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A Logical Space Transportation Strategy

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ABSTRACT

Even before the first launch of the Space Shuttle in April 1981, the debate had begun on the characteristics of follow-on space transportation systems. The debate continues today and has intensified, as the need for low-cost space transportation becomes more manifest. The range of vehicle concepts includes single and multi-stage systems, fully and partially reusable concepts, vertical and horizontal launch and landing, and rocket and airbreathing propulsion. In fact, one could conclude that the debate has taken a life of its own and in some instances is perhaps based more an emotional argument rather than solid technical conclusions and logical examination of pressing transportation needs. As a result, those responsible for making system development decisions have not been sufficiently driven to consensus and action. Of course, all agree that reducing launch costs is critical to future space programs and the expansion of space for the benefit of humankind, and positive steps have been taken to invest in critical technologies aimed at that goal. However, exactly what systems are needed and who will build and operate them remains part of the debate.

A more rational analysis of the near-term requirements for space transportation leads to a different focus on candidate transportation system options. For example, the world is presently limited to two system capabilities for placing humans in orbit--the U.S. Space Shuttle and the Russian Soyuz--with the Shuttle being the planned, primary means of supporting future Space Station operations. Some would question the wisdom of total dependence on singular capabilities for assured human access to space. Dependence on Soyus is currently complicated by internal Russian political and financial uncertainties. In addition, most would agree that reliance entirely on the Space Shuttle system for human transport represents a justifiable concern for the possibility of an operational International Space Station with no practical way of transporting people to or from it.

This paper will discuss options for assured access to space and the transportation of people and priority cargo to the Space Station. These options include concepts that require no new technology and that may be made operational for reasonable developmental investment. The development and operation of these concepts will also provide more time to advance the technologies needed for a much more efficient space transportation system to replace the Space Shuttle. A logical approach to near-term space transportation will also allow the debate to continue until a consensus is reached as to the solution for an advanced system that best satisfies long-term transportation requirements.

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INTRODUCTION

At the time this paper was proposed, the first author planned to present a space transportation systems architecture that could be deployed in the near-term to satisfy launch requirements with little or no advanced technology and with minimum financial investment. However, the National Aeronautics and Space Administration (NASA) recently embarked on an industry-led study (Space Transportation Architecture Study) to define space transportation architecture options that will satisfy NASA's launch needs over the next two decades and that will reduce launch cost for the Agency's programs. Because the first author is currently involved in the evaluation of the industry-proposed architectures, he has been placed in a position of conflict with respect to personally proposing architectures that may appear biased towards a particular space transportation approach to accommodating a total future mission scenario. It is for this reason, and the fact that much recent attention has been given to alternate means for human transport to orbit, that this paper will focus only on the requirements for space transportation systems that consider the need for assured human access to space.

There are many systems concepts that can provide assured access to space, and each of the concepts considered may prove to be a viable approach to satisfying the need. This paper presents a view of the desirable characteristics and top-level programmatic and technical requirements for an assured human space access capability. The information presented herein is mostly drawn from the work conducted over a period of several years at NASA's Langley Research Center and supported by several industry design efforts. The focus of those efforts was the definition of a concept designated the Personnel Launch System (PLS). The development of the concept is well summarized, including much discussion on related requirements, in Reference 1. The PLS concept was matured to a sufficient level to establish considerable confidence in the technical and programmatic approach, and it was based on research on lifting-body vehicles during the 1960's. It is therefore believed that the research effort on the PLS forms a credible basis for defining the top-level requirements and systems options for an assured access capability. Although this paper references the extensive research at the Langley Research Center, it is not intended to advocate any particular concept but rather to provide the rationale and requirements for such a vehicle system.

The need for a space transportation vehicle to provide assured human access to space has been proposed by several groups tasked to define future space-related requirements and concepts. For example, the Leadership and America's Future in Space Group of 1987 produced a report commonly called the "Sally Ride Report," (Reference 2) that stated, "The United States should seriously consider the advisability of a crew-rated expendable to lift a crew capsule or a logistics capsule to the Space Station. The crew capsule would carry only crew and supplies, would launch on the expendable vehicle, would have autodocking capability, and might also be used for crew rescue." Other related recommendations include that of the 1990 Presidential Commission on the Future of the U.S. Space Program, referred to as the "Augustine Report" (Reference 3). It stated, "NASA should initiate design effort so that manned activity in the Space Station could be supported in the absence of the Space Shuttle. Crew recovery capability must be available immediately and provision made for the relatively rapid introduction of a two-way personnel transport module on a selected expendable launch vehicle."

PROGRAMMATIC AND MISSION REQUIREMENTS

It is assumed that the Space Shuttle will continue to be the primary space transportation system of the United States for the foreseeable future and will support International Space Station (ISS) construction and operations. It is also assumed that advanced space transportation technology and technology flight demonstration programs will continue until the development of a Space Shuttle replacement system is affordable and advantageous to the Government and industry. Until that time, transporting people to space will be mainly accomplished with the Space Shuttle. Another option available for transporting people to space is the Russian Soyuz, but some may question the longer-term availability of this option. Therefore, total reliance on the Space Shuttle and the Soyuz may not be the most prudent approach to support the ISS or other missions that require on-demand transportation of people and priority cargo to and from Earth orbit.

The demand for assured space access is focused on Space Station crew rotation and the delivery and return of priority cargo from space. Previous studies suggest that the availability of an assured access capability would serve to complement and extend the life of the Space Shuttle, not replace it. An assured space access capability could also complement any new Reusable Launch Vehicle (RLV) option. Other possible requirements include orbital rescue, satellite servicing and inspection or other missions where human access to space is required. A new system for assured access must satisfy the requirements of placing people and priority cargo into low Earth orbit, of a cost effectiveness greater that the Space Shuttle, of improved crew safety and reliability, and of increased operational performance margins.

Another aspect of a vehicle that provides assured human access to space is the potential application of the concept to assure crew return from the ISS in emergency situations. A Crew Return Vehicle (CRV), as currently envisioned supporting ISS operations, would be available for use during emergencies that hopefully never occur. In other words, considerable investment may be made in the development of a vehicle we hope to never use. Therefore, the design of a CRV based on emergency-driven crew return requirements alone may not be the best approach. It is suggested that an assured human access vehicle, designed to meet the two-way requirements of launch to orbit and return, could also be a much more cost-effective solution to satisfying CRV requirements.

The assured access vehicle comprehensively studied in Reference 1 was referred to as the Personnel Launch System (PLS), and the remainder of this paper will use the PLS results derived from that well-documented study as a basis for assured access vehicle requirements. The PLS and CRV vehicles will have many of the same general mission requirements. The near-term capacity requirements will generally be from six to eight passengers and, if not designed only for automated entry and landing, they will require a pilot and co-pilot as part of the manifest. Each PLS mission is expected to last a minimum of 3 days, and an included space propulsion system provides at least 335 m/s on-orbit-maneuvering capability to reach the ISS from low-Earth orbit. It is envisioned that to minimize the development cost, the reusable assured access vehicle would be appropriately sized to be launched on existing, or slightly modified, expendable launch vehicles modified to meet human-rating requirements. For application as a CRV, the vehicle would be sized to fit in the Space Shuttle cargo bay for routine transport to the ISS or recovery for periodic maintenance.

VEHICLE DESIGN REQUIREMENTS

General

In order for a PLS to be developed at the lowest possible cost and to be available within a reasonable timeframe, extensive use of current technologies and off-the-shelf components is warranted. Studies of applicable concepts indicate that there are no technology barriers to an efficient design, and a successful development effort could be initiated with little risk. The vehicle design must give priority to crew safety during all phases of the mission. For either the case of autonomous entry and landing or for inclusion of a pilot in the operation of the vehicle, the vehicle must possess a controllable and flyable design. There must be adequate accommodations for the passengers throughout the mission including design for effectively handling of a variety of emergency situations. In addition, to limit the cost of development and operations, the vehicle design must permit ease of manufacturing, operation, and maintenance. More discussion on these points will follow later.

The requirement that the vehicle be capable of docking and berthing with the ISS and the advantage of alternate landing site capability are obvious. To limit vehicle loads and accommodate deconditioned or sick/injured passengers, entry and landing accelerations must be held to acceptable levels--below 2 g's is highly desirable. Of primary importance for either PLS or CRV applications are the requirements for entry cross-range and the landing method. For more effective operation as an assured access vehicle and for accommodation of the widest variety of emergency scenarios, a large entry cross-range capability is very desirable; on the order of 2,000 km has been suggested by most studies of related concepts. In addition, the selected landing method has been shown to be most important. For crew safety, rapid recovery, minimum refurbishment expenses, and the least investment in recovery infrastructure, runway landing appears to be the most desirable landing method. With a 2,000 km cross-range and assuming a capability of landing on runways of at least 3 km, one can define scenarios for landing the vehicle at any time. For example, as shown in Table 1, the assumption of five worldwide existing Space Shuttle landing sites, permits a runway landing from every orbital pass.

1100 nmi maximum crossrange capability for PLS

Orbit Number	Orbit inclination = 28.5°	Orbit Inclination = 51.6°
1	KSC, EAFB, HAFB, BJ	KSC, EAFB, SA, MAB
2	KSC, EAFB, HAFB, BJ	KSC, EAFB, MAB
3	KSC, EAFB, HAFB	EAFB, HAFB
4	EAFB, HAFB	EAFB, HAFB
5	HAFB	KSC, EAFB, HAFB
6	HAFB	KSC, EAFB
7	HAFB, SA	KSC, EAFB
8	SA	EAFB
9	BJ, SA	HAFB, SA
10	BJ, SA	HAFB, SA
11	BJ, SA	SA
12	BJ, SA	MAB
13	KSC, SA	MAB
14	KSC, BJ, SA	MAB
15	KSC, EAFB, BJ	KSC, MAB

All Space Shuttle approved sites available for PLS runway landing

KSC = Kennedy Space Center
EAFB = Edwards Air Force Base
HAFB = Hickam Air Force Base
SA = King Khalid, Saudi Arabia
BJ = Banjul, Gambia
MAB = Moron Air Base, Spain

Table 1. Daily Day/Night Landing Opportunities by Orbit

Aerodynamics

As can be seen in Figure 1 (Reference 4), in order for the PLS to achieve an entry cross-range of 2,000 km, the vehicle's aerodynamic configuration must be designed with a hypersonic lift-to-drag ratio (L/D) of about 1.4 (similar to a Space Shuttle).Configurations demonstrating L/D values in this range include much-studied lifting bodies, and for this and many other practical reasons, the lifting body most probably would be the configuration of choice for a PLS.

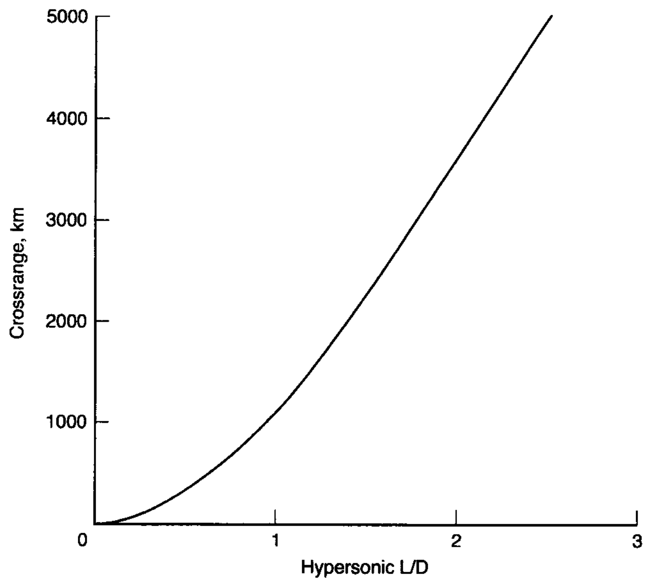

Figure 1. Variation of Entry Crossrange with Hypersonic L/D

While offering good hypersonic aerodynamic characteristics, the subsonic aerodynamics of a lifting body can be a compromise in flight characteristics across the speed range. For acceptable landing at reasonable speeds (on the order of the Shuttle) and requiring a runway length of less than 3 km, a subsonic L/D of greater than 4.0 is desirable; a real challenge for the lifting body. As demonstrated in References 5 and 6, with extensive wind tunnel testing, complimentary computational fluid dynamic studies, and careful attention to aerodynamic design details, a lifting body can achieve the landing objectives while providing a vehicle with handling qualities at Level 1 on the Cooper-Harper rating scale, a requirement set forth in the recently released requirements for human rating (Reference 7).

Aerothermodynamics and Thermal Protection

Although considerable advancement has been made in Thermal Protection System (TPS) technology since the development of the Space Shuttle, assured access vehicles as those studied in References 8 and 9 can rely on the Space Shuttle's state-of-the-art TPS. As shown in Figure 2, by properly configuring the PLS and selecting an entry trajectory to minimize entry heating loads, Space Shuttle reusable TPS is more than adequate for the windward surfaces with carbon-carbon used only on the nose and leading edge areas. Flexible Reusable Surface Insulation (FRSI) blanket material is completely sufficient for protecting the rest of the surface area. For more enhanced durability and lower life-cycle cost associated with PLS operations, current, more mature TPS technologies would certainly be applicable. Serious consideration should also be given to including metallic TPS in the design. A decision to use enhanced TPS technology should result from trades that compare cost, operational efficiency, and structural weight.

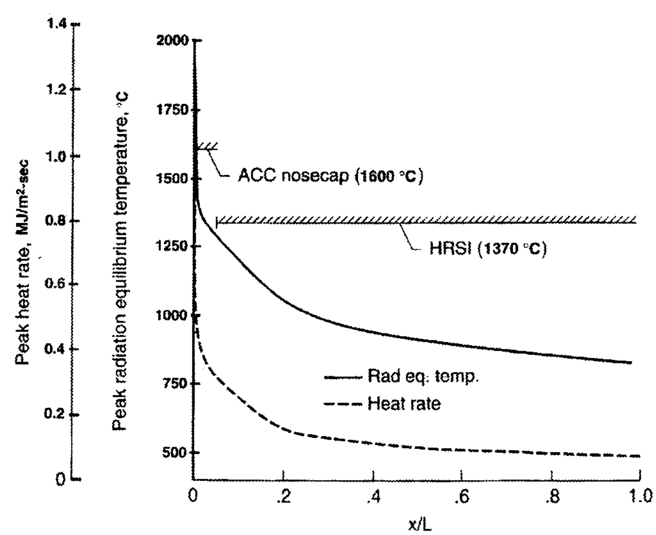

Figure 2. Windward Centerline Peak heating Distribution/MaterialRequirements

Structures and Materials

To be compatible with the widest possible variety of expendable launch vehicles, the PLS vehicle must be designed with a maximum gross take-off weight of less than $16X10^3$ kg including all propellants, launch escape systems and vehicle adapters. PLS studies have shown that by using conventional aluminum structures concepts, such a weight goal is very achievable, even with a 20 percent structural weight margin included at the conceptual-level design (References 10 and 11). More extensive use of up-to-date materials and structures technologies such as aluminum-lithium or composites can reduce the overall vehicle weight and increase the design margins for expected structural loading. As with the selection of any technology, the selection of a material or structural concept should be based on the subsequent development and operational costs for the PLS application. It is probable that more current design studies will result in the newer materials being selected. In addition, for the lowest cost, the overall structural concept selected for the PLS must be as easy to fabricate as possible. For example, extensive PLS structural design considerations resulted in the selection of a cylindrical crew cabin vessel to minimize weight and keep fabrication cost to a minimum. Further discus-sion of minimum fabrication cost considerations is presented later.

Guidance and Control

The requirements for the PLS guidance and control system appear to be relatively straight-forward using current technologies for a lifting-body configuration as that described in References 6 and 12. For use as an assured space access vehicle or as a CRV, the vehicle can be designed for piloted and/or automated entry and landing at a reasonable vertical and horizontal speed at touchdown. It has been shown that with a subsonic L/D of at least 4.0, a lifting body can be made to land at a vertical velocity at main gear touchdown of less than 1.5 m/s and a horizontal touchdown velocity of less than 100 m/s. It has also been shown that adequate aerodynamic tailoring of the configuration can result in a subsonic L/D on the order of 4.5 to 5.0 with corresponding reductions in the landing speed.

While provisions for a pilot being in control demand that the vehicle demonstrate handling qualities of at least a value of two on the Cooper-Harper scale, a value of one was demonstrated for the PLS during ground-based research using motion simulations (Reference 6). In addition, during these landing simulations, a capability to land during crosswinds of up to 13 m/s and autopilot touchdowns within 240 m of nominal longitudinal touchdown with initial energy dispersions of ±25 percent were also demons-trated. These studies also suggested that a combi-nation of the unique characteristics of the lifting-body configuration and landing angle-of-attack may require careful attention to vehicle design details to ensure that the pilot's view from the cockpit is not obscured.

Safety

Specific PLS requirements that focus on important crew safety aspects of the concept gave emphasis to launch abort capability and protection of the crew during subsequent vehicle recovery. The inclusion of ejection seats is always an option. However, intact vehicle abort during all mission phases is obviously very desirable and may permit a more overall simple structural design.

Launch pad emergencies can be accommodated in at least two ways. Where 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 way. Of course, this mode of escape requires that the vehicle provide the flexibility for the crew to rapidly evacuate. Crew egress studies using a full-scale mockup of the PLS design in Reference 13 demonstrated the ability to evacuate the crew in less than 30 seconds from either the top or rear hatches of the design. In the event of a more serious, immediate emergency on the launch pad, a launch escape system integral to the launch configuration is required. Such a system was extensively studied and presented in Reference 14. A launch abort adapter with fast burning, high thrust separation rockets fitted between the PLS and the booster would work in a manner similar to the abort tower of the Apollo/Saturn launch system. Studies have shown that the system must be designed to escape beyond a distance where the PLS and crew would experience less than a 70 kPa overpressure and would not be exposed to greater than 8 g's acceleration during the abort maneuver. The system requires just over 2 seconds warning of a pending major emergency; admittedly a significant launch booster design challenge. Under certain condi-tions following abort, the vehicle may be pro-vided enough energy for a Return to Launch Site (RTLS) runway landing as described in Reference 14. However, assuming that the launch-aborted PLS would subsequently be parachuted to a water landing, the vehicle would have to be designed for structural and dynamic integrity during and following the entrance into the water. For example, it would be a requirement that there be more than one exit hatch for crew egress and that at least one of these hatches remain unsubmerged, thus providing safe, easy egress from the vehicle after touchdown.

During a nominal ascent, there should be multiple abort modes. They include RTLS to a runway landing, abort to an ocean landing by parachute, an trans-Atlantic landing (TAL), and Abort to Orbit (ATO). Studies of abort modes for the PLS are also described in Reference 13. During the initial part of the launch trajectory, the primary emergency abort mode should be firing the emergency escape rockets followed by gliding flight to subsonic speeds and a RTLS maneuver or deployment of the parachute system to an ocean landing. Depending on the launch site, inclination of the intended orbit, and type of launch vehicle, an abort to a coastal or inland landing site is possible over a portion of the launch trajectory. Under worst case conditions, an ocean landing abort mode could cover as much as 70 percent of the launch trajectory. Under these circumstances, the crew is rescued following landing, but the vehicle may sustain salt water and impact damage requiring a degree of refurbishment. Both the vehicle and crew are recovered in the TAL or ATO modes, which cover the remaining 30 percent of the ascent trajectory. If the expendable booster has an engine-out capability, ATO would be the preferred abort mode.

Reliability

Much of the mission assurance and confidence of crew survivability and vehicle recovery will be the result of designed-in reliability of the PLS and launch booster, the incorporation of a launch escape system for emergencies, and the inclusion of acceptable margins in the overall design. Currently, there is growing debate on the proper role of humans in controlling vehicles like the PLS and the potential benefits to improved crew and vehicle safety. Previous PLS designs effectively accommodated pilot control of the vehicle while also providing for automated entry and landing. Current technology is fully capable of satisfying automated control requirements, and the role of humans-in-the-loop in providing additional assurance of survivability and mission success could become more of a policy (and somewhat emotional) issue. For the most effective overall design of any future space transportation vehicle, the confidence of crew survival and vehicle recovery must be derived from appropriate trade assessments. These trades should search for a cost-effective balance of vehicle systems reliability, degree of human control, and the inclusion of other provisions such as escape capability. The goal for overall vehicle system reliability should be at least 0.999 with 0.99 as an absolute minimum. For robustness, vehicle design margins as large as practical must be considered. For example, the following would be desirable: (1) a structural design margin of at least 1.5 and a structural design life of at least twice the vehicle operational life, (2) a mechanical design life at least 2.5 times the operational life, (3) an engine operation never to exceed 80 percent of maximum take-off thrust, and (4) average mechanical equipment operating power levels of no more than 80 percent of maximum operating capability. (Reference 16)

Efficient Operations and Low Cost

For the lowest vehicle life cycle cost, the designer must capitalize on the lessons learned from the Space Shuttle Program. The assured access vehicle must be of a simplified design with particular attention paid to the ease of its production. For example, results of the PLS design studies (Reference 17) showed that for aiding in the production process, design consideration should be given to manufacturing breaks in the structure to reduce tooling requirements and assist in the ease of subsystem installation during assembly. A separate, one-piece heat shield structure installed late in the production process should also be considered.

The vehicle must be designed for maintainability and operability, and most agree that this implies that the vehicle should be designed for airline-type maintenance procedures involving simplified ground operations and quick vehicle turnaround. The concept of "design for system access" is the foundation for minimum operations cost. While the inclusion of capability for built-in tests of system and subsystem condition is extremely important, the location of subsystems for ease of maintenance, replacement, or repair is also critical. For example, one of the key provisions in previous PLS designs was the location of subsystems for access external to the crew pressure vessel. With the additional capability of accessing these subsystems through removable panels in external vehicle surfaces, this allowed the ground maintenance to be accomplished much like working under the hood of an automobile. From Reference 16, the goal for accessibility of each subsystem for inspection, test, or replacement should be less than one serial hour, and each subsystem should be designed as a Line Replaceable Unit (LRU) with removal and replacement times not to exceed one serial hour. Further, the goal for Vehicle Mean Time Between Repairs (MTBR) should be 10 or more flights.

Another key provision for operational efficiency is that of runway landing rather than other obvious alternatives such as recovery from water landing or landing at desolate or isolated sites. Runway landing offers simplified, less costly vehicle refurbishment and less damage potential than landing at these other sites, and minimizes landing impact loads on deconditioned or injured crew. Other operations features that will help assure minimum cost include designing the vehicle for standard missions and returning to the launch site after a mission. This would eliminate ferry requirements after a nominal mission. The vehicle should be designed for landing at (or aborting to) available worldwide sites and for ease of transporting the vehicle from the landing site to the launch site if they are different.

Human Factors

The human accommodation requirements of an assured access concept are well covered in Reference 13. In summary, the top-level requirements include the accommodation of the 5^{th} to

95^{th} percentile people, and the vehicle must be of sufficient size and configuration to permit rapid emergency and routine ingress and egress on the pad and after touchdown. It must also permit rapid, easy evacuation of injured crew. Previous studies indicate that at least 1.42 m^3 per person provides an acceptable volume for an adequately equipped vehicle to accommodate most, if not all, crew requirements. In addition to the previously discussed requirement for two hatches, a standard cabin atmosphere of 100 kPa with enough gas supply for at least one repressurization is required.

Technology Requirements

For the lowest development cost, the assured access vehicle should be designed using low risk, state-of-the-art-technologies and off-the-shelf components where appropriate. Related studies described in Reference 11 indicate that considering maturity levels of 1993, the technologies required to satisfy the design and operational requirements of the PLS were either already available or under development. Only two areas required any significant advancement, and these were technologies involved in the PLS computer architecture/software area and systems for vehicle built-in test and evaluation. The rest of the required technologies were, at the time, matured to an off-the-shelf level, and many were already in use on the Shuttle. For example, the Orbital Maneuvering System/Reaction Control System (OMS/RCS) concept and the TPS were both Shuttle technologies. Structures involved the use of standard aluminum or composites, and the use of available fighter aircraft modified landing gear. Flight controls and avionics were designed of standard spacecraft and aircraft systems, and electromechanical actuators were used in the design. Lithium and/or NiCad batteries provided the needed power, and the environmental control and life support systems were derivatives of the Shuttle systems.

LAUNCH VEHICLE REQUIREMENTS AND OPTIONS

The PLS spacecraft does not possess major propulsion of its own other than on-orbit maneuver capability. Instead, it relies upon launching it on top of a separate launch vehicle. As described in Reference 1, PLS test launches utilized the Titan III expendable launch system while operational launches were to utilize a lower cost launch vehicle under study called the National Launch System (NLS).

Today, there are a number of possible launch vehicle options that can offer launch of the assured human access vehicle into orbit. Titan IV is an available asset although launch costs would be greater than that of Titan III. Lower cost options include the former Soviet Union systems Zenit and Proton that are presently being marketed in the United States by Boeing and Lockheed-Martin, respectively.The Ariane 5 represents an international launch system that could provide Europe with an independent means of assured human access to ISS and other missions. In the United States, the Evolved Expendable Launch Vehicle (EELV) program is maturing with the Boeing Delta 4 using a new RS-68 propulsion unit and the Lockheed-Martin EELV based on RD-180 propulsion. Either of these systems have enough lift capacity to place a PLS into orbit.

The selection of a launch system for the assured human access vehicle will depend on issues of cost and availability as commercial markets vie for the use of these systems. The cost to human-rate these launch vehicles is a factor that must be considered, and the adaptability of the launch vehicle to carry the PLS spacecraft is a design issue. For example, in the Reference 15 study, an adapter system was designed to carry the PLS on the Titan III and NLS launch vehicles without the PLS moldline shape being modified in any way. This is an important consideration as changes in moldline shape of the PLS can have consequences in terms of the aerodynamic and landing characteristics of the PLS spacecraft. Finally, the placement of the assured access vehicle at the top of the launch vehicle stack affords an easier opportunity for launch escape rather than the instance of a spacecraft being placed within the launch vehicle stack itself. Also, launch escape motors can be attached to the launch adapter and not the spacecraft itself thereby reducing integration issues and easing detachment from the spacecraft as the spacecraft reaches orbit.

DEVELOPMENT OPTIONS

An assured access-to-space vehicle of the type discussed above could be a valuable asset to the world's human space transportation capability and in providing greater confidence in the continuity of ISS operations. As this paper has attempted to indicate, the development and operation of such a system may be the next logical step for a near-term solution to space transportation needs. Referenced studies have shown that the development of the system can be achieved at a relatively low cost and at a low risk using current technologies. However, there is at least one additional consideration in deciding how to develop such a system:

The International Space Station is an international asset, and each participating country has a vested interest in assuring that access to the facility is maintained. In other words, getting to, and from, the ISS could be viewed as an international responsibility. For that reason, it is a logical assumption that the development of an assured access, or PLS-type, system could be a joint international development and operational responsibility. The advantages to this approach are obvious, but they include minimizing the initial investment of any single nation and more easily capitalizing on the availability of the number of booster options for the concept. In addition, any participating country could have access to the concept for further applications, such as satellite servicing, orbital rescue, or other orbital sortie missions.

SUMMARY

The foregoing discussion has focused on presenting the rationale and top-level requirements for a new space transportation system. The Space Shuttle will continue to be the primary transportation for supporting International Space Station operations for the near future, but its availability for any space mission may be dependent upon experiencing no major system failure or accident. Therefore, the requirement for an alternative means for supporting the ISS suggests the need for a new system that would provide assured human access to space. The new system could guarantee continuity of ISS operations in the event of a situation where the Shuttle is unavailable and provide an option for meeting emergency crew return requirements. The need for such a system has been identified on numerous occasions by studies on the future uses of space. The assured access vehicle requirements, as presented, suggest the feasibility of developing a vehicle using current levels of technology maturity and with minimum investment cost and development risk. The requirements and design features presented are for an assured access concept that can be operated with minimum life-cycle cost.

The assured access vehicle design must give priority to crew safety and successful vehicle recovery during all mission phases. The design must provide a cost-effective balance of vehicle systems reliability, degree of human control, and the inclusion of provisions such as crew escape. The inclusion of an off-the-pad escape system in the launch configuration is a very desirable feature as are abort options throughout the launch trajectory.

For minimum cost, the vehicle must be of simple design with sufficient systems and operations margins and features to facilitate production, maintenance, and operation. A key to operational simplicity is the requirement for runway landing that permits greater flexibility for vehicle and crew recovery following a mission and very desirable options for ascent abort. Previous studies have shown that a properly designed vehicle can effectively land on a runway of 3 km length either under pilot control or with autoland systems.

There are a number of booster options for placing the vehicle into orbit. In the United States, Titan IV, Zenit and Proton launch systems are available today. The Evolved Expendable Launch Vehicle program will soon provide other options for placing the assured human access vehicle into orbit at lower cost. The Ariane 5 launch vehicle provides Europe and the other ISS partners with an additional means of accessing ISS and performing other missions using an assured human access vehicle.

Finally, because the ISS is an international asset, transportation to and from it is an international responsibility. For this reason, and to minimize the investment cost for a single nation, the development and operation of an assured access vehicle could be a joint venture involving all ISS partners. A beneficial result of this development approach would be that each nation would also have use of the concept to satisfy its individual space transportation needs where the vehicle's capability would be applicable.

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