amounts of testing depending on component maturity, flight criticality, and operational environment. The use of previously flown components can save significantly in the development program and will be the approach taken whenever possible. For new designs and significantly modified components, extensive testing will be required to qualify and provide the failure and lifetime characteristics. Simple approaches to environmental and interface simulation will be used when possible. However, to minimize the operational costs, tests designed to insure operational life capability will be required. The commercial airline techniques for individual subsystem categories will be examined to determine the most cost-effective flight qualification approach.

Conclusions

The baseline subsystem selection and software sizing for the HL-20 PLS for each contractor and some alternatives have been presented in this article. Differences due to the crew size change and minor design modifications have been discussed. Both baseline concepts utilize current technology systems, many of which have flight histories. Other selected components have considerable development heritage in other programs. There are no subsystem technology breakthroughs required for the development of this concept. Both the designs focus on ease of maintenance, have considerable similarity, and are complementary. Thus the two sequential contractor studies with different perspectives gives credibility to the viability of the concept approach.

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