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A PROPOSED IMPLEMENTATION STRATEGY FOR BUILDING A SHARED SPACE INFRASTRUCTURE* **

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Abstract

This paper describes an achievable and affordable approach for building a shared space infrastructure. This infrastructure will benefit all three space sectors—commercial, civil and national defense—by providing new and enhanced shared capabilities that will improve the safety, reliability and affordability of their robotic and human space operations.

The proposed Phase 1A (2000-2017) infrastructure will be comprised of commercial Reusable Launch Vehicles; a Shuttle-derived, unmanned, heavy-lift launch system; four low Earth orbit (LEO) spaceports; spaceport-based interorbit transports capable of reaching geosynchronous orbit; and, an in-space logistics support capability. During Phase 1B (2018-2025), the infrastructure expands the size of the LEO spaceports to accommodate specialized user needs, adds new Earth-to-orbit low cost launch systems for durable cargo, adds upgraded interorbit transports to provide support lunar and deep space exploration, and adds first-generation interplanetary spaceships to extend routine transportation to lunar orbit. This space infrastructure will also be capable of supporting a manned Mars exploration program and robotic probes to near-Earth asteroids and comets.

This paper focuses on a strategy for building and financing this shared space infrastructure. Specifically, it describes an acquisition strategy for Phase 1A that effectively uses current space technology and infrastructure capabilities to reduce programmatic risk and enables achieving an initial operational capability in 2012. Further, it describes an approach for financing the fabrication and operation of the Phase 1A infrastructure and covering necessary transportation transition costs using funds already budgeted for in the present government spacelift budget.

Introduction

The potential for future growth in commercial, civil and national defense space operations, especially with regard to human and complex robotic activities in space, is constrained by widely held perceptions of what is achievable and affordable to undertake at this time. The purpose of this paper is to argue that these perceptions are outdated; that in reality the United States now possesses the technological capability to build a robust shared space infrastructure that will set the stage for revolutionary advancements in the space operations of the commercial, civil and national defense space sectors.

This is the fourth paper in a series that describes how to build a robust space transportation, habitation and in-space logistical support infrastructure in the first two decades of the new century. The first paper discussed the importance of carefully and systematically undertaking the planning of an integrated space infrastructure, defined operational needs that such an infrastructure should meet, and proposed a general architecture for this infrastructure.[1] The second paper identified a concept for economically building large space bases in low Earth orbit to meet an integrated space infrastructure's need for permanent human habitats in space.[2] The third paper proposed a specific shared infrastructure including: reusable launch vehicles (RLV) for "aircraft-like" access to low Earth

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[*] The views expressed in this paper are those of the authors and do not necessarily reflect the position of the United States Air Force or NASA.

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orbit; large spaceports in LEO capable of providing safe habitation for 100-150 people; interorbit transports based at the LEO spaceports; and, an integrated network of logistical support capabilities utilizing these RLVs, interorbit transports and spaceports.[3]

This fourth paper discusses the maturity of the technology base required to build the proposed Phase 1A space infrastructure and proposes a strategy and timeline for developing the individual infrastructure elements in order to achieve an initial operational capability in 2012 and a full Phase 1 capability by 2025. A preliminary funding budget to implement the Phase 1A infrastructure is discussed to demonstrate that despite the significant enhancement to space operations enabled by the proposed space infrastructure, the cost of building and operating this infrastructure is comparable to what is currently budgeted for Government spacelift alone and may be achieved through the judicious reallocation of these funds combined with a shift to the use of commercialized space services.

Space Infrastructure Objectives

Phase 1 (2000-2025) will design, develop, build, deploy and operate an integrated, commercialized space infrastructure extending from the Earth's surface to the surface of the moon. This infrastructure will enable routine and affordable human and robotic space operations in circumterrestrial and circumlunar space and on the moon. It will provide transportation, habitation and in-space logistical support for specialized commercial and governmental space operations similar to the support provided by analogous commercial and governmental terrestrial infrastructures. This shared space infrastructure will also support human and robotic explorations of Mars and near-Earth asteroids and comets.

Phase 2 (2026-2050) will expand the shared space infrastructure to enable extensive human settlement and industry in circumterrestrial and circumlunar space and on the moon. The infrastructure will be extended to Mars and near-Earth asteroids and comets to support the initial permanent base on Mars and the exploitation of resources from non-planetary solar bodies. The infrastructure will support the direct human exploration of the other planets and the first robotic interstellar exploration missions.

Phase 1 (2000-2025) Infrastructure Description

Phase 1A (2000-2017) Infrastructure Elements

- Reusable launch vehicles: Provide "airline-like" transport of people and materiel to and from LEO. Payload capacity is approximately 13,000 kg. At least two different designs will be operated to provide assured access.

- Shuttle-derived vehicle (SDV): Unmanned Saturn-V class expendable launch system derived from current Space Shuttle technologies and launch facilities. Used to launch large space infrastructure components (e.g., spaceport modules) as well as large specialized payloads such as space-based radar and large geostationary communication satellites. Payload capacity is approximately 90,000 kg.

- Interorbit transports: Small RLVs that extend the transportation network for people and materiel throughout circumterrestrial space. Launched via RLVs or SDV. Payload is approximately 1000 kg (internal); additional payload carried externally. Delta-V approximately 5000 m/sec (internal fuel); additional Delta-V with external tanks. Enhanced interorbit transports will be capable of landing and taking off from the lunar surface and providing point-to-point transport on the moon. At least two different designs will be operated for redundancy.

- LEO Spaceports: Large modular space stations that are the destination for the RLVs, bases for the interorbit transports, and the base for in-orbit logistical support services. Built using large modules, 8.4 m (27 ft) in diameter by 30.5 m (100 ft) in length, manufactured using Space Shuttle external tank technologies and launched via the SDV. Initial capability supports 100-150 people; expandable to 300-400 people by adding additional modules to meet the specialized needs of infrastructure users. Figure 1 shows a notional spaceport design with a long hub incorporating large airlocks to which configurable spokes are attached. Spaceport expansion is through adding additional spokes.

- In-space logistics support: Includes satellite inspection, repair, servicing, deployment and retrieval; free-orbiting facility maintenance; space suit servicing and repair; communications support; propellant and power supplies; waste product collection; medical and recreational facilities; en route passenger facilities; bonded warehousing; water, air, propellant and toxic material storage and spare parts stocking; emergency rescue and damage control; and, facility management.

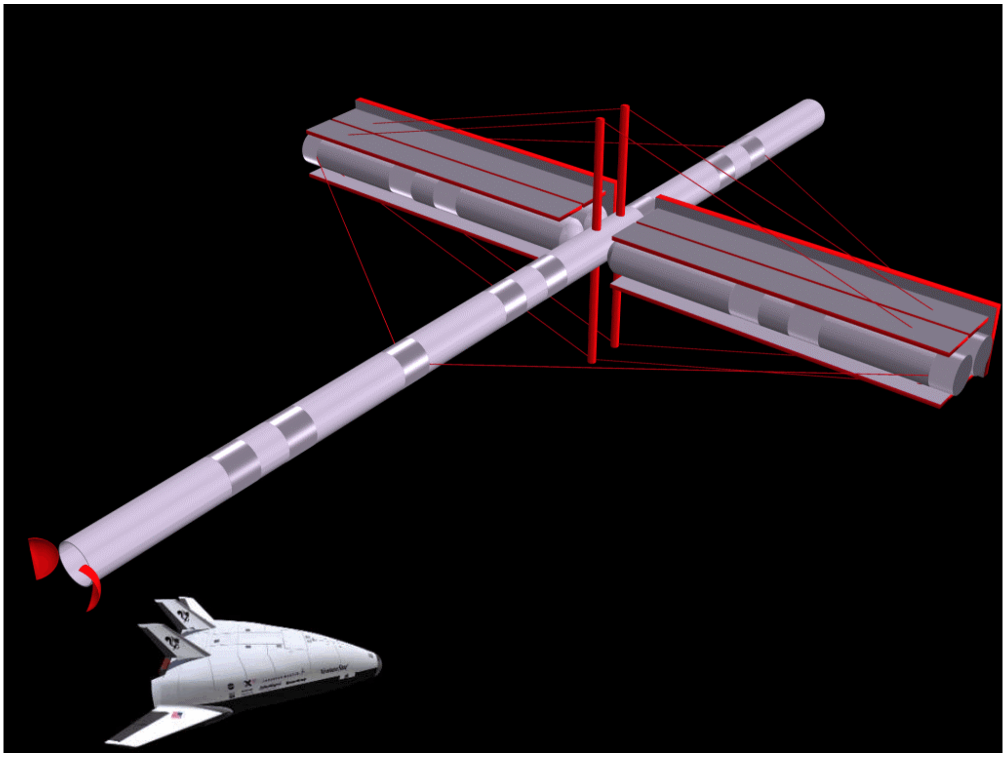

Figure 1

Baseline modular spaceport shown with Lockheed Martin SSTO VentureStar RLV; one of several candidate RLV designs.

Phase 1B (2018-2025) Infrastructure Elements

- Interplanetary spaceships: Large reusable transports launched into orbit on the SDV and based at the spaceports. Provide transport from LEO to lunar orbit and return. Carries modified interorbit transports as lunar landers.
- Unmanned durable cargo launch system: Optimized to provide low-cost spacelift to the LEO spaceports for propellants, air, water, and certain other durable cargo such as frozen foods. Examples of this launch system include maglev launch-assisted systems and laser-boosted launch systems.
- Lunar orbit and surface spaceports: Built using modular elements derived from LEO spaceport modules.

Phase 1 Technology Readiness

The widely held perception is that the technologies needed to build the proposed space infrastructure are not sufficiently mature. Hence, the consensus is that the United States is many years away from any serious consideration of beginning to build such an infrastructure. The strategy described herein for building the shared space infrastructure specifically targets this common misperception by identifying the robustness and readiness to proceed of the critical technologies required to build the Phase 1A infrastructure systems. The intent is to clearly demonstrate that the United States now possesses the technological capability to design, build and operate a substantial and affordable shared space infrastructure.

RLVs

The most challenging aspect of building the space infrastructure will be the development of RLVs to provide safe, reliable and operable access to LEO. Achieving this goal is a necessary step to truly open the space frontier. Fortunately, the United States has been aggressively working towards this goal.

The Space Shuttle, first flown nearly 20 years ago, was the first step towards achieving this goal. Subsequent technology development through such programs as the National Aerospace Plane (NASP), the McDonnell Douglas Delta Clipper DC-X, several past and current Air Force spaceplane technology programs, the current X-33 and X-34 technology development programs, and substantial industry in-house research and development has significantly advanced the state-of-the-art in these two decades. Since the beginning of the NASP program in the mid-1980s, nearly $5B has been invested in RLV technology development with significant advancements. The current NASA-Lockheed Martin X-33 program will culminate this series of efforts with building and flight testing a sub-orbital demonstrator of one configuration of a single-stage-to-orbit (SSTO) RLV. This program in conjunction with the NASA-Orbital Sciences X-34 and work undertaken by the Air Force focusing on achieving aircraft-like operability with RLVs will establish the current state-of-the-art for critical rocket-powered RLV subsystem technologies such as propellant tanks, thermal protection systems, autonomous flight control systems and advanced aerothermodynamic vehicle configurations.

Given that rocket-powered RLVs are the cornerstone of the shared space infrastructure, it is important to understand that achieving safe, reliable and operable space access are the primary design objectives. The feasibility of achieving SSTO RLVs with sufficient design robustness to satisfy these objectives will not be determined until the X-33 test flights are completed and the test data reduced and analyzed. Should SSTO RLVs not be feasible without further technology advancement, these same technologies will enable quite capable two-stage-to-orbit (TSTO) RLVs to be built. The practicality and affordability of the proposed space infrastructure is not significantly impacted with the use of TSTO systems. Trade studies may indicate that TSTO system configurations are preferable to SSTO alternatives when all necessary design requirements are addressed.

SDVs

The proposed Shuttle-derived Vehicle is based upon previous unmanned, heavy-lift launch system concepts that made use of the manned Space Shuttle technologies, individual components (e.g., the solid rocket boosters) and Shuttle launch facilities to provide a Saturn V-class spacelift capability (Figure 2). Concept studies and program cost estimates for such SDVs date back to at least the mid-1980s. The development of the SDV is generally viewed as a low risk program because it draws extensively upon flight-proven hardware, existing manufacturing processes and established launch capabilities.

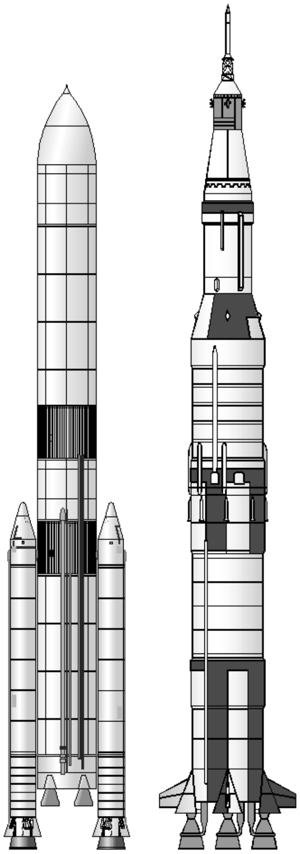

Figure 2

Shuttle-Derived Vehicle and Saturn V

Interorbit Transports

Staring in 1990, McDonnell Douglas, under government contract, successfully designed, built and flight tested a 20,000 kg, 12 m tall, fully reusable rocketship with aircraft-like operability (Figure 3). While it was not viewed as a prototype interorbit transport at the time, the DC-X fully represented the size, propellant fraction and flight agility needed by interorbit transports. The DC-X also demonstrated the critical vertical takeoff and landing capability required for surface landing, such as on the moon. The successful DC-X program coupled with the continuing RLV technology development efforts provides confidence that the technology base needed to build interorbit transports exists today.

Spaceports

After the RLVs, the spaceports will most likely present the greatest technical challenge in building the space infrastructure. The risks associated with this

Figure 3: DC-X Landing

effort will be mitigated by adopting a design and assembly procedure that draws upon the technical expertise and experience gained with the development and construction of the International Space Station (ISS) and the flight experience with the Russian space station Mir. These risks are further mitigated through the judicious reuse of ISS subsystem technologies such as solar power arrays, environmental control systems, communication systems, internal power distribution systems, space suits, personnel airlocks, etc., to reduce development time and increase confidence in subsystem performance.

The primary difference in the design of the spaceports compared with the ISS is the size of the modules. ISS modules, with the possible exception of some specialized applications, are too small for spaceport needs. For example, the spaceport's two airlocks are designed to accept internally two RLV payload modules to transfer personnel and cargo into the spaceport (Figure 4). Each of these payload modules will be comparable in size to the ISS modules—approximately 4.5 m (15 ft) in diameter by 9.1 m (30 ft) in length. To reduce the risk associated with building these larger modules, the fabrication processes and facilities used to build the large aluminum tanks for the Space Shuttle External Tank and, ultimately for the SDV core propellant tanks, will be used to fabricate the spaceport modules. As these fabrication processes are well established and drawing upon the ISS experience, designing and building the larger spaceport modules is believed to be low risk.

In-Space Logistics Support

Of the Phase 1A infrastructure elements, the one with which we have the least experience is on-orbit logistical support. Experience with the repair of the Hubble Space Telescope shows that such logistical support will be more difficult than comparable undertakings on the Earth. It is clear that space systems requiring logistical servicing will need to be specifically designed to permit such servicing to be undertaken as a routine day-to-day activity. The design experience with the ISS, which will require a significant level of on-orbit servicing, is the first step in developing a successful set of space logistics design methodology and practices. The ISS capabilities will be further enhanced with the spaceport design that emphasizes internal rather than external subsystem placement and has large airlocks to bring satellites and interorbit transports into a pressurized environment for servicing.

The strategy proposed to develop, build and operate the shared space infrastructure is to use a government-designated "authority," organized and operated as a commercial enterprise that will have the charter for acquiring the shared space infrastructure services needed by the Government. This proposed approach is built upon three basic premises.

First, the shared space infrastructure proposed herein will not happen until it receives Government endorsement. This is not a new situation. Many major infrastructures, such as George Washington's National Road (what is now Interstate 70 west from Washington D.C. to Illinois), the Erie Canal, the Panama Canal, the intercontinental railroads, and the early stages of the Internet, did not come about until the Government backed these projects. Many of these have required the specific endorsement of the Congress (e.g., the Tennessee Valley electrification program and the Panama Canal). Such endorsements are critical to demonstrating national resolve to support the project. This demonstration of resolve, in turn, encourages private investment in the ancillary specialized operations that will use the capabilities of the infrastructure. It also encourages private investment in

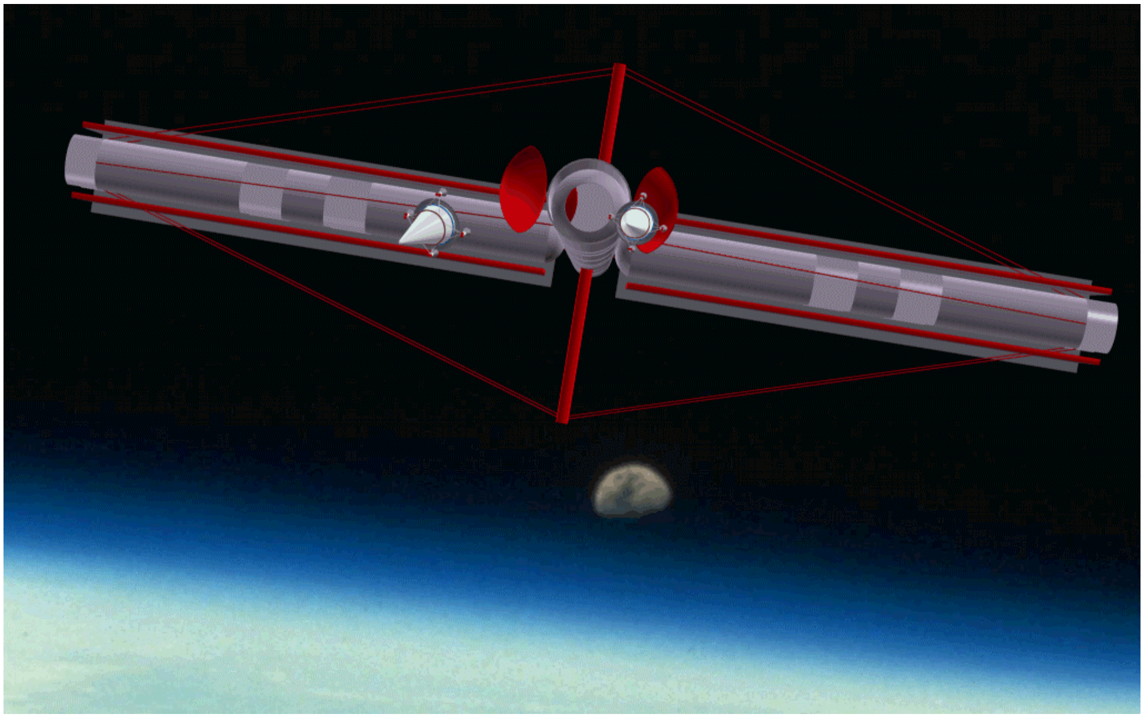

Figure 4

View of spaceport airlock with internal pressure door and external "space doors." Two interorbit transports are also shown. The airlock is an example of a large fully-assembled spaceport module launched into orbit using the SDV.

bonds issued to raise funds for the building of the infrastructure.

Second, the acquisition and operation of the shared space infrastructure must be carefully organized to successfully integrate its many diverse elements (not all of which have been discussed due to limitations on the length of the paper). Because the space infrastructure is not to be operated as a Government service, a non-government body must be created to execute the acquisition of the infrastructure and to oversee its operation. To achieve this careful integration, a successful approach that is often coupled with Government endorsement has been the use of a government-designated "authority" to provide the management for the building and operation of the infrastructure. Such an authority would become the agent for the Government but with the additional clear responsibility to also serve the needs and promote the participation of the commercial space sector. To remove the potential for conflict of interest, the designated authority would be overseen by a small "board of directors" appointed by the president with the consent of the Congress.

This approach sidesteps the intricacies of inter-government agency cooperation that would otherwise be required. It establishes a clear customer-supplier relationship while maintaining a clear line of legal responsibility for ensuring that U.S. obligations under international law are observed. It also permits the Government to focus on defining its technical and performance needs that must be addressed through the shared infrastructure and to put its program acquisition efforts into the new and upgraded specialized civil and national defense systems that will utilize the infrastructure.[*]

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[*] This is not to imply that Government technical and programmatic expertise would not be used. Critical issues such as flight safety certification will require direct Government consultation. Government organizations, such as laboratory and test facilities, would be directly involved just as they now participate in supporting commercial programs. Government program management expertise, particularly expertise with advanced military flight systems, may be expected to be used to help develop risk management strategies to balance program

An alternative to the use of a designated authority is to use a commercial consortium such as the United Space Alliance that now provides much of the support for the Space Shuttle. The breadth of space infrastructure operations, the multi-decade period of performance and, particularly, the potential for conflict of interest with the shrinking number of aerospace companies may preclude such a commercial arrangement for this purpose. For example, it may be expected that Boeing and Lockheed Martin, the two primary partners in United Space Alliance, would compete for the RLV development contracts.

Third, the Government would support its official endorsement of the project by entering into contractual agreements with the designated authority to provide space infrastructure-related services to the Government. Essentially, the Government contractually agrees to accept and pay at negotiated rates for services such as spacelift, on-orbit logistical support and servicing, etc., provided the specific terms of performance are met. These service contracts provide the "anchor tenancy" for the space infrastructure and, in turn, will be used to raise funds to begin to build the space infrastructure. These service contracts will create a new group of space enterprises such as spaceline and spaceport operators that will in turn release contracts to industry to provide RLVs, interorbit transports, spaceport components, etc.

This proposed strategy ensures that most services, e.g., RLV spacelift, provided through the auspices of the authority are actually delivered through competitively selected commercial providers. Similarly, space facilities used by the authority, such as the spaceports, would be leased from commercial real estate leasing companies. This approach helps to ensure that a large non-commercial organization is not created and to maximize commercial participation and competition in building and using the space infrastructure. Essentially, this approach creates the initial demand for new services and encourages the creation of new service providers that can also support the needs of specialized commercial, civil and national defense space sectors.

Implementation Schedule

Obviously, a complete program schedule, as well as the Phase 1A cost estimate discussed below, will require study and analysis beyond the scope of the preparation of this paper. However, a notional schedule can provide an understanding of how the various elements of the infrastructure interact to create a general framework of understanding upon which more in-depth assessments can be built.

For simplicity, Phase 1 activities are assumed to begin in the year 2000. In that year, the Space Infrastructure Authority or SIA is created with the federal charter to build a shared space infrastructure to achieve the Phase 1 objectives. Agencies of the federal government issue memorandum of agreements with the SIA for spacelift, interorbit transport and on-orbit logistical support for civil and national defense needs. These memoranda identify threshold and goal technical performance characteristics, such as payload size and mass. They also identify the targeted initial delivery dates and rates of usage, such as the number of RLV spacelift flights per year. The SIA raises the initial operational funds and issues requests for proposals for the specified infrastructure services and on-orbit facilities necessary to execute and support these services. Once technical performance and costs are defined, formal contracts between the SIA and the Government are finalized. These provide the basis for raising funds necessary to develop and achieve the initial operational capability and for releasing contracts to the commercial service providers that will provide the bulk of infrastructure capabilities.

A notional schedule for Phase 1A (2000-2017) is shown in Figure 5. This phase involves the development and deployment of two RLV fleets, the SDV, four LEO spaceports and the interorbit transports that will be based at these spaceports.

RLVs

The RLV program begins in 2001 and may be expected to reach first operational flight status in 2006 following its flight tests and conditional spaceflight certification by the Government. Operational RLV flights will begin slowly and ramp up as experience is gained and the inevitable problems are solved. Over a three-year period, these RLVs will take over the Government spacelift roles now met with the Space Shuttle and expendable launch vehicles (ELV). By 2009, two or three RLV fleets will be flying a combined total of 40 to 50 flights per year for the SIA. Of this total, about half will be used to meet Government needs for ISS support and satellite delivery. The remaining flights will be used for on-orbit development and testing of interorbit transports and spaceport and other on-orbit infrastructure systems.

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technical, cost and schedule risk and to perform independent risk and progress assessments.

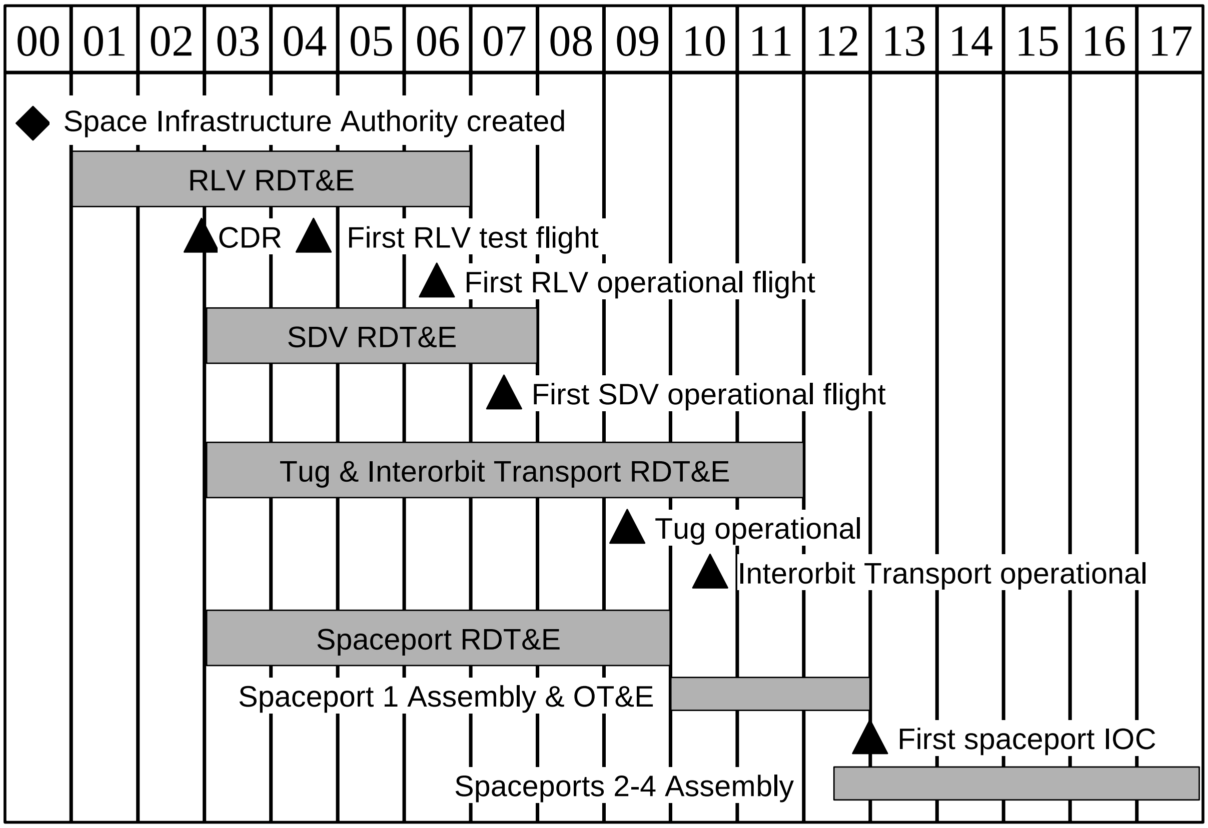


Figure 5: Notional Phase 1A (2000-2017) space infrastructure development schedule

The SIA demand for RLV services during this time is expected to require less than half of the capacity of these systems. The commercial spaceline operators of the RLVs will be free to sell this excess spacelift capacity on the commercial market. This would include meeting the demand for additional Government flights when its needs exceed the baseline number of Government flights included in the spacelift contract with the SIA. Competition between the two or more spaceline operators, intentionally established by the SIA, should result in significantly lower costs for these "market" flights.

SDV

The development of the SDV is expected to be a low risk program specifically because it intentionally uses mature technologies and existing manufacturing and launch facilities and personnel. The SDV program will begin once the RLVs complete their critical design reviews. In Figure 5, this is shown as occurring in early 2003.

The SDV will achieve initial operational flight status in 2007, about one year after the first operational flights of the RLVs. The initial rate of SDV launches will be low—one to two per year—because of the need to share launch facilities with the Space Shuttle. By design, as the manned Space Shuttle missions transition to RLVs and the Space Shuttle is phased out, the number of SDV flights will increase to about five to six flights per year to meet SIA needs. As with RLVs, excess SDV capacity may be sold on the commercial market.

Interorbit Transports

Like the SDVs, the development of the interorbit transports is expected to be a low risk program. This development program will also begin in 2003 following the successful completion of the RLV critical design reviews.

Two versions of each of the two interorbit transports will be developed. The first is essentially a space tug that is designed to aid in the assembly of the spaceports and handling RLV payload modules. The second is the full interorbit transport that will extend the transportation network out to geosynchronous orbit, primarily for satellite positioning and servicing.

On-orbit testing of the interorbit transports will be undertaken starting in 2007 for the tug and 2009 for the full interorbit transport. By design, these transports will be carried into orbit in the payload bay of the RLVs. Beginning in 2007, RLVs will be used to ferry prototype and initial production interorbit transports into space for test and evaluation and pilot training. These RLV flights will be part of the baseline number of flights already contracted for with the spaceline companies by the SIA.

The tug will achieve operational status in 2009 to support the initial spaceport module launches. The interorbit transport will become operational in 2011 to provide initial on-orbit satellite servicing. They will also provide space search and rescue support for the assembly of the initial spaceport and related on-orbit systems such as the propellant servicing facility.

<u>Spaceports</u>

The development of the spaceports will be undertaken in parallel with the SDV due to the close synergy between these two systems. Following appropriate ground testing, prototype airlock, hub and spoke modules will be launched into orbit using SDVs in 2007-2008 for test and evaluation. Prototype tugs will be used to position and control these modules and to test procedures to be used to mate spaceport modules together. RLV flights will ferry engineering and test crews into orbit and be used to recover the SDV’s primary liquid propellant engines and avionics module. (As described in detail in Reference 2, the SDV’s liquid oxygen and liquid hydrogen propellant tanks are incorporated into the spaceport design to provide additional inhabitable volume. This means that the main engines and avionics modules can be recovered in orbit and returned in RLVs for reuse and further reducing the cost of SDV spacelift.)

The SDV flights to place the first spaceport’s modules in orbit will begin in 2009 to coincide with the phaseout of the Space Shuttle. Over two years, the required eight SDV flights will be flown to place the seven spaceport modules and associated equipment (e.g., solar arrays) into orbit. RLV flights will bring tugs, interorbit transports and ISS modules modified as “space construction shacks” to the space construction site. They will also transport the spaceport construction crews; replenishment supplies for the crews, tugs and interorbit transports; and, smaller spaceport components that cannot withstand the SDV launch environment. It is expected that 25 RLV flights will be used during each of these two years—flights already included in the baseline SIA contracts—to support the assembly of the first spaceport.

The first spaceport assembly will be completed in 2011. On-orbit test and evaluation, initial crew training and the initial stockpiling of logistics support equipment and materiel will be completed in 2012, at which time the first spaceport will become operational.

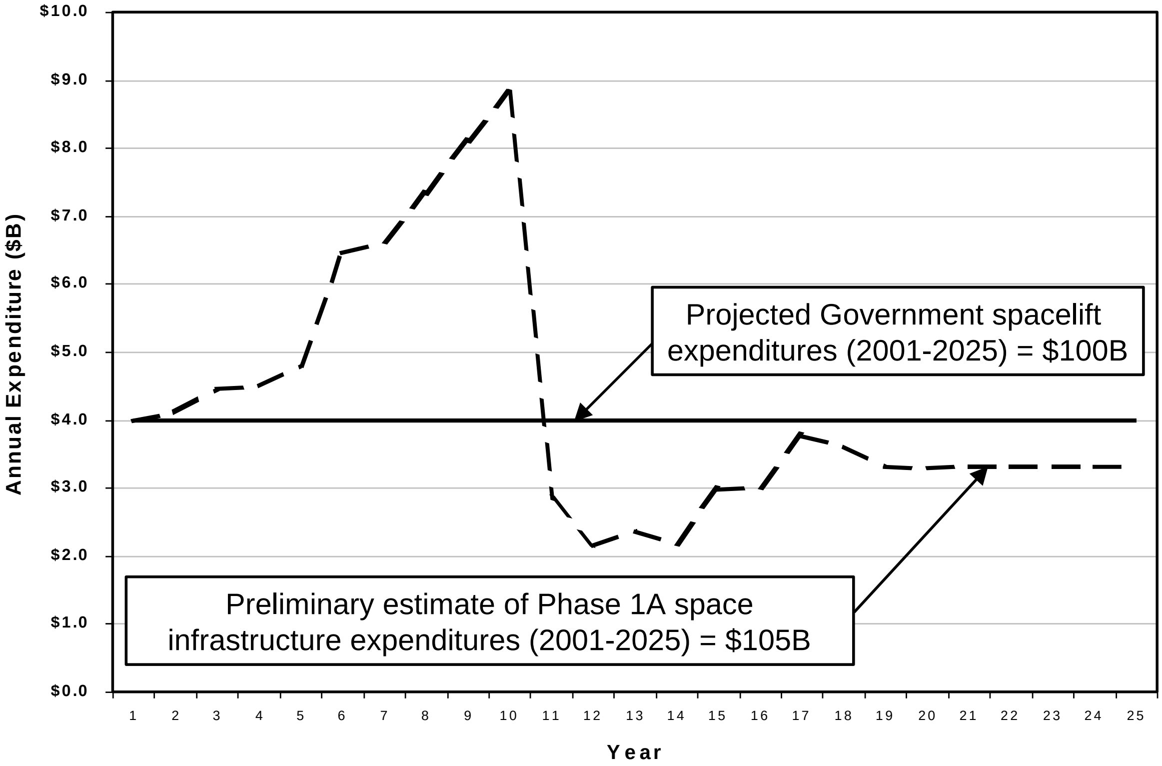
By maintaining serial production of the fabrication and launch of spaceport modules, three additional spaceports will be built in 2012-2017. Depending upon demand, the expansion of the first spaceports to add specialized user facilities may also be undertaken during this time. This serial production approach will maintain a steady baseline of SDV launches in support of the SIA until at least 2020 when the expansion of the last of the spaceports may be expected to be completed.

These four spaceports are to be positioned in orbital inclinations of 15, 30, 45 and 75 degrees. Coupled with the substantial performance capability of the interorbit transports, this spaceport orbital spacing permits circumterrestrial space out through geosynchronous orbit to be reached for providing on-orbit logistical support. Also, as commercial passenger-carrying RLV flights increase, this spaceport positioning supports providing space search and rescue capabilities throughout LEO.

Implementation Costs and Affordability

Figure 6 compares the current projected costs of Government spacelift with a very preliminary estimate of the Phase 1A space infrastructure costs. The current projected Government spacelift costs includes the Space Shuttle, medium class expendable launch vehicles (ELV), and the Titan IV. The FY01 cost is estimated at approximately $4B. Over the 25 years (2001-2025) of Phase 1, the total projected Government spacelift costs are $100B. (No adjustments for inflation are included in these estimates since these are used only for affordability comparisons.)

The authors have prepared a very preliminary estimate of the costs to develop, build and operate the Phase 1A infrastructure described herein. This estimate includes two fleets of four RLVs (of two different designs for assured access), the SDV, two fleets of eight interorbit transports (of two different designs for redundancy) and the four spaceports (baseline configuration with four spokes). The estimate also includes the cost of operating existing spacelift systems, such as the Space Shuttle, during the three year transition period to full RLV flight operations, the



development costs of the payload modules for the RLVs and new and modified ground launch facilities. This estimate includes over 1400 RLV flights, including 24 RLV flights per year to meet continuing Government spacelift needs for ISS support and satellite delivery, and nearly 60 SDV flights.

The authors' cost estimate for Phase 1A infrastructure elements, including their operation through 2025, is $110B. This includes a $47B estimate for engineering and manufacturing development and production costs for the RLVs, SDV, interorbit transports and spaceports. However, for simplicity, this cost estimate does not include any estimates of offsetting income from commercial user fees for on-orbit logistical support services and spaceport user fees. Such fees may be expected to cover a significant percentage of the recurring annual operational costs of approximately $3B.

There is no sidestepping the issue that the cost of building and operating the proposed Phase 1A shared space infrastructure will be significant. However, compared with the projected cost of Government spacelift over the same 25 years, it was found that the two costs were comparable. Stated in another way, from the Government's budgetary perspective, the cost of building and operating the shared space infrastructure proposed herein is approximately the same as the cost that the Government now plans to spend only on Government spacelift. Hence, it may be concluded that the proposed shared space infrastructure offers an affordable alternative to the current spacelift-only path while providing a significant enhancement in overall Government and commercial capabilities in space.

Conclusions

One hundred years ago, as the 1900s approached, the technologies that would transform our civilization in the 20th century were coming out of the laboratory to redefine our civilization—radio, automobiles, electricity, medical science, quantum mechanics and airplanes.

Now as the horizon of the 21st century approaches, the technologies that will again redefine our civilization are emerging. Prominent among these will be the technologies that will bring our transformation from a space exploring to a spacefaring nation. The shared space infrastructure proposed herein provides a technologically achievable and affordable means to begin this transformation—a transformation that will be critical to this nation's continued prosperity and world leadership.

While it is difficult to clearly see what lies beyond this new horizon, we approach it with the same enthusiasm and confidence as did our forefathers at the beginning of the 19th and 20th centuries. Only this time, when we speak of "to boldly go," our eyes will turn upward towards the newly accessible space frontier.

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1 J. Michael Snead, “Space Infrastructure Planning,” Proceedings of the Fifth International Conference on Engineering, Construction and Operations in Space, Albuquerque, NM, 1-6 June 1996, American Society of Civil Engineers, Volume 1, page 360.

2 J. Michael Snead, “Building Large Space Bases in Low Earth Orbit,” Proceedings of the Fifth International Conference on Engineering, Construction and Operations in Space, Albuquerque, NM, 1-6 June 1996, American Society of Civil Engineers, Volume 1, page 367.

3 J. Michael Snead and Walter E. Hammond, “Air Force, NASA and Commercial Cooperation in Establishing a Robust Space Infrastructure," Proceedings of the Sixth International Conference and Exposition on Engineering, Construction and Operations in Space, Albuquerque, NM, 26-30 April 1998, American Society of Civil Engineers, page 693.