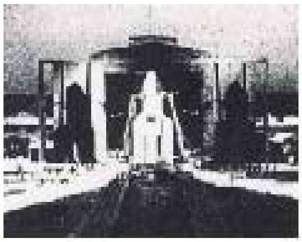
Part I: 2002

Introduction

A spaceport is a facility from which launch vehicles are sent into space, transporting the people and equipment needed to conduct commercial, scientific, and technological endeavors in orbit and beyond. Most people know what a spaceport looks like: an industrial complex where rockets are processed and launched into space. Few people outside the aerospace industry are aware of the specific apparatus, processes, systems, and operations needed to launch, control, and recover spacecraft.



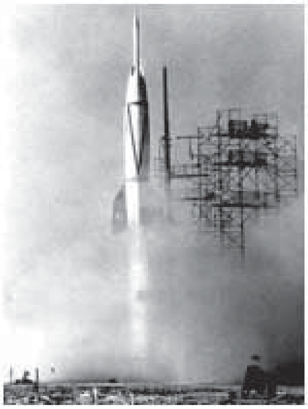
1929 Launch Vehicle Hangar
The Woman in the Moon

Early visionaries predicted the design of spacecraft and space structures that are commonplace today. Science fiction writers, artists, and filmmakers in particular have shaped impressions of space travel by envisioning sleek, powerful rockets launched from complex facilities on Earth and in orbit. One dramatic vision of a modern spaceport appeared in Fritz Lang's classic 1929 movie, *The Woman in the Moon*. Lang, notable for having invented the launch countdown sequence, showed a launch vehicle hangar in this movie that is remarkably similar to facilities in use in 2002. Nearly 50 years after Lang, George Lucas depicted spaceports as bustling hubs of commerce and transportation in the *Star Wars* movies. Future spaceports will be as much a part of daily life as airports are today.

Dr. Robert Goddard and the first liquid-fuel rocket (Photo: NASA)

Another pioneer was Dr. Robert Goddard, who in 1926 launched the first liquid-fuel rocket on a 184-foot flight into a snow bank on his Aunt Effie's farm in Massachusetts. Dr. Goddard built the motor, pump, and cooling system for the liquid-oxygen rocket in a workshop that was little more than a garage. In 1930, Dr. Goddard moved to Roswell, New Mexico, where he fabricated more powerful liquid-fuel rockets. Despite limited resources, he managed to build a vehicle that delivered an unprecedented 900 pounds of thrust—a remarkable feat of aeronautical engineering for that time.

Dr. Goddard's pioneering effort laid the groundwork for the German engineers who developed the A-4/V-2 rockets during World War II. Their test facilities and infrastructure at Peenemünde on the Baltic coast were a vast improvement over Dr. Goddard's modest laboratory. At Test Stand VII, the Germans had an assembly building with 10-story-high doors, a mobile test frame that carried the rocket over a water-cooled blast shield, a "Meillerwagen" transporter, and a hydraulic erector that raised the rocket to a vertical position at the launch site for fueling and liftoff.



Successful launch of the German liquid-fuel A-4 rocket (Photo: NASA)

Dr. Werner von Braun
(Photo: NASA)

The Germans first launched the liquid-fueled A-4 successfully in October 1942. The A-4 was as tall as a four-story building, weighed 14 tons fueled, and generated 25 tons of thrust at liftoff.

After the war, the US Army relocated a German team led by Dr. Werner von Braun to White Sands, New Mexico, to assemble rockets from existing components. By 1946, the team was testing those rockets. The first launch from Cape Canaveral, Florida, in 1950 was a modified V-2 rocket called "Bumper 8," assembled by the team at White Sands. Technicians used a painter's scaffold as the gantry to service the rocket, and the control center was a converted tarpaper bathhouse surrounded by sandbags.

The German team was relocated to the Redstone Army Arsenal outside Huntsville, Alabama, where they built an improved V-2 rocket named the "Redstone." By 1953, the US Army was lobbying to launch the first US satellite into orbit using the improved V-2 rocket. The Soviet Union's successful launch of Sputnik in October 1957 hastened US plans for its own satellite launch. In January 1958, a Redstone rocket launched the first US satellite, Explorer I, from Cape Canaveral.

Redstone Test Flight
(Photo: NASA)

Extending the Cold War into space served to unify competing US efforts into a new civilian space program. In October 1958, NASA was established as a US government agency dedicated to peaceful exploration of space. Nearly 3 years later, on May 5, 1961, Alan Shepard became the first American in space aboard a Mercury Redstone rocket for a 15-minute suborbital flight.

Following Shepard's historic flight, President John F. Kennedy saw the opportunity to establish US preeminence in space and challenged Congress to develop and fund a program that would safely send astronauts to the Moon and back within the decade. Despite an ambitious schedule and unprecedented technical obstacles, Congress embraced the challenge. NASA began the task of creating the world-renowned Apollo program.

Apollo 17
(Photo: NASA)

NASA had countless hurdles to overcome, including designing a new rocket that could propel astronauts beyond Earth's orbit, land on the Moon, and safely return to Earth. Preliminary studies indicated the program would need a huge rocket requiring an enormous amount of propellant, surrounded by a large buffer of land to ensure the safety of local residents. To create this buffer, NASA purchased 90,000 acres on the east coast of Florida adjacent to the Cape Canaveral Air Force Station (CCAFS), which had been acquired by the Department of Defense for military purposes a decade earlier. In December 1963, the NASA portion, known as the Merritt Island Launch Area, was renamed the John F. Kennedy Space Center (KSC) in honor of President Kennedy.

The facilities required for the Apollo lunar program were difficult to imagine at that time, even for the most experienced industrial architects. Facilities would have to be built to process and launch the giant Saturn V rocket—36 stories high, generating 7.5 million pounds of thrust, and carrying a 150-ton payload into low-Earth orbit. Saturn V was five times the size of anything previously flown. The huge first stage required an ocean-going barge to transport it to the Cape Canaveral launch site. The launch complex designed for this vehicle was a 4-year, $800-million construction project (in 1963–1964 dollars) and included a giant vehicle assembly building (VAB), mobile launcher platforms, a crawlerway for the crawler-transporters, launch pads featuring fixed and rotating service structures, and a launch control center (LCC). The design and construction of these facilities were considered to be one of the most awesome engineering projects ever undertaken.

Apollo 17 night launch
(Photo: NASA)

Over the years, as space flight matured and launch operations continued at KSC, the spaceport's facilities evolved to support different launch vehicles. Vehicles launched into low-Earth orbit with human crews had to return safely to Earth. The increased use of crewed missions imposed rigorous safety requirements. Robotic missions had lower safety margins than crewed missions because robotic equipment could be flown on expendable launch vehicles (ELVs) and were used only for single missions. KSC's ability to launch both crewed missions and ELVs meant more missions could be flown, which made space flight more attractive to businesses interested in exploiting space for profit. In 1973, when NASA agreed to the upgrade of a Delta launch vehicle specifically for use by RCA's communications satellite program, SATCOM, the commercial space industry was born. John Christopher, then vice president of space programs at GE American Communications, Inc., said "the upgrading of the Delta vehicle . . . was the first true commercial launch vehicle hardware venture."[1]

Kennedy Space Center
Vehicle Assembly Building
(Photo: NASA)

The commercial space industry has flourished since those early days. Today, sophisticated satellite-enabled technologies promote advances in communications and transportation. Satellite-linked wireless telephones, automobile global navigation systems, and television programming have been developed using commercial space technology delivered via spaceports.

By 2020, possible breakthroughs in health care may result from space-based pharmaceutical research, and advances in communications, power generation, and power distribution will be seen. By 2050, commercial spacelines may routinely transport passengers and goods to low-Earth orbit.

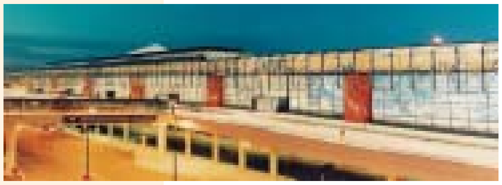
Ah, but a man's reach should exceed his grasp,

Or what's a heaven for?

—Robert Browning 1855

A network of regional spaceport hubs eventually will facilitate these markets. Due to the customer base and business climate, the public demand for expanding commercial access to space will evolve over time.

Spaceports



Baltimore/Washington International Airport (Photo: Maryland Aviation Administration)

Early 21st century spaceports are Earth-based facilities that launch space vehicles and their payloads into space and, if necessary, land them on return. Contemporary spaceports are similar to the modern airport in design and operation. In most jurisdictions, an airport is a positive economic force that fuels state, regional, and local economies. The revenue generated by the Baltimore/Washington International (BWI) Airport increased from $5.3 billion in 1998 to $6.5 billion in 2000.[2] “BWI Airport is clearly one of the strongest economic engines driving the State’s prosperity, creating greater job opportunities, and providing Maryland with a direct link to the global marketplace,” said Maryland Governor Parris Glendening.[3] According to a study commissioned by the state in 2001, the airport directly or indirectly supports nearly 85,000 jobs in the Baltimore-Washington region. Passengers and visitors to BWI contributed $2.8 billion to the local economy, and overall airport activity generated $770 million in state and local taxes.[4]

Since airports generate impressive revenue and taxes, it is easy to see how decision makers might view spaceports as potentially attractive investments. The commercial space business does have a significant economic impact today. The Federal Aviation Administration (FAA) reports that “US economic activity linked to the commercial space industry in 1999 totaled over $61.3 billion. Commercial space transportation was directly and indirectly responsible for $16.4 billion in employee earnings in the United States. Over 497,000 people were employed in the United States as a direct or indirect result of commercial space transportation and related industries.”[5]

World revenue for all segments of the space industry will grow from about $44 billion in 1996 to nearly $105 billion in 2002.

—Trends in Space Commerce, US Department of Commerce 2001

These figures do not tell the whole story, however. Space flight remains a high-risk, high-cost endeavor when compared to air travel. The world’s air transportation system is mature, routine, and safe. Enormous infrastructure investments have been made over the last eight decades to bring the system to this point. A contemporary urban airport can process about 750 flights a day, moving thousands of passengers and crews and tons of cargo from one location to another. Airlines and airport operators profit from this high demand.

In contrast, the demand for commercial access to space is low, and the high cost of processing and launching payloads will continue to suppress demand for the foreseeable future. Additionally, a number of technical, safety, and economic obstacles in the commercial space industry must be overcome before spaceports can begin to achieve the financial success of airports. Contemporary spaceport planners face a daunting challenge: they must forecast the infrastructure needed to support customer-driven payload requirements, but recognize that demand will increase on an evolutionary, not revolutionary, scale. At this point in the evolution of spaceports, investment decisions may be prompted by national, regional, or state pride, or by the desire to maintain technical competence, but they should not be based solely on financial return. Some spaceports are restricted by geography, but with certain compromises, they could be feasible someday in landlocked areas. Regardless of location, however, spaceports will need subsidies until the commercial space industry develops sufficiently.

Virginia Space Flight Center (Photo: VSFC)

Today, almost two dozen active spaceports worldwide are capable of launching payloads into orbit; two of them have launched people. Of the four US civil spaceports licensed by the FAA, three have launched commercial payloads: Spaceport Florida, California Spaceport, and the Kodiak Launch Complex (KLC) in Alaska. The fourth spaceport is the Virginia Space Flight Center (VSFC) in Wallops Island, Virginia. Despite this encouraging start, the FAA Office of Commercial Space Development estimates that in the next decade, an annual average of 46 commercial payloads will be flown on 32 launches worldwide.[6] This is not nearly enough demand to profitably support current US civil spaceports, let alone new spaceports.

The projected commercial market cannot sustain all of the launch systems that are here today, let alone all of the systems that are going to be in place by the end of next year.

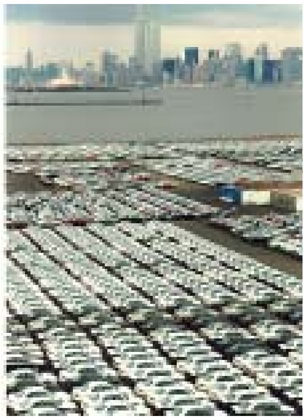
—Wilbur C. Trafton
President,
Sea Launch,
in *Space News*,
May 28, 2001

Facility Models

Spaceports have much in common with airports and seaports. All are involved in transporting people and goods to distant locations, provide protection from the environment, and have facilities for maintenance and repair. But each has specialized transport methods and infrastructure as well.

Port[7]

Transportation links and their accompanying ports and stations have always been at the center of transportation services. Ports in particular are often important factors in the economic growth of regional economies as well as strategic focal points for administrative and military control. Historically, ports developed in areas with favorable physical geographical features such as deepwater harbors and river convergence. With modern transportation modes, economic viability, environmental concerns, and safety issues have become determining factors in port development, especially airports and spaceports.



Port Authority Auto Marine Terminal
Jersey City/Bayonne, NJ
(Photo: PA NY/NJ)

From a purely logistical perspective, ports serve several functions, regardless of whether they transport passengers or freight.

- They are terminal points for movement of people or goods.
- They are consolidation or distribution points for traffic.
- They can act as transshipment points.
- They can act as inter-modal exchange points.
- They can act as value-added points where inputs are processed and then sent out in a different form.
- They can be linked to other ports by roads, air corridors, rail tracks, and shipping lanes and thus serve a function within a wider network context.

Ports generally provide a combination of these functions at one time. A port's primary function may be limited to serving as an access point for local traffic at the end of a network link; at the other extreme it may be a "mainport" that provides all these functions.

There is a tendency to view each particular type of port (seaport, airport, spaceport) as being unique. Although different types of ports have their own specialties and unique features, these should be considered within the context of the multiplicity of features common to all types of ports along with the scope for transferring skills and practices among them. This commonality enables the adoption of advancements in management and technology systems to multiple port types. In addition, most port-related public policies can be applied to different types of ports.

The spaceport, the newest addition to the port family, has generally been treated as a special case because of the nature of the activities involved: much of its traffic is unidirectional, it conducts a limited type of business, the traffic is high value, and environmental and safety considerations are more critical. Nevertheless, spaceports also share features with more traditional types of ports, and can benefit from advances originating in those sectors.

Transportation is a network activity. Very few passengers or consignments of goods simply travel directly from one point to another. Even if they do, the vehicle carrying them usually travels within a more complex pattern of movements. This is not new; 300 years ago, the Atlantic mercantile trade was dependent on triangular movements among Europe, Africa, and the Americas, Modern transportation modes, however, are shaped more by customer preferences and advances in communications systems.

Transportation sectors have also become more integrated with information transaction and control systems. Improved technologies facilitate precision tracking of vehicle and consignments, optimize the scheduling of crews and vehicles, and enhance processes such as scheduled vehicle maintenance and minimum path routings. Within the framework of freight supply chain management, systems such as electronic data interchange integrate production processes, minimizing required inventories levels. Technical advances in port handling and intermodal exchange, from air- or ship-to-ground modes, for example, reduce damage and transit costs.

In the air transportation industry, the development of hub-and-spoke operations has allowed airlines to reap the economic benefits of scale, scope, and density while enjoying revenue enhancement generated by economies of network presence. In addition, technical developments such as computerized reservations systems and online ticketing have contributed to these economies of network presence. The hub-and-spoke model has also worked well for ground-based transportation systems, and may become increasingly relevant to the evolving spaceport-based transportation sector. Other advances in the air transportation industry include improved systems controls that have optimized crew, aircraft, and gate utilization, and reduced maintenance and other ancillary costs. These technologies have applications across the spectrum of transportation modes, including spaceports.

The importance of effective transportation systems within a broader logistics framework is evidenced by the number of transportation and logistics specialists appointed to company boards, by the high salaries of those qualified in the fields of logistical and transportation management, and in the corporate structure of many companies. Transportation infrastructure planning committees concentrate on the most efficient uses of their infrastructure networks, incorporating the most recent advances in these systems (i.e., Intelligent Transportation Systems).

Contemporary transportation models and systems have significantly reduced overall logistical costs; nevertheless, several broad issues remain to be fully addressed in a number of emerging areas.

Technological and systems changes that have occurred in the different transportation sectors have not been adopted uniformly. Air freight (including integrated express services) and passenger transportation have been at the forefront of the logistical revolution. This may be partially due to greater familiarity with modern technologies, but it may also be institutional because they were freed of government regulation before other sectors. Since virtually all transportation services are provided within a network context, informational and technological transfer among modes is possible. However, this transfer seems to be impeded by the traditional unimodal orientation of those in specific sectors who have little experience in movement between modes

Most movements of passengers and freight are intermodal, but the analysis or approach to logistics is often still unimodal, or at least biased toward one leg of a movement supplied by a single mode. Integrated logistics is slowly changing this process, reflected in many of the programs and algorithms now commonly employed in the process. However, generally only the larger shippers and carriers employ staff with skills, training, and expertise applicable to different transport modes. The role of consolidators in this context is changing, since they offer services incorporating elements of multimodalism, and have the expertise to upgrade to more advanced programs. In addition, globalization and internationalization have increased the importance of international logistics to the US economy. Advanced international logistics minimizes the transaction costs of imports and exports, and is potentially a high-value earning sector in its own right.

New transportation patterns are emerging along with new communications systems. The most important of these is the growth of e-commerce, an industry that transacts orders and payments electronically and delivers products directly to the door. This approach to household delivery, combined with modern distribution systems, has a wide range of ramifications. There are important issues related to the communication phase of commerce and distribution of the product, including the coordination of information on product availability and delivery time, locating warehouses and production sites, identifying modes of transportation, and coordinating corresponding issues of reverse logistics. To date, this process has proved problematic, partly because of differing underlying approaches to communication and logistics and also because of poor systems management and technology interfaces.

In addition, the primary roles of the public and private sectors are unclear. The philosophies of the two are often different, and developing a viable interface between them is difficult. Communication between the two sectors is hampered by differences in the modeling and analytical techniques used. Their models usually operate at different levels, based on unique assumptions and scenarios.

The hub-and-spoke system, with a core port linked to other ports, forms the basis of most efficient logistics structures. This system is the standard operating method for both the US Postal Service and its private competitor, FedEx, which operates its main hub in Memphis, Tennessee. Memphis is also a hub for rail freight networks, roads, and a waterway system. Another example is the mainport development at Rotterdam in The Netherlands. Hub-and-spoke systems allow for maximum utilization of mobile capital (planes, trucks) by ensuring high load factors (economies of density). Savings are enhanced if a large number of origins and destinations are served (economies of scope). The range of potential destinations the hub can reach provides users with access to numerous markets (economies of market presence). Applications of this system to spaceport-based transport systems of the future will probably use international hub-and-spoke operations on Earth, in addition to adapting the concept to space itself, involving the space station, the Moon and Mars.

The technical issues involved in constructing the optimal network, the optimal level of service along links, and the optimal number of hubs is complex. In practice, these issues often involve a high degree of judgment as well as trial and error. While many key issues are already familiar, others are new and less easily articulated. Some of the issues involved in defining this structure are the following:

- The number and location of ports. Issues surround the scale of ports (primary/secondary) and their transshipment, consolidation, and terminal functions within the overall network configuration. This raises questions of optimal port hierarchies and the market areas where they offer services.

- Degree of direct service (omitting hubs). Direct service can offer customers a faster but more costly service. It also may mean more empty running if business is not balanced between points. The tradeoff calculations are complex, especially within a competitive network context.

- Level of banking. At hubs involving transshipment and consolidation, all mobile capital must arrive and depart within a specified time frame. The tradeoffs include the degree of idle time between banks, using large units of mobile capital with infrequent banks versus smaller units of capital with more banks, the mix of large and small units of mobile capital, the nature of the transshipment facility, and the degree of secondary sorting.

- Routing over network links. This type of routing creates problems between more direct routes with fewer en route collections or deliveries and slower, cheaper routes with more collections or deliveries. Routing assignment has attracted considerable attention but still is an imperfect art.

- Types of traffic carried. This may involve issues of mixed passenger and cargo traffic (e.g., belly hold cargo on planes) as opposed to specialized traffic. Even within the freight sector, this can be broken down further into general consignments, containers, packages, and other categories.

- Transportation Network Issues. The degree to which the transportation network issues are treated as part of the overall production process and the extent to which they are seen as standalone activities raises other issues, such as the extent to which companies should transport their own goods and the degree to which outsourcing is optimal.

- The extent to which multimodal services are supplied. Although most movements are multimodal, transportation suppliers do not necessarily provide all the transportation. The optimal mix of transportation services provided by any supplier depends on the synergies among the various modal networks and how costs and revenues are allocated. Optimization requires simulations across various single and multimodal options.

- The importance of inter-firm alliances. If a transportation supplier cannot (for institutional reasons) or will not (for economic reasons) offer a comprehensive service, it may join with others in an alliance. Alliances are now common in the airline industry for passenger movements, and are increasing in sectors such as rail freight and ocean freight. It is difficult to know which networks offer optimal networks, as seen in numerous failed airline alliances.

- Network scheduling problems for mobile capital and labor. In particular, projections of labor shortages over the next decade in sectors such as trucking and railroads are likely to be made worse if the social conditions of employees are not improved. Crew scheduling is particularly difficult because the people involved are concerned about hours worked and the work location. Improved speed and rush deliveries can leave crews some distance from their initial starting point.

- Emerging constraints on how the various components of a network may function. Environmental concerns which impact the location, nature, and operation of ports are unlikely to abate in the future. System optimization within this new institutional framework will require better data analysis and more flexible modeling.

Airport

The FAA defines an airport as "an area of land or water that is used or intended to be used for the landing and takeoff of aircraft, and includes its buildings and facilities, if any."[8] Local, state, and Federal laws and regulations govern everything about US airports, from construction planning to aircraft operations. Additional rules and regulations direct the certification and licensing of pilots, aircraft maintenance employees, and other key personnel. The required facilities for commercial service airports include designated runways, taxiways, and aprons; hangars for servicing and maintaining aircraft; fuel storage and loading stations; boarding and baggage areas; passenger and freight terminals; administrative offices; and air traffic service facilities. Local jurisdictions—not the FAA—fund and operate airports.

LaGuardia Airport Control Tower—New York (Photo: PA NY/NJ)

FAA air traffic controllers perform the control functions governing aircraft takeoff, in-flight control, and landing at commercial service airports. They work in 21 air route traffic control centers (ARTCCs) located across the country, in approach facilities that control traffic close to the airport, and in control towers on the airport grounds. The FAA operates these facilities according to the *Facility Operation and Administration Manual* (FAA Order 7210.3, February 24, 2000). This manual sets forth the job requirements, responsibilities, rules, and procedures for such areas as hours of duty, security and medical services, weather equipment and information, and in-flight operations. The basic operating equipment in ARTCCs includes flight progress strips, radar displays, communications displays, and automated equipment arranged by airspace sectors.

Seaport

A seaport is a port with facilities for seagoing ships. Seaports are highly autonomous. Seaports and maritime activities operate with relatively greater independence from government regulation than do airports, although they must comply with rules and procedures generic to all industrial activities. These regulations address vessel, passenger, personnel, cargo, and facility safety in addition to state, national, and international rules and covenants governing harbors and transoceanic shipping lanes. Captains and pilots of vessels and certain other key personnel must be certified and licensed.

Cargo shipping at Port Everglades, Florida (Photo: Port Everglades)

Facilities at a major commercial seaport include piers; docking and embarkation spaces; baggage handling areas; load arms; straddle stackers for containerization movement; tugging, piloting, and stevedoring services; dry and liquid bulk cargo facilities and berths; freezer and chill facilities; warehouses, fuel storage, and refueling sites; and auxiliary marinas and bulkheads for small craft.

Spaceport

A spaceport is a special case in the family of port facilities. Much of its traffic is unidirectional; it supports a specialized business niche; its payloads, launch vehicles, and equipment are very costly; and environmental and safety considerations are paramount.

A spaceport includes the facilities, equipment, personnel, and vicinity required to prepare a spacecraft for flight, initiate and manage the flight, and perhaps receive the craft at the end of the flight. For Earth-based spaceports, vicinity refers to the land (or sea) occupied by the facilities and equipment. For space-based spaceports, vicinity refers to the orbit and operations envelope around the spaceport. Unlike an airport, a spaceport can be dispersed over several locations, including down-range instrumentation facilities and space-based communications equipment.[9] Today, abort landing sites are unique to KSC and are not typical of all spaceports.

Orbiter Processing Facility—
Kennedy Space Center
(Photo: NASA)

A spaceport shares some basic characteristics of both airports and seaports, with one exception: a spaceport affects a wider range of air and land corridors during launch and landing. Also, for the near future, spaceports will be much more complex than airports because of the high-energy propellants, narrower safety margins, and extremely complicated and redundant systems they require.

The two types of space vehicles currently in use are Expendable Launch Vehicles (ELVs) and Reusable Launch Vehicles (RLVs). ELVs are used only once to carry payloads into space. RLVs are launched into orbit and return to Earth, landing on runways like airplanes.

A spaceport accepts a payload from a customer, integrates the payload into a launch vehicle, prepares the vehicle for flight, and launches the vehicle and its payloads into space. Once in orbit, the payload either permanently deploys into space, as is the case for communications satellites, or it performs experiments and sends data sent back to Earth. A payload designed to be returned to the customer after flight is flown on an RLV.

Spaceport infrastructure includes receiving and processing facilities; laboratories and “clean-rooms” for vehicle and payload assembly, testing, checkout, and integration; fuel storage and fueling sites; specialized transportation equipment; launch pads; and, where RLVs are used, landing runways and support structures are typically required. Facilities are needed for crews and passengers, and for animal, plant, and microbial travelers. Spaceports must provide range and weather services in addition to other specialized facilities at or near the launch site. For RLVs, alternate landing site facilities must be available.

The US Department of Transportation (DOT) licenses commercial spaceports. To date, the body of specific laws, regulations, and procedures applicable to spaceports is less comprehensive than those for airports and seaports. As a result, spaceport operators have

Space tourism will materialize faster than most people think, with short flights as soon as 2004 and a gravity-free hotel hoping to offer longer escapes by 2017.

— Howard Wolff,
Wimberly Allison,
Tong & Goo
Architects, Planners
and Consultants
1999

more autonomy in formulating unique procedures for internal processing and daily operations. The enabling authority for funding and operating commercial launch activities derives from legislation enacted by the states in which the spaceports are located. Some daily operations are governed by Federal laws and regulations generic to all industrial functions, such as the Occupational Safety and Health Act.

As commercial demands for launch services grow and launch sites proliferate, spaceports could be based in regions rather than in individual states. Adjacent states would have a vital interest in the authority and operation of a regional spaceport that would serve the transportation needs of its citizens and businesses. However, officials thus far have been unwilling to commit their state's resources to a spaceport located in another state. Ideally, all states in a region would be responsible for the planning, development, funding, and operation of a regional spaceport, and interstate consultation, cooperation, and accountability would be necessary. Although states may be reluctant to adopt this concept, the first successful regional spaceport will likely become the model for those that follow.

Methods of Ownership and Operation

Most US civil spaceports are likely to be owned and operated by authorities, commissions, or boards established at the state or regional level. This ownership concept has worked well for large, city-specific or regional airport complexes and for the three pioneering US spaceports with orbital capabilities. For example, the Metropolitan Washington Airport Authority runs Reagan National Airport and Dulles International Airport in the Washington, DC, area. The chief executive officer and his staff report to a 13-member board of local business people that decides how revenues from concessions and gate fees will be spent. The board can also issue bonds for building. Future civil spaceport owners and operators will have several organizational options to choose from, as described below.

Private Ownership/Fixed Launch Site

A developer of a single-class launch vehicle might choose to develop and operate a spaceport for an initial investment of at least $300 million (in year 2000 dollars).[10] This option has distinct advantages, including the ability to select an optimal location to enhance launch system performance and reduce costs. The owner/operator also exercises complete control of scheduling and is relatively free of outside influences. The ability to operate under fewer US Government rules and regulations may make this an attractive alternative despite the development cost.

Pegasus vehicle attached under a Lockheed L-1011 aircraft (Photo: Orbital Sciences Corporation)

Private Ownership/Mobile Launch Site

Pegasus and Sea Launch are the existing mobile launch systems. Pegasus is an air-launched vehicle taken aloft attached to the underside of a Lockheed L-1011 aircraft and released. Pegasus can then carry a payload of up to 1,000 pounds to low-Earth orbit. Sea Launch is another private mobile spaceport that uses a converted oil rig platform at an equatorial launch site. Its ocean-based launch services provide commercial satellite customers with a direct route to geosynchronous transfer orbit. The Sea Launch Zenit-3SL rocket can lift a spacecraft of more than 12,000 pounds or place a payload into a higher perigee (lowest point of its orbit), helping satellite operators attain a longer satellite service capability. Sea Launch's use of marine operations reduces launch infrastructure and minimizes operational costs. Over the past 40 years, several successful floating launch vehicle test programs have used the ocean as a launch pad. This concept may well be proposed by a future launch service provider. Another potential mobile launch system is the proposed Boeing Air Launch System, which would use a modified 747 aircraft to carry a launch vehicle to high altitude before release.

Sea Launch transferring vehicle to launch pad
(Photo: Sea Launch Company)

Public Ownership/Shared Facilities

The Florida Space Authority, Virginia Commercial Space Flight Authority, and California Spaceport currently use the public ownership/shared facilities model. The Federal Government owns many of the launch preparation and operations facilities but shares them with the civil operator, who may have to provide only a launch stand and associated equipment. Such an arrangement is advantageous in that it provides expensive and often unique facilities and launch personnel at an incremental cost. However, many customers perceive the disadvantages of a shared facility to be uncertain scheduling and mandatory compliance with a government bureaucracy.

Kodiak Launch Complex
(Photo: KLC)

State Ownership/Federal Government Financing

The Kodiak Launch Complex (KLC) is owned and operated by an authority established by the state of Alaska and funded by the Federal Government. All facilities accommodate Castor 120 and smaller rockets on both suborbital and low-Earth orbit polar launches. KLC offers adequate port facilities, a regional airport, and an adequate transportation system. The island also has air and sea shipment transfer capability available at Anchorage, 250 miles to the north. This model is difficult to replicate because of the investment needed to design and construct the facility. In this case, the Federal Government provided the necessary $26-million investment.

Federal Government Ownership/ Contractor Operations

In the future, the Federal Government could, as a matter of national interest, fund the development of a spaceport and lease the operations to a launch vehicle developer, private corporation, or state or regional authority. This endeavor is similar to the expansion of airport capabilities, especially in the construction of runways and taxiways. For airports, the airport trust fund largely supports such expansion, and is supplemented by the passenger facility charges paid by the traveling public. The last airports owned and operated by the Federal Government were Dulles International Airport and Reagan National Airport, both in the metropolitan Washington, DC, area.

Port Authority of New York and
New Jersey cargo handling
(Photo: PA NY/NJ)

Independent Public Authority

Taxpayers view an independent public authority favorably. The Port Authority of New York/New Jersey (PA NY/NJ) is an example of a financially independent, self-supporting public agency that receives no tax revenues from any state or local jurisdiction and has no power to tax. The PA NY/NJ relies almost entirely on revenues generated by users through tolls, fees and rents. In 1999, the PA NY/NJ handled more than 89 million airline passengers and 2.7 million tons of air cargo, and, without using tax dollars, earned $253 million on gross revenues of $1.4 billion at the three major airports in that region.[11] Given the success of the PA NY/NJ, an independent public authority may prove to be an excellent model for future civil spaceports.

Foreign Trade Zone (FTZ)

Major hub airports and seaports such as Orlando International Airport (FTZ 42) and Port Canaveral (FTZ 136) enjoy a commercial advantage known as a Foreign Trade Zone. Congress created the FTZ authority to permit foreign and domestic merchandise to be admitted into the United States without formal customs entry or payment of duties. For example, avoidance of a duty rate of 4.0% on a $100 million payload saves the customer $4.0 million. For this reason, FTZs appeal to commercial interests in states served by the spaceport. Advantages include deferred warehousing, distribution costs, and duties; reduced assembling, processing, manipulating or manufacturing costs, and duties; and elimination of costs and duties in the event of export or damage. British, French, Italian, German, and Japanese aerospace companies now send communications satellites and components to FTZ 136 for processing and launch. "The success of FTZ 136 is recognized worldwide," says Rodney Ketcham, chairman of the Canaveral Port Authority Commission. "Countries such as Italy, South Africa, and the Ukraine are using it as a blueprint for their own proposed free trade zones." During Fiscal Year 2001, Foreign Trade Zone 136 served 56 businesses, provided employment for 133 people, and had a regional impact of $85 million. It encompasses three hubs covering nearly 4,200 acres in Brevard.[12]

In terms of political control, the problem is obvious. No sensible commercial operator wants to share a launch system with NASA when the agency could disrupt commercial schedules for agency needs at any time. The near mass exodus by the airlines from the CRAF military call-up program after the CRAF was activated for the Gulf War is a case in point.

—SAS's Space Launch Initiative Policy Clarification

Spaceport Design Considerations

Safety is the most important factor in spaceport design. A spaceport can be considered successful if it meets its customers' needs for payload processing and launch services in a safe, reliable, cost-competitive, and user-friendly manner. The factors that ultimately dictate spaceport size and design cost are the following:

- **Location** of the spaceport, principally driven by the customer's needs and requirements, which include orbit inclination and latitude
- The portion of the **commercial space market** the spaceport will serve
- **Public interest** and related implications of safety and spaceport impact on the immediate community and environment
- A **spaceport authority** with the responsibility of managing, controlling, and directing spaceport operations
- The **spaceline companies** that will process and launch their vehicles from the spaceport

These factors invite specific questions that must be answered before a particular spaceport design can be pursued. For example, will the spaceport support only existing launch vehicle and spacecraft designs? Will the design plan take into account possible unique and innovative launch systems such as those using magnetic levitation? Will the spaceport be designed for RLVs, ELVs, or both? What about human flight versus robotic-only missions? Will payloads be processed onsite or processed elsewhere and transported to the spaceport? To answer these and other questions, a closer look at these design factors is in order.

Location

A spaceport requires certain attributes that directly relate to its geographic location. These are clear down-range facilities, payload-to-ground station accessibility, payload optimization, and orbit inclination.

Clear Down-range Facilities. The spaceport must have a clear down-range area where spent launch stages and/or aborted launch vehicles can return to Earth without injuring people or property. Range limitations are usually expressed in terms of launch azimuth—the range safety limits or the ground tracks of a launch vehicle that do not traverse populous land masses—and distance down range.

Payload-to-Ground Station Accessibility. In most cases, a payload customer will require access to the payload in orbit through the use of available ground facilities. Azimuth constraints at the spaceport will determine whether the payload can be delivered to an orbital inclination with a ground track that reaches a latitude acceptable to the customer.

Payload Optimization. A spaceport should be located to maximize efficiency in delivering a payload mass into orbit. The orbit inclination of most US spacecraft is about 30 degrees, which is where the orbital plane intersects the equatorial plane at 30 degrees. This is why the current predominant launch site is Cape Canaveral at 28.5 degrees north latitude. A due east launch adds the Earth's surface rotational speed—about 1,300 feet per second—to the horizontal velocity acquired by that launch vehicle. Similarly, a launch from the spaceport at Baikonur, Kazakhstan, located at about 51 degrees north latitude, adds only 940 feet per second to the horizontal velocity of the launch vehicle.

Changing the launch azimuth of the powered flight of the launch vehicles can result in higher orbital inclinations, but with a commensurate reduction in the velocity increment from the Earth's rotation and a related reduction in payload capacity. Achieving an orbital inclination lower than the latitude of the launch site requires orbital plane change maneuvers and additional performance from the launch vehicle.

Because the demand is so great for the delivery of payloads to geostationary or geosynchronous orbits in the equatorial plane, a launch capability at or near the Earth's equator is favorable. A site at that latitude takes full advantage of the Earth's surface rotational velocity at that inclination, about 1,500 feet per second.

Orbit Inclination. The three major orbit inclinations are geosynchronous, geostationary, and polar. All payloads in geosynchronous and polar orbits have significant revenue potential and should be considered in spaceport development. The demand by some customers for other orbits may dictate the location of a proposed spaceport.

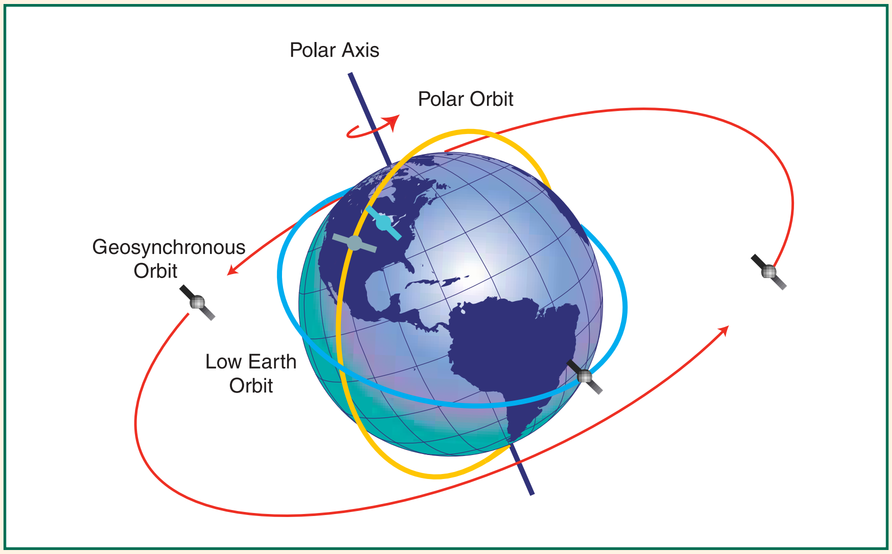


Illustration: Glennan Graphics

Orbit inclinations

The azimuth of a line is the angle the line makes with a north-south line. Azimuth is measured to right, or clockwise. For space flight purposes, south is always zero degrees. Azimuth is measured from zero to 360 degrees unlike bearing directions, which are measured in 90-degree quadrants.

- **Geosynchronous orbits** can be at any Earth inclination and are usually at altitudes where the orbit period directly relates to the period of the Earth's rotation (12-hour, 24-hour, or 48-hour) in which they may have a repeating ground track (12-hour, 24-hour, 48-hour, or any other). Communication with geosynchronous payloads requires steerable tracking antennas at the ground stations.

- **Geostationary orbits** are particular types of geosynchronous orbits in which the orbit inclination coincides with the Earth's equatorial plane and the orbit period coincides with the Earth's rotation rate. The ground track is a fixed point on the Earth's surface at the equator. Communication with geostationary payloads requires only the widely-used fixed-orientation antennas at the ground stations. Geosynchronous launches are usually associated with payload launches to low-Earth orbit altitude. Subsequent delivery to geostationary Earth orbit then occurs through two or more burns of a propulsion stage associated with the payloads.

- **Polar orbits** at any altitude are in a plane perpendicular to the Earth's equator and pass over the North Pole and South Pole. A polar-orbiting satellite can scan the entire surface of the Earth in one 24-hour period. Satellites in low-altitude polar orbits can obtain enhanced resolution of Earth observations for resource and weather information.

Market Decisions

Spaceport developers must decide what part of the commercial space industry to target in their strategic goals and plans, as commercial space market segments have very different operational requirements. Specific operations will in turn determine the type, size, and possibly the location of the spaceport. A spaceport launching crews and passengers into orbit, for example, requires a more complex infrastructure than a spaceport specializing in robotic launches. Spaceport developers must consider each market's requirements for the following:

- Launch vehicle sizes and types (expendable or reusable)
- Payload size, weight, orbit, power, and environmental resources
- Payload operations and/or deployment on-orbit
- Crew and passenger versus robotic missions
- Vertical and/or horizontal launch and landing

A well-conceived master site plan also is essential. Developers intending to offer multiple services will have to evaluate parallel site development or, more likely, evaluate a site's development over several years. It is not sufficient simply to identify a parcel of available real estate as a future spaceport and expect financiers, entrepreneurs, and prospective customers to commit their resources. The decision to develop a site must be market driven; otherwise, the spaceport risks becoming a burden on taxpayers or other investors.

Public Interest

A spaceport authority is responsible for minimizing potentially adverse effects on the physical environment surrounding the spaceport and for protecting people in the local and regional area from potential launch malfunctions and other risks. Spaceport developers should plan and implement these actions in consultation with appropriate officials of local, regional, state, and Federal Governments; the interested public; and other stakeholders. Specific public interest requirements are outlined in relevant sections of this guide related to safety, security, and compliance with applicable regulations.

Spaceport Authority

A spaceport authority has ultimate control over all spaceport operations, similar to the control of airport operations by airport authorities. A spaceport authority resolves any conflicts of use and determines priorities for launch schedules, range use, and other facilities uses. The spaceport authority provides the land and the infrastructure necessary to launch payloads with the associated launch systems. Security, safety, fire, general utilities, water, electricity, and propellants and gas handling are some of the basic services provided, along with separate generic launch pads and runways, if necessary. Spacelines may have the option, with suitable planning, to provide vehicle-specific launch sites or pads on the spaceport facility.

Spacelines

Spacelines is a relatively new term, used in the same context as airlines. Spacelines one day will be the interface between spaceport customers and spaceport operations. Spaceport developers need to understand these roles, as well as the differences among various spacelines and how they might use the spaceport. A spaceline will be a client of the spaceport and provide services to its own customers.

X-40A Flight Dynamic
Test Vehicle
(Photo: NASA)

In 2001, launch vehicle manufacturers served as spaceline companies. Future spacelines may purchase launch vehicles directly from manufacturers and offer space launch services to payload customers using spaceport facilities. Payload preparation and integration will continue to be performed by payload and launch vehicle personnel, who are the most knowledgeable of specific launch vehicles and systems. Safety is, and always will be, the most critical requirement facing spaceline companies.

Spaceport Operations

The two primary operations a spaceport performs—payload processing operations and spaceline vehicle operations—are described in this section, along with the responsibilities of the spaceport, the spacelines, and payload customers. Figure I-1 depicts the operational overview of a full-service spaceport.

Kennedy Space Center is the model used for the spaceport operations described in this section.

Launch vehicle processing (Photo: NASA)

Payload Processing Operations

Payload processing operations are the coordinated steps of accepting, processing, testing, installing, launching, operating, and possibly returning the payload to the customer. Figure I-2 depicts the payload processing flow at a spaceport, showing the responsibilities, processes, and facilities involved.

Receiving and Inspection. Upon arrival at the spaceport, payload customer support equipment and flight hardware undergo visual inspection to identify any damage incurred during shipment. Clean-room facilities are provided to protect against contamination of the flight components.

Individual Systems Testing. Any flight hardware components shipped separately are installed on the payload carrier before individual system verification testing begins. This testing sequence also includes pressurized leak tests of fluid and gaseous systems.

Crawler transferring *Discovery* to launch pad (Photo: NASA)

Integrated Systems Testing. After completion of the individual systems testing sequence, an integrated systems test is performed to assure that no unacceptable electrical or mechanical interference exists between the payload systems and vehicle systems. Payloads using a spin stabilization system (e.g., communication satellites) might consider using the facility support provided by the spaceport to verify proper operation.

Transfer of Payload to Launch Vehicle. The payload's fluids, gases, or fuel systems are serviced before the payload is transferred to the launch vehicle. If required, the payload is encapsulated in an aerodynamic fairing. During transport to the launch vehicle, required cleanliness levels and temperature control are maintained. A verification test is conducted after mating the electrical, fluid, and mechanical interfaces between the payload and the launch vehicle.

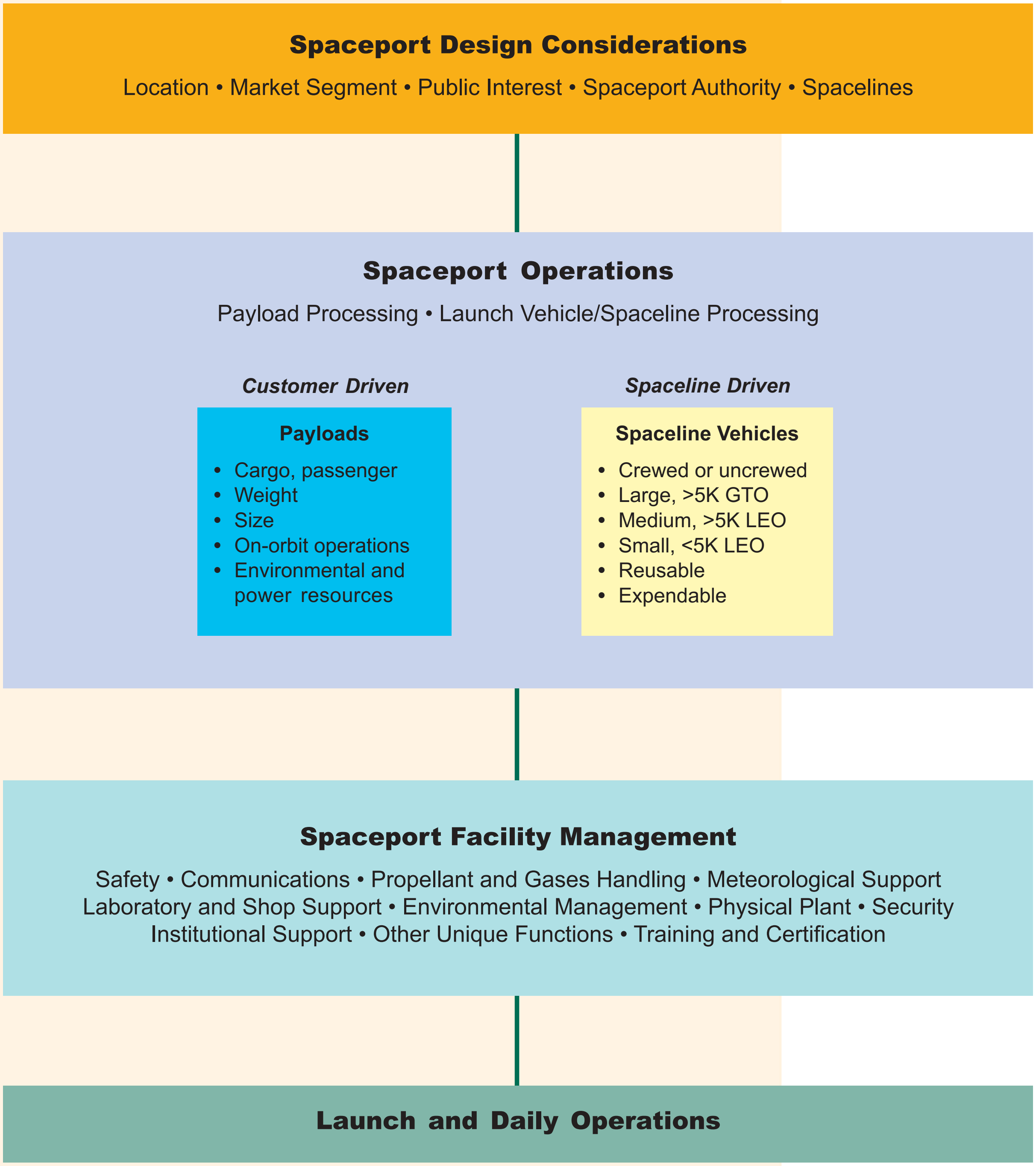


Figure I-1. Spaceport operations flow

Responsibility	Process	Facility
Customer	Deliver Payload for Flight Inspection and Testing	P/L Receiving and Checkout
Customer	Completion of Mechanical/Electrical Buildup	P/L Receiving and Checkout
Customer	Individual Systems Verification Testing	P/L Receiving and Checkout
Customer	Pressure/Leak Test of Fluid/Gas Systems	P/L Receiving and Checkout
Customer	Integrated System Test	P/L Receiving and Checkout
Spaceline	Spin Test	Spin Test Facility
Customer	Servicing of Fluid, Gas and Fuel Systems	P/L Hazardous Gas/Fluid Facility
Spaceline	Transfer to Launch Vehicle	
Spaceline	Mechanical/Electrical Mate with Launch Vehicle	LV Assembly and Checkout
Customer / Spaceline	Integrated Systems and Interface Testing	LV Assembly and Checkout
Spaceline	Transfer to Pad	
Spaceline	Launch	Launch Pad or Runway
Customer / Spaceline	On-orbit Operations	
Spaceline	Landing and Recovery	Landing Pad or Runway
Customer / Spaceline	Launch Vehicle and Payload Safing	Landing Pad or Runway
Spaceline	Return Payload (P/L) to Customer	Shipping and Receiving Dock

Figure I-2. Spaceport payload (P/L) processing flow and responsibilities

Other Payload Considerations. The maturity and complexity of payload systems are the major factors in determining the level of additional testing needed. This testing may range from participation by the payload customer in a Countdown Demonstration Test (CDDT) to full-scale launch vehicle or payload integration systems tests. Depending upon the specific payload, payload systems may be required to be activated for launch. In the case of flight hardware and payloads from other nations, some form of standardized infrastructure must be defined to handle and process cargo. These issues touch on national security concerns and may invoke US Government involvement to ensure that defense and national security policies and procedures are observed.

Spaceline Vehicle Operations

Procedures for processing launch vehicles are similar to those for processing payloads. Figure I-3 shows the vehicle processing flow for an ELV, and Figure I-4 shows the more complex process for the Space Shuttle. The major systems are integrated into the final vehicle flight system for launch at the pad. The complexity and sensitivity of some orbiter systems drive most of the processing of Shuttle components.

Receiving and Temporary Storage. A customer's flight hardware and equipment may be received and inspected in either an air-conditioned Assembly and Checkout (A&C) facility or a non-air-conditioned facility. The A&C facility is specifically designed to house the flight hardware and personnel. The non-air-conditioned facility provides electrical power, lighting, and conditioned coolant/purge air as part of basic facility support. Most customers prefer using an A&C facility because it involves less mechanical handling of the launch vehicle hardware and equipment. Functions performed by the spaceline during this stage of processing include the following:

- Installation of separately shipped flight component hardware
- Electrical power distribution tests
- Individual electronic (computer, instrumentation, communication) system tests
- Fluid system pressure/leak checks
- Integrated systems tests

The interfaces between the launch vehicle and the payload systems are verified using payload simulators where appropriate.

When required, solid-fuel rocket segments/stages are received and inspected in an air-conditioned storage and processing facility adequately separated from other processing facilities, as dictated by applicable explosive quantity-distance calculations. All pyrotechnic devices (explosive bolts, linear shape charges, etc.) used by the launch vehicles and payloads are received, inspected, stored, and prepared for prelaunch installation in an isolated common-use facility.

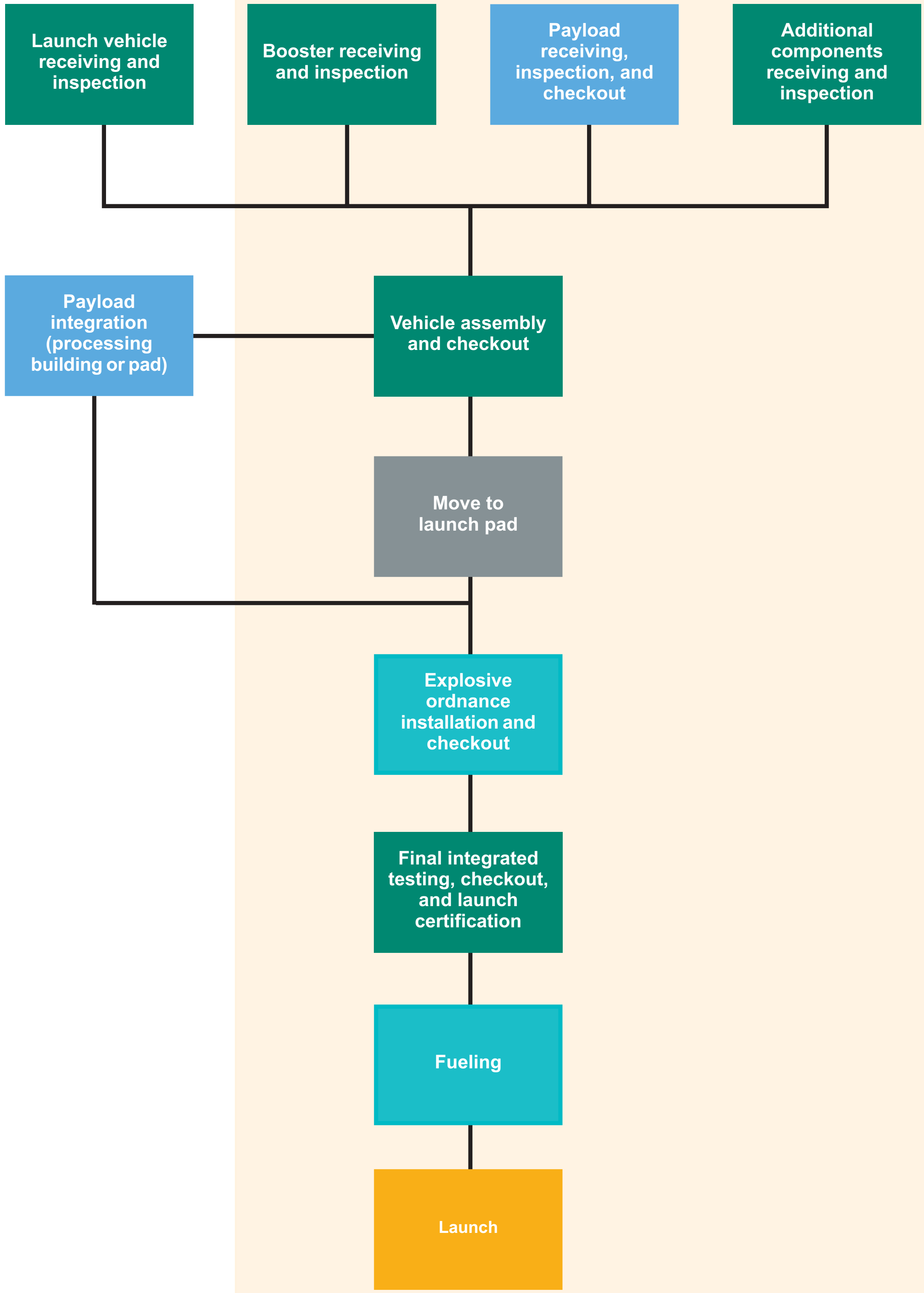


Figure I-3. Expendable launch vehicle processing flow

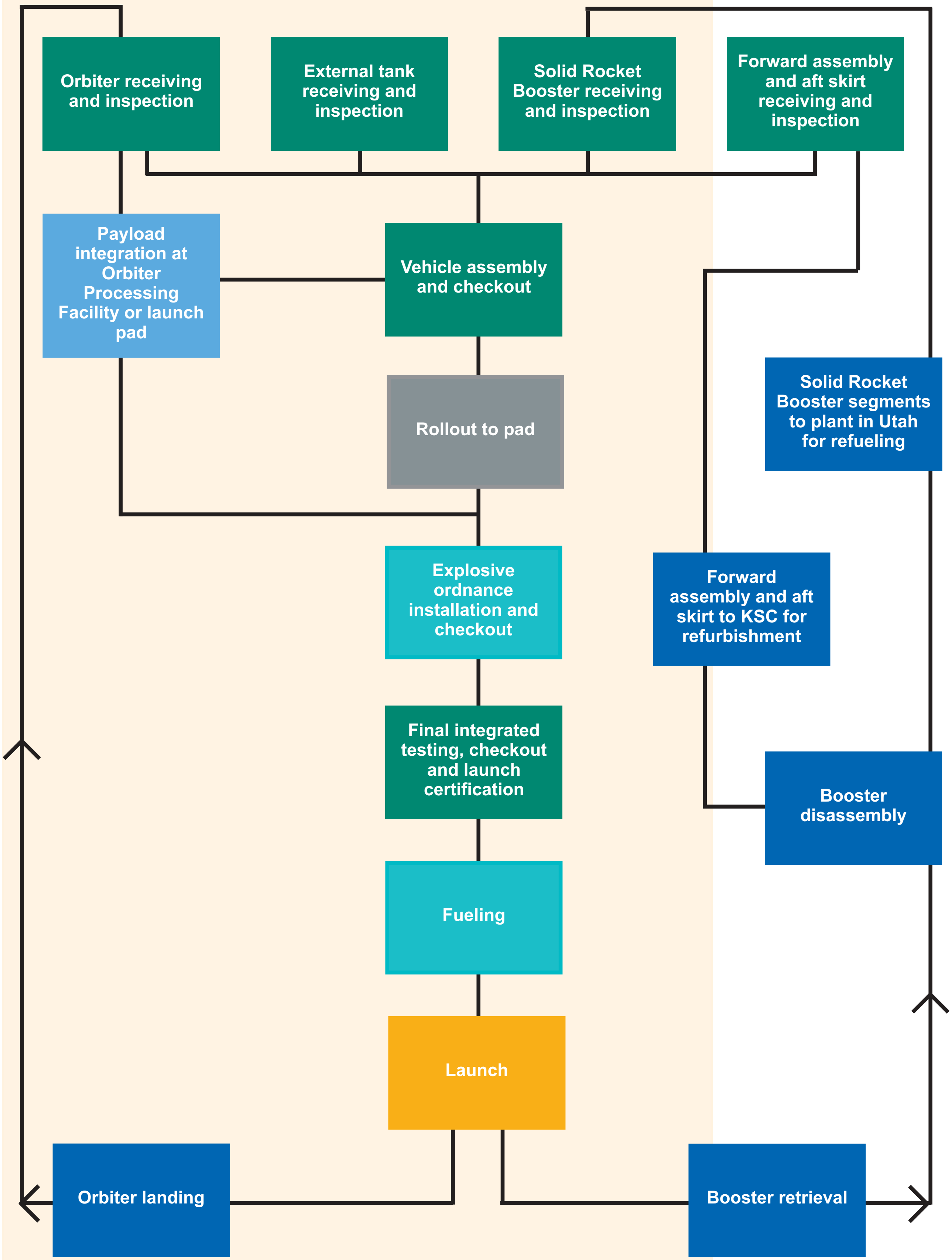


Figure I-4. Space Shuttle processing flow

Assembly and Checkout Function. Both ELV segments and the various stages of RLVs may be processed in A&C facilities. For reusable stages, the facility provides post-landing system safing, the process used to eliminate or control hazards, fuel/oxidizer drain operations, and other processing required prior to beginning preparations for the next launch. A&C facilities for horizontal launch vehicles need to be located near a runway to minimize the required towing distance.

Depending on vehicle manifests and launch schedules, the A&C function may be accomplished in several different buildings, each sized to accommodate a specific class of launch vehicles. The A&C facility is a generic air-conditioned building outfitted with one or more overhead cranes for lifting individual launch vehicle stages (e.g., in those instances where a multiple-stage launch vehicle requires horizontal integration). The A&C facility provides an operational television and intercom system, purge air, specialty gases, and system timing. Data links (via landline and radio frequency transmission) between the A&C facility and the Launch Control Center (LCC) are provided to display and record launch vehicle and institutional support system test results. The spaceline provides all unique access stands and vehicle-specific checkout equipment used for assembly and checkout. The spaceport authority supplies a mini-set of computer hardware identical to that used in the LCC. This enables the spaceline to complete end-to-end integrated vehicle testing independent of the potential scheduling difficulties involved in using shared LCC resources.

Payload Integration. This phase of processing involves physically connecting the mechanical, electrical, and fluid interfaces between the payload and launch vehicle. Post-mate testing of these interfaces verifies that proper connections were made.

Payload integration
(Photo: NASA)

Horizontal Integration. Payload-to-launch vehicle mating is performed in the A&C facility for those payloads requiring horizontal integration. The A&C facility may provide a 100K (no more than one part contaminant per 100,000 parts) clean-room capability for non-encapsulated payloads. A properly conditioned clean air coolant/purge facility is provided for payloads that require it.

Vertical Integration. For non-encapsulated payloads requiring integration in a vertical assembly facility or on the launch pad, a 100K clean-room environment and lifting crane may be provided. The spaceline and/or payload contractor is responsible for operating the facility crane.

Launch Vehicle Transfer from A&C Facility to Launch Pad (Vertical Launch). For vertically launched vehicles that are horizontally mated, a horizontal transporter/erector vehicle (TEV) is used to transfer the vehicle from the A&C facility to the launch pad. The launch vehicle is rotated from a horizontal to a vertical position on the launch pad. The TEV provides a mechanical strong-back support and erector device, conditioned coolant/purge air, electrical power, and other services required by the launch vehicle and payload during transfer operations. If the spaceport authority supplies the TEV, the TEV needs a standardized design capable of servicing several different classes of launch vehicles. Individual spacelines are then responsible for providing any required mechanical attachments that interface with the standardized TEV.

Launch Vehicle Transfer from A&C Facility to Runway (Horizontal Launch). A spaceport authority supplies the tow vehicle that relocates the horizontally assembled vehicle from the A&C facility to the fueling area and subsequently to the runway for launch. A portable conditioned coolant/purge air unit and electrical power generator is available for use as required by the launch vehicle and payload during transfer operations.

Launch Pad Design Configuration (Vertical Launch). For maximum flexibility, multiple launch pads might be provided, each designed for use by various launch vehicles of similar size and configuration. In the event of launch damage to one pad, having shared pads ensures minimal impacts to future launches. Standardized mechanical, electrical, and fluid interfaces are provided for launch vehicle and payload services. Ideally, launch vehicle and payload designs should be compatible with generic facility interfaces. Access platforms should be adjustable, as required, to provide coverage of the entire vehicle. In cases where a spaceline provides justification for dedicated use of a launch pad, generic pad design concepts are preferred. This ensures continued future use of launch resources by follow-on launch programs without requiring demolition and/or extensive modifications of the pad structure.

Tow launch of a Kelly Space and Technology Astroliner (Photo: Kelly Space and Technology, Incorporated)

Launch Pad Operations (Vertical Launch). Launch vehicle and payload operations at the pad include testing and verifying that mechanical, electrical, and fluid interfaces are correctly configured for fueling and launch.

Countdown Demonstration Test Operations (CDDT). CDDT operations ensure that the launch vehicle and payload hardware and software systems are compatible with the support systems supplied by the spaceport authority. CDDT operations for the first version of each flight vehicle include launch vehicle fueling. As confidence in the proper operation of ground and flight systems increases with multiple launches, ground processing costs may be lowered by reducing or even totally eliminating CDDT test requirements. While no additional spaceport authority facilities are required to support CDDT, tests will impact other operations at the spaceport and will require proper scheduling of limited personnel and resources.

Horizontal transport of the vertically launched Kistler Aerospace K-1 (Photo: Kistler Aerospace Corporation)

Runway Operations (Horizontal Launch). Corporate, logistical supply, tow, and other aircraft supporting launch operations also use these facilities. The requirements associated with horizontal launch dictate the specific payloads, customer equipment, and size of the runway. In the case of runway recoverable RLV stages, landing requirements apply.

Titan launch vehicle on the pad at KSC (Photo: USAF)

The type of fuel and oxidizer used by the launch vehicle determines the required area of clearance (fallback) to be observed during fueling operations. Although the normal fueling precautions observed at commercial airports suffice for common kerosene fuels, even these fuels present significant safety concerns when placed in proximity to large quantities of liquid oxygen. Therefore, remote protected areas are needed for transferring kerosene fuels and highly explosive fuels such as liquid hydrogen. The transfer of volatile, combustible chemicals and oxidizers requires significant safety precautions.

Launch Control. The Launch Control Center (LCC) performs countdown operations for all launches. From the LCC, management and safety personnel can clearly observe all flight vehicle and ground operations.

The spaceport provides secure personal computer (PC) hardware with a standard operating system to record launch vehicle, payload, and institutional data links for analysis and historical review. The launch vehicle and payload contractors provide the software required for data manipulation and display unless the spaceport provides the necessary support. The use of encrypted World Wide Web data allows remotely located customer personnel to evaluate test results in near real-time and make timely inputs. Off-the-shelf PC hardware monitors the institutional system instrumentation. Fiber-optic landlines, radio frequency communications systems, and antennae provide the required data links between the LCC and the launch vehicle.

Launch view from KSC Launch Control Center (Photo: NASA)

To eliminate the costs associated with a mandatory tracking antenna system, the Tracking and Data Relay Satellite System (TDRSS) or a similar capability can be used to acquire launch data. Likewise, Global Positioning System (GPS) data can track the launch vehicle coordinates during ascent. These satellite-based capabilities also can be used during RLV landing operations.

Inflight Operations. Prospective customers are advised of their responsibilities to build and develop their own mission control and orbital support systems. A spaceport must have service connections to all mission control centers, especially those that extend services to space operations customers on a commercial basis or an appropriate government/industry/education basis. As part of its infrastructure, a spaceport provides facilities and services to offer mission, flight control, and/or network services as options to prospective customers.

Examples of such control centers today are as follows:

- NASA's Mission Control Center (Texas) for crewed missions (Shuttle, Space Station, etc.)
- NASA's mission control centers at the Goddard Space Flight Center (Maryland) and the Jet Propulsion Laboratory (California) for robotic missions

Many other control facilities at government, private industry, and educational locations handle communication programs, weather programs, and Earth observation programs.

Shuttle *Atlantis* landing at KSC (Photo: NASA)

Spaceport Landing Operations for RLVs. Landing requirements unique to RLV operations are described below. Some items pertain only to crewed RLV operations.

Landing and Navigational Aids. Systems required to autonomously land an RLV or to assist crewed RLV landings include GPS, Tactical Air Navigation (TACAN), and Microwave Landing System (MLS). In addition to the initial equipment purchase, installation and continuing maintenance costs, periodic flight tests, and certification of the ground components and spaceline operators are needed.

Arresting System. Working together, spaceport developers, launch vehicle designers, and the spaceport authority must address the need for a runway arresting system in the event of a landing overrun or brake failure.

Visual Landing Aids. These systems were developed during the Space Shuttle program under the guidance and evaluation of the astronaut corps. Although the MLS provides data critical to final approach and landing, the following visual landing aids further assist the flight crew and provide backup capability to the MLS:

Ground-based arresting gear (Photo: Engineered Arresting Systems Corporation)

- Precision approach path indicator (PAPI) lights (outer glide slope)
- Physical aim point (background to PAPI lights)
- Ball/bar lights (inner glide slope)
- Xenon floodlights (night landings)
- Distance-to-go markers
- Runway touchdown markings

Runway Convoy Operations. Equipment and services must be provided on the runway before a vehicle can be towed to a maintenance hangar. These operations are as follows:

Purge. The spaceport authority provides the general purge requirements for gases and fluids to the vehicle operations contractor to accomplish the purge of gases and fluids from the vehicle systems after landing.

Coolant. Requirements to provide cooling upon landing are vehicle- or payload-specific and are supplied by either the spaceline or the payload customer.

Vehicle Ground Power. Most vehicles require ground power for some portion of post-landing operations. Vehicle-specific power units supplied by the vehicle manufacturer connect to ground power.

Other elements critical to runway operations include the following:

- Tow tractor and tow bar
- Crew egress vehicle
- Toxic and hazardous vapor detection and dispersion capability
- Toxic vapor corridor identification
- Airborne search and rescue capability
- MEDEVAC capability
- Medical support
- Fire, crash, and rescue support

Contingency Landing Site Operations for RLVs. In the event of an onboard system failure after launch, mission abort is preferred to vehicle destruction for a robotic RLV and is mandatory for a crewed RLV. Weather at a desired landing site can also dictate the use of alternate landing sites.

Contingency landing sites are expensive. In addition to the facility, equipment, and labor costs of the contingency site, people with critical skills must be relocated from the spaceport to the contingency site. By examining the requirements and risks associated with contingency sites, some operational cost savings may be possible, but not at the expense of safety, especially on crewed vehicles.

All runway equipment, systems, and personnel required for the primary spaceport must also be considered for a contingency landing site.

Location considerations include cross-range capability and ground track. Abort categories are helpful in determining landing sites and may include return-to-launch-site (RTLS), abort-once-around (AOA), end-of-mission (EOM), and ascent-abort (AA).

Historical weather data are also helpful in evaluating candidate sites. The number of required contingency landing sites must be determined based on a cost-and-schedule tradeoff. The increased cost of the site(s) must be evaluated against the increased scheduled launch probability in the event of weather constraints or ground equipment failure at the primary site. In addition, contingency landing site options enhance crewed RLV safety even further.

Selection of an alternate landing site requires a written agreement addressing liability issues, site safety requirements, interruption or clearance of normal aircraft operations, means and time of advanced landing notice, cost reimbursement, an understanding of what conditions would cause a landing at that site, and what is to be expected of landing site resources. Such an agreement will be required at any site, whether it is provided by NASA, the Department of Defense (DoD), a commercial airport, or a foreign government.

DoD has historically supported NASA in the area of contingency landing operations by providing facilities, equipment, personnel, and an attractive reimbursement arrangement. In the past, the only charge to NASA has been for additional costs associated with a mission's specific requirements. Using DoD resources to support a commercial profit-making operation may warrant further consideration and development.

Commercial Landing Site Operations for RLVs. Safety considerations may limit the use of many commercial airports for landing RLVs. If commercial airports are used, they are subject to all of the above requirements. Airports may be more attractive than Federal sites, if only to avoid the bureaucracy often associated with government-owned and government-operated facilities. FAA regulations apply in either case.

Use of foreign landing sites warrants US State Department involvement and concern for the stability of the political relationship at the foreign site. Applicable provisions of the International Treaty on Arms Reduction (ITAR) apply, since launch vehicles are covered, by definition, as weapons. Other issues could involve sensitive or non-approved payloads that the foreign country may want to tax and/or subject to customs duties. Construction of new landing facilities, the most costly option, should be considered last.

Launch Vehicles and Facility Support Requirements. The type of spaceport facilities required to process launch vehicles depends on the particular class of vehicles being processed. Table I-1 shows the facilities needed for four generic classes of launch vehicles.

Equipment/Facilities	Robotic (Non-RLV)	Crewed (Non-RLV)	Crewed RLV (Vertical)	Crewed RLV (Horizontal)
Rail/Water/Air Transport Terminal	Required	Required	Required	Required
L/V Checkout Facility	Required	Required	Required	Required
Payload Checkout Facility	Required	Required	Required	Required
Solid Rocket Checkout Facility	Possible	Possible	Possible	Possible
Flight Crew Quarters		Required	Required	Required
Fuel/Oxidizer Storage/Servicing Facility	Required	Required	Required	Required
Launch Control Facility	Required	Required	Required	Required
Vertical Launch Pad	Required	Required	Required	
L/V Segment Recovery Ships	Possible	Possible	Possible	Possible
Landing Runway/Pad	Possible	Possible	Required	Required
Deservicing Facility			Required	Required
Remote Abort Landing Site(s)			Required	Required

Required Capability   Possible Facility Requirement

Note: Robotic and crewed (non-RLV) options may include recoverable/reusable segments.

Table I-1. Launch vehicle type and facility support requirements

Responsibilities

The spaceport authority primarily provides facility scheduling, site management, and infrastructure. The spaceport authority must ensure the safe conduct of spaceport operations needed to support launch and landing activities. This includes generic launch and landing facilities, range control interface, and all necessary infrastructure, including propellant acquisition and storage, basic security, and fire protection. The spaceport authority is responsible for procuring and safely storing fuel and oxidizer products required by spacelines to support their customers.

Launch vehicle manufacturers are responsible for designing launch vehicles to accommodate all fluid connection hardware necessary to interface with the spaceport authority's standardized connections. Only spaceline or spaceport authority personnel are authorized to transfer fuel/oxidizer from the ground storage facilities to the flight hardware.

Customers pay the spacelines to launch their payloads. Customers are responsible for defining payload requirements and test schedules, while spacelines are required to communicate the launch vehicle's ability to accommodate these requirements.

The spaceport authority integrates the support requirements, supplies contracted services, provides area security for hazardous operations, and resolves schedule conflicts.

To achieve maximum use of spaceport facilities and ensure that proposed facility use schedules are met, the spaceport authority and its customers must agree contractually on the consequences of launch vehicle or payload schedule delays. These are particularly important when the delay affects other customers with scheduled launches using the same facilities.

Facility Management

Prior to 1990, responsibility for American major space launch bases and ranges at Cape Canaveral Air Force Station (CCAFS) and Vandenberg Air Force Base (VAFB) belonged to the US Air Force (USAF). Responsibility for Wallops Flight Facility (WFF) belongs to NASA. Companies under contract to the Federal Government performed many of the operations and maintenance functions such as base infrastructure, range support, safety reviews and analyses, and safety system maintenance.

Today, the Federal Government still owns these bases. The USAF leases and licenses real property to commercial companies providing launch operation services to state spaceport authorities but retains ownership. Commercial operators of the spaceports are responsible for operating and maintaining their own payloads, the launch vehicle processing facilities, and the launch complexes. Commercial operators also are responsible for some aspects of ground safety and operations at the launch sites.

Fuel farm
Propellant storage
(Photo: NASA)

A spaceport provides the following facilities, programs, and services to its launch customers:

- Safety (including range safety and public safety)
- Communications
- Propellants and gas handling
- Laboratory and shop support
- Meteorological support
- Environmental management
- Physical plant maintenance
- Security
- Institutional support
- Other unique functions

Safety

Safety is paramount. Spaceport safety ensures that the general population, property, and other resources are properly protected at all times during launch and ground operations. Safety includes providing public and personnel safety; environmental impacts; range safety; compliance with international agreements; risk evaluation; and fire, crash, and rescue services.

Regulations promulgated by the FAA, the Occupational Safety and Health Administration (OSHA), State Department, United Nations (UN), and/or the Environmental Protection Agency (EPA) govern some of these safety-related activities. Additional factors unique to a commercial spaceport may be established through separate legislation; others may be modified from existing standards or developed specifically for the spaceport.

The spaceport's safety responsibilities include establishing safety requirements, standards, and procedures; overseeing ground operations (e.g., hazardous materials operations); complying with safety requirements and national consensus standards for government personnel and equipment; and complying with EPA regulations.

Spaceport master siting plans are affected by the type of launch vehicle and the specific operations to be conducted. The physical site must be large enough to protect the surrounding community and contiguous launch operations in the event of hazardous gas leaks or explosions during launch or landing operations. The master plan siting facilities within the boundaries of the spaceport should ensure that a hazardous operation or storage of hazardous materials at one facility minimally affects parallel operations at other spaceport facilities.

Public Safety. For the three existing Federal launch sites, the safety responsibilities of arranging the clearing of air and sea routes are distributed among the USAF, NASA, and the FAA. For commercial spaceports, the FAA has proposed to adopt the explosive safety practices used at Federal launch sites. These criteria, known as Quantity–Distance (Q–D) requirements, serve to separate people and property from potentially explosive sources, and have long been used to mitigate explosive hazards to acceptable levels. They prescribe the minimum distance separating explosive hazard facilities, surrounding facilities, and public locations, based on the type and quantity of explosive material within the area. The FAA must approve an explosive site plan before any facility using explosive hazards can be constructed within the Q–D area. A commercial spaceport developer would be required to develop this plan in compliance with the applicable Q–D requirements.

Separate sets of FAA and EPA rules govern other (nonexplosive) toxic hazards. A license to operate a launch site is not a guarantee that all launches proposed for the site will be approved. Each launch is subject to individual FAA review and licensing.

Personnel Safety. OSHA regulations require each employer (contractor or commercial operator) to be responsible for the safety of its employees and equipment. In addition, a launch site operator is responsible for preventing unauthorized personnel from accessing the site and for properly receiving visitors. The launch site operator also must inform customers of limitations of onsite use; schedule and coordinate hazardous activities conducted by customers; and notify adjacent property owners and local jurisdictions of impending flights. Launch site operators must also keep records, track license transfers, investigate accidents, and monitor the use of explosives on the site.

Environmental Impacts. Federal law currently requires the FAA to assess the environmental impacts of constructing and operating a proposed launch site. The FAA also has to determine whether launch activities will significantly affect the quality of the environment. Licensing the operation of a launch site is a major Federal action for purposes of the National Environmental Policy Act (NEPA) – 42 United States Code 4321 *et seq*. NEPA section 102(2)(C) requires an environmental impact statement (EIS) to be developed for all major Federal actions affecting the environment. This means an EIS is required for every launch from a Federal launch site, which forces Federal agencies to take a broad perspective when considering the full range of environmental implications. An EIS also provides useful information to stakeholders and decision makers. The requirement for an EIS also applies to non-Federal entities and their actions whenever Federal approval is required.

The FAA must prepare an environmental review that considers reasonable alternatives to the proposed site. According to Council on Environmental Quality regulations, as interpreted by the courts, an applicant may not use the purchase of a site or construction at the site to limit the array of reasonable alternatives to that site's usage. As a result, an applicant must complete the environmental review process before constructing or improving the site. The FAA will not issue a license if an environmental review is not conducted in accordance with all applicable regulations and guidelines.

Range Safety. The FAA assigns flight safety responsibilities almost exclusively to the launch site operator. Range safety requirements are documented in *US Air Force SW127-1* and *NASA KSC Management Instruction 1710.1G.*

Night launch trajectory at KSC (Photo: NASA)

Abort/destruct guidelines provided to the Range Safety Office (RSO) vary, depending upon the type of launch vehicle to be flown. Due to current vehicle design and range safety considerations, locating the spaceport at a site remote from major cities and primary aircraft and shipping lanes is ideal. The site also should be accessible to a highly integrated transportation infrastructure. The solution so far has been to locate spaceports in coastal areas or, in the case of Sea Launch, in the ocean.

Real estate ownership is critical to the successful operation of a spaceport. Ownership implies ultimate authority, responsibility, and full liability. This can lead to unyielding attitudes in cases where the owner asserts complete control over the physical site. In these cases, discussions of environmental issues, safety concerns, and launch range support can be contentious, making customer service particularly difficult to deliver.

International Agreements. As part of the formal licensing process, a policy review is conducted to determine whether the application presents any issues affecting US national security, foreign policy interests, or any international obligations of the US Government.

A major aspect of the policy review is an interagency review, in which government agencies examine the proposed licensing of the launch site from their respective interests. The Department of Defense (DoD), State Department, and NASA typically participate in the review. Interagency reviews also consider relevant agreements made under the UN Charter. Under the 1972 UN Convention on International Liability for Damage Caused by Space Objects, governments are liable for injury or damage to third parties caused by vehicles or payloads launched under their jurisdiction.

Risk Evaluation. To obtain launch site location approval, an applicant must prove to the FAA that a launch can occur from the proposed site without jeopardizing public health and safety. Launches from existing sites are affected by this restriction only when the applicant is new to the site or a different class of launch vehicle is flown. Specific methods are required to demonstrate the suitability of the site for launching various classes of launch vehicles. Each proposed spaceport launch site must be evaluated for each class of vehicle proposed to be launched. This includes orbital, guided suborbital, or unguided suborbital expendable launch vehicles (ELVs) as well as reusable launch vehicles (RLVs).

An applicant can choose the method for developing a flight corridor for each representative RLV, orbital or guided suborbital ELV, and develop a set of impact dispersion areas for unguided suborbital ELVs. If a flight corridor or set of impact dispersion areas exists that does not encompass populated areas, no further analysis is required. Otherwise, the FAA requires a risk analysis.

Fire, Crash, and Rescue. In addition to normal fire training, flight crews must receive special training in rescue and hazardous conditions unique to spaceport operations. Fire, crash, and rescue facilities must be designed and built to the operational scale of the spaceport for fuels and oxidizers used for the space vehicles and for onsite protection as appropriate. The spaceport must provide adequate personnel and equipment to cover emergency situations ranging from minor mishaps to catastrophic events. Standard fire engine and Emergency Medical Technician (EMT) equipment must be sized to aid the spaceport workforce and space vehicle passengers in the event of an emergency. The exact protective apparel needed for emergency workers is determined by the hazardous materials the spaceport uses. Before flight vehicles can be issued airworthiness (and spaceworthiness) certificates by the FAA or other government entity, the spaceport must have a plan for handling potential catastrophes. Since firefighters are not trained in area control, security and fire safety personnel must work together closely. Generic training and certification are sufficient except in areas where special hazardous products are stored and used. Special training must be provided for especially hazardous situations and crew rescue.

Fire truck on standby with Shuttle carrier aircraft (Photo: NASA)

Wallops Island antenna
(Photo: NASA)

Communications

All phases of launch preparations, launch, on-orbit operations, and landing need electronic transmission, reception, and recording of voice and data. Electronic data systems and communications are the only means to control vehicles and payloads and receive information on Earth. Some of the required communications systems and equipment are described below.

Instrumentation. Instrumentation provides the means for measuring, transmitting, and displaying the status and condition of various facility, flight, and ground systems used in spaceport launch preparations. Included are sensors, signal conditioners, transmitters, copper and fiber-optic cables, decoders, and display hardware. A new spaceport cannot totally determine instrumentation requirements until the launch vehicles are identified. With advanced planning and design, the major portion of cabling and fiber optics can be installed during spaceport construction.

Operational Intercom System (OIS). An OIS is required for voice communications during the various stages of launch vehicle and payload processing, especially during final countdown and launch. An OIS is necessary for real-time discussion and problem resolution of launch systems status and is used to conduct management polls and launch approval. Automation of launch systems status and decision-making may eventually reduce human involvement, but is not likely to eliminate the requirement for OIS anytime soon.

Information Technology (IT) Support. Although customers and tenants can provide IT support, an integrated and uniform site system is more desirable. Such a system should address equipment and software purchase; repair, maintenance, and modification; systems administration; troubleshooting and assistance; security; and training.

Television Systems (Operational Support and Public Access). The two categories of TV systems are operational (OTV) and public access (PATV). OTV is used to visually and remotely monitor critical launch systems and areas during various phases of processing and launch. PATV is not critical to the launch process, but provides the media and public with launch information. OTV is a valuable tool in documenting events for future analysis, problem resolution, and possible accident investigations. Crewed flight operations increase the demand for PATV. Some OTV components can be used to simultaneously satisfy PATV requirements and avoid duplication of costs.

Phone, Fax, and Mobile Communications. Spaceport personnel need access to different types of communications media. Onsite cable and signal relay towers and an interface with offsite commercial service providers should be considered. Mobile radios are useful for remote and temporary operations and where fixed OIS installation is not practical. The spaceport must provide bandwidth frequency assignments and control.

A major concern is how spaceports will control access to cell phones for official onsite use.

Timing and Countdown System. Because launches require precise countdown and launch times, the spaceport must generate, distribute, integrate, and display a standard and universal timing signal at all required sites and work stations.

Paging and Area Warning System. This system is necessary to provide adequate warning and instructions in the event of adverse weather conditions, operational emergencies, and routine area evacuations. Administrative paging is integral to this system.

Site Frequency Control. Frequency control is a legal requirement. With the large number of systems using electronic frequencies, the spaceport must establish a central point of documentation and control to avoid conflict with the surrounding community and other government installations.

Propellants and Gas Handling

A spaceport must pay particular attention to decisions regarding propellants and gases because of concerns about personnel and environmental safety, costs, and the public interest. Customer requirements ultimately determine the launch vehicles to be used and the propellants and gases required. A spaceport must estimate the quantities and identify the sources for required propellants and gases. Many of these chemicals are hazardous, and some are even toxic. Compliance with OSHA requirements is necessary.

Each chemical product requires a separate system for handling, storage, and distribution. Each product is also subject to specific safety regulations and handling requirements known as quantity–distance radii and toxic vapor corridors. For potentially explosive propellants, a quantity-distance radius is established to define the distance between product storage and the nearest inhabited building. Handling of toxic liquids and gases requires a similar radius but also requires the identification of a potential toxic corridor based on existing wind conditions in the event of an accidental spill or leak. Spill containment is an important consideration in designing storage facilities for these commodities. The spaceport must provide special protective suits for personnel who work near systems containing toxic fuels and oxidizers. When considering propellants, gases, and toxic materials, the following factors should be addressed:

- Purchasing availability
- Manufacturing options
- Storage and distribution systems
- Special transportation vehicles
- Component cleaning capability
- Disaster response

At times, customers will require certain specialty propellants and gases. The spaceport operator will not purchase these supplies but will provide for their safe storage. The customer usually provides separate fueling and handling capabilities for small quantities of specialty items.

Laboratory and Shop Support

Requirements for onsite laboratory and shop support are individually evaluated on the basis of cost, frequency of use, and commercially available alternatives. Some labs and shops support ongoing processes while others support failure analysis and the investigative process. Contracting with offsite commercial facilities for all or part of this support should be explored. The following support list was developed from experience and may not be applicable to all spaceport development and operations.

- Malfunction lab
- Failure analysis lab
- Nondestructive testing
- Chemical analysis
- Calibration lab
- Heavy equipment repair
- Battery shop
- Proof load shop (certification)
- Mobile generator shop
- Space suit shop
- Mobile launcher platform shop
- Engine shop*
- Hypergol system maintenance*
- Tire and wheel shop*
- Atmosphere revitalization system*
- Waste collection system*

* candidates for offsite RLV shops

Meteorological Support

Meteorological support is a critical function surrounding launch and landing decisions, and a spaceport benefits from having access to a totally integrated weather system. A historical meteorological database is a valuable tool in assessing the capability of a candidate site to support frequent launches. When establishing a new spaceport, cost and time considerations may dictate the use of an existing database from a nearby site, assuming an acceptable level of risk.

Observation Capability. The capability to determine and record weather data on an hourly basis, 24 hours per day, is vital to developing the historical meteorological database necessary for accurate forecasting. Significant improvements have been made in recent years with automated weather stations developed specifically for remote sites.

These stations not only measure and record data, but can respond to queries, reprogramming, and adjustments in real-time when connected to a phone system. They can also be programmed to periodically transmit data through existing weather satellites.

Forecasting. Accurate forecasting implies that human involvement is needed to observe and analyze real-time data. Weather conditions and forecasts on launch day assume equal importance with the status of on-board flight systems. Weather forecasting is likely to improve with technology, but human observers will perform this service imperfectly for some time to come.

Meteorological Measurements. A number of measurements are taken:

- Temperature, relative humidity, and dew point
- Surface wind speed and direction at critical locations
- Wind speed and direction aloft
- Visibility
- Precipitation
- Cloud cover and height
- Lightning detection, measurement, and prediction
- Weather radar
- National and international weather system access
- Airborne observation capability (successful crewed approaches and landings)

Nighttime lightning strikes—National Severe Storms Laboratory (Photo: NSSL)

Launch Commit Criteria Development. A specific set of weather conditions that permit or prevent an attempted launch must be developed carefully, as a launch can be delayed when even one factor is out of limits.

Landing Commit Criteria Development. A similar set of criteria must be developed for landing weather conditions for RLV operations. Since the launch site is also a potential ascent–abort site, a launch decision is based on both launch and landing criteria. Landing criteria may be different from launch criteria for several reasons, such as the distance between launch and landing sites at the spaceport, time differential between launch and potential abort landing, and crosswinds at the landing site. Weather conditions may vary significantly between two relatively close sites.

For RLVs, the landing decision following an orbital mission is complicated because a commitment must be made an hour or more before the scheduled landing time, based on forecasted weather. Once a mission initiates an irreversible de-orbit burn, landing options are seriously limited or nonexistent.

Requirements for RLV contingency landing sites make launch and landing decisions even more complex. A potential ascent–abort site must also meet the established landing criteria based on a weather forecast. If a mission uses more than one ascent–abort site, it has to meet weather conditions at only one in order to launch. Although additional landing sites drive up initial and operational costs, they also increase launch probability on any given day, possibly eliminating the cost of rescheduling a launch.

Environmental Management

A sound environmental management program is a primary concern in spaceport development and operation. Responsible environmental management is necessary to meet legal requirements, preclude operational delays, and satisfy the concerns of the local community. State and Federal laws require the development of environmental impact statements to operate a spaceport. Stakeholders, spaceport operators, and customers must be closely involved in this process. A spaceport can hire contractors to perform comprehensive environmental impact studies and assessments, but will need an in-house environmental management system. The early identification of hazardous operations and waste generation is essential.

Bald eagle at KSC near Merritt Island Wildlife Reserve (Photo: NASA)

Facilities, equipment, procedures, and licenses must be developed for identifying, labeling, collecting, and storing materials; containing spills; and treating and disposal of waste and other materials. Environmental monitoring includes air and groundwater sampling and hazardous waste monitoring. A spaceport must develop contingency plans and containment and recovery procedures for hazardous waste spills and accidental releases.

Physical Plant Maintenance

In-house personnel or contractors perform physical plant maintenance. Either the spaceport authority or the designated operator is responsible for integrating and coordinating maintenance activities. After construction, the spaceport must consider sustaining engineering as a part of this function. Initial facility construction costs are low in comparison to the costs of maintaining a spaceport facility. The following maintenance categories need to be addressed during the planning and cost development stages:

- Building and structures
- Utilities
- Electrical generation and distribution
- Backup power generation
- Water
- Sewer
- Heating and air conditioning
- Lighting
- Elevators
- Fire detection, alarms, and sprinkler systems

Security

Security has become critical since the events of September 11, 2001. Security provides the necessary protected environment for launching space vehicles. Almost every aspect of access to space has high cost and high visibility, and uses highly explosive propellants and toxic gases. Any perturbation in the handling of these propellants can have catastrophic consequences.

Unconstrained access to space provides for national security, a use that elevates a commercial spaceport to the status of both a national and international resource. Just as the FAA assigns the overall responsibility for security to the airport operator, it would be consistent with 2001 policy that the local spaceport authority would provide security for the spaceport. Individual space service providers would have to secure areas of the spaceport under their control

A spaceport security organization focuses its protection on human-made hazards that could interfere with normal operations, ranging in severity from a minor disruption to a full-scale emergency. Reporting to the spaceport authority, the security organization is responsible for security within the physical boundaries of the spaceport. Security measures mitigate malicious damage and hazards to an acceptable level of risk and control innocent intrusions into areas that would cause others to be at risk.

In the event of a disaster, the spaceport may call upon the security organization to respond to external damage caused by a space vehicle losing control around or even some distance from the launch facility.

Many factors must be evaluated to determine the amount and kind of protection a spaceport needs. To determine the degree of risk, relative criticality and relative vulnerability must be analyzed. Hazards can be divided into three broad categories: theft of assets or property, sabotage or human-caused emergencies, and espionage of proprietary or governmental documentary information. Some fundamental questions must be answered in developing an overall security system:

- What is the potential damage?
- Is there evidence of a clear security hazard?
- Is there a definite security risk to the organization?
- What is the effect of physical security measures on organizational efficiency?
- Do the physical characteristics of the facility or location impose limitations on the security program?
- To what extent do budgetary limitations affect physical security measures?

As with all security measures, these questions need to be continually reevaluated.

A combination of systems comprise primary security. Passive systems consist of some form of barrier, which can be natural and/or artificial obstacles to entry such as water, fences, concrete barriers, maze-like entry, etc. Intelligent barriers could have remote sensing and/or an alarm capability. Active barriers are usually operated by security personnel, either onsite or remotely via electronic means. Careful personnel screening reduces the risk of workers committing accidental or intentional destruction.

Common security methods include the following:

- Barriers (geographic or human-made)
- Patrols
- Gates
- Records
- Threat assessments
- Contingency plans
- Restricted area access control
- Lock and key control
- Vehicle control
- Personnel control
- Training
- Badging
- Video monitors
- Motion/heat sensors
- Lighting
- Facility surveillance
- Air and sea surveillance

Institutional Support

In developing new spaceports or expanding existing ones, the adequacy of existing facilities must be evaluated against the need for new construction, along with the adequacy of equipment, personnel, and maintenance procedures. Spaceport developers can use this section of the handbook to help determine the services or alternative capabilities the spaceport will provide.

Subcontracting some of these functions may be economical, particularly for limited- or single-use spaceports. Launch frequency will help determine the support requirements. Launch vehicle/spacelines, payload operators, and customers who use the spaceport may have to reimburse the providers, especially at a commercially operated spaceport. In a commercial environment, it may be feasible to combine the operations of the spaceline and the support contractor at a single purpose or limited-use spaceport.

Developers of a multiuse spaceport should consider providing services under one organization or contract or combining institutional support with technical support. Costs to be considered include facilities (space), equipment, vehicles, and personnel.

Transportation Services. A robust transportation support infrastructure is essential to move equipment, instruments, systems, and personnel through the spaceport. The payload customer or spaceline arranges and pays for all commercial road, rail, sea, and air transportation related to their individual operations.

Motor Pool. A spaceport must consider the fleet of vehicles needed for onsite customer and spaceport operator use, in addition to maintenance of the fleet. If required, a spaceport authority contractor can provide equipment purchase, lease, and maintenance services.

Rail. A spaceport must determine its onsite rail requirements, offsite commercial interfaces, the equipment required, and the associated responsibilities for rail operation and maintenance. Rail transportation has been used in the past to deliver oversized solid rocket motor segments and some fuels and oxidizers. If required, a spaceport authority contractor can provide equipment purchase, lease, and maintenance services.

Shuttle's external tank arriving at KSC by barge (Photo: NASA)

Sea. Water transportation is an attractive alternative for deliveries too large for railways, air transport, or roadways (e.g., Space Shuttle external tanks and various transporters manufactured overseas). Even if a nearby seaport is available, it may be advantageous to connect the seaport to the spaceport by a canal. However, this option may require expensive dredging, bridge modification, and maintenance.

Air. Air transportation may be used to deliver payloads and flight systems under certain conditions if a runway is available nearby.

Medical Support. Spaceport operations involve hazardous operations for site employees, flight crew, and passengers who may require immediate medical attention and treatment. A spaceport should consider providing medical support onsite because of the nature and potential magnitude of emergencies and the distance to medical facilities in nearby communities.

Super Guppy cargo plane (Photo: NASA)

In defining medical support requirements, the following topics deserve detailed analysis:

- Occupational health (worker physical exams and certification)
- Environmental health (monitoring)
- Flight crew support (crewed RLV)
- Community interfaces (hospitals)
- Onsite first aid and emergency medical services
- MEDEVAC capability (helicopters and ambulances)
- Employee health gym

Miscellaneous Services. Spaceport authority contractors provide institutional custodial services, road and ground maintenance, printing and reproduction services, photographic support, and food services. Other onsite contractors will abide by spaceport authority guidelines for printing in common areas. In private areas, launch contractors may institute their own printing and reproduction facilities.

The launch services contractor provides in-flight meals.

The spaceport can provide photographic and audiovisual support for payload closeouts and other requirements for a fee; otherwise, the launch services contractor can provide these services.

The spaceport provides additional services to include:

- Onsite, overnight, and US mail services
- Waste disposal, landfill use, community interfaces on these issues, and environmental approvals and permits
- Warehousing and delivery services

Other Unique Functions

Airport Operations (Non-RLV-Specific). If an airport exists at or near a potential spaceport proposed for ELVs only, it may be possible for the spaceport to use the airport for administrative aircraft and special delivery of spacecraft and other payloads. In addition, consideration should be given to spacecraft that fit into existing airport-structured operations, if possible. In any case, the spaceport should evaluate the following equipment, services, and facilities:

- Runway, overruns, and taxiways—apron, tow-way (RLV), aircraft maintenance hangar(s), operations building, control tower
- Aircraft landing aids—lighting (approach, centerline, edge, apron, taxi), Visual Approach Slope Indicator (VASI) lights, Instrument Landing System (ILS), radar, meteorological support
- Fuel storage and distribution
- Air-to-ground communications
- Special vehicles—crash trucks, tow tractor, sweeper/vacuum, fuel trucks
- Air traffic control capability
- Astronaut training support (crewed RLV)
- Personnel training and certification
- Contingency plans

Port Operations. Construction and/or dedicated operation of a seaport in conjunction with a spaceport could occur if entrepreneurs find ocean launches worth pursuing. Spaceport developers should address the following topics when considering such a possibility or when modifying an existing port to meet proposed spaceport operational requirements:

- Facilities
- Port
- Pier
- Waterways
- Equipment—tugs, retrieval ships, communications
- Dredging capability
- Seaborne search and rescue
- Seaborne security

Shipping cargo from Port Canaveral, Florida (Photo: Canaveral Port Authority)

User Fees. User and customer fees are a major issue in the successful operation of any commercial spaceport now and in the future. A customer's commitment to use a specific spaceport must be based on a complete contract that specifies the projected costs well in advance of any site use. A fair, accurate, and rapid-response cost-estimating system and policy on behalf of the spaceport authority are a must. All parties must clearly understand in advance the events and circumstances, if any, that could alter the negotiated fees. An open-ended policy requiring the reimbursement of all actual costs incurred onsite will probably not attract many customers or their financiers. A flat-fee concept, on the other hand, may not be attractive to the spaceport authority. A well-planned approach that results in some reasonable financial risks for both parties may be the best solution.

Public Affairs Support. The constituencies the spaceport serves and the goals it seeks to accomplish define the public affairs function. The commercial nature of the spaceport requires a strong marketing program to attract and continually support customers and potential customers of launch site services. Substantial public investment in the development and operation of the spaceport, whether through direct subsidies or tax concessions, implies the public's right to know. Congress or state legislatures will insist that the spaceport keep the public informed of its activities. The media should be interested in covering launches and other newsworthy events at the spaceport.

The spaceport should provide a coordinated, consistent approach to public affairs activities. All operations should speak with one voice and supply common marketing, information services, media support, and customer and public support to commercial partners at the spaceport.

The public affairs function should be aligned with the spaceport's long-range goals and yearly objectives, allocating resources accordingly and measuring progress toward those goals and objectives. In addition to the long-range program, an annual Public Affairs Plan should clearly identify the spaceport's objectives for the year. The annual plan should include both quantitative and qualitative measures of success and should be updated as needed.

Community Functions. A successful spaceport, particularly a commercial venture, exists within a community. The relationship between a spaceport and its community is vitally important to sustain mutual growth. A successful spaceport can bring many benefits to a community, including the infusion of capital for new or upgraded infrastructure, the creation of highly skilled jobs, and tax and investment revenue. However, significant disadvantages accrue if development is not managed carefully, including unplanned demands on community services, housing, and public transportation and pollution or environmental degradation. The community must be engaged early and openly in the planning process. By inviting the citizenry to present its concerns, public support and integrated planning for the mutual benefit of the spaceport and the community are more likely. Internships offered to college and technical school students offer a tremendous opportunity to assure a continuing supply of highly skilled workers and managers.

Airshow at Oshkosh, Wisconsin (Photo: Experimental Aircraft Association)

An economically diverse community with a business-friendly government can positively affect business development for the spaceport. A broad business base offers a wide range of resources to potential spaceport customers and brings a pro-business approach to zoning, permitting, tax incentives, and the like. A progressive, stable community with good schools, medical facilities, and public infrastructure also makes it easier to attract employees and customers to the spaceport.

It is in the spaceport's best interest to continually find ways to enhance the growth of its neighboring areas. The commercial entities that plan and operate the new spaceport must work cooperatively and openly with community businesses and political leaders. Cooperation ensures that all aspects of spaceport planning and development will have a positive impact on the surrounding area and provide for continued economic viability of the community.

Factors to consider in evaluating a spaceport's potential impact on a community are as follows:

Housing. The existing housing near a spaceport may be inadequate to meet the requirements of new spaceport employees. To avoid sprawl, housing development must be carefully planned and involve builders, real estate professionals, and city planners.

Education. A sudden influx of new students may overburden existing schools. Coordination among the school board, city planners, and spaceport officials is essential to ensure the right mix of educational facilities and resources. Spaceport officials should consider ways to support educational initiatives, perhaps by recognizing teachers, donating supplies, or mentoring students.

Medical. The potential medical needs of employees, visitors, and spaceport customers must be considered, along with the adequacy of existing medical facilities to deal with potential spaceport-generated emergencies and disasters.

Public Transportation. Existing public transportation systems must be evaluated to determine their adequacy for future employees, visitors, and spaceport customers. Improvement plans must be coordinated with area transit companies.

Communications. Potential upgrades of communications infrastructure such as trunk lines, T3 connections, and fiber-optic cable must be identified and then coordinated with area telephone and cable companies.

Utilities. Existing power, water, and waste systems must be evaluated to determine whether they can accommodate any new or special requirements the spaceport may impose (such as those needed to handle specialized fuels). Coordination with utility companies and the local government is necessary to integrate new requirements with public needs.

Roads. Existing roads must be able to handle potential increases in vehicular traffic. The volume and flow of employee, visitor, and spaceport customer vehicular traffic must be evaluated. The special requirements of heavy-load, extra-width, or water-access traffic should be considered. Upgrade plans must be coordinated with the public works department.

Tax Structure. The economic impact of a potential spaceport may also affect the community's tax structure. This possibility must be evaluated in terms of the following factors:

- Increased tax base
- Direct investment dollars
- Revenue from visitors
- Revenue from spaceport customers
- Ripple effect of indirect spending (e.g., supplies and family needs)
- Potential tax incentives based on increases in revenues, number of available jobs, and dollar amount of infrastructure investments

Florida Space Authority officials discussing comprehensive spaceport master plan (Photo: Florida Space Authority)

Government. The degree to which the spaceport will encourage local businesses must be evaluated in terms of fees, zoning, permits, and long-range planning.

Major community-related questions that must be answered are as follows:

- To what extent should the community participate in decisions affecting the spaceport and its operations?
- Who should be included in any joint planning body?
- To what extent can and will the spaceport provide funding and other resources to upgrade community assets?