

Spaceport Master Planning: Principles and Precedents

Constance M. Adams^{*}
Futron Corporation

Georgi Petrov[†]
Synthesis int'l

THESIS

As a nexus of multilevel, complex and often disparate functions, a spaceport must be planned from the outset to accommodate all the requirements of a jet-capable regional airport plus those driven by the technologies of spaceflight.

INTRODUCTION

While the past two years have witnessed marvelous breakthroughs in private space initiatives and in commercial support for spaceflight, the specific issues inherent in the design of spaceports require special examination. The airport paradigm has evolved over the course of the twentieth century from its basic functionality of airfield or runway strip and hangar to a complex transportation nexus of rail, air, road and sea transit, supported by various hospitality and training functions and other logistical functions. To date, spaceflight has been restricted to government programs which can accommodate internal planning and the ability to leverage other facilities, both military and civilian, to meet its needs. The advent of commercial spaceflight will effect a radical change in the operational requirements for launch facilities, and along with these operational shifts come associated technical complexity that cannot always be met by leveraging publicly owned resources. In addition, there is every reason to expect that the facilities supporting commercial space access will follow a similar pattern of formal transformation to that which traces the history of air access, as technologies emerge and mature and as the market grows from the initial handful of wealthy suborbital tourists to a mass market we can now only imagine.

Based on this supposition, we infer that a financially and technically viable commercial spaceport will need to be capable of supporting not only the same strong and unambiguous connections and ground functions a regional airport can accommodate, but also the logistical and strategic resources necessary to enable flexible support of a changing array of space access technologies (e.g., launch pads, fuel farm, runways for horizontal takeoff and landing, efficient means of transporting resources across the site, etc). Along with these physical aspects of the specific architecture necessary to add the spaceflight element to a transportation facility are the invisible architectures dictated by launch range safety and ground operations (telemetry; communication; guidance, navigation and control, recovery range, SAR).

In this paper we propose to review the history of air access facility types in the context of a dual evolution of commercial market and technology, identify aspects of the mature airport that offer useful paradigms for spaceport planning and suggest a probable pattern of typological evolution for the spaceport that may permit more accurate phasing of development for new facilities. Future papers will delve deeper into some details of these typological phases and will offer a list of design principles for robust spaceport planning and development.

^{*} Architect/Space Architect/Operations Integration Engineer, Futron Corporation, constance.adams1@jsc.nasa.gov, AIAA member

[†] Space Architect/Engineer, Synthesis int'l, gpetrov@alum.mit.edu, AIAA member

PRECEDENTS: THE AIRPORT

On August 6, 2006, the **New York Times** Sunday Style section headline proclaimed, “My Other Vehicle is a Gulfstream”¹. The accompanying photo, which covers nearly half the section’s front page, shows a regional airport runway covered chock-a-block with private jets of varying sizes, parked so closely together that very little tarmac is visible between the splayed wings and fuselages. As the story asserts, private air travel has now become so affordable that “even the merely rich can afford private flights”. To most of us living today, this image is not terribly startling; yet eighty years ago it would have stunned the public. Even as Fritz Lang, Frank Lloyd Wright and other early visionaries of the twentieth century were depicting large urban or suburban tracts whose airspace was peppered with personal aircraft, the reality of air travel prior to Charles Lindbergh’s transatlantic solo in 1927 was very different. “Air mail” postal service was established in 1918, and prototype “aerodromes” featuring a hangar and open landing field began to spread in earnest in the mid-1920s. Until the frenzied explosion in airfield construction that immediately followed the Lindbergh flight, in fact, only a few handfuls of humans had either the resources or the inclination to engage Orville and Wilbur Wright’s wondrous technology and experience flight for themselves. Those who did were predominantly aviation enthusiasts, relatively well versed in the engineering of their aircraft and in the theory behind their function². In this sense, the period was not unlike today’s tiny but avid community of space voyagers; and the evolution of commercial spaceflight may reasonably be expected to continue to follow similar patterns.

Although not often recognized as such, the design of air traffic facilities represents one of the greatest challenges in the design field. In the complexity of embedded systems and the critical importance of integration with regard to multiple operational requirements, the airport can be considered a technology like any other. During its experimental phases it underwent aggressive testing and adapted new solutions in response to failures in every area. It principally involves harmonizing the connection between three disparate and complex sets of operational requirements or **programs**; and the strategies for achieving this reconciliation evolved through several phases of technical, economic, social and political transformation. While a view of the development of air travel through each of these lenses can be extremely illuminating, for the purposes of this project we will limit ourselves to tracing the development of these programs as the principal operational arenas that comprise an airport so as to remain focused on the goal of establishing useful planning and design principles for the first generation of commercial spaceports.

Two programs present themselves even from the earliest days of commercial flight, although it is only since the 1970s that it has become common in aviation planning parlance to refer to “airside” and “landside” facilities and operations. **Landside** operations include the processing of passengers and their baggage “without being physically close to the aircraft. In addition, sufficient ancillary facilities, such as concessions ... and the like, are located in landside facilities to provide amenities to facilitate a pleasurable experience for the passenger. **Airside** facilities ... focus on the efficient servicing of aircraft, including fueling, loading and unloading.”³ Looking carefully at both programs serves to demonstrate the complexity of the overall airport plan. In the simplest terms, landside functions support the passenger and airside supports the aircraft. But at any greater detail, the appearance of clarity slips away. Landside facilities are served by road and rail, carrying automotive and livery traffic as well as subway or other local forms of rail. Not only passengers and ticketing personnel must be efficiently delivered to the landside facility, but food, drink, goods and cleaning services as well. Passenger baggage is taken and commuted to the airside program independently of the passenger. Outside the airport terminal, but still a part of landside operations, are extended elements such as car rental, shuttle buses, hotels and parking lots. Commercial spaceports will also need to be capable of

receiving passengers from numerous locations and in addition, of accommodating them onsite for training, medical checks, and tourism.

Looking from the terminal outward in the opposite direction, airside facilities must support equipment and personnel for fueling, inspecting and maintaining aircraft, flight personnel and baggage handling and transfer. Gates must somehow deliver passengers to the aircraft, fuel storage facilities must be supportable and serviceable, and aircraft must be able not only to park and taxi to and from the runways but to do so both as quickly and as safely as possible. How spacecraft will taxi from their assembly and processing facilities to the launch site is one of the primary engineering and planning decisions any spaceport designer must undertake. Finally, the invisible architecture of flight operations—airport management and flight control centers—must be accommodated in every airport. Flight Operations for a commercial spaceport will require all the equivalent infrastructure and also space communications capability, as well as facilities for training and certifying flight directors.

The demonstrated tendencies of transportation technologies to change and of demographic groups to shift patterns have been nowhere more visible than in the century-long history of the airport. In order best to meet future changes, it is clear that flexibility in sizing and layout of both airside and landside operations is desirable. Best practice in airport planning today tends to separate the facilities designed to serve the landside program from those supporting airside activities to the greatest extent possible. After all, taxiing aircraft have very different requirements than pedestrians and ground transportation; the difference in scale of operations alone strongly suggests different design responses to each. However, attention to air traffic and ground traffic still does not completely encompass the whole of the airport's operational requirements. It is clear in reviewing the paradigms according to which airports have accommodated these dual programs that two other form-driving programs must be added to the list.

The first of these is **cargo**—the processing and transfer of goods independently of passenger operations (i.e., non-baggage commercial and noncommercial goods). Air cargo has played a large role in commercial flight from its earliest days, when commercial aviators relied upon delivery of the mail in order to stay afloat when passengers were scarce. Today, the growing reliance on air transport of goods via such carriers as Federal Express, DHL, UPS and others has pushed major air cargo companies to take over less-used regional airports or to build private air facilities at major hubs to serve more efficiently their specific requirements independently of passenger airports. Nonetheless, virtually every airport must accommodate air cargo transfers both by and for their commercial airlines and by air cargo carriers. Therefore, cargo operations share runways and taxiways, and even aircraft, with passenger airside operations; and while these principally occupy airside facilities, their needs are different from passenger airside requirements. Also, cargo does not tend to overlap with passenger based landside facilities but does require access to the same roads and rail lines that also serve the passenger terminals. Cargo will continue to play a large role in commercial spaceport operations, both in the need to import and accommodate goods to support the ground facilities and also to support delivery and processing of spacecraft components and hardware for launch. Since spacecraft cannot deliver themselves to their launch site, runways must exist that are capable of supporting a fully loaded Airbus Beluga, Boeing SuperGuppy or other spacecraft-carrying planes, the equivalent of landing an Airbus 380, a 747 or a C5.

While the cargo function has in a sense coexisted at the side of passenger landside and airside facilities, it was not until the last of the three main phases of airport typological evolution that a programmatic element has existed at the boundary otherwise separating landside from airside.

This function, **security**, arose in response to the early wave of hijackings in the 1970s and has reached a new level of significance in air travel since 2001. One way of looking at the security function is its focus, for all intents and purposes, on “sanitizing” airside operations and preventing contaminants (in the form of threatening persons or objects) from invading the aircraft. Thus, the security cordon on the one hand absolutely separates primary landside from primary airside operations. Once passengers have cleared security, they have essentially left all links to the city behind and are prepared for flight. At the secondary level, however, the presence and decreasing porosity of the security function force a transfer of operations such as concessions, vending and other passenger amenities from landside to airside facilities. Security has always played an important role in federal space launch facilities, with the public kept at a considerable distance from all ground and space operations—this is even more exaggerated in the Russian program, whose very launch facility was purposely mismarked on maps until the fall of the Soviet Union. As commercial spaceflight comes ever closer to being a reality, the security cordon will necessarily move somewhat inward to permit greater involvement on the part of potential investors, suppliers, customers and families; but it is safe to assume that it will remain an important part of the plan for any new spaceport.

In addition to the operational functions represented by airside and landside requirements, a physical airport must also accommodate the technical functions that serve the facility’s “Metabolic” program. This includes all equipment and **utilities** that support the principal Landside and Airside functions, such as power, concessions, baggage handling from ticketing to aircraft to carousel, and aircraft and facility maintenance and servicing. Proper treatment of this program in a discrete manner—and properly integrated with the air and land elements—has been shown to result in dynamic, highly efficient facilities capable of high volume and long-term growth. The placement of metabolic elements, like the security function, can dramatically improve the efficiency and long-term flexibility of a site. Whether the airport’s planners anticipate the security cordon to truncate the landside closer to the landside metabolic stream or farther from it, is an additional discriminator in the overall design and efficiency of the facility.

In studying the physical manifestation of the airside and landside requirements over the eighty-year evolution of airport design by trial, error and success, several lessons have emerged with regard to design principles. First, all successful design solutions have chosen one of three fundamental typologies for their response; second, each of these types tends to favor one of the programs over the others; and third, even those which appeared well balanced evinced some signs of dysfunctionality. How these functional or programmatic elements—landside, airside, cargo, security and utilities—have been treated in the development of formal typologies responsive to the airport paradigm, is a fruitful and lengthy discussion of its own and will be addressed in further detail in another study. For now, let us take a quick look at the history of the airport paradigm and a reasonable projection of what the next few decades will hold for spaceport development.

A BRIEF HISTORY OF THE TYPE

As with any new development, the airport has evolved over the past century in parallel with two concurrent (but not always harmonious) phenomena: changes in social patterns related to air travel, and changes in aviation technology. Both of these evolutionary streams have imposed new requirements upon all the fundamental components that comprise an air traffic facility, though not in equal degrees. For instance, while the growing popularity of air travel influenced the design of landside facilities to accommodate passengers, eventually the greater rate of growth in landside requirements in turn levied demands on airside assets and on the overall metabolic functionality of the facility as a whole. On the other hand, while the advent of the jet

engine primarily forced new requirements on such airside facilities as runways and airspace, eventually this new technology also revolutionized the landside activities by enabling a dramatic drop in the cost of air travel relative to the standard of living.

Difficult as it may be to project at this time, there is no reason not to anticipate a similar duality of impacts due to “system creep” in both the market and technology engaged in commercial spaceflight over time. The value of studying the evolution of the airport archetype is the potential for substantial cost savings to spaceport developers by planning these very costly and technically complex facilities for longterm flexibility and robustness in response to changing external requirements.

Upon review of airports over the past century, we find that we can characterize their evolution in three fundamental phases, as follows:

Airport Period 1.: Evolution of Flight [1910-1930]

At the very beginning of passenger air travel, individual aviators were still making historic journeys and those lucky few who were able to afford passenger travel did so with a sense of adventure accompanied by expectations of luxury similar to those aboard ocean liners despite the obvious hardships of flying. An elegance surrounded each passenger’s ticketing and waiting area, and the limited baggage permitted was handled by the service providers from curbside to curbside. “Airfields” were located close to the center of town. Ideas proliferated about the eventual ease and universality of air access that included plans to build airstrips across neighborhood rooftops to enable residents to commute to work by air. Reality, however, meant that most airfields were cow pastures with one or more hangars and a small passenger building at one edge. After Lindbergh’s flight, in the late 1920s, terminals were built up and some runways were paved to support larger planes using prevailing winds.

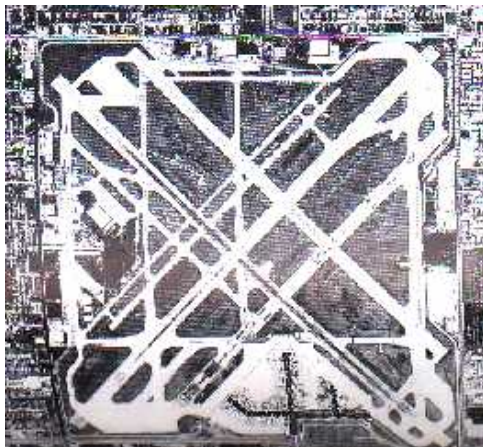


Figure 01: Chicago Midway aerial view



Figure 02: Chicago Midway

Principal Type: Point Access

The earliest type of airport assumed a relatively direct point relationship between the landside access (passengers) and the aircraft. In most cases the single, centralized passenger terminal similar to the railroad terminal served as a processing and waiting area; when a flight was ready for boarding, passengers would depart the terminal at one point and walk out onto the tarmac to climb the stairs up to their waiting aircraft.

Examples:

Chicago's Midway airport is an excellent example of this type, and many major cities still have a small commuter airport dating from this era, when easy access to the Central Business District was desirable and the (often unpaved) airfield enabled omnidirectional takeoff and landing to meet the requirements of the small propeller driven aircraft of the time .

Advantages of Point Access type: very simple and direct access.

Disadvantages of Point Access type:

Unsuitable for large volume of travelers or jet aircraft due to bottlenecks in both terminal and apron.



Figure 03: Madrid Barajas Airport

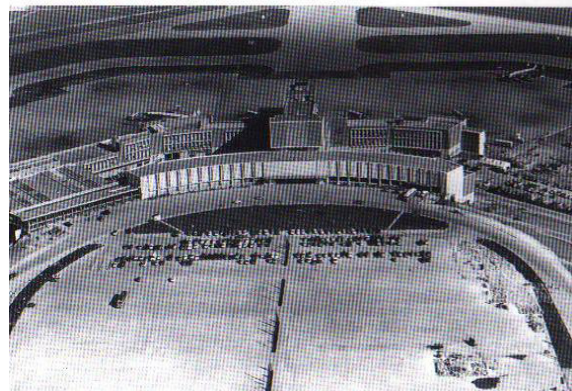


Figure 04: Madrid Barajas Airport

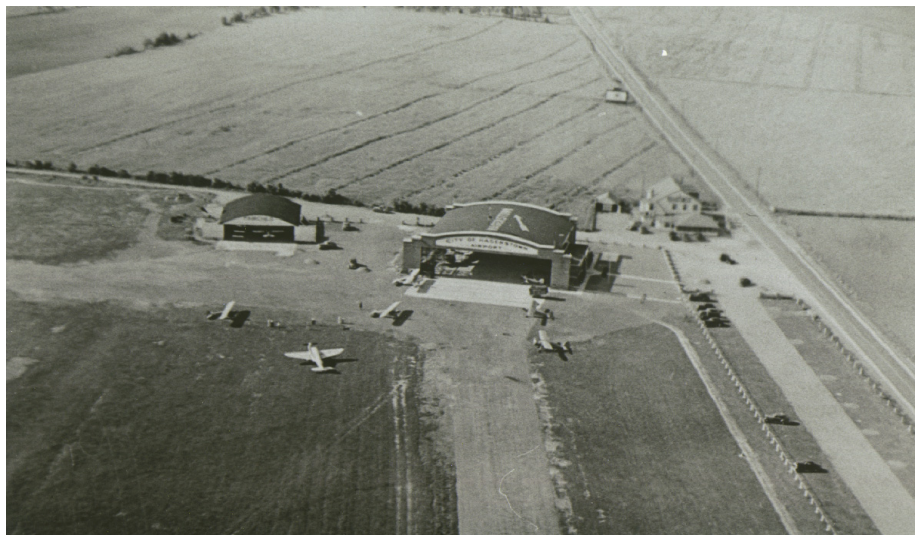


Figure 05: Hagerstown Regional Airport

Airport Period 2: Evolution of Air Carriers [1930-1970]

By 1930, the effects of the Air Commerce Act of 1926 were being felt in the United States. As the market for commercial flight picked up, many companies already in the transportation business (including several railroad magnates and Henry Ford himself) decided to invest in air travel. Private air carriers sprang up in large numbers across the US, Europe and Latin America, and the market went through a rapid lifecycle between 1930 and WWII. The formation

in 1938 of the Civil Aeronautics Board (CAB) reduced the number of new carriers entering the market and also introduced regulations for air travel. Many regional airports were laid out during this period, for the first time with sufficient acreage to permit growth. Thanks to the improvements made in aviation technology during the Second World War, particularly the development in 1949 of the DeHavilland Comet—the first commercial jet aircraft—air travel became more available and the carriers providing air service developed stronger brand identities. Every decade's projections for the growth of the industry were consistently outstripped in reality by some orders of magnitude. As the volume of customers and the availability of aircraft grew, so did the need for good airside logistical support and maintenance. Air carriers began to build their own facilities at municipal airports to accommodate airside operations as well as to accommodate passengers and instill a sense of brand loyalty.

Principal Type: Hybrid

As air travel increased and airports grew, it was clear that point access typology cannot accommodate the volume of traffic or the apron room needed to support jet technology. In addition, the economics of commercial air travel generated an increasingly competitive atmosphere between carriers. Multiple terminals began to spring up between the access road and the runways so that the landside access appears decentralized although airside activities are still centrally controlled. Hybrid airports of the mid-twentieth century arose in the era of heavy corporate-identity and loyalty such that each airline would build and maintain its own terminal, with the port authority playing a planning role. However, in the 1960s the FAA and regional airport authorities began exerting greater influence over airports, insisting on uniform terminals and all traffic in conformance with a centralized master plan. This development added considerably to safety and usability, as well as to economic stability as airline revenues rose and fell.

Examples:

New York's John F Kennedy airport is the prime example of the agglomerated hybrid type; at Chicago O'Hare and Los Angeles LAX, greater uniformity of style was imposed on the carriers' terminals.

Advantages to the Hybrid type:

Air carriers enjoy greater control over the passenger's total experience, and will pay to keep their assets in good working condition. Diversity of formal solutions results in uneven experiences but enables greater range of experimentation.

Disadvantages to the Hybrid type:

Optimized for point-to-point travel. Difficulty of ensuring continuity of service both airside and landside meant that transferring between air carriers left passengers and their baggage in logistical limbo; also, security and other services must be separately addressed in each terminal.

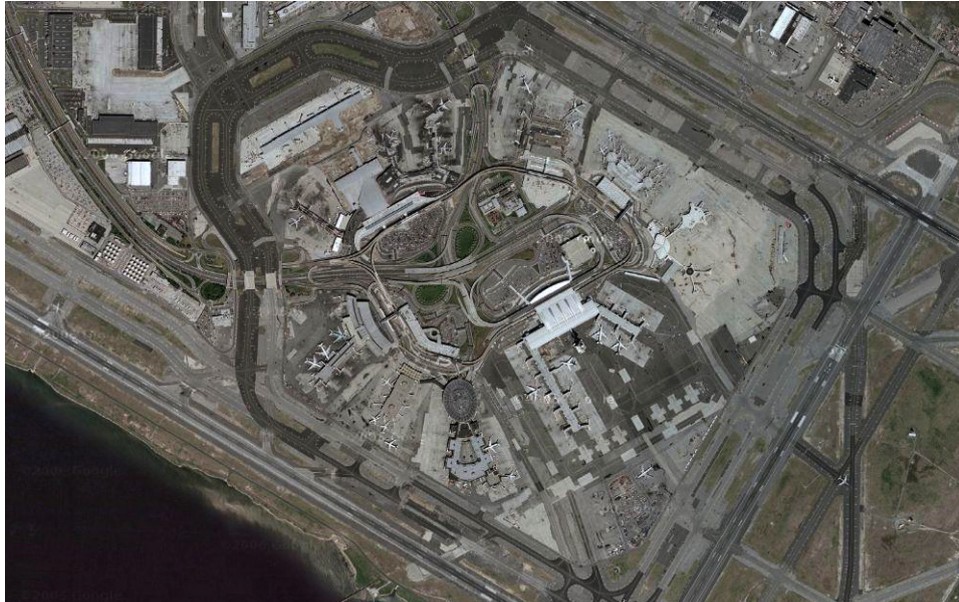


Figure 06: JFK layout in New York each airline developed its own terminal



Figure 07: TWA terminal, JFK - pinnacle of air carrier architectural branding



Figure 08: Uniform multi-terminal layout at O'Hare International in Chicago

Airport Period 3: Evolution of Market, Technology and Regulation [1970-2005]

On January 22, 1970, the first Boeing 747 “Jumbo Jet” landed at Heathrow Airport with a full complement of 324 passengers on board, momentarily shuttling in the modern era of mass air travel.⁴ Jet engines had a dramatic effect on airport design in two ways: on the one hand, the greater range and noise of the aircraft required runways too long for the older airfields and with sufficient buffer to reduce the effects on noise pollution on residential neighborhoods; and on the other, the increase in range and capacity enabled virtually everyone to fly and opened up the skies to virtually every destination the public desired. The need to invest in significant new infrastructure to support this phenomenon enabled local, state and federal governments to apply new regulations to air travel and introduced the monolithic airport whose identity is more informed by local culture than by corporate branding. After the Air Deregulation Act of 1978, air carriers engaged in price wars established “hub” airports and point-to-point travel succumbed to hub-based transfers that increased revenues. The impact of transfer flights on landside operations and design requirements was dramatic, as formerly efficient point-to-point airports became nightmares for passengers desperate to make connections in perpendicular movement to the planned landside accommodation.

Principal Types: Hoop and Bar

Bar type:

All landside functions are laid out in a bar shape, parallel to airside functions. Landside operations are isolated at one end of the facility, at a central ticketing and processing terminal; passengers are then shuttled to remote gate concourses situated in the middle of an articulated apron that connects directly to taxiways with minimal taxi time between gate and runway. This type is characterized by its long, continuous bar-shaped concourses with landside traffic in the center and airside traffic all around on both sides. This is a later evolution which assumes the ability to move the ticketed passengers from the processing terminal to their gates on parallel concourses smoothly and efficiently without crossing the flow of airside traffic.

Examples:

The first “bar” type airport was Dulles International. The distance from curbside to jetway was alienating prior to the security challenges of the 1970s; but once hub travel began, Atlanta Hartsfield’s new bar plan revived the type and demonstrated its relentless efficiency in transferring passengers (or, at least, their baggage) between flights. The only major US airport to be started in the past decade, Denver International Airport, is a replica of the Atlanta bar typology.

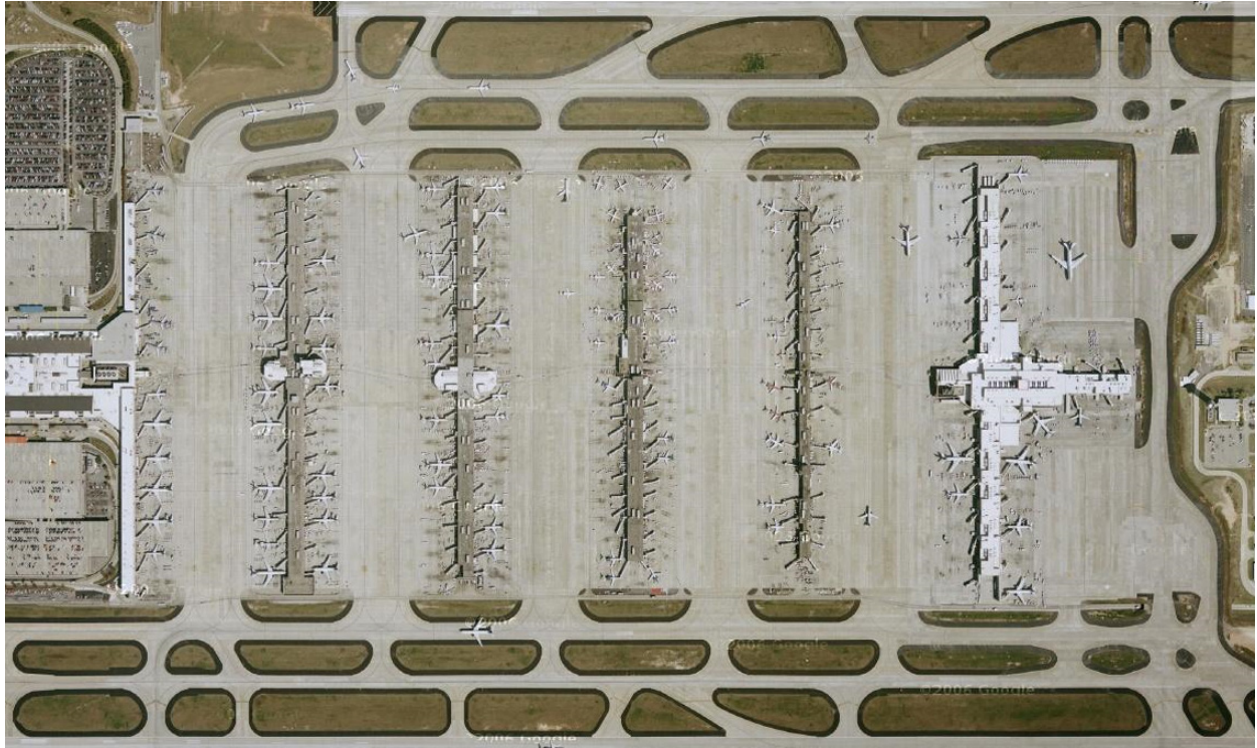


Figure 09: Hartsfield Jackson Atlanta International Airport



Figure 10: Washington Dulles International Airport



Figure 11: Dulles Passenger Terminal, with a view of airside support functions at lower level

Advantages of the Bar type:

Functionality can expand by adding bars; also, flow of certain airside operations is very good and taxi time is minimized.

Disadvantages of the Bar type:

Flow of landside operations between concourses is badly congested; also, metabolic or utility system must be doubled or more to accomplish its task. As security is tightened, access from the processing terminal to concourses is a major bottleneck, with only a single access point for all airport passengers.

Hoop type:

Landside/airside intersection describes an arc of a circle, with landside access traffic forming a single arterial core in the center. The smaller inner circumference better accommodates foot passengers and slower speed traffic such as cars. With airside functions on the outside of the arc, the broader space along each radian easily accommodates larger, faster vehicles and permits greater leeway in parking an aircraft with a broad wingspan. It has been argued [Wells and Young] that this type is a projection of multiple point-access solutions around what is often referred to as a “chain of pearls”⁵. In general, the geometry of this type balances airside functions against landside ones with interesting results. As each terminal fills out into a total circle, the more luxurious the airside access is on the one hand but the less efficient the landside and metabolic functions are; in a full circle terminals, also airside functions require more infrastructure than is efficient or necessary to do the job and security becomes an extremely costly operation. Also, while this type offers a very efficient experience for the destination traveler, those passengers who must change planes—particularly between terminals—find themselves confronted with a Herculean dash and the likelihood of missed flights. These conditions taper off in extremity as the arc of the hoops softens; Charles de Gaulle, for instance, is much easier to traverse on the landside than DFW even if the ratio of open tarmac to aircraft is somewhat reduced.

Examples:

There are different versions of this type. The Kansas City Airport features a cloverleaf with circular terminals that encompass all landside parking in their center and allow aircraft total range around the exterior of the circle. Dallas/Fort Worth Airport has a modified version of this layout, with semicircular terminals split along a bar of car traffic, and aircraft navigating the outer field on both sides. In the slenderest adaptation of this form, Charles de Gaulle Airport’s

Terminal 2's split lozenge shapes offer fewer gates at the exterior but greater concentration of activity on the landside.

Advantages of the Hoop type:

The shallower hoop type evolved in recent years has spun off a separate curvature for metabolic functions, thus achieving the greatest integration and optimization across systems so far. Passenger transfers are relatively straightforward in a shallower hoop airport.

Disadvantages of the Hoop type:

Deeper hoops are more costly to support per gate and risk stacking delays as more transfer flights fill the profile. Transfer time on landside rises considerably as the arc deepens.

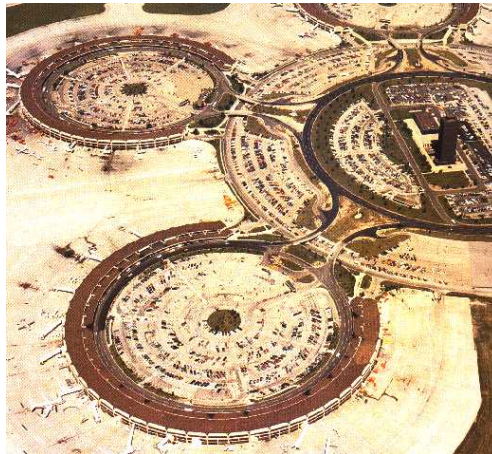


Figure 12: Kansas City Airport—ideal point-to-point facility

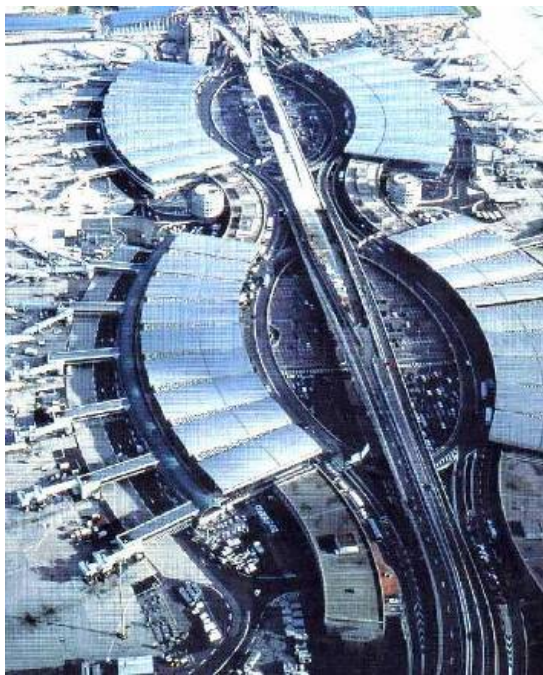


Figure 13: Charles de Gaulle (CDG) Terminal 2
-shallower arcs facilitate transfers

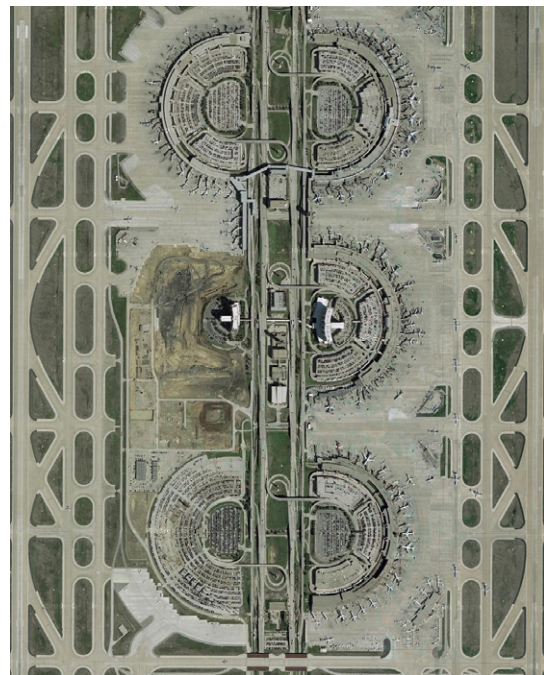


Figure 14: Dallas/Fort Worth (DFW)

APPLICABILITY TO FACILITIES FOR SPACE ACCESS

As a complex technology required to support other complex technologies and multiple operational profiles, the airport is generally understood to have entered its operational phase. Therefore, any facilities built to support commercial spaceflight as the next generation of transportation should be planned from the outset with a keen awareness of the airport as prior art, including its history and full range of operational and technical requirements. It is likely that any facility built to accommodate the carriers who will pioneer space access using the X-prize technologies will most closely resemble the point-access type of airport in overall layout. However, even starting with this type, the cost and effort of constructing physical and operations facilities for any spaceflight capability are such that a phased approach to master planning that takes into account the possibility of its evolution into a more sophisticated and efficient paradigm over time will significantly add value for the investors and reduce technical and financial risk as strategies mature.

Let us conduct a quick review of the operational requirements (program) for both facilities.

AIRPORT OPS REQUIREMENTS

Ground access—road, rail

Runways for aircraft
[private jets to cargo planes]

Runway maintenance

Taxiways

Fuel farm—
jet fuel, gasoline, diesel

Operations support

Flight crew

Ground vehicle management

Control tower

Air traffic

Airport Management,
strategic, operational and fiscal

Airport Engineering

Aircraft ground operations

SPACEPORT OPS REQUIREMENTS

Ground access—road, rail, water

Runways for aircraft
[private jets to jumbo cargo aircraft]

Runway maintenance

Launch pads --vertical, horizontal

Launch Range surveillance and support

Transportation to launch facilities

Ground systems restoration / turnaround

Fuel farm—
jet fuel, gasoline, diesel, solid and liquid propellants

Operations support

Flight crew, trainers

Ground vehicle management

Control tower

Mission operations center

Ground operations, vehicle telemetry, flight ops

Spaceport Management, strategic, operational and
economic

Spaceport Engineering

Spacecraft preflight operations

[AIRPORT OPS, cont'd]	[SPACEPORT OPS, cont'd]
	Spacecraft postflight operations
Aircraft maintenance facility	Aircraft maintenance facility
	Spacecraft element assembly and integration
	Spacecraft checkout
Cargo and baggage handling	Payload handling and assembly
Cargo and baggage loading and unloading	Payload integration
	Passenger cargo integration
Airport logistics	Spaceport logistics
Passenger drop-off, care	Passenger processing
	Passenger training
	Medical screening and support
Emergency medical services	Emergency Search-And-Rescue, launch range safety and medical services
Security -- Federal, port authority	Security-- Corporate, port authority
Conference facilities	Conference facilities
Air Carrier offices	Launch Carrier offices
Hotels	Passenger hostel facilities
	Tourist facilities
Restaurants	Commissary / restaurants
Supply management	Supply management
IT and Logistics Information Systems	IT and Logistics Information Systems
Passenger services	Customer Services for commercial astronauts, families, tourists, commercial space entrepreneurs

Table 01: Comparison of airport and spaceport operational requirements

The spaceport functions represented here are taken from a study done by the NASA Kennedy Space Center's Advanced Spaceport Technology Working Group (ASTWG) in the spring of 2003. What is most interesting about this comparison is the extent to which the fundamental operations and requirements of a space access facility mirror those of an airport. Even in the areas where extra functions are necessary to support space operations, these functions are such that they may be treated as additional to the basic day-to-day operations of an airport, of a specialized but not exotic type.



Figure 15: Preparations for Zero-G Training on the KC-135



Figure 16: Space Cargo and Training Aircraft: Boeing SuperGuppy and KC-135

Such strong correlation between the operational requirements [or program] of each type supports the assertion that the airport is a valid example of “prior art” technology when planning a spaceport for commercial use. Consistent with the best practices of design engineering, the spaceport planner who follows this approach will have access to a database of lessons learned and alternate paradigms [or planning strategies] that can add considerable value in risk reduction and management.

EYES TOWARD THE HEAVENS

Applying the pattern of air travel’s evolution described earlier in this paper to spaceflight, we may expect to see similar evolutionary stages in the technology and social patterns of space travel, and prepare to meet these with a corresponding phasing of the facilities that support air and spaceflight. This projected pattern may look a bit like this:

Air/Spaceport Period 4: Evolution of Spaceflight [1960-2005]

Drivers and constraints:

Just as the first period of air travel involved the evolution of flight from a risky endeavor undertaken only by a few experts, so has spaceflight in its first phase been restricted to those supporting government-run programs whose goal was first to achieve and then to sustain a presence in space. Unlike early attempts at flight, space access evolved in an atmosphere of intense concern for national security which both fostered the R&D investment necessary to develop the technologies and rendered the parallel programs of the USA and the USSR all but inaccessible to the public. Therefore spaceports were not designed to accommodate commercial activity nor parallel technological efforts; in addition, they have been developed one program at a time, leveraging existing resources where possible and without the ability to

anticipate what requirements future generations of spaceflight technology might levy on their facilities. Safety has played a heavy role in restricting further development of launch facilities due to the need for a wide launch safety range within the anticipated low-elevation trajectory of the spacecraft. Likewise, orbital inclination affects the desirability of specific locations for launch to space.

Resources:

Due to these constraints and to the cost of building new vertical launch facilities, both major spaceflight programs have found ways of reusing their infrastructure from generation to generation. Existing runway resources such as military airfields were leveraged to address three principal areas of operations: development and testing of horizontal takeoff and landing programs such as the X-15 and the lifting body X-planes, the delivery of cargo and equipment including spacecraft modules, and training of crewmembers and flight support specialists. In addition, existing vertical launch resources such as missile test ranges were leveraged both in Kazakhstan and on the southern Atlantic coast of the United States, and converted into long-term launch facilities. The Russian approach, relying on rail lines for transportation of vehicles and major cargo across the launch facility, has proven to be extremely robust. Major areas of indicated improvement for future facilities principally revolve around the testing, processing and maintenance of spacecraft and spacecraft components. Ground processing and logistics issues may be pinpointed as the source of most if not all space fatalities to date, and remain largely unaddressed as an open source of risk for future programs.

Access:

Even after easing of political hostilities, both spacefaring governments retained a degree of control over their equipment and programs. In the last few years of this phase, the Russian program began to make non-critical parts of their program available for commercial exploitation, including training and flying private investors to the International Space Station for brief stages known as “taxi flights”. This phase may be thought officially to have ended with the disbursement of the first X-Prize for commercial achievement of suborbital flight. However, in terms of infrastructure even the commercial efforts stimulated by the X-Prize challenge have tended to leverage existing publicly-owned infrastructure (including Baikonur Kosmodrom, Dnepr launch range and the Dryden AFB facilities at Mojave Airport) rather than develop their own facilities for development, support, and launching of vehicles and training and support of crewmembers.

Market:

During this early stage there is very little market for commercial spaceflight, due both to the cost and the complexity of getting an individual to orbit. Many “blue sky” ideas are proposed and the desire to stimulate a viable space access market begins to grow.



Figure 17: Launch of Apollo 11

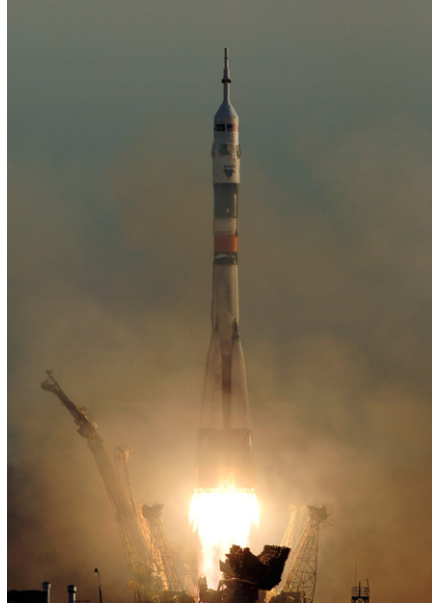


Figure 18: Launch of Soyuz



Figure 19: Launch of Proton

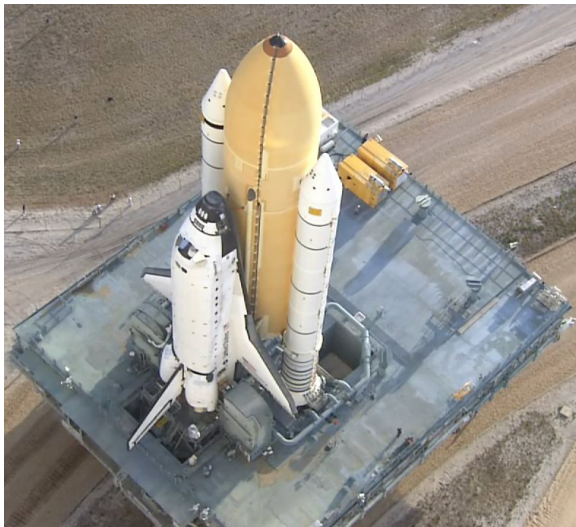


Figure 20: Shuttle "stacked and packed" on crawler



Figure 21: Soyuz Rocket on train to launch pad



Figure 22: KSC 39A Launch Pad with Shuttle



Figure 23: Baikonur LS250 Launch Pad with Energia



Figure 24: Lessons Learned: Texas National Guardsmen with a piece of OV-101 Columbia, February, 2003



Figure 25: Crash of M2F2 test vehicle



Figure 26: X-15 landing



Figure 27: Shuttle Orbiter horizontal landing at KSC



Figure28: Aleksei Leonov and Deke Slayton during Apollo-Soyuz



Figure 29: Dennis Tito

Air/Spaceport Period 5: Evolution of Commercial Access [2005 – 2035?]

Drivers and Constraints:

Beginning with the disbursement of the first X-Prize for commercial suborbital flight to Burt Rutan in 2005, the era of commercial access to space officially set in.

In the early phase of commercial spaceflight, the most critical constraints will be twofold: technical and economic. Even as some city-states and regional governments begin to invest public money in the purchase and planning of tracts for spaceport development, the wide range of technologies in development and test stages to take passengers on suborbital and orbital flights will set up a risky period during which infrastructure providers will be forced to bet on particular systems and plan their facilities to support them. Technologies which are still experimental or developmental in maturity will not attract a mass market; this phase will be characterized by the winnowing of the field of possibilities by maturation of a few systems for commercial spaceflight and the down-selection of options in favor of these. The space carrier industry will start out allied with the technology developers (e.g., Blue Origin, Virgin with Scaled Composites, Kistler with Space Adventures) and each will live or die in this stage according to their system's success rate. Economics and regulatory guidelines will also drive the space carrier industry. Once governments have established guidelines to support and regulate space commerce, we can anticipate an upward tick in the market of would-be astronauts due to a heightened perception of safety.



Figure 30: X-Prize Winner Space Ship One mounted to White Knight carrier



Figure 31: Sea Launch offers flexibility

Resources:

As in the early days of flight, when landing fields developed to support early airpower in World War I were converted into regional “aerodromes”, the first commercial phase of spaceflight will leverage existing, publicly-owned and underutilized facilities for private events. Already the former Dryden test flight field at Mojave, California, has hosted large audiences for the spectacle of the first private suborbital flight, and further X-Prize competitors gather annually at the future site of the Southwest Regional Spaceport (SRS) near White Sands, New Mexico, to give public demonstrations of their recent technical achievements. Like Mojave Airport, the SRS leverages airspace that has already been cleared by and for a nearby government facility. Similarly, Bigelow Aerospace and other private enterprises have leveraged assets formerly

belonging to the Soviet military for their launch services. Thus, commercial space enterprises will overcome the economic hurdle of initial infrastructure investments by leveraging formerly public resources for the purposes of private enterprise. Until the market boom that will define entry into the third and mature phase of commercial spaceflight, the resources behind spaceports will be a combination of this kind of leveraged activity and joint enterprise with regional authorities such as the States of Oklahoma, New Mexico and Florida and similarly-sized city-states like Dubai or Singapore, who have all declared their intentions to build commercial spaceports; in other words, the early “astropreneurs” will likely all share a portion of their risk (the spaceport) with the taxpaying public. Just as early airport construction often met with local resistance and scorn on the basis of a wasted expenditure of public funds, spaceport developers can expect to have to woo local communities. Regional spaceport authorities that do not engage in careful planning for long-term technical maturity and flexibility of the facility will face economic challenges during this period.

Access:

Due to lingering technical risk and economic pressure, access to space will remain limited by economic factors. However, during this phase access will broaden tremendously. As it does, commercial spaceports will need to develop long-stay hostels and facilities for medical observation and training of the new cadre of space travelers, as well as tourism and grandstand facilities for public observation of launches and landings.

Market:

The early commercial market will include such extreme space tourists as Tito and Shuttleworth along with a small cadre of notable daredevils and wealthy enthusiasts. Just as Charles Lindbergh personally led a charge into the air and WWI flying ace Eddie Rickenbacker formed Eastern Airlines, so will the first leaders of this market be individuals of high profile who themselves want to fly to space. This category already includes individuals like PayPal inventor Elon Musk, Virgin records founder Sir Richard Branson, and Budget Hotels entrepreneur Robert Bigelow. Others who are in their social circles or wish to join them, will join the early commercial space market. However, unlike the early days of air travel, today’s culture of litigation and liability will probably slow this process until the technical maturity challenges are largely overcome.

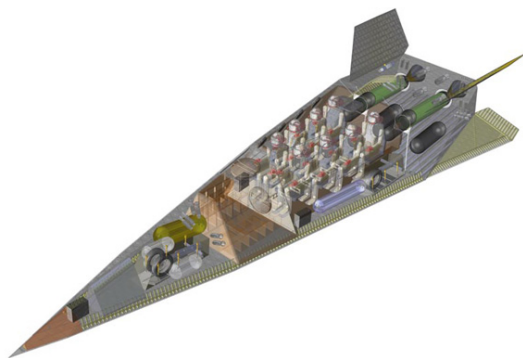


Figure 32: Silver Dart

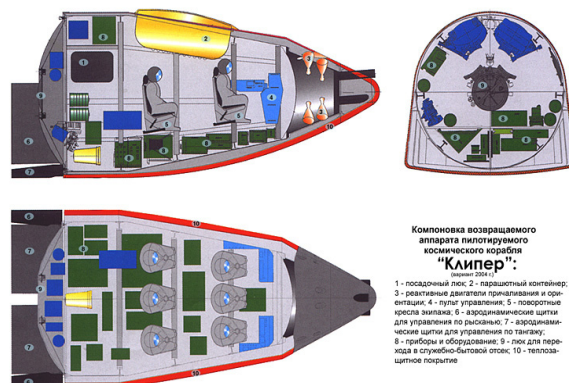


Figure 33: Kliper



Figure 34: Mojave Spaceport

Spaceport Period 6: Evolution Of Space Travel Market, Commerce And Regulation **[2035? --]**

Drivers and Constraints:

This phase will not begin until at least one system for space access has been declared fully operational (we use the term as opposed to experimental systems, as defined by the Columbia Accident Investigation Board in 2003⁶) and the risk to carriers of economic repercussions in the event of failures is brought under control. Once it begins, regulations to protect launch range and safety will continue to drive spaceport site selection and viability, as will the ability of the spaceport to accommodate large numbers of passengers and participants, and a number of simultaneous discrete operations such as training facilities, vehicle integration tasks, and passenger preparation for more than one space carrier at once. Later in this phase, space carriers and/or consortia will undertake construction of orbital or lunar based tourist facilities; planning, building and supporting these facilities will require significant new infrastructure on the ground, ideally as closely linked to the processing, cargo, launch and operations centers as possible.

Resources:

Proper planning on the part of spaceport developers in the prior phase will make resources available during this phase for expansion of the facilities to accommodate mass access to space.

Access:

Access will grow from a small market of wealthy enthusiasts to near-universal access to space.

Market:

The drivers, constraints and paradigms listed above suggest that the market for space access will remain small for an extended period of time but, once opened, will expand at a rate beyond expectations.

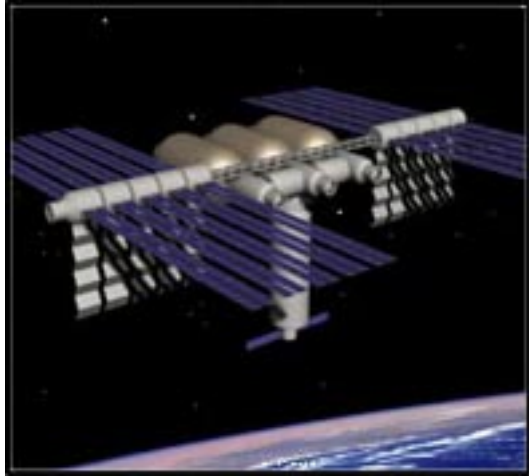


Figure 35: Bigelow Aerospace proposed orbital hotel

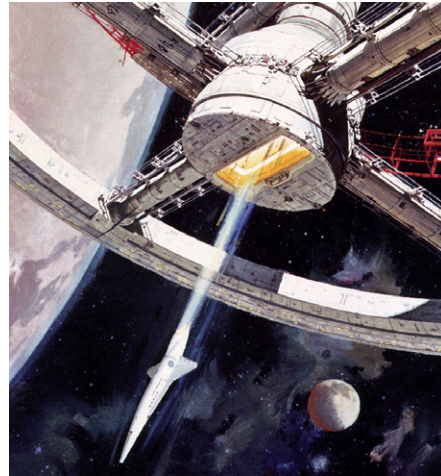


Figure 36: 2001 Orbital spaceport

FORWARD WORK

Based on these projections for operational requirements, preliminary planning concepts for commercial spaceports can be developed that take into account the requirements of various launch platforms, local or regional leverage points, and the need to plan for different rates of growth. Long-term mass utilization is still difficult to envision, but the precedent of air travel strongly suggests that it must be anticipated. We are currently undertaking several ideation exercises to anticipate basic planning requirements for generic spaceport phasing, and the development of a preliminary list of good planning principles for future airport or spaceport design. These studies will form the basis of future papers.

SUMMARY

We have demonstrated that the airport is a complex technology that has passed its experimental phase, and that the airport is a valid example of “prior art” technology when planning a spaceport for commercial use. When contemplating the principles which will govern the robust and efficient planning of spaceports, the lessons of nearly a century of air traffic planning and design can be applied with confidence so long as fundamental ideas are understood and properly translated with enough flexibility to allow and anticipate growth and change over time. While a commercial spaceport designed for today’s market would be necessarily rather modest, the cost of infrastructure that must be invested in undertaking one means that it is not financially sensible to begin planning and development of such a facility without a sustainable plan for clear and phased growth over the next fifty years or more.

ACKNOWLEDGMENTS

In large part, this paper’s conclusions are based on the results of two original studies led by the author, both of which remain as yet unpublished. The first of these, conducted in 2000 at the

University of Houston's College of Architecture and supported in part by the Sasakawa International Center for Space Architecture (SICSA), involved analysis of airport planning typology and resulted in a preliminary taxonomy of the airport paradigm based on an overview of several hundred facilities and the in-depth study of several dozen major airports. During the course of this four-month study, a team of researchers visited an additional ten airports, and conducted intensive interviews at six of these.

The second study sought to synthesize information gathered in the first by assigning code values to fundamental operational elements and reviewing the relationship between these both within specific installations and then across airport types. Additionally, a similar study was begun to collect data on space launch facilities and to infer similar operational elements where information was not publicly available. A preliminary set of findings from this study was collected in a poster presented at the 2002 World Space Congress in Houston, Texas. Of particular assistance in compiling this information were Angel Rivera and Ardis Wenda.

This paper seeks to summarize key elements of both studies as they may be practically applied to principles for the design and planning of facilities to support both air travel and space travel. The author regrets that the dearth of specific published references supporting our assumptions prevents this work as yet from establishing firm quantitative assertions; however, it is hoped that time will permit the research referenced herein to be completed and made available to reviewers. In the interim we would like to suggest that colleagues will find the preceding conclusions to be reproducible and invite any readers with similar or divergent findings to contact us.

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NOTES

¹ Guy Trebay, "My Other Vehicle is a Gulfstream", NYT, Sunday, August 6, 2006

² Alastair Gordon, Naked Airport, Chapter 1

³ Wells and Young, page 207.

⁴ BBCnews "On This Day 22 January 1970: Heathrow welcomes first 'jumbo jet'" http://news.bbc.co.uk/onthisday/hi/dates/stories/january/22/newsid_3725000/3725963.stm

⁵ Callahan and Birk, "Airports for Future Aircraft – A Planning Guide", p.2.

⁶ CAIB report, Volume I, August 2003