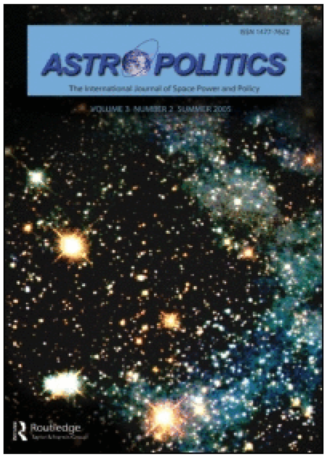

Astropolitics
The International Journal of Space Politics & Policy
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713634457

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Online Publication Date: 01 January 2008
To cite this Article: Snead, James Michael (2008) 'Spacefaring Logistics Infrastructure: The Foundation of a Spacefaring America', Astropolitics, 6:1, 71 - 94
To link to this article: DOI: 10.1080/14777620801908200
URL: http://dx.doi.org/10.1080/14777620801908200

Astropolitics, 6:71–94

ISSN: 1477-7622 print
DOI: 10.1080/14777620801908200

SPACEFARING LOGISTICS INFRASTRUCTURE: THE FOUNDATION OF A SPACEFARING AMERICA

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The American spacefaring dream, which envisions average Americans being able to safely and routinely travel to and work in space, remains the American public's benchmark for measuring progress in America's human space enterprises. This article begins with a brief review of the ideas and developments that led up to the formation of the American spacefaring dream in the late 1950s. It continues with discussion of how building new logistics infrastructure capabilities has enabled America to lead the world in opening new physical and technological frontiers and why this provides a successful model for fulfilling the American spacefaring dream of opening the space frontier. The article concludes with the identification of specific planning objectives to guide the development, construction, and operation of an integrated American spacefaring logistics infrastructure.

Surprisingly, almost two generations after Apollo 11, neither America nor any other country is yet a true spacefaring nation. None possesses the spacefaring capabilities needed for humans to routinely and safely access space and operate in space. This status stands in sharp contrast to the general recognition that, as highlighted in the United States (U.S.) National Space Policy, America will significantly benefit from becoming a true spacefaring nation with full freedom of action in space. What is missing is the spacefaring logistics infrastructure that forms the core of America's spacefaring dream. This dream of Americans, to be able to safely and routinely access and work in space, as spacefarers, remains the benchmark for assessing American progress in space.

This article focuses on how this American spacefaring dream can now start to be realized. Specifically, this work focuses on how America can undertake the transformation from an aging space exploring nation to a vibrant spacefaring nation by, first, focusing

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America's aerospace industries on building and operating an integrated spacefaring logistics infrastructure and, then, using the newly acquired mastery of human space operations to enable the emergence of a new generation of commercial space enterprises. This combination of new spacefaring infrastructure, new industrial mastery of spacefaring operations, and new commercial space enterprises will take America into a new era of the space age where America is truly spacefaring.

Birth and Decline of the American Spacefaring Dream

On 10 May 1869, America became a true continental nation. With great celebration across the nation, just four years after the end of America's Civil War, the setting of the golden spike signaled the completion of one of the most challenging logistics infrastructure projects of the century—the first North American transcontinental railroad. A journey across the continent, that once took about six months with great hardship, would soon be completed in as little as four days on the interconnected railroads stretching from New York City to California.

Today, transportation, like most infrastructures, is taken for granted. Most of the world is accessible with great comfort, acceptable safety, and reasonable economy. Peoples of most nations exploit the integrated global transportation infrastructure to travel for business, education, migration, curiosity, and relaxation. Most travelers do not give a second thought to the significant commitment and investment that went into providing the logistics infrastructure that literally stretches from one's doorstep to almost every desirable destination on seven continents. Further, whether on a short trip or an international trip, arriving at the destination and then returning home safely is taken for granted.

Logistics infrastructure has the peculiar quality of the mundane—slipping into the background of life, at least when all is going well, in a modern nation. Yet, such infrastructure distinguishes a developed nation and forms the tapestry of modern life. In many parts of the world, people no long live on the Earth but on and in infrastructure. Build a comparable infrastructure, enclose it to provide a compatible environment, and living on the Moon or Mars or in the voids between the planets in O'Neillian colonies would be little different from life in major cities.

Recognition of the possibility of travel beyond the atmosphere into space first emerged in the fiction writings of Jules Verne and H.G. Wells. Traveling to space, at least the possibility of doing so, transitioned from science fiction to science fact with the many works of Konstantin Tsiolkovsky at the same time the Wright Brothers were leading humanity down the path to powered flight. European space scientists, such as Hermann Oberth and Eugene Sänger, continued these efforts in the 1920s, while Robert Goddard led comparable American efforts. The Society for Studies of Interplanetary Travel was established in the Soviet Union in 1924, drawing on Tsiolkovsky's pioneering work. The German Spaceflight Society was founded in 1927, the American Interplanetary Society was founded in 1930, and the British Interplanetary Society was founded in 1933. These efforts were followed by the *golden age* of science fiction, starting in 1939, where the genre of hard-science fiction became popular, drawing from the emergence, in real life of new technologies such as ballistic missiles, radar, jet-powered aircraft, and nuclear energy.

Post World War II, the imaginations of science fiction continued to be transformed into reality. In 1946, the first photographs of the Earth from space were taken using a captured German V-2 rocket. That same year, Arthur C. Clarke published a technical paper describing what today is referred to as geostationary orbits (GEO) and GEO communication satellites. The sound barrier was *broken* in 1947—shattering the public myth that aircraft were unable to fly faster than the speed of sound. This opened the door to the high-speed flight necessary to reach space in manned vehicles.

In 1950, a program to develop a fusion bomb—using the energy source that powered suns—was announced by President Truman. In 1951, the U.S. Congress authorized the construction of the first nuclear-powered submarine that would be capable of continuous underwater operation—not unlike the nuclear-powered spaceships of science fiction. In only a century and a half, America had advanced from successfully applying steam power to transportation to harnessing one of nature's ultimate energy forms—fission nuclear energy. Finally, news of these remarkable technological advancements was seen by an increasing number of Americans in their homes on television—another transformation of science fiction into reality.

In 1949, against this background of the growing public awareness of rapidly changing technologies, the concept of humanity becoming a spacefaring civilization emerged from the confines of science fiction and societies of space enthusiasts. Willy Ley published a popular book, *The Conquest of Space*, describing the spacefaring logistics infrastructure of orbiting human space stations and interplanetary spaceships.[1] The Hayden Planetarium in New York City sponsored the First Symposium on Space Flight in October 1952. Dr. Wernher von Braun, the German rocket scientist behind the V-2 and then a leading member of the fledgling American military rocket program, emerged from the seclusion of the military's efforts to discuss his ideas on how America could use advanced rockets to explore space.

The public's awareness of von Braun's ideas accelerated in 1952 with the publication of an article in *Collier's* magazine, then a leading American popular press publication. Under the title of "Man Will Conquer Space Soon: Top Scientists Tell How in 15 Startling Pages," four million copies of *Collier's* described the ideas of von Braun and his contemporaries using techno-realistic paintings by Chesley Bonestell. The popularity of the first article led to four more, through April of 1954, describing aircraft-like space access, space stations for in-space logistics support, reusable spaceships to take explorers to the Moon, and finally man's first visit to Mars. These articles were followed by three Walt Disney TV shows—"Man in Space" (1955), "Man and the Moon" (1955), and "Mars and Beyond" (1957)—then the staple American family television show. From the public's increasing fascination with space, the American spacefaring dream was borne.

By 1958, the year after Sputnik, the American spacefaring dream had crystallized into an actionable scenario. The National Aeronautics and Space Administration (NASA) had been created to separate civilian space operations, such as exploration, from the rapidly developing military space operations. In 2003, Dr. Roger Launius wrote that the American space dream was defined in the late 1950s as a:[2]

> ...space exploration scenario centered on human movement beyond this planet and involving these basic ingredients accomplished in essentially this order:
>
> 1. Earth-orbital satellites to learn about the requirements for space technology that must operate in a hostile environment;

2. Earth orbital flights by humans to determine whether it was possible for humanity to explore and settle other places;
3. develop a reusable spacecraft for travel to and from Earth orbit, thereby extending the principles of atmospheric flight into space and making routine space operations;
4. build a permanently inhabited space station as a place both to observe the Earth and from which to launch future expeditions to the Moon and planets;
5. undertake human exploration of the Moon with the intention of creating Moon bases and eventually permanent colonies; and
6. undertake human expeditions to Mars and eventually colonize the planet.[3]

This scenario had two elements: space exploration and civilian space operations. Space exploration is seen in steps 1, 2, 5, and 6, while the spacefaring logistics needs are addressed in steps 3 and 4. If executed in a deliberate manner, this effort could have led to an initial reusable space access system and a permanently manned space station in the mid-1970s and the initial lunar landings in the late 1970s or early 1980s, with possibly subsequent initial Mars human exploration in the 1990s.

This logistics-centered scenario was abandoned, however, by President Kennedy's decision in 1961 to respond to the Soviet Union's cold war technological challenge by accelerating America's civilian manned space program. Kennedy's revised scenario by passed steps 3 and 4 and proceeded directly to the lunar exploration part of step 5. The spacefaring logistics core of the scenario, intended to enable humans to safely and routinely access and operate in space, was not created.

Launius addressed this point:

> Not long after the first lunar landing in July 1969, President Richard Nixon told an assembled audience that the flight of Apollo 11 represented the most significant week in the history of Earth since the creation. Clearly, at least at that time, the President viewed the endeavor as path-breaking and permanent, a legacy of accomplishment on which future generations would reflect as they plied intergalactic space and colonized planets throughout the galaxy. Dr. Hans Mark, director of NASA's Ames Research Center during the 1960s, recently voiced a less positive result for Apollo. 'President Kennedy's objective was duly accomplished, but we paid a price,' he wrote in 1987, 'the Apollo program has no logical legacy.' Mark suggested that the result of Apollo was essentially a technological dead end

for the space program. It did not, in his view, foster an orderly development of spaceflight capabilities beyond the lunar missions.[4]

When the first transcontinental railroad project was completed, it provided an operational logistics capability that completed the rail transportation revolution of making the U.S. internally accessible to all Americans. Over the next three decades, three more transcontinental railroads were built to open the American West fully. In sharp contrast, as Mark noted, Apollo left no comparable operational logistics capability. Therefore, the American spacefaring dream faded as Apollo wound down since it left no operational capability enabling Americans to follow the Apollo explorers into space, to continue opening the space frontier.

After more than three decades, the American space program remains derailed. Fortunately, it can be salvaged. Abraham Lincoln said, "With public sentiment, nothing can fail. Without it, nothing can succeed." If it is important, perhaps vital, for America to become a true spacefaring nation, then the American public's interest in and support for the vision of America as a true spacefaring nation must be rekindled. Accomplishing this requires that the American space program return to its roots and undertake building the missing spacefaring logistics elements. This will integrate space, starting with the Earth-Moon system, into the terrestrial logistics infrastructure. As a result, average Americans, as spacefarers, will be able to readily access and operate in space.

The true importance of the transcontinental railroads was not to just transport a new generation of Lewis and Clarke explorers west. Their importance was that the distant western territories became integrated logistically and economically with the more established eastern states and territories. The difference between America as an aging space exploring nation and America as a vibrant 21st century spacefaring nation lies with building the enabling spacefaring infrastructure. Defining a renewed American commitment to become a true spacefaring nation, centered on building an effective spacefaring logistics infrastructure, will reinvigorate the American public's sentiments towards space because it will create real opportunity for average Americans to fully participate in opening the space frontier.

The Renewed Importance of America Becoming Spacefaring

Two generations after Apollo 11, the American spacefaring dream and the nation's need for substantially improved spacefaring capabilities have converged. This started with the 2001 Congressionally chartered *Commission to Assess United States National Security Space Management and Organization*, known as the Space Commission. Despite its focus on national security space management and organization, the Commission's first conclusion in the executive summary identified the importance of America's ability to operate in space effectively: "The Commission unanimously concluded that the security and well being of the United States, its allies and friends depend on the nation's ability to operate in space."[5]

The Commission further noted that America stands on the threshold of a new era of the space age, enabled by new mastery of space-faring operations, where the value and importance of commercial, civil, and national security space operations will grow:

> The first era of the space age was one of experimentation and discovery. Telstar, Mercury and Apollo, Voyager and Hubble, and the Space Shuttle taught Americans how to journey into space and allowed them to take the first tentative steps toward operating in space while enlarging their knowledge of the universe. We are now on the threshold of a new era of the space age, devoted to mastering operations in space.[6]
>
> Mastering near-earth space operations is still in its early stages. As mastery over operating in space is achieved, the value of activity in space will grow. Commercial space activity will become increasingly important to the global economy. Civil activity will involve more nations, international consortia, and non-state actors. U.S. defense and intelligence activities in space will become increasingly important to the pursuit of U.S. national security interests.[7]

Later in 2001, the Department of Defense (DoD) released a mission needs statement reflecting the desire to pursue increased spacefaring operational capabilities. Titled, *Operationally Responsive Spacelift (ORS)*, two mission objectives were identified that emphasized the need for improved space access and new operational capabilities to reposition and service satellites in space:

> ORS involves two sub-tasks. (1) Transporting Mission Assets to, through, and from space. This task encompasses the spacelift missions of delivering payloads to, or from, mission orbit and changing the orbit of existing systems

> to better satisfy new mission requirements. It also supports emerging missions like space control, missile defense, and force application. ORS must be available on demand, flexible, and cost effective. The second sub-task, (2) Spacecraft Servicing, encompasses traditional satellite operations activities, but it could also include resupply, repair, replacement, and upgrade of space assets while in orbit. Mission priority, cost trades, and technological advances will dictate the method for accomplishing these objectives.[8]

In 2002, a second Congressionally chartered commission reintroduced the importance of America being a spacefaring nation with the ability to explore and exploit space. The report of the *Commission on the Future of the United States Aerospace Industry*, referred to as the Aerospace Commission, stated:

> The Commission concludes that the nation will have to be a space-faring nation to be the global leader in the 21st century—our freedom, mobility, and quality of life will depend on it. America must explore and exploit space to assure national and planetary security, economic benefit, and scientific discovery. At the same time, the United States must overcome the obstacles that jeopardize its ability to sustain leadership in space.[9]

In 2006, the overarching U.S. National Space Policy was updated. The background section of the policy states:

> For five decades, the United States has led the world in space exploration and use and has developed a solid civil, commercial, and national security space foundation. Space activities have improved life in the United States and around the world, enhancing security, protecting lives and the environment, speeding information flow, serving as an engine for economic growth, and revolutionizing the way people view their place in the world and the cosmos. Space has become a place that is increasingly used by a host of nations, consortia, businesses, and entrepreneurs.
>
> In this new century, those who effectively utilize space will enjoy added prosperity and security and will hold a substantial advantage over those who do not. Freedom of action in space is as important to the United States as air power and sea power. In order to increase knowledge, discovery, economic prosperity, and to enhance the national security, the United States must have robust, effective, and efficient space capabilities.[10]

The Way Forward

Tragic circumstances did not enable the findings of either of the two commissions to be acted on. The shift in national security priorities brought about by the terrorist attacks of 11 September 2001 and the Iraqi War prevented any significant DoD assessment and investment in improved spacefaring logistics capabilities. The tragic loss of the Space Shuttle Columbia, and the subsequent crisis atmosphere in the American human spaceflight program, accompanied by continuing difficulties with providing logistical support for the International Space Station (ISS), have yielded the same outcome regarding the findings of the Aerospace Commission. Yet, as the National Space Policy emphasizes, the importance of space to American future prosperity and security is clear. The key question is how to obtain the "robust, effective, and efficient space capabilities" that America must have. The answer is to focus national space priorities on achieving mastery of spacefaring operations, as this is required for America to cross the threshold to becoming a true spacefaring nation.

Logistics Infrastructure's Role in Establishing Mastery of Operations in New Frontiers

Opening new frontiers requires infrastructure. Building and operating such infrastructure requires industrial mastery of how to operate in the new frontier with acceptable safety and economy. Without the development of this industrial mastery, frontier opening stagnates in the exploration phase or the rugged individual settler phase. It does not progress to resource extraction, local industrialization, settlement, and interconnected economic and social development. In other words, civilization is not created.

With the formal end of the American War of Independence in 1783, the British royal decree forbidding settlement of the Ohio Valley ended when the new United States assumed sovereignty over these lands. In an agrarian society, fertile land is wealth. The land rush westward, that would take place over the remainder of the 18th century and most of the 19th century, began in earnest. Yet, transportation technologies in America were still very primitive. Horse-borne packs or simple horse-drawn carts, as had been used for millennia, were the norm for moving to and within the frontier. As the population west of the Alleghany Mountains increased, trade with the eastern states started. Packhorse trains carried pelts, ginseng, and whiskey east and returned with salt, iron, sugar, and simple manufactured goods.

Once the U.S. took title to the Louisiana Territory in 1803, both public and private infrastructure development began. Road building, epitomized by the National Road, helped to create a skilled labor force capable of building durable stone bridges able to resist spring floods. Canals soon followed to provide the first means to move bulk agricultural products from the Ohio Valley to the eastern markets economically.

While interstate roads and canals would remain primary transportation modes for over two generations, the true 19th century transportation logistics revolution was the introduction of steam power. While the popular image of the level of technology existing in America in the early 1800s is characterized by Lewis and Clark's famous, but primitive, 1804–1806 Voyage of Discovery, this was not the case. The very next year, Robert Fulton started commercial steamboat passenger and cargo operations on the Hudson River connecting New York City and Albany with scheduled, two-way river transportation. Just five years later, in 1812, this was repeated with the introduction of commercial steamboat operations based in New Orleans and serving the lower Mississippi River.[11] Representative of the rapid growth in this first form of mechanical transportation, steamboats transported three million passengers (1855) and eight million tons of cargo (1851) on just the Ohio River.[12]

Starting in 1825, steamboats were joined by steam-powered railroads—the form of mechanically-powered transportation that would ultimately dominate internal transportation in America for almost a century. Beginning with only 40 miles of track in use in 1830, over 190,000 miles were in use by 1900.[13]

Over the course of just two generations, the territories west of the Alleghany Mountains witnessed a steady migration of people combined with a tremendous expansion of industrial capabilities made possible by the influx of settlers. Keelboat and flatboat construction mastery of the late 1700s transferred to western steamboat construction in the first decades of the 1800s. Road bridge masonry construction mastery transferred to canal aqueducts and locks. Iron production mastery transferred to manufacturing steam engines and steam boilers; then to rail locomotives and steel rails; and, finally, to steel bridges, steel cable, steel buildings, and steel ships.

With each progression, industry also expanded laterally, as apprentices became new masters moving on to start new competing businesses and provide derivative products and new services exploiting the capabilities of the new infrastructure. Most notable was the application of steam engines to manufacturing.

This significant advancement replaced water wheels, and human and animal power. With stationary steam engines for power and steam-powered transportation, industry could now be located near the source of their raw materials while having ready and timely access to their markets.

This familiar bootstrap approach was often repeated throughout the 19th and 20th centuries. Building new infrastructure creates a new mastery comprised of new expertise, experience, and industrial capabilities. While one segment of this new mastery continues to expand the current infrastructure, other segments work to improve the infrastructure to gain competitive advantage and to exploit the infrastructure by providing new infrastructure-enabled products and services. Finally, entrepreneurs tap this new mastery to create entirely new industries and wealth.

At the start of the 1800s, America was a largely seafaring and agrarian nation of about five million nestled along the Atlantic coast. Its roads were few and poor and, outside of shipbuilding, it had few industries. By the end of the century, it was a continental and heavily industrialized nation of 70 million. All of the primary 20th century infrastructure of transportation, communications, energy, and food production were well established across the country. As a result, America was well positioned, from an infrastructure point-of-view, to meet the global challenges it would face in the 20th century. Had America not invested in logistics infrastructure development throughout the 19th century, it would have been well behind the power curve in having the technological, industrial, and population resources needed to successfully meet its global challenges as a great power in the 20th century.

Crossing the Threshold to True Spacefaring Operations

The Space Commission spoke of crossing a "threshold to a new era of the space age, devoted to mastering operations in space." The Aerospace Commission said that the U.S. "must overcome the obstacles that jeopardize its ability to sustain leadership in space." U.S. National Space Policy defined the need for "robust, effective, and efficient space capabilities." Current American-planned human space operations can be assessed against these important qualitative benchmarks.

The Vision for Space Exploration (VSE), should it continue, will take humans back to the Moon to continue the scientific exploration started in the Apollo program. The issue with the execution of the VSE is that, like Apollo before, no useful infrastructure will be established that advances America's general spacefaring capabilities. While not a fault of NASA, this represents the simple fact that NASA's exploration and scientific discovery mission does not, as it should not, include building and operating general-purpose infrastructure.

While the public has not grown excited about VSE, there is strong public interest in on-going commercial human spaceflight activities focused on suborbital operations. However, achieving commercial suborbital human spaceflight will not fundamentally advance near-future spacefaring capabilities. This is because suborbital human passenger spaceflight does not actually transport passengers to Earth orbit, but falls well short of this in terms of performance and flight system design sophistication. Therefore, the development of such systems will not significantly advance American mastery of space operations.

As current American government and commercial plans for future human space activities will not achieve the needed improvement in U.S. spacefaring capabilities, what instead should be done? The simple answer is for America to do what America has done well for over two centuries—follow the explorers into the space frontier; building the needed spacefaring logistics infrastructure along the way; and, in the process, establishing the new American mastery of spacefaring operations that is now clearly needed. Only this approach will rectify the lack of "robust, effective, and efficient" spacefaring operational capabilities identified in the U.S. National Space Policy as being vital to America's future in space. Properly undertaken, this will significantly benefit future human and robotic space exploration and scientific discovery, enhance national and planetary security, and promote the growth and expansion of American commercial and governmental space enterprises. By following this path, America will cross the threshold to became a true space-faring nation.

Spacefaring Logistics Infrastructure Implementation Objectives

Well-executed infrastructure projects require a clear definition of the objectives to be accomplished. Implementing an integrated

American spacefaring logistics infrastructure will need to achieve the following seven objectives.

1. ESTABLISH ROBUST, EFFECTIVE, AND EFFICIENT SPACEFARING LOGISTICS CAPABILITIES THROUGHOUT THE EARTH-MOON SYSTEM

The needed initial capabilities include:

- improved passenger and cargo space access achieving *aircraft-like* safety and operability for passenger transport to and from Earth orbit;
- in-space logistics facilities in low Earth orbit (LEO) providing a "Midway Island" within the Earth-Moon system to serve as a logistics depot to support and encourage expanding human and robotic spacefaring operations; and
- in-space mobility for passengers and cargo with *aircraft-like* safety and operability enabling routine and frequent human transport throughout the Earth-Moon system.

The emphasis on *aircraft-like* safety is very important. It is a distinguishing factor between today's space exploration level of acceptable human safety, generally referred to as *human-rated*, and the level of safety needed to enable broad and successful American spacefaring enterprises.

Space is not the first environment in which routine human operations are undertaken in environmental conditions that can lead to significant injury or loss of life. Such operations, when first undertaken, are generally always more life threatening when mastery of operations in the new environment is low. However, as mastery increases, so does the ability to increase the protection of human safety until the operations reach an acceptable level of safety. Human safety assurance is, effectively, a measure of operational mastery.

2. UTILIZE TECHNOLOGY READINESS LEVEL 6–9 TECHNOLOGIES TO MODERATE SCHEDULE, COST, AND PERFORMANCE RISK

Technological risk planning for new space efforts is extremely important, especially when vital new operational capabilities are needed. The Technology Readiness Level (TRL) scale can be used to assess the maturity of technologies proposed for use in flight-critical and mission-critical applications. A TRL of 1 represents a new idea while a TRL of 9 represents a fully mature technology in routine operational use.

Systems engineers in charge of developing proposed solutions for near-term programs—programs that are ready to begin conceptual design leading to, within 12–24 months, the selection of the preferred configuration—usually make use of TRL 6–9 technologies to moderate risk. TRL 6 technologies are those in which a subsystem prototype, using these technologies has been shown to work acceptably well, when tested or used in an environment representative of the proposed system use. For achieving the necessary advances in performance, operational capabilities, and safety, TRL 6–9 technologies are the usual choice to define preferred configurations with acceptable cost, schedule, and performance development risk.

When new space programs are initiated, especially new space transportation programs, considerable advocacy develops for incorporating less mature but, potentially, more beneficial technologies. Advanced airbreathing engines or new materials are typical examples. Proponents of such new technologies passionately argue that the needed delay in selecting the preferred configuration required to complete the maturation of the technology will yield significant performance improvements or cost reductions.

Sir Robert Watson-Watt, the British father of radar, faced such technology selection decisions when he was directed to develop the coastal radars that would prove crucial during World War II's Battle of Britain. When selecting from among different proposed solutions with varying levels of technological maturity, Watson-Watt argued to "give them the third best to go on with; the second best comes too late; the best never comes."[14] In other words, implement the "third best" solution "that can be validated and deployed without unacceptable cost or delay."[15] This is referred to as Watson-Watt's Law of the Third Best.

To be clear, a third best solution is not simply an updated version of an existing operational system or even a step backwards to a previous approach. A third best solution is a new system design that wisely makes use of the best of the available technologies to achieve necessary and desired advances in performance, operational capabilities, and safety with acceptable cost, schedule, and performance risk.

Usually, the third best solution is the choice that knowledgeable systems engineers—not research scientists—would make to solve a problem or provide a new operational capability they are charged with developing. The systems engineers have a success criterion to bring a new capability into successful operation, while research scientists are usually focused on finding funding to continue research of personal or organizational interest. For this reason, the choice of the technological solutions to incorporate into a near-term solution must be made by the systems engineers. This is especially important for infrastructure programs where understanding and moderating technical risk is critical to on-time and to on-cost execution.

3. ESTABLISH A NEW PUBLIC-PRIVATE PARTNERSHIP TO DEPLOY AND OPERATE THE INITIAL SPACEFARING LOGISTICS INFRASTRUCTURE

Large-scale infrastructure projects are generally complex. Not only is protecting the safety of the involved and non-involved public a primary consideration, but quite often they involve vital public services, such as transportation, water supply, and power generation. Further, their implementation usually requires the careful integration of new physical systems and facilities with the delivery of new logistics products and services. Such complex infrastructure projects are best undertaken by public-private partnerships that organize and harness the strength of American industry while providing needed pubic oversight to ensure that public safety is appropriately protected, that critical new public infrastructure is deployed and operated as intended, and that public funds or public funding guarantees are used wisely.

For such large public works programs, a special authority, commission, or not-for-profit corporation is generally established to provide the necessary public oversight, planning direction, and financial control. Rather than assigning the infrastructure development responsibility to an existing government agency, this approach has these advantages:

- the purpose, responsibilities, required operational capabilities, internal structure, implementation timeline, and public accountability can be clearly defined;

- a clear line of authority can be established and potential conflicts of interest or internal organizational competition for project funding, resources, and priorities can be avoided;
- a new budget line item for the organization can be created, which helps to segregate needed public funding for the infrastructure effort from other governmental costs;
- the authority can be legally enabled to issue bonds, in the name of the government, to raise the capital required for the development and construction of the infrastructure; to issue contracts for the construction and operation of the infrastructure; and to raise revenue to help retire the incurred debt; and
- the authority can be staffed by people whose primary motivation is to successfully build and operate the infrastructure, rather than being internally reassigned to undertake a task for which they may have little personal interest.

4. UNDERTAKE THE PROJECT IN A FEDERAL BUDGET-AFFORDABLE MANNER

Building and operating infrastructure is a central role of government. The federal budget has two types of expenditures related to infrastructure—on-going operations and new infrastructure construction. As vital as building a new spacefaring logistics infrastructure may be, the needed federal expenditures for this new effort will be in competition with other government spending priorities. A sound rationale is needed to gain approval of the needed funds.

Currently, the federal government expends $5–6 billion per year on government spacelift to transport humans, cargo, and satellites to space. Most of this expenditure is for the Space Shuttle whose operations are now planned to end by 2010. Once the new infrastructure becomes operational, this level of expenditures for improved space access for transporting humans, cargo, and satellites to space would not increase the federal budget or take funding away from other expenditures. Over the initial 25 years of operation of the new spacefaring infrastructure's space access capabilities, this level of funding would provide $125–150 billion (today's dollars) for government utilization of replacement Earth-to-orbit transportation. Hence, by only continuing the current level of federal expenditures on space access, the government, as well as private U.S. space operations, will gain access to the substantially improved space transportation services provided by the new spacefaring infrastructure.

The second component of needed new federal government spacefaring infrastructure investment is for improved in-space operational and transportation capabilities. Today, the federal government does not make any space infrastructure investments to specifically support in-space commercial and governmental space operations, such as satellite deployment and servicing, space solar power utilization, space tourism, lunar mining, asteroidal resources recovery, and emergency services. The current space component of the U.S. gross domestic product (GDP) is estimated to be approximately $100 billion.[16] To sustain existing and encourage new economic activity, total government expenditures in the U.S. on public infrastructure totals about 2.5% of the GDP, of which the federal government pays about 25%.[17] Applied to the space GDP, this would indicate that new infrastructure expenditures of $2.5 billion per year would bring spacefaring infrastructure investment, to support in-space commercial and government operations, in line with other segments of the economy. Hence, over the quarter century of the initial operations of the integrated spacefaring logistics infrastructure, this would provide an additional $62.5 billion (today's dollars) for new spacefaring infrastructure development beyond the Earth-to-orbit transportation investments discussed above.

While the approximate $200 billion for spacefaring logistics infrastructure development over 25 years sounds large, keep in mind that the total U.S. GDP during this time period will exceed $350 trillion, while the space GDP will exceed $2.5 trillion in today's dollars, not including future economic growth. This proposed level of federal government spacefaring logistics infrastructure investment would constitute only about 0.06% of the nation's GDP over this time period, with most of this already included in current federal expenditures. Further, this level of spacefaring logistics infrastructure spending would only equal about 2% of the nearly $9 trillion in government infrastructure funding that will be spent over that 25-year period.

5. DEVELOP AMERICAN INDUSTRIAL MASTERY OF OPERATIONS IN SPACE

A nation will become spacefaring as its industries become masters of human operations in space. For industry to gain this mastery, as noted previously, building and operating public logistics infrastructure has proven to be a highly successful starting point. This is especially true for infrastructure serving human needs where public safety is a primary consideration.

A relevant example is the emergence of Boeing and Douglas as successful builders of commercial jet airliners in the late 1950s. Jet-powered flight represented a new era of aeronautics with high subsonic flight speeds where compressibility effects were significant and new swept wing designs were needed; flight at higher altitudes where passenger compartment pressurization and new, larger fuselage structural designs were needed; and, obviously, the use of the new jet engines. While Boeing and, especially, Douglas had prior commercial aircraft production experience with piston-powered, propeller-driven airliners, the move to commercial jet airliners proved technically challenging. The British *Comet*, the first commercial passenger jet airliner, suffered several in-flight failures in the early 1950s showing that designing successful jet airliners was not an easy advancement over propeller-driven aircraft. Douglas and Boeing solved the new technical challenges by drawing on the experience, expertise, in-house industrial capabilities, and external vendors and suppliers acquired through their military jet aircraft contracts. How this came about offers important insights into organizing private industry to build a safe and effective spacefaring logistics infrastructure.

After World War II, the U.S. military moved quickly to transition to jets. A key element of the U.S. military's aircraft industrial strategy was to place aircraft design and production responsibilities with private industry to strengthen America's industrial base and promote competition. As a result, during the military's transition to jets in the late 1940s and early 1950s, industry's contracts to develop new military jet aircraft led to industry's initial mastery of jet aircraft design and production. This new mastery was quickly tapped to transition these technologies to commercial applications such as the Boeing 707 and the Douglas DC-8.

What made this approach successful was not that industry simply had government design and production contracts. Critically important to success was the program management and technical execution oversight provided by the military aircraft program offices. Certainly not without flaws during execution, the advantage this provided to industry, however, was that the successful engineering principles and practices were documented and shared. Government engineering handbooks, standards, specifications, and systems engineering processes were developed that would then be used to develop and produce safe and operable military and commercial jet aircraft. Effectively, these handbooks, standards, specifications, and processes, combined with the specific experience, expertise, and manufacturing capabilities of industry, became America's new mastery of jet aviation.

American industry's current lack of mastery of spacefaring operations is very similar to their lack of jet aviation mastery in the late 1940s. Instead of military jet aircraft, the government's need for improved national spacefaring operational capabilities is the critical deficiency that needs to be addressed today. Instead of establishing industry's mastery of jet aviation, industry now needs to gain mastery of spacefaring operations. Instead of using a public-private partnership to build new military aircraft to develop the needed industrial mastery of jet aviation, a public-private partnership to build new spacefaring logistics infrastructure will enable industry to gain the needed mastery of spacefaring operations. Finally, just as industry rapidly transitioned their new jet aviation mastery to commercial products and devices, American industry will be well positioned to use their new spacefaring mastery to significantly expand American commercial spacefaring operations, can this be all one done?

6. PROMOTE THE EXPANSION OF U.S. COMMERCIAL SPACEFARING OPERATIONS

All businesses require access to enabling infrastructure—transportation, communications, water, waste removal, emergency services, workers, and so on—to engage in profitable commerce. Much of this enabling infrastructure is funded and built through some form of public-private partnership. Federal, state, and local governments understand the importance of infrastructure in attracting and retaining business investment. For this reason, they elect to use public funds to make major infrastructure investments—for example, land purchases, new roads, airport runway expansions, water and sewer system expansions, communications, and large business centers—explicitly to make localities and states competitive for new business investment. Building and operating the initial spacefaring logistics infrastructure will support the growth of American commercial space enterprise in three ways.

The first tier of benefiting commercial space businesses will be those directly involved in developing and constructing the spacefaring logistics infrastructure. Involving possibly over $100 billion in new development and construction contracts to build the Objective 1 capabilities, this will provide significant opportunities for existing and new engineering development and construction companies to become directly involved with 21st century spacefaring commerce. The new mastery of spacefaring operations gained through these efforts, combined with the *ownership* of the design of specific infrastructure systems and facilities, will enable these first tier companies to develop and market derivative products to new government and commercial customers. A comparable jet aviation example was Boeing's exploitation of its work on the first jet bombers and tankers to enable it to market the Boeing 707.

The second tier will be the new business enterprises formed to operate the new infrastructure. While the initial infrastructure systems and facilities may be owned by the public, they will be managed and operated by private businesses. This will grow the service side of spacefaring commerce to support government and commercial users' demand for infrastructure services. For example, private spaceline companies formed to operate the initial fleets of fully reusable aerospaceplanes could provide human passenger transport services to LEO for a space hotel operator.

The final tier will be the new entrepreneurial space companies formed to use the infrastructure to provide new services and products to the marketplace. Space hotels catering to space tourists are one obvious example. Space solar power, providing a new source of renewable energy for both space and terrestrial energy needs, may be another example. The tremendous growth of comparable third tier applications of the Internet, the Global Positioning Satellite navigation system, and satellite and terrestrial wireless communications infrastructure provides a measure of the potential for space entrepreneurial business development once ready access to spacefaring logistics infrastructure capabilities are established.

7. ENCOURAGE AND PREPARE THE FUTURE SPACEFARING WORKFORCE

One important implication of building new infrastructure is the need for new workers to build and make use of the infrastructure. The development of the Internet and the subsequent tremendous growth of information technology economic activity dependent on the backbone Internet communications infrastructure is a clear example of how new infrastructure creates significant demand for new workers.

Building an integrated spacefaring logistics infrastructure will enable space to be industrialized on a scale and in ways that are difficult to anticipate today, just as the commercial applications of the Internet were difficult to predict in the 1980s. Yet, once the obstacles of building the spacefaring logistics infrastructure are overcome, entrepreneurs will quickly move to fill the new economic *vacuum* that the infrastructure will create. The race for space will begin in earnest.

For the future American technological workforce, this pending large demand for skilled workers needs to be addressed as part of the planning of the execution of building the spacefaring infrastructure. In the 19th and 20th centuries, when large government infrastructure programs were undertaken, providing the needed number of workers was comparatively easy because, for most construction jobs, on-the-job training was able to produce large numbers of workers having the needed construction skills for building dams, roads, canals, and so on. The excitement of the project coupled with the higher wages generally provided the needed numbers of workers, even in places as remote as Panama, Nevada, and Alaska.

This will not be the case for the industrialization of space. Most jobs will require substantial technical and, probably, specialized training. The training of such workers must effectively start in the 7th grade when students *elect* to take the necessary math and science courses to prepare for the science, engineering, and other specialized technical education and training that are needed to produce an entry-level worker. Ramping up the American aerospace industry to build and effectively make use of the new spacefaring infrastructure will not be as simple as encouraging "Rosie" to trade her apron for a riveting gun to help build military aircraft in World War II. For example, one conservative estimate of the work-years required to design and develop a new, two-stage, fully reusable aerospace plane is 125,000. If this would be undertaken over seven years, it would require an experienced technical workforce of about 20,000. In addition, this is for just one of several such systems needed for the initial spacefaring infrastructure.

In 1961, President Kennedy tapped America's spacefaring dream to enlist the nation in fulfilling his goal of landing a man on the Moon by the end of the decade. Achieving this goal was an important national accomplishment in terms of meeting the challenges for world leadership then facing America. Today, America faces comparable challenges with respect to space. Once again, the American spacefaring dream needs to be used to motivate America's youth to help their nation meet its spacefaring challenges of the 21st century. The difference this time is that by focusing on building infrastructure, and not just renewing human space exploration, the American spacefaring dream can be fully realized.

In the early 19th century, the advice to America's youth was to "go west," as that was where substantial opportunity existed and where their help was needed to develop America into a continental, industrial nation. Today, as America commits to becoming a true spacefaring nation, the advice to America's youth must be to study math and science because the spacefaring goal cannot be realized without substantial numbers of educated and motivated technology workers. Hence, in conjunction with developing American industry's mastery of spacefaring operations and encouraging the expansion of U.S. commercial space operations, motivating and preparing the future American spacefaring workforce is also an important spacefaring logistics infrastructure implementation objective.

American youth are increasingly knowledgeable of the economic potential of intellectually demanding careers. While they seek challenging and satisfying careers, they also seek career stability and personal economic success. Transforming the American spacefaring dream into reality—starting with building the initial spacefaring infrastructure to be followed by the second- and third-tier commercial spacefaring enterprises—provides a powerful and optimistic vision for America's future that will encourage America's youth to undertake the education and training required to become part of this future.

Finally, American aerospace industry is broadly distributed across the nation. With the further advantage of a distributed workforce enabled by the Internet, the growth of the American aerospace industry associated with building, operating, and using the spacefaring infrastructure can see effective participation from across the country. For the next two generations, at least, most of the economic activity associated with design, development, production, and operations will take place on the ground, not in space. All states, regions, and localities can be directly involved in this new era of the space age. This will enable the creation of substantial numbers of middle-class math- and science-jobs all across the country. Most infrastructure programs enjoy strong political support because of the potential economic benefits associated with building and using the infrastructure. For space, the entire nation can share in this benefit as the American spacefaring dream is realized.

Conclusion

Throughout its two centuries of existence, America has been on the leading edge of opening new frontiers, both physical and technological. Consistently, America has successfully followed the path of building new logistics infrastructure followed by exploiting the new industrial mastery of operations and the new infrastructure to settle and industrialize the frontier. These efforts have created substantial new business opportunities, created significant new wealth, raised the standard of living, and helped to prepare America for successfully meeting the challenges of the future.

Opening the space frontier has been a dream of the American public since the 1950s. Realizing this dream has proven difficult because the necessary investment in spacefaring logistics infrastructure capabilities has not been made. As other nations also clearly see the potential value of space, America must boldly act to sustain its leadership position. This is not the time to remain timid in space. On 25 May 1961, President Kennedy said, "Now it is time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, which in many ways hold the key to our future on Earth." America must again take "longer strides" in space. It must leave behind the first era of the space age, where the primary focus was on exploration, and enter the next era focusing on mastering spacefaring operations and exploiting this new mastery for the nation's greatest benefit.

Notes

1. Ley's book was an update of ideas first introduced in 1931 in a book of the same title by David Lasser, the founding president of the American Interplanetary Society.
2. Roger D. Launius was previously the Chief Historian of NASA and currently is the Chair of the Division of Space History at the Smithsonian Institute's National Air and Space Museum.
3. Roger D. Launius, "Kennedy's Space Policy Reconsidered: A Post-Cold War Perspective," *Air Power History* (December, 2003): 22.
4. Ibid, 26.
5. "Report of the Commission to Assess United States National Security Space Management and Organization," January 11, 2001, p. 5.
6. Ibid, 11.
7. Ibid, 12.
8. "Mission Need Statement, AFSPC 001-01, Operationally Responsive Spacelift" (United States Air Force, December 20, 2001), p. 3.
9. "Final Report of the Commission on the Future of the United States Aerospace Industry," November, 2002: viii.
10. "United States National Space Policy," August 31, 2006: 1.
11. The 120-foot long steamboat *New Orleans*, built in Pittsburgh, traveled over 2,000 miles down the Ohio and Mississippi Rivers to New Orleans.
12. Charles Henry Ambler, *A History of Transportation in the Ohio Valley* (Westport, Connecticut, Greenwood Press, 1970), pp. 181–184.
13. *Historical Statistics of the United States: Colonial Times to 1970*, Part 2 (U.S. Department of Commerce, Bureau of the Census, 1975), pp. 728–732.
14. Sir Robert Watson-Watt, *Three Steps to Victory* (London: Odhams Press Limited, 1957), p. 74.
15. Arthur M. Squires, *The Tender Ship: Governmental Management of Technological Change*, (Boston: Birkhäuser, 1986), p. 122.
16. *The Economic Impact of Commercial Space Transportation on the U.S. Economy: 2004* (FAA Office of Commercial Space Transportation, February, 2006), p. 1.
17. "Trends in Public Infrastructure Spending" (Congressional Budget Office, May, 1999), p. 1–3.