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# Spaceport Infrastructure Cost Trends

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**The total cost of employing a new or revised space launch system is critical to understanding its business potential, analyzing its business case and funding its development. The design, construction and activation of a commercial launch complex or spaceport can represent a significant portion of the non-recurring costs for a new launch system. While the historical cost trends for traditional launch site infrastructure are fairly well understood, significant changes in the approach to commercial launch systems in recent years have required a reevaluation of the cost of ground infrastructure. By understanding the factors which drive these costs, informed decisions can be made early in a program to give the business case the best chance of economic success. The authors have designed several NASA, military, commercial and private launch complexes and supported the evaluation and licensing of commercial aerospaceports. Data from these designs has been used to identify the major factors which, on a broad scale, drive their non-recurring costs. Both vehicle specific and location specific factors play major roles in establishing costs.**



## I. Introduction

It is critical for launch vehicle operators and other stakeholders to understand the factors and trends that affect the non-recurring costs of launch site infrastructure. These costs are often an area of concern when planning for the development of a new launch vehicle program as they can represent a significant capital investment that must be recovered over the lifecycle of the program. Over the past decade, with an increase emphasis on commercial access to space, there have been several large changes in the way launch facilities have been approached. Designers for commercial vertical launch sites have sought to apply methods to reduce both the upfront and operational costs of launch facilities. In additional launch vehicle designers have been designing vehicles that are more operationally responsive and can use existing infrastructure, such as air launched systems. The following analysis looks at current and historical cost trends for both traditional (primarily vertical) launch site infrastructure and that of commercial horizontal aerospaceports.

## II. Tradition Launch Site Infrastructure Cost Factors

Traditional vertical launch site infrastructure typically requires a large vehicle-specific capital investment. The types of infrastructure required can vary based on a number of launch vehicle parameters, but in general the key cost components of a launch facility include:

- Launch pad deck / ramp
- Flame deflector / trench
- Launch service building
- Launch mount
- Umbilical tower / service structure
- Lightning protection system
- Launch rail
- Propellant systems
- Water systems (deluge, sound suppression, fire)
- High pressure gas systems
- Power, lighting, data, communications
- Vehicle processing / integration facility or structure
- Transporters / Ground support equipment
- Crew access / emergency egress

While not all of these items are required for each launch vehicle, it is important to understand how vehicle requirements, such as the factors listed below, may drive the costs of each of these systems and ultimately affect the total cost of the launch site.

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## A. Launch Vehicle Factors

There are a wide range of launch vehicles that are supported by traditional launch sites. In generally the launch vehicles are processed in either a horizontal or vertical configuration and readied for a vertical launch, generally from a fixed point on the earth's surface. Current, active examples of these types of launch vehicles include the Atlas V, Delta IV, Falcon 9, Antares, Ariane V, and the Russian Soyuz. Each launch vehicle type has unique physical characteristics, operational and mission requirements that directly affect facilities costs.

### *1. Launch Vehicle Size*

The size of the launch vehicle is a primary factor in determining the size of the launch complex facilities and equipment. The concept of vehicle size includes physical dimensions, weights, and overall thrust. In general the larger the vehicle, the more expensive the infrastructure is. For example, small rockets can launch from rails, which may be mounted to over the road trailers, while large rockets launch from mounts with exhaust ducts, access facilities, propellant supplies, and capability for onsite vehicle assembly and integration. Very large rockets typically launch from mobile launch platforms and may require all the above plus sound suppression and ignition overpressure systems. Just as important as actual vehicle size is "design" vehicle size. Frequently, a program decides to oversize a launch complex for a much larger growth vehicle or family of vehicles. Since cost is a function of size, this frequently leads to an inflated launch complex cost which cannot be supported by the business case.

### *2. Types and Numbers of Propellants*

Every propellant type requires a unique set of systems to support its safe operation.

1) Solid propellants require large capacity cranes for component lifting, storage facilities with adequate separation distance, and transportation routes and systems that account for the continuous presence of propellant within the vehicle.
2) Cryogenic propellants require unloading facilities, storage facilities with adequate separation distance, transfer equipment, spill containment, and gas purge and pressurization systems.
3) Hypergolic propellants require separate unloading facilities, storage facilities with adequate separation distance, transfer equipment, spill containment, and gas purge and pressurization systems. They also require special spill ventilation, breathing air systems, and scrubbers.
4) Liquid Hydrocarbon systems require unloading facilities, storage facilities with adequate separation distance, transfer equipment, spill containment, and gas purge and pressurization systems.
5) Peroxide systems require unloading facilities, storage facilities with adequate separation distance, transfer equipment, spill containment, purge systems, pressurization systems, and dilution / disposal systems for de-tanked, unusable propellant.
6) Hybrid systems require large capacity cranes or hoists for component lifting, transportation routes and systems which may account for the continuous presence of propellant, unloading facilities, and gas purge and purge and pressurization systems.

Every new propellant type added to a launch vehicle adds a host of support systems to the launch complex. Each of these systems carries significant associated additional costs and few of the systems can share resources with other systems.

Examples of the cost effects of using a large variety of propellant types are both the Space Shuttle and Titan IV launch complexes. Solid propellants, Cryogenics (LO2 and LH2), and Hypergols (fuel and oxidizer) were all used in these launch vehicles making them some of the most expensive launch complexes constructed in the country to date.

## B. Operational Strategy

In this context, operational strategy represents the assembly, integration, testing, and launch plan for the launch complex. The operational strategy selected has a major cost impact on the launch complex. The key parts to this strategy are:

1) Flight Rates
2) Reusability
3) Integration Method
4) Vehicle Orientation

### 1. *Flight Rates*

If the operational plan provides for few launches per year, facility and equipment utilization is low and a minimum number of facilities are needed. As flight rates increase, facility utilization increases, necessitating additional facilities, launch complexes, or more complex operational strategies.

### 2. *Reusability*

If the vehicle utilizes reusable components, facilities and equipment for its recovery, transport and recycling are required. Approaches that include the potential for a fully reusable first stage may require additional infrastructure to refurbish and certify the stage for its next mission.

### 3. *Integration Method*

The two basic operational strategies for launch vehicles are "Build on Pad" (BOP) and Integrate-Transfer-Launch" (ITL). BOP requires extensive facilities at the launch complex for component handling, payload processing and for assembling the major vehicle and payload components in the launch orientation at the launch complex. These facilities are then exposed to high structural loads and corrosive and abrasive environments at launch. ITL provides for vehicle and payload assembly and integration at a location other than the launch complex. The integrated vehicle is then transferred to the launch complex, where it is loaded with propellant (if required) and launched. Most launch complexes are not purely BOP or ITL, but a mixture of the two. High launch rates frequently require an ITL strategy to reduce "on pad" time to support the desired rate.

### 4. *Vehicle Orientation*

Vehicle orientation during processing is the primary driver in determining the support facility height. As vehicle support facilities become very tall, their incremental unit cost increases, due to wind, seismic, and other factors. Access for both horizontal and vertical orientations is problematic. However, horizontal configurations provide more opportunity for use of commercial equipment to accomplish the access. Vehicle orientation during launch greatly affects the real estate required and overall launch complex configuration. Vertical launch orientation develops a high specific foundation loading under a small area, necessitates a method of deflecting the exhaust and frequently necessitates a method of managing the local acoustics. Frequently, horizontal component transfer precedes the vertical launch, requiring large support equipment to effect the rotation to vertical. A Horizontal launch orientation requires support to the vehicle during initial ground motion, typically via a rail, but often no provisions for exhaust deflection or acoustics are provided.

## C. Location Factors

Location of a launch facility can have a major impact on the launch complex's costs. The factors that influence the cost are the availability of existing useable infrastructure, the potential for shared access with site partners, economic incentives and the geographical location of the site.

### 1. *Existing Infrastructure*

The extent of existing useable infrastructure plays a substantial role in determining the launch complex's cost. The operative word is "useable". Existing infrastructure which is in poor condition, improperly configured, or too small to support the vehicle could add to the overall cost.

Ideally, one would like to locate a new launch vehicle on an underutilized active pad which was sized for a slightly larger vehicle. Such was the case in locating the Spaceport Florida Authority launch pad at SLC 46 at Cape Canaveral Air Station. The explosive quantity distance siting was for a larger vehicle. The existing exhaust duct was adequate in size. The existing power, water, and communication infrastructure was in good condition and substantially adequate. Major modifications consisted of a launch mount and new mobile access structure.

Similarly, in the mid 1990's Lockheed Martin located their West Coast Athena launch complex at SLC-6, which had exhaust ducts and access structures sized for the much larger Space Shuttle.

More typical, when utilizing an old abandoned launch site, there are few above grade launch structures useable for the new vehicle. Below grade utilities (such as water piping) may require replacement to avoid failure under the launch environment. Underground environmental contamination is common and may require expensive cleanup.

New, previously undisturbed sites present no opportunity for infrastructure reuse, but can also present fewer cost unknowns.

*2. Site Partners & Economic Incentives*

If the launch rate allows, unused time on the launch complex can support launch operations for a different vehicle. This can result in launch complex costs being shared among multiple programs. For vehicles of similar size and propellant class, it is reasonable to provide multi-vehicle launch complexes. (SLC-46 supports the Trident, Athena, Taurus, and other vehicles.)

As launch vehicles progress towards horizontal takeoffs and aerospaceport type operations, multiple site partners may become commonplace, even among dissimilar vehicles. Currently Orbital Science Corporation's Pegasus vehicle is launched from airfields which also support traditional aircraft.

Cooperative partners may also be found in the various organizations which are designated to support space business within a state or region. Frequently these can be an advocate for the launch complex within the local community and legislature, assist with financing and provide tax and employment credits. By conducting discussions with the agencies of multiple states, special tax, financing and other economic incentives may offered. Including these incentives in the site selection decision is important. The incentives offered could become a deciding factor in where to best locate a particular launch site.

*3. Location, Location, Location*

The worldwide geographical location chosen to situate the launch complex greatly affects its cost. Site factors, such as seismic zone and hurricane wind exposure, affect both the cost of launch complex facilities and can affect the operational strategy. Other, more subtle, site specific issues such as ocean salt spray, temperature, operational winds, or the fine dust of the Australian outback also affect costs. The basic logistics of bringing in skilled labor and construction materials and of exporting a controlled technology also increase total launch facility costs.

Access to the launch complex affects the facilities required for the operational plan. Transporting large solid rocket motors from the manufacturing location to a remote launch complex may require a new port, a railroad extension, or both. Transporting large liquid core vehicles may require an airfield or port expansion and provisions to manufacture or deliver cryogens locally. The vehicle geometry frequently is the determining factor in selecting the transportation method. Some vehicle components are too large to transfer by aircraft. Some are so bulky as to require barge transport.

Certain cultures are more receptive than others to this type of business. The environmental regulations and social opinions of the chosen location also affect how extensive (and expensive) the launch related environmental and social planning activities will be.



## III. Aerospaceport Infrastructure Cost Factors

Much of the previous discussion also applies to the new aerospaceports. A major difference that aerospaceports have versus traditional launch sites is that existing underutilized airport infrastructure can be used with little or no modification to support the operation of horizontal Reusable Launch Vehicles (RLV), thereby reducing the non-recurring cost associated both operations. It is possible to greatly reduce the overall infrastructure cost when compared with traditional launch site. Many of the same cost factors still apply with additional perspective.

### A. Launch Vehicle Factors

Currently there are a wide range of horizontal RLVs in development that utilize a variety of operational approaches. The one similarity with all approaches is the aviation-like integration, processing and mode of operations. In most instances the vehicles take off from a runway horizontally like traditional aircraft to begin their missions. An excellent example of a launch vehicle that can take advantage of aerospaceport infrastructure is the Orbital Sciences Pegasus, which utilizes a modified L-1011 as a carrier aircraft for the air-launched Pegasus rocket. Two other vehicles in development include Virgin Galactic's SpaceShipTwo / WhiteKnightTwo and XCOR's Lynx; both of which utilize aviation-like infrastructure to support their missions.

*1. Launch Vehicle Size*

The launch vehicle size directly impacts the infrastructure that is required for vehicle processing. RLVs can frequently utilize existing infrastructure such as aviation hangars. The size of those hangars is directly related to the size of the vehicles. The length, wingspan and tail height all affect the size of the hangar that is required, which ultimately affects the cost. The runway length and width requirement of the vehicles, which can be directly related to the vehicle size, also affects the total cost. In the case of smaller RLVs, shorter runways, on the order of 8,000 ft may be all that is required, while larger RLVs will require runways that are 12,000ft or longer. If an existing site already has a runway of sufficient length and width, then no additional costs may be incurred, however if the aerospaceport is being built new, or the existing airport does not have a runway that is long enough, then the cost to build or extend the runway and taxiway may be significant.

#### 2. *Types and Numbers of Propellants*

Just as in traditional launch vehicles, the numbers and types of propellants utilized can increase the infrastructure costs of spaceport. A variety of common propellant combinations are utilized for RLVs including:

- Liquid Oxygen / RP-1
- Liquid Oxygen / Methane
- Ammonium Perchlorate Composite Propellant (APCP)
- Nitrous Oxide / HTPB
- Nitrous Oxide / Nylon
- Nitrous Oxide / ABS

A common trend with RLVs is to minimize the total number of propellants on the launch vehicle. This approach greatly reduces the number and complexity of propellant loading systems. In general the costs for propellant loading systems is highest for all liquid vehicles and lowest for all-solid vehicles. The cost for propellant loading systems for hybrid launch vehicles falls in between.

It is common for airport runways and taxiways to be constructed with an asphalt surface. Some oxidizers, like liquid oxygen, can react explosively, under the right conditions, if accidently spilled on asphalt. It is therefore preferred that propellant loading operations and potentially other spaceport operations occur on a concrete surface. Additional infrastructure costs may be incurred at sites that have asphalt surfaces.

### B. Operational Strategy

The operational strategies for RLV's vary greatly and directly affect the types and cost of infrastructure that is required at an aerospaceport.

#### 1. *Mission Type*

There are a variety of missions that can be supported at an aerospaceport, including tourism, scientific, educational, transport, and defense missions. For suborbital space tourism, the passenger experience is of utmost importance and may drive the need for a spaceport to invest in additional facilities to enhance the "experience". This could include the need for passenger terminal facility for the spaceflight participants and their families. A good example is Spaceport America, in which great emphasis was placed on the total passenger experience. For scientific and education missions, additional clean rooms or workspace may be needed to prepare, test, and recover the scientific experiments. As the prospect for high speed point-to-point suborbital transport of passengers and cargo gets closer to reality, additional facilities and airspace coordination will be required. For commercial aerospaceports that also provide support of defense related missions, additional infrastructure including secure facilities will be required. If specific missions or operators require onsite mission training, visitor centers, or museums, additional infrastructure investments will be required to provide these facilities, adding to the cost.

#### 2. *Suborbital vs Orbital*

Horizontal RLVs have the capability to support both suborbital and orbital mission profiles. Orbital missions require large flight corridors that can extend several thousand miles, while suborbital missions can be completed within a few hundred miles of the spaceport. The development of orbital flight corridors could become a costly and challenging endeavor if the spaceport is not already located within close proximity to an existing range with established orbital launch azimuths. Orbital missions may also require greater access to clean room and secure facilities depending on the requirements of the mission and the spacecraft.

#### 3. *Unique Vehicle Operations*

Some RLV operational strategies may drive requirements for costly infrastructure changes. The timing of the firing of the rocket engine (vs. aircraft engines) is an important decision point, affecting flight profile and risk management. Some RLVs utilize a front skid instead of a front tire for landing operations. Depending on the material used for landing, the skid could potentially damage runways that are constructed from asphalt. Concrete runways are preferred for RLVs that land with front skids.

*4. Spaceport Licensing and Environmental*

Commercial aerospaceports must be licensed as a "launch site" by the FAA Office of Commercial Space before they can begin commercial operations. The process of receiving a launch site operator's license can take several years cost between $500,000 and $3,000,000 depending on the site, proposed operations, and environmental sensitivities. Often, many proposed aerospaceports complete a feasibility study before seeking their license to determine what the potential licensing and infrastructure costs may be to become a licensed commercial spaceport.

### C. Location Factors

The location of a commercial aerospaceport has a direct impact in the potential cost, operational flexibility, and business case for support commercial space operations. Similar to traditional launch sites, the factors that influence the cost are the availability of existing useable infrastructure, the potential for shared access with site partners, and the geographical location of the site.

*1. Existing Infrastructure*

If an aerospaceport utilizes an existing Airport with sufficient infrastructure available, the potential cost to support commercial space operations is fairly modest, on the order of $1 Million. However, if the aerospaceport is being constructed from the ground up to provide all of the required infrastructure, such as Spaceport America, then the total costs are actually in the same range at traditional facilities in the $200 Million range. The pieces of infrastructure that are typically the most costly include runway and taxiway extensions, processing and integration facilities, terminals and spaceflight training facilities.

*2. Site Partners*

Many aerospaceports are also active commercial or general aviation airports. It is critical that spaceport operations do not have a negative effect on existing revenue generating aviation operations and users. Some of the concerns expressed by Airports and Airlines have included: fears of spaceport operations imposing delays on commercial aviation operations, fears of accommodating unpowered glided return of some RLVs, and fears of potential separation distances caused by the loading of rocket propellants. As the numbers and types of RLVs increase and concurrent ground operations evolve, it will be common for multiple launch operators to share infrastructure and conduct commercial operations in close proximity to each other at commercial aerospaceports.

*3. Location, Location, Location*

A worldwide network of commercial spaceports is currently developing and the location of those spaceports is a critical consideration. Different locations may serve different roles in the spaceport network. Suborbital space tourists will be interested in the whole "experience" of space travel and may prefer tourist destinations or remote locations. High speed transit services will be more concerned about endpoint proximity to specific high passenger volume business locations. As the prospect for point-to-point suborbital space travel continues to mature, it will be important that the nodes in the spaceport network are positioned in such a way that they provide quick access to major global cities with destinations such as New York, Sydney, and London.

## IV. Infrastructure Cost Trends

### A. Traditional Launch Sites

The total nonrecurring infrastructure cost for traditional launch sites can be in the $10's of Millions, $100's of Millions or Billions depending on the above discussed factors. A useful historical approach for bracketing the infrastructure costs was quantified in 1961 by the NASA published "Handbook of Astronautical Engineering", edited by H. H. Koelle. One portion of the book suggested a Log – Log relationship between cost of space launch facilities and the launch vehicle's lift off thrust. The relationship helps quantify what is intuitively known: Small rockets use significantly less total infrastructure than large rockets. Figure 1 is an escalation to today's dollars of the RS&H data to illustrate this facilities cost to vehicle thrust relationship. Using data from RS&H's proprietary cost database and other published cost data, historical and estimated launch facilities costs for a range of existing and proposed launch vehicles were plotted.

As can be seen, the facilities cost to vehicle thrust relationship is still a useful approach to quickly bracket the potential launch infrastructure costs for many vehicles.

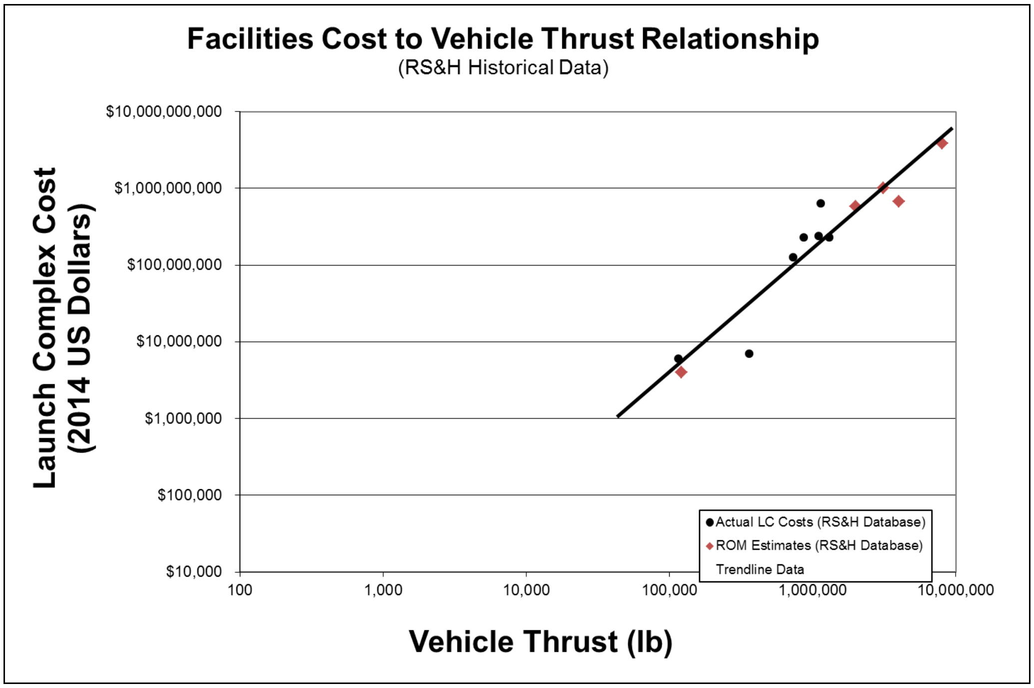


**Figure 1. Facilities Cost to Vehicle Thrust Relationship**

From an order of magnitude approach, it is common for launch vehicles with around 1,000,000 lbs of thrust to incur facilities costs in the $100 Million+ range.

### B. Aerospaceports

In many cases there is an excellent match among the RLV requirements and an airports existing underutilized infrastructure. For these airports, the upfront costs to become and aerospaceport are comprised of spaceport planning and licensing activities because there are few modifications required to facilities or hardware. Planning and licensing activities include technical feasibility studies, business case and financial feasibility assessment, preliminary environmental analyses, launch site license application, NEPA documentation, and master planning.

Spaceport America reportedly cost more than $200 Million to develop. Those commercial airports deciding to expand into aerospaceports require significantly less funding than this to become operations. The cost to develop the various planning documents varies from site to site. The median amount a spaceport spends on these documents is around $750,000 in 2014 dollars, with the average being around $1,000,000.

### C. Hybrid Spaceports

Some spaceports, such as Spaceport America are licensed to support both horizontal and vertical operations. Another example is Mojave Air and Spaceport, which supports both horizontally launched RLVs as well as Vertical Takeoff Vertical Landing (VTVL) launch vehicles. In these instances where a spaceport provides support for multiple methods for launch, addition infrastructure is required which result in higher total infrastructure costs.

## V. Summary

The authors have been following the cost trends of launch infrastructure for over two decades. During this time the simple relationship among launch vehicle thrust and infrastructure cost has remained a straightforward and quick method to understand the basic cost range expected for a vertically launched vehicle.

The advent of horizontally launched vehicles (RLVs) represents a cost departure form historical data. The RLV's ability to launch from a runway, without ground based service towers or umbilicals results in opportunities to provide launch services from many of the existing underutilized airports around the globe - at a fraction of the previous cost. Should horizontal launch develop and grow the infrastructure costs of the launch support facilities will drop accordingly

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