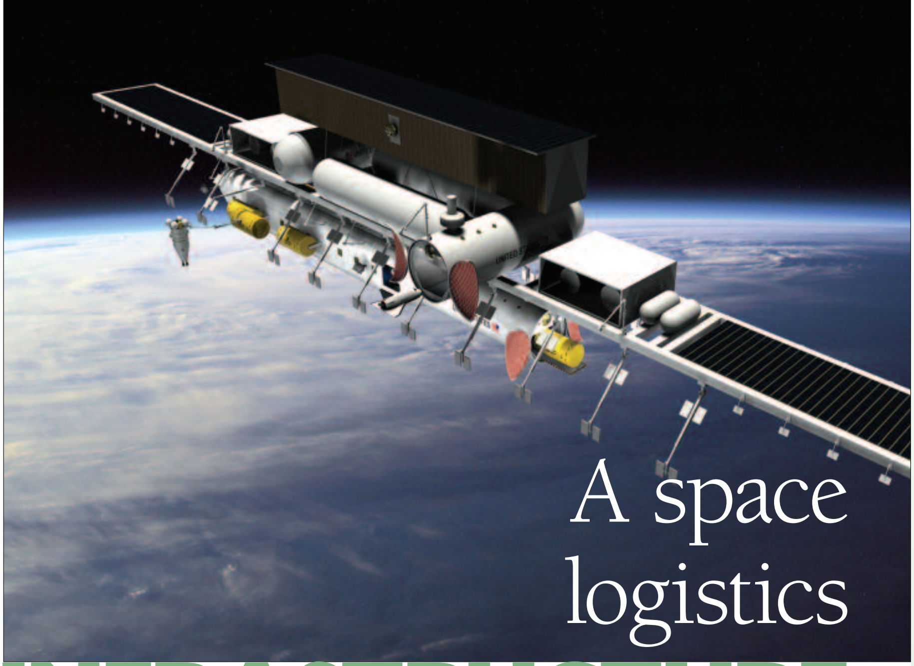


A space logistics INFRASTRUCTURE for the near term

To be truly considered a spacefaring nation, the U.S. must first achieve routine, safe, and affordable space operations. A major barrier to realizing this capability is the misconception that such operations can be attained without the development of an integrated space logistics infrastructure. However, studies now show that this vital step could be accomplished over the next 25 years with technologies available today.

by **James Michael Snead**
Aerospace engineer
Air Force Research Laboratory

For longer than expected, civil, commercial, and national security operations in space have remained difficult to execute safely, effectively, and affordably. Yet the U.S. retains its desire to become a true spacefaring nation and is committed to overcoming the operational challenges this presents.

These challenges arise from the expectation that routine, safe, and affordable space operations can be executed without an integrated space logistics infrastructure. But as history has repeatedly shown, establishing logistics infrastructure has always been necessary for opening new frontiers. Fortunately, the U.S. aerospace industry now has the ability to develop, deploy, and operate an integrated space logistics infrastructure that would turn the U.S. into a true spacefaring nation during the next 25 years. This infrastructure would include aircraft-like space access for passengers and cargo, heavy spacelift, in-space logistics support for human and robotic space operations, and aircraft-like in-space mobility throughout the Earth-Moon system

In the aerospace industry, the technology readiness level (TRL) scale is used to assess the maturity of new technologies. The scale ranges from a minimum value of 1, for basic principles observed and reported, to a maximum value of 9, for the actual systems in operation.

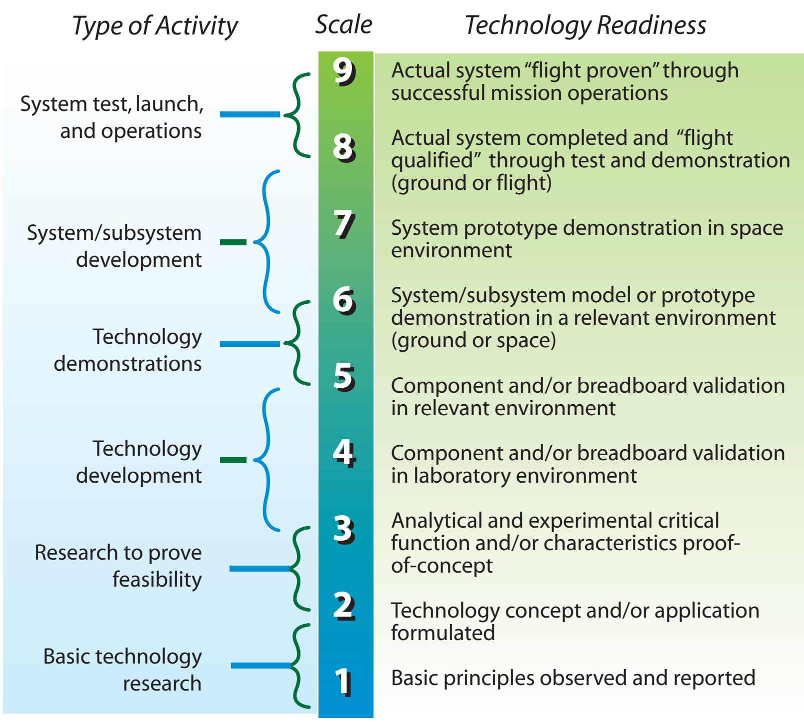
It is generally accepted that when a new concept's enabling technologies reach or exceed a TRL rating of 6—defined as "system/subsystem model or prototype demonstration in a relevant environment (ground or space)"—they are mature enough to support a decision to initiate system development. Hence, system concepts employing enabling technologies rated at TRL 6+ are near-term solutions.

With one exception, described later, these system concepts employ TRL 6 or higher technologies and thus may be considered near-term solutions.

Establishing aircraft-like space access

Fundamental to deploying a useful space logistics infrastructure is achieving space access for passengers and cargo in a manner that is safe, operable, routine, and increasingly affordable—generally described as being "aircraft-like."

Accomplishing this will require new, *fully reusable* space access systems that are developed, produced, tested, and operated using aircraft-style systems engineering principles and practices similar to those used in military and commercial aircraft development and certification. Full reusability will be needed to meet a fundamental criterion of aircraft-like operations: that each production flight sys-



The technology readiness scale is used to assess the maturity of technologies that can be used in new systems.

tem can be explicitly demonstrated, through acceptance flight testing, to be operationally safe before being placed into service to routinely and frequently carry passengers and cargo.

Of the single- or two-stage system design options for fully reusable space access systems, only two-stage-to-orbit (TSTO) rocket-powered systems can be developed today with TRL 6+ enabling technologies. This conclusion is based on recent government conceptual design studies by the Air Force Aeronautical Systems Center and Air Force Research Laboratory that were closely correlated with similar industry studies. This TSTO approach will now allow the development of fully reusable TSTO space access systems to be initiated with a reasonable expectation that the initial operational capability could be achieved within six to eight years.

A modest fleet of six operational TSTO systems—three each of two different designs—would provide an initial aircraft-like, assured space access capability. With each of the six systems flying once a month on average, the initial fleet flight capacity would be approximately 50 flights a year. As the systems mature and turnaround time decreases—consistent with aircraft experience—the fleet flight capacity may be expected to increase to about 100 flights a year. Assuming an 80/20 split of cargo to passenger missions, this fleet could transport approximately 960 tons of cargo (at 12 tons per mission), and 200 passengers (at 10 passengers per mission) to LEO each year.

While these TSTO systems will meet most cargo transport needs, transporting heavy and oversize components will also be required to launch extremely large satellites and transport large orbiting facility and spacecraft assemblies to LEO for final assembly. The ability to launch such payloads to LEO will be critical for establishing an integrated space infrastructure serving a broad customer base. The obvious solution is to develop an unmanned, shuttle-derived system capable of launching Saturn V-class payloads into LEO.

Within the integrated space logistics architecture, this new heavy spacelifter would provide a new capability to launch extremely large satellites and to transport large orbiting facility and spacecraft assemblies to LEO for final assembly.

LEO space logistics bases

The initial orbiting facilities would be 20-person space logistics bases. Two are envisioned, the first at 28.5° inclination and the second at 51.6° inclination. From these bases, logistics operations could be undertaken to support expanded human and robotic space operations throughout most of the Earth-Moon system.

The primary new logistics capabilities provided by these bases would be using large, pressurized space hangars to transform on-orbit servicing into routine activity. Launched via the shuttle-derived heavy spacelifter, the hangars would be approximately 10 m (33 ft) in diameter and 37 m (120 ft) long. By using these hangars, most on-orbit servicing now undertaken extravehicularly would be conducted inside the hangar's pressurized, shirt-sleeve environment.

The second important logistics capability would be a "space dock." All terrestrial logistics infrastructure includes the ability to assemble equipment and facilities at forward operating locations. To accomplish this in LEO, the base's space dock would be used to assemble large facilities (such as space hotels), large satellites, and large crewed spacecraft. The space dock would also be used to store construction materiel and to berth large spacecraft between missions.

The large space hangars and space dock together would enable the establishment of a standardized space maintenance process that integrates system design, in-space assembly, scheduled and unscheduled servicing, technician training, and spares management. As a result, the design, development, testing, and sustainment of new space systems would become increasingly aircraft-like, sharing common components, in-space testing and servicing capabilities, and established parts supply chains.

In-space mobility

A Delta-V mission requirement of appropriately 8,400 m/sec (27,500 ft/sec)—plus an allowance for midcourse corrections, rendezvous, and docking—will enable LEO-based spacecraft to reach and return from most destinations of interest within the Earth-Moon system.

Of particular interest is the overlap in mission performance needed for transportation to and from geostationary orbit (GEO)—missions of primary interest to commercial and national security operations—and transportation to and from the Lagrangian points and low lunar orbit. Fully reusable LEO-based spacecraft designed to access GEO would also have sufficient performance to reach and return from the Lagrangian points or low lunar orbit. Hence, logistics spacecraft designed to deploy or service satellites in GEO could also have a dual mission capability: to provide transportation to support human space exploration missions to the Moon and to deploy and service science platforms at the Lagrangian points.

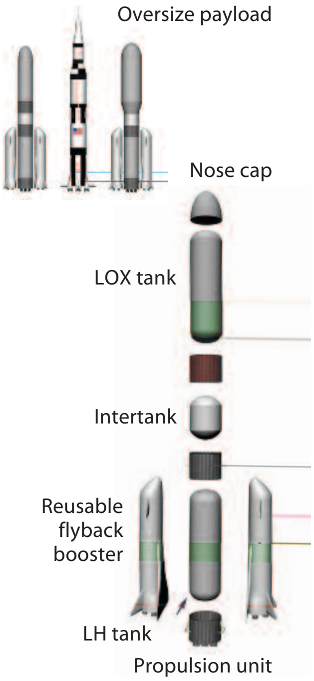
- In the near term, in-space mobility would be provided by a family of medium-sized, LEO-based, fully reusable spacecraft referred to as space logistics vehicles (SLVs). The smaller SLV tug would support LEO space logistics base operations, such as materiel handling and passenger transport, while the larger extended-range configuration (SLV/ER) would establish the first fully reusable space mobility capability within the Earth-Moon system for transportation passengers and cargo.
- In the mid-term, in-space mobility would be augmented by large, crewed, fully reusable spacecraft called space logistics transports, or SLTs. Similar in concept to a floating dry dock used for ship repairs, the SLTs provide integrated logistics support throughout the Earth-Moon system. In addition to transporting passengers and cargo, the SLTs would incorporate a large pressurized space hangar to provide on-site logistics support—inspection, servicing, repair, assembly, replenishment, and system upgrade—within a pressurized work environment similar to that available at the LEO space bases. Common components, in-space testing and servicing capabilities, and established parts supply chains could then be readily used to support new human and robotic space operations.

The SLT concept is an expanded version of a similar idea proposed in 1997 by Stanley Borowski and Leonard Dudzinski of NASA Glenn. Like their concept, the SLT would incorporate liquid oxygen-augmented nuclear thermal propulsion to enable round-trip missions within the Earth-Moon system without the use of aerobraking. This space nuclear thermal propulsion subsystem is the one element of the SLT design that is not yet TRL 6, but is TRL 4-5.

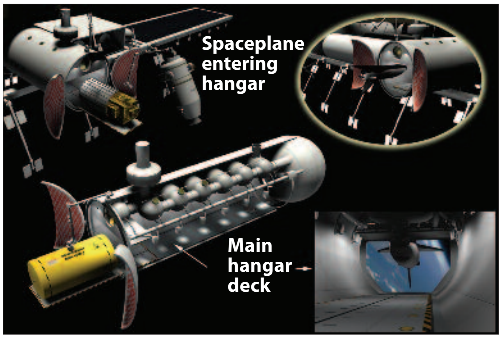
One example of an SLT mission could be to support the deployment of a new class of GEO satellites that require final on-site assembly of large solar arrays or large aperture antennas. An SLT would be parked in GEO to serve as the temporary "space dock" to position and control the satellite as it is assembled. An SLV tug would be taken along to provide on-site handling and positioning of satellite components, while SLV/ERs would be used to ferry satellite components to GEO from LEO and to rotate SLT crewmembers.

The SLT's space hangar would be used to prepare the satellite's components for installation, to service the SLV tug, and to support emergency rescue and assembly "glitch" recovery operations. After satellite assembly and checkout is completed, the SLT would return to its LEO space logistics base, where it would be berthed at the space dock for maintenance and replenishment.

A similar mission supporting human exploration on the Moon would be to locate an SLT at the L1 Lagrangian point or in low lunar orbit. SLV/ERs would ferry passengers, cargo, and propellants to the SLT, where they would be loaded onto lunar shuttles for delivery to the lu-

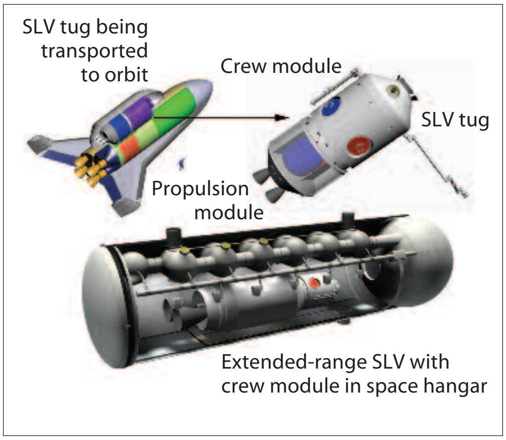


Shuttle-derived heavy space launch system uses a vertically stacked arrangement to provide flexibility in carrying oversize payload and to facilitate reuse of the core propellant tanks in building large orbiting facilities. This configuration uses fully reusable flyback boosters derived from the first stage of the fully reusable TSTO space access systems.



The space logistics base's hangar will have three maintenance areas: the main hangar deck, the aft spherical work bay, and the upper work compartments. A small passenger spaceplane is seen entering the main hangar deck for on-orbit inspection before returning to Earth.

Near-term space logistics vehicles would provide the intitial in-space mobility.



nar surface bases. Periodically, the on-station SLT would be relieved by another SLT to return to LEO for maintenance and resupply.

Organization and funding

This space logistics architecture emphasizes the use of TRL 6-9 technologies, especially for near-term, fully reusable space access systems. This is critically important, because it minimizes the uncertainties associated with predicting performance, cost, and schedule. With the resulting reduction in program risk, the acquisition strategy could shift to an infrastructure-oriented organizational and funding approach.This would enable greater flexibility in government oversight during development and production. Also, as discussed below, it would enable the costs of development and production to be covered using government-backed bonds rather than annual appropriations.

Large public infrastructure projects are generally undertaken through special government organizations. These may be called commissions, as in the Panama Canal Commission, or authorities, as in the Tennessee Valley Authority. Through legislative action, not-for-profit government corporations are created and vested with the authority to undertake public works and to raise the necessary funds by selling government-backed bonds. These corporations also manage the collection of fees and tolls, retire debt, direct the operation, maintenance, and improvement of the new infrastructure, and contract with private enterprises to build, operate, and use the new facilities.

To oversee the building of an integrated space logistics infrastructure, a Space Logistics Authority would be established. It would lead a new government-industry partnership emphasizing the use of commercial resources and space logistics service providers to establish the new infrastructure. This authority would direct the overall effort, establish the infrastructure systems architecture, select and approve specific approaches through competitive bidding, take ownership of key capital equipment and facilities, manage the contractors that build and operate the infrastructure, lease equipment and facilities to commercial operators, and raise and disburse the funds.

This approach would create substantial new opportunities for U.S. aerospace companies of all sizes to compete for developing, building, and operating the many elements of the infrastructure, as well as providing the new commercial space services made possible by the new infrastructure.

Modern logistics infrastructure is the foundation of a technological civilization. Despite this importance, building new infrastructure generally requires government financial underwriting through monopolies, tax subsidies, debt forgiveness, grants, or direct ownership and operation. Current federal government annual appropriations for space access operations total $5 billion-$6 billion each year. Over a 25-year period, this would provide a $125 billion-$150 billion financial pool that could be used to pay for the recurring operating costs of the two modest fleets of reusable space access systems (flying about 20 missions per year) *and* be used to retire the debt incurred for their development and production.

Emphasizing the use of mature technologies, combined with the reduction in program risks, means that the development and production of these two fleets of TSTO reusable space access systems could be debt financed, like most government infrastructure programs. Once operations begin and the old launch systems are retired, the same level of annual federal appropriations—$5 billion-$6 billion a year—would be applied to meet the new recurring operational costs for government space launches and to retire the debt.

With this infrastructure approach, the development of two TSTO fully reusable space access systems—as the first elements of an integrated space logistics infrastructure—could be undertaken without requiring an increase in current annual appropriations.

This new space logistics infrastructure would significantly benefit commercial, civil, and national security space operations by increasing their safety, effectiveness, and affordability. Building an integrated space logistics infrastructure is a vital and achievable step for transforming the U.S. into a true spacefaring nation.