Developing the Operational Requirements for the Next Generation Launch Vehicle and Spaceport

Eric J. Staton

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School of Aerospace Engineering
Space System Design Laboratory
Georgia Institute of Technology
Atlanta, Georgia 30332-0150

Advisor: Dr. John R. Olds

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Acronyms and Symbols

APU	Auxiliary Power Unit
C.G.	Center of Gravity
ECLSS	Environmental Control and Life Support System
ET	External Tank
FAR	Federal Aviation Requirements
HDP	Hold Down Post
ISS	International Space Station
JSC	Johnson Space Center
IPPD	Integrated Product and Process Development
IVHM	Integrated Vehicle Health Maintenance
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MCC	Main Combustion Chamber
NASA	National Aeronautics and Space Administration
OMDP	Orbiter Maintenance and Down Period
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
RCS	Reaction Control System
RLV	Reusable Launch Vehicle
RSS	Rotating Service Structure
SCAPE	Self-Contained Atmosphere Protective Ensemble
SRB	Solid Rocket Booster
SSC	Space Shuttle Carrier
SSTO	Single Stage to Orbit
STS	Space Transportation System
TSTO	Two Stage to Orbit
UPS	United Parcel Service
VAB	Vehicle Assembly Building
WBS	Workforce Breakdown Structure

1.0 Research Goal

Currently, within the National Aeronautics and Space Administration (NASA) and the launch vehicle design community, there is an ongoing push to develop the next generation launch vehicle. The design that is chosen will replace the aging space shuttle fleet. Some of the driving factors of any design for the next generation launch vehicle are performance and weight. The greater the performance and less weight the more capacity there is for payload. However, intertwined with performance and weight is a tug-of-war with operations. From an operation stand point there are criteria that need to be met that are in direct contrast to a vehicles design for performance. Within the design community, a balance between operational efficiency and safety and vehicle design needs to be found in order to design an effective launch vehicle.

Regardless of the performance capability of a vehicle, if it is not easily maintained, costs associated with operations will make any vehicle economically nonviable. This paper looks at the design of the next generation spaceport and discusses whether the vehicles that will use it should drive its design or whether the spaceport should drive the design of the vehicles. Studying the aircraft industry over the past 100 years, we see that it was able to create airports and aircraft that work together. From the standpoints of economic efficiency, maintenance, turnaround time, personnel, and man-hour requirements, the aircraft industry developed a workable method. The launch vehicle industry's long-term goal is the development of a Space Transportation System (STS) closely mirroring that of the aircraft industry. By examining how the aircraft industry has gone about designing aircraft in order to simplify ground operations, thus making aircraft economically viable to operate, and applying these learned lessons to the space program, a new guideline or design mentality for developing spaceports and launch vehicles can be generated. These new guidelines would, for the first time, more closely integrate efficient operational realities into early design decisions. This paper takes a first step in the process of developing new guidelines for looking at the similarities between aircraft/airport and shuttle/spaceport operations. By examining the design decisions involved in aircraft design, it is hoped that similar design decisions can be applied to the development of next generation launch vehicles so that in conjunction with a spaceport, the spaceport/launch process will begin to closely mirror the operational efficiency of a major United States airport.

2.0 Introduction

The arrival of the twenty-first century brings an unknown future for the United States space program. In the last decade, the United States space program has experienced enormous cost overruns for the International Space Station (ISS), an ever decreasing number of shuttle flights, cancellation of the X-33 and Venture Star programs, possible closure of NASA facilities, possible privatization of the shuttle fleet, and accelerated budget cuts due to a refocusing of national priorities. Currently, NASA has begun the Space Launch Initiative (SLI) in an effort to develop a second-generation reusable launch vehicle that can replace the aging shuttle fleet and breath new life into the space program. However, at the center of any such design is the operation and design of a next generation spaceport with the capability to meet the needs of the next generation reusable launch vehicle (RLV).

NASA's SLI has set forth the following goals to be met for the next generation RLV.[i]

Loss of mission:	1 in 200 flights
Loss of crew or passengers	1 in 10,000 flights
Cost:	$1000 per pound to orbit
Turnaround time:	< Shuttle

The goals set forth by the SLI have an effect on every aspect of a vehicle's design from performance to operations. Nevertheless, launch vehicles are designed from the stance of performance, allowing this criterion to take full control of the design. As designs progress, less emphasis is placed on fully understanding how design decisions effect the ground operations of the vehicle.

In December 2001, the X-33 lost its battle for survival and was cancelled. While the reasons for its cancellation are complex, two reasons were it's less than optimal performance during testing, and the wide range of complications that occurred. Similar problems occurred in the 1970's during the design of the space shuttle, which had many of the same goals that the X-33 had. What was delivered to NASA at that time was a vehicle with operational inefficiencies. What was supposed to have a turnaround time of weeks has a turnaround time of months. Engines that were designed for 55 starts are removed, torn down, and rebuilt for each flight. The Thermal Protection System (TPS) was to be simple to maintain, but actually requires tens of thousands of man-hours and is an extremely fragile system. A maximum of twenty-four hours was specified to change the shuttle payload out while on the pad. Currently, this operation takes days. These are just a few of the operational inefficiencies present in operating the space shuttle. Each of these operational inefficiencies increased the number of operational personnel required to support the shuttle, generated the need for detailed and complex support systems, and required an enormous infrastructure including facilities at the Kennedy Space Center, and the overhaul base in Palmdale, California. The differences between what was desired and what was delivered increased the cost of operating the shuttle fleet and increased the dollars per pound to orbit, making the shuttle extremely expensive to operate.

As a first step in creating a guideline for developing the next generation spaceport, the operational characteristics of an aircraft/airport and shuttle/spaceport need to be examined so that a comparison between the two can be made. This comparison will be the starting point in determining factors to consider when designing a next generation spaceport that will allow it to be more efficient than KSC, and in determining whether the spaceport should drive the design of the launch vehicle or whether the launch vehicle should drive the design of the spaceport.

3.0 Background

The first step in developing a guideline for the design of the next generation spaceport and reusable launch vehicle is to gain an understanding of how airports and spaceports operate today. This section will look at how airports in general operate, and examine how a specific airline, Delta Airlines at Hartsfield International Airport in Atlanta, operates, contrasted with how the current spaceport, the Kennedy Space Center, operates the shuttle.

3.1 Aircraft Operations

From the invention of the first aircraft to its becoming one of the most popular modes of transportation, the ground operations of aircraft have become extremely streamlined. From the beginning, aircraft manufacturers and aircraft operators were plagued with the task of making aircraft economically viable to build and operate, thus creating a close tie between aircraft manufacturers and the airlines. With each new aircraft designed, the costs of acquisition for the airlines increase due to research, development, manufacturing, and new technologies used onboard the aircraft. These costs, in addition to operating costs on the part of the airlines, are passed on to consumers in the form of ticket prices. For an airline to survive in a competitive market place the price of an airline ticket must be kept in control and not allowed to increase beyond reason. To accomplish this, aircraft must spend a minimal amount of time on the ground. Every moment an aircraft is on the ground is time that it is not making money for the airline. The solution is aircraft designed for quick turnaround times. The simpler and quicker it is to safely turn around an aircraft, the more appealing that aircraft is to an airline company. This section, Aircraft Operations, will take a look at the ground handling operations of a commercial airliner.

From the time an aircraft lands to next take-off there be a series of operations that occur. These operations are broken into three broad categories: ramp services, on-ramp aircraft servicing, and onboard servicing. A detailed breakdown of these categories is as follows:[ii]

Ramp Services: Supervision
Marshaling

	Start-Up
	Moving/Towing Aircraft
	Safety Measures
On-Ramp Aircraft Servicing:	Repair of faults
	Fueling
	Wheel and Tire Check
	Ground Power Supply
	Deicing
	Cooling/Heating
	Toilet Servicing
	Potable Water
	Demineralized Water
	Routine Maintenance
	Non-Routine Maintenance
	Cleaning of Cockpit Windows, Wings, Nacelles, and Cabin Windows
Onboard Servicing:	Cleaning
	Catering
	In-Flight Entertainment
	Minor Servicing of Cabin Fittings
	Alteration of Seat Configuration

3.1.1 Ramp Handling

Ramp handling or ramp servicing includes operations dealing with an aircraft while it is in motion on the apron proceeding to its assigned gate, and the operations associated with pushing back the aircraft from the terminal prior to departure. Each gate has a supervisor in charge of all aircraft operations at a particular gate. The supervisor's activities ensure that there is coordination between operations and that there are no unnecessary ramp delays. The first operation that takes place is taxiing, where the pilot is directed, by a method called marshaling, to an exact parking location which allows the passenger bridge to be moved into place and allows access to the aircraft. Marshaling also includes positioning and removal of wheel chocks, landing gear locks, engine blanking covers, pitot covers, surface control locks, cockpit steps, and tail steadies.[iii] During ground operations, safety measures are put in place to protect ground personnel, passengers, and aircraft in the event of an accident. Finally, ramp handling includes the tow tractor used to push back the aircraft from the gate for departure.

3.1.2 Aircraft Ramp Servicing

Aircraft ramp servicing includes preparing the aircraft for departure. This does not include servicing done within the cabin of the aircraft, or loading and unloading of cargo/baggage. Several operations done to prepare an aircraft for departure occur both in parallel and in series to each other.

Auxiliary Power Unit (APU)

Once an aircraft has reached its gate, the passenger bridge is moved into place and the ground APU is connected to supply power to the aircraft once the engines have been shut down. The APU supplies power to all onboard systems, lights, and cockpit control panels, in addition to heating/cooling the interior of the aircraft while it is on the ground. Many aircraft have a self-containing APU onboard that is sufficient to supply power to the aircraft while on the ground. A ground APU is used to reduce fuel costs and to cut down on apron noise. In certain cases, where an aircraft is sitting on the apron for some time without the operation of an APU, a climate auxiliary mobile heating or cooling unit is connected to the aircraft to supply climate control within the cabin.

Fueling

Fueling is a relatively simple operation for aircraft. The engineer who is responsible for the availability and provision of adequate fuel supplies supervises the fueling of the aircraft, and ensures that the correct quantity of uncontaminated fuel is supplied in a safe manner.[iv] The fueling is completed in two methods, one is the use of a mobile tanker (a fuel truck that is pulled up next to the aircraft to fuel it), and the second method is a mobile dispenser that fuels the aircraft from the apron through the use of a hydrant system.

Scheduled and Unscheduled Maintenance

Delta, like most airlines, has an equipment list that helps the maintenance team know when certain pieces of equipment need to be changed out. Simple equipment change outs normally take place at the terminal, and more extensive equipment change outs require the aircraft to be temporarily pulled from service and taken to a maintenance bay. While at the gate, the operations personnel and pilot complete a walk around to look for any exterior damage that might have occurred in flight and report them to maintenance for repair. This includes any minor faults reported by the captain in flight. In addition to checking the exterior of the aircraft for damage, the tires are visually checked for damage that might have occurred during the last takeoff and landing cycle.

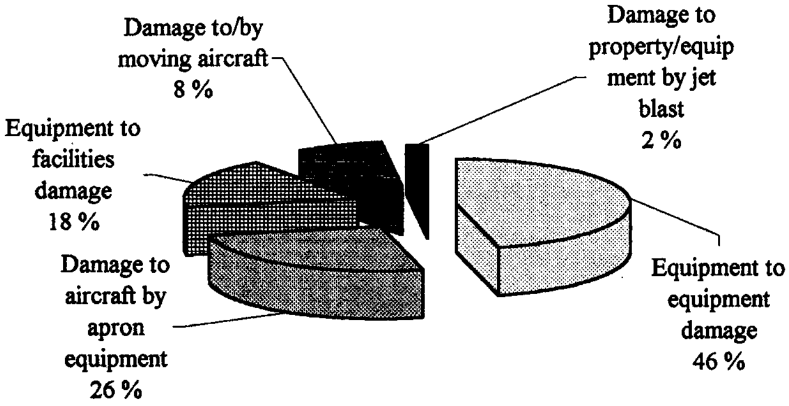


Figure 3.1: Apron Incidents/Accidents[v]

Figure 3.1 shows the causes of damage to an aircraft when it is on the apron. These incidents/damages result in unscheduled maintenance that could require the aircraft be pulled from service if the damage cannot be repaired at the gate. Unscheduled maintenance can have the effect of delaying a departure and cause passengers to experience delays or problems in meeting connecting flights at the arriving airport. Over the course of a day, incidents such as this could significantly effect on-time arrivals/departures at several major airports.

3.1.3 Onboard Servicing

While outside the cabin the aircraft is being refueled and checked for any exterior damage, a series of operations are being completed inside the aircraft. Once the engines have been shut down and the APU connected, the cargo deck is accessed and cargo/baggage is removed while in the cabin, passengers prepare to disembark the aircraft. Once the passengers have deplaned, a crew of three to eight, depending on the size of the aircraft, begins the process of cleaning the cabin. The cleaning of the cabin consists of the following operations:[vi]

1) Exchange of blankets, pillow, and headrests
2) Vacuuming carpets
3) Removal of all litter
4) Restocking of seatback pockets
5) Cleaning and restocking of galleys and toilets
6) Washing all smooth areas, including armrests

In addition to cleaning the cabin and restocking the galleys, demineralized water for the engines and potable water are also replenished during servicing.[vii]

3.1.4 Ground Equipment and Personnel

Figure 3.2 shows a typical servicing arrangement for the Boeing 777 for a typical turnaround. The figure shows the placement of all support vehicles for easy access to the galley, lavatory, fuel tanks and cargo deck. All of the vehicles are moved into place once the aircraft has come to a stop at the gate. No elaborate structure is required to turn the aircraft around. The reverse will be shown to be the case for the space shuttle.

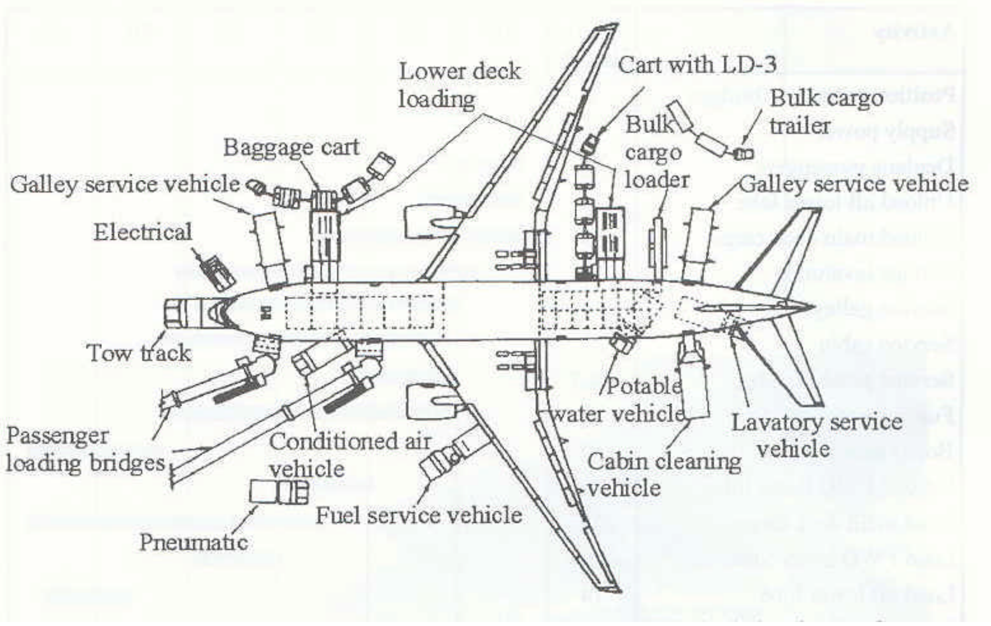


Figure 3.2: Boeing 777 Servicing Arrangement for a Typical Turnaround[viii]

Each airport is set up slightly differently depending on the needs of that airport. These needs may be based on where it is located (airports that witness a harsher winter would have on location equipment used for deicing an aircraft), or flight capacity (an airport with a high flight rate per day may invest in equipment that helps decrease the turnaround time and the number of pieces of equipment being moving around the apron). An example of this is shown in Figure 3.3.

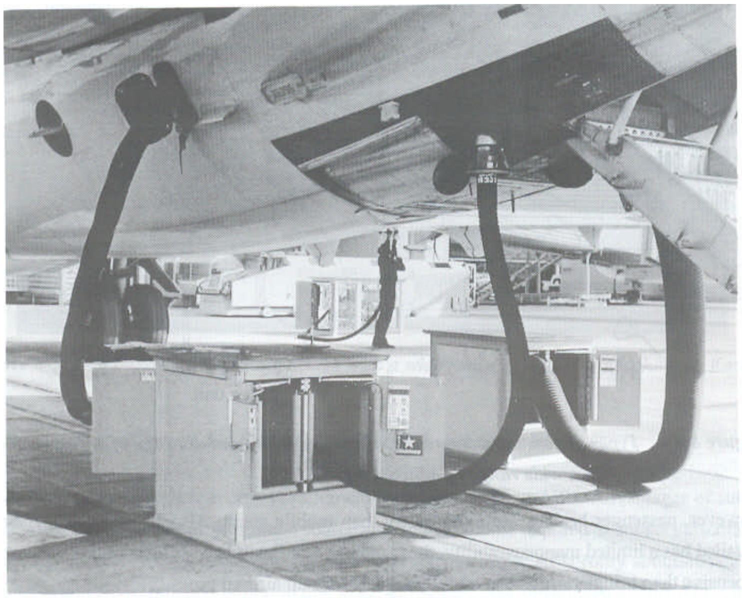
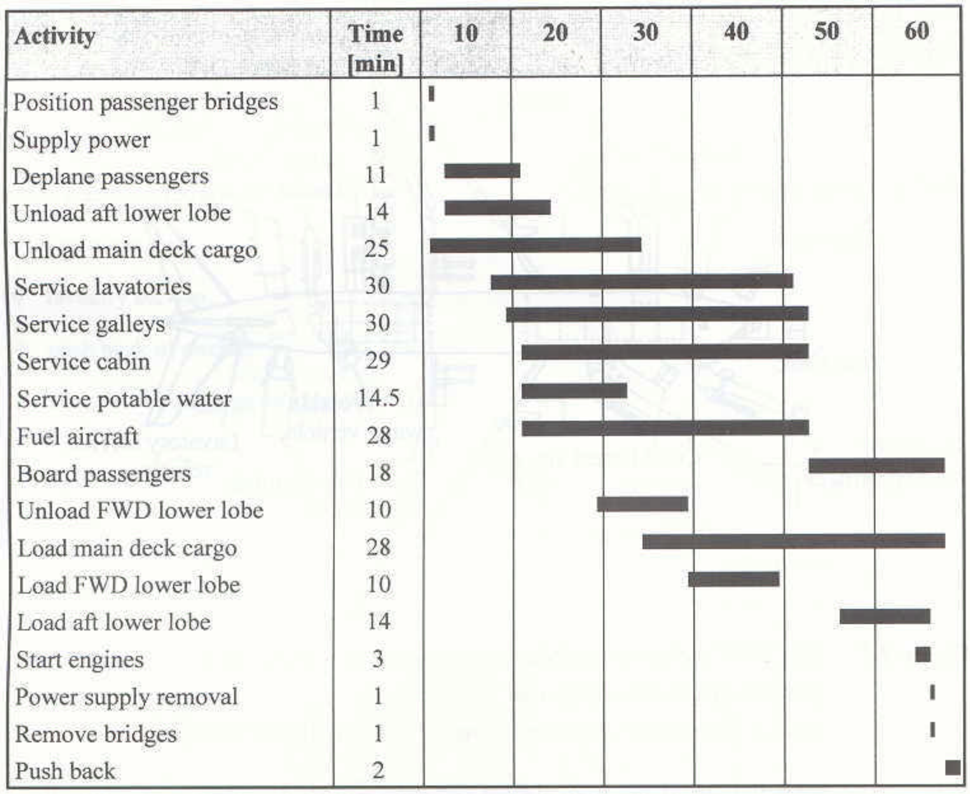


Figure 3.3: Fixed Ground Support Equipment[ix]

Some airports have employed a vehicle free apron system where all or most of the ground equipment is permanently fixed to the apron. Figure 3.3 shows a system, where fuel and power are supplied to the aircraft. A vehicle free apron eliminates the time required to move ground equipment into place, eliminates the chance of any damage being done to the aircraft because of moving equipment into place and away for departure, and decreases the number of equipment vehicles moving around the airport and apron.

Table 3.1 shows a walk through for turning around a Boeing 747 including activities performed and the time taken for each activity. It is important to note that this is just an example, and would vary from aircraft to aircraft and even vary between 747s depending on any scheduled or unscheduled maintenance. By examining this table, it can be seen that unloading the main cargo deck, servicing lavatories, servicing galleys, refueling, servicing the cabin, and loading the main cargo deck are the most time consuming operations taking anywhere between twenty-five and thirty minutes. However, all of these activities can and are performed at the same time. The two activities that really determine the turn around time of an aircraft are not a single activity, but an entire process. The first is the processes of deplaning passengers, cleaning the cabin and boarding new passengers. This entire process takes approximately 58 minutes of the 60minute turn around time. The second process is the unloading and loading of cargo/baggage. This process takes approximately 53 minutes. The actual servicing of the aircraft is not the most time consuming process, the processes dealing with the passengers are.

Table 3.1: Boeing 747 Servicing Turnaround Time Table[x]



Activity	Time [min]
Position passenger bridges	1
Supply power	1
Deplane passengers	11
Unload aft lower lobe	14
Unload main deck cargo	25
Service lavatories	30
Service galleys	30
Service cabin	29
Service potable water	14.5
Fuel aircraft	28
Board passengers	18
Unload FWD lower lobe	10
Load main deck cargo	28
Load FWD lower lobe	10
Load aft lower lobe	14
Start engines	3
Power supply removal	1
Remove bridges	1
Push back	2

International flights operate slightly differently than domestic flights. Based on data obtained from Delta Airlines, the turnaround time for an international flight can be from 3-4 hours. This is due, in part, to maintenance. International flights have maintenance work done in between flights. Sometimes the maintenance work can be completed on the apron, and at other times it is necessary to move the aircraft to a maintenance facility. However, most domestic flights have a turn around time of less than an hour. For Delta Airlines, the longest domestic flight turnaround time is for the Boeing 767, which takes one hour ten minutes. It is interesting to note that the turnaround time for the Boeing 767 is longer than the turnaround time of the Boeing 747 as shown in Table 3.1. The difference in turnaround time can be attributed to the irregularity of deplaning and boarding passengers. Table 3.1 is an engineering spec provided by Boeing showing what they estimate the turnaround time should be, not what it actually is. This accounts for why a slightly smaller aircraft has a larger turnaround time.

3.1.5 Aircraft Maintenance

When aircraft engineers design an aircraft, they also plan when scheduled maintenance should occur. Delta Airlines has several basic maintenance intervals. The first and most common are layovers that usually take more than five man-hours and are completed at a maintenance station. The next scheduled maintenance are cabin maintenance visits which occur on 42-day intervals and require 24 man-hours of operations. The cabin visits are an inspection of the cabin for overall conditions and cleanliness. Specifically, maintenance would check to make sure all seatbelts are present, all seat, galley, and lavatory functions work properly. And finally, the carpets, sidewalls, and seat covers are checked to see that they are not dirty.[xi] The next level of scheduled maintenance occurs every 500-flight hours, and is called a service check. A service check is performed by maintenance, and includes changing filters (engine/air conditioning systems), checking the condition of emergency type equipment, quick external inspections of the aircraft, and the checking of tires, breaks, and landing gears.[xii] Service checks require, on average, 50 man-hours, and are generally completed overnight. Lube visits are the next maintenance check. They occur every 3000-flight hours, and require 53 man-hours of work, generally done overnight. The lube visits are aimed at specific lubrication needs of the airframe, specifically flight controls and landing gears.[xiii] The final maintenance level occurs every 6000-flight hours, 3000-flight cycles or 18 months, whichever occurs first. The maintenance that occurs at this level is a detailed inspection of key components that are crucial to the aircrafts safety. Once every six years, a major overhaul, also know as a heavy maintenance visit, of the aircraft is completed. This consists of removing seats, floors, and walls so that a close inspection can be performed. Table 3.2 shows the maintenance program for the 767-400 every 18 months (on average).

Table 3.2: 767-400 Maintenance Program[xiv]

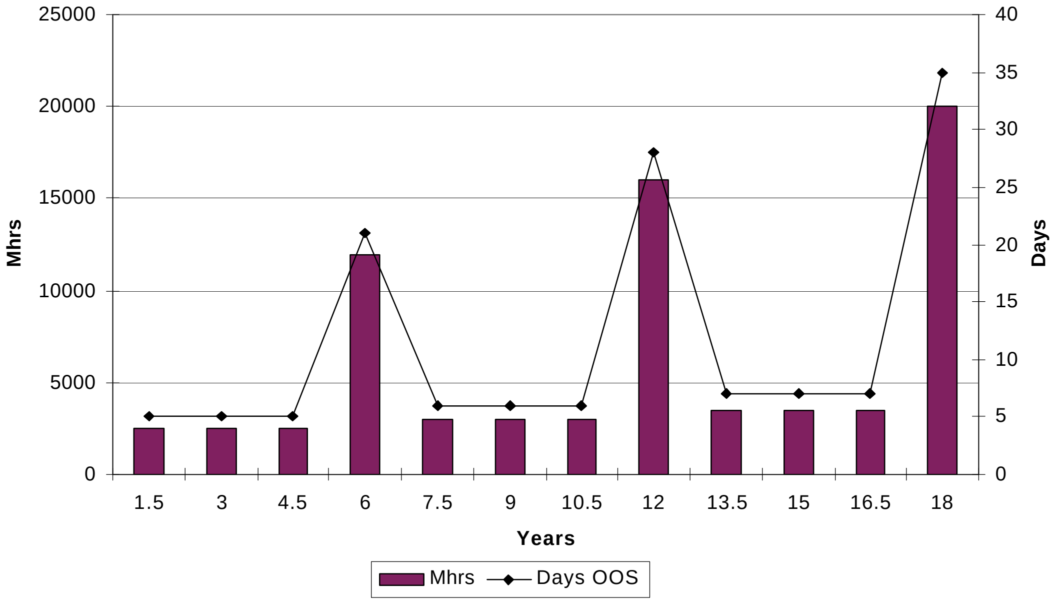


Table 3.2 shows the number of man-hours and the number of days out of service (OOS) for the maintenance of the 767-400. Every 18 months, maintenance requires, on average, 2500 man-hours and approximately 5 days out of service. However, it is interesting to note that as the aircraft ages the number of man-hours and days out of service increase. The same is true for the heavy maintenance visits, which occur every 6 years. These visits range from12,000 man-hours (21 days out of service) at 6 years to 20,000 man-hours (35 days out of service) at 18 years. This indicates that as aircraft age, the amount of time necessary to complete maintenance increases in order to maintain specified levels of safety.

3.2 Shuttle Operations

Comparing operational processes of the space shuttle and an aircraft is a complicated problem due to the nature of each vehicle and the industries in which they exist. Aircraft have been around for nearly one hundred years and the process of operating them safely and reliably has been constantly reworked over the decades to arrive at the streamlined processes we see today. The aircraft industry has also produced turnaround times of thirty to sixty minutes. This is an important factor in making airlines economically viable. The shuttle, on the other hand, is a first generation reusable launch vehicle that has been in operation for twenty-three years for a total of 109 flights. These 109 flights can be broken down into the five space shuttles, of which no two are exactly alike because of requirements and construction history during the orbiters fabrication. Add to this the fact that each shuttle mission takes it through a wide regime of flight conditions that can, and do, produce excepted results that must be addressed before the next launch. Finally, each shuttle is specifically configured for a particular mission that is planned months and sometimes years ahead. The shuttle, like any next generation vehicle, is a complex and integral system that requires many man-hours and precise attention to detail in turnaround. The current STS has an average turnaround time of three months. NASA's SLI has put forth the turnaround time requirement of one week, maximum. This is an improvement over the present three-month shuttle turnaround time, but not the thirty-sixty minute turnaround time of airliners. This section will take a look at the operation of the space shuttle in an effort to identify time-consuming operations contrasted with similar operations that airliners have been able to streamline.

3.2.1 Landing

The beginning of the shuttle operation begins when the mission ends, the landing. Unlike aircraft, the shuttle is completely immobile under its own power after it lands. Aircraft have the ability to taxi to their respective gate under their own power because their engines are still in operation after landing. The shuttle, which performs a powerless landing, has no means of taxiing. In addition, the shuttle uses some twenty-eight different types of fluids onboard. Some of these are toxic and extremely hazardous to the ground and flight crews. The first step of operations is to test and secure the area around the shuttle. This involves ground team members in Self-Contained Atmosphere Protective Ensemble (SCAPE) suits who measure and monitor the hazardous fumes that come from the ammonia boilers and Orbital Maneuvering System OMS)/Reaction Control System (RCS) thrusters.[xv] If the ground team detects any hazardous fumes, work on the shuttle is delayed until the fumes dissipate to safe levels. Without any unforeseen complications, it takes the shuttle forty-five minutes to cool down before work can begin on the exterior.

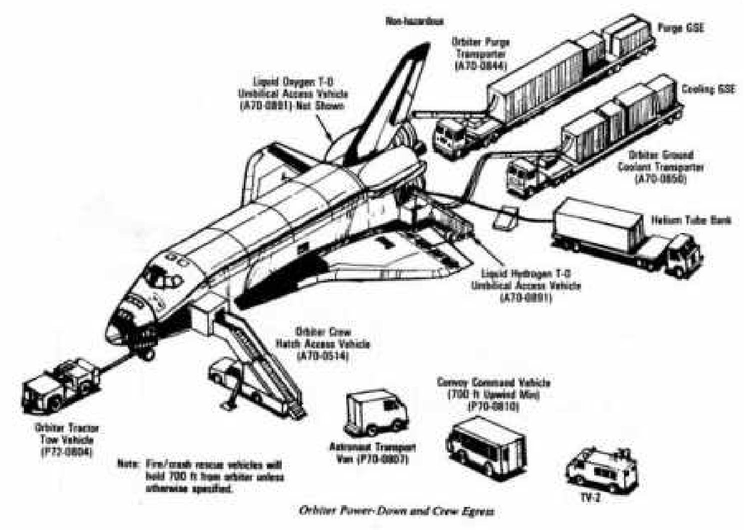


Figure 3.4: Initial Access and Safeing Process[xvi]

Once it has been determined that it is safe for the ground crew to approach the shuttle, the ground cooling, purge, and crew equipment are brought up. The two cooling support units are connected to the orbiter’s right and left T-0 umbilical panels. Next, the crew hatch access vehicle and transport van arrive to egress the crew while the orbiter tractor is attached to the orbiter’s nose gear. Once the shuttle crew has exited, ground operations continue for three and a half hours before the shuttle is towed to the Orbiter Processing Facility (OPF). The orbiter is powered down to the essentials, where what remains to be powered is powered from the on board fuel cells until the power can be transferred to ground support equipment stationed in the OPF. This is done in part to prevent any OMS/RCS leaks from occurring. Throughout the entire access and safeing process, an initial visual inspection of the Space Shuttle Main Engines (SSME), Thermal Protection System (TPS) and structure is completed. Finally, the orbiter is towed to the OPF.

By now, the shuttle has been on the ground for over three hours. In the same amount of time, three to six aircraft could have been turned around at a single gate. For the landing operations of the shuttle some of the most time consuming operations deal with cooling and purging the shuttle of hazardous fluids.

Figure 3.5: Safeing Operation on Discovery[xvii]

3.2.2: Orbiter Processing Facility

The OPF is unlike anything seen within the airport system, especially as a tool for turnaround. The concept of such a facility within the aircraft industry would increase the size and cost of building and maintaining an airport, and would, in many cases, be completely useless as there is nothing about turning around an aircraft that demands a structure of this type. The shuttle is quite different in this respect. The OPF is the main hub of activity for the shuttle between the time it lands and later heads to the Vehicle Assembly Building (VAB) to be mated to the External Tanks (ET) and Solid Rocket Boosters (SRB) for its next mission. There are several operations that take place serially and in parallel within the OFP. The OPF operations include payload and crew reconfiguration, structural and mechanisms inspections and repairs, TPS work, SSME processing, OMS/RCS processing, electrical power systems checks, environmental control and life support system (ECLSS) checks, and APU/Hydraulics work, in addition to communication, avionics, and flight control systems checks. Work on nearly all of these systems is not isolated to the OPF, but continues in the VAB and on the launch pad. This would be comparable to completing turnaround operations for an aircraft from the moment it landed, to its gate, and back out to the runway.

Figure 3.6: The Orbiter Being Moved into the OPF[xviii]

While the work completed in the OPF is quite extensive, this section will concentrate on the reconfiguration of the payload, the evaluation of the TPS, and the SSME processing since they are the biggest driving factors in turnaround time. In addition to having the largest impact on turnaround time, they have similar components within the aircraft industry, passenger/cargo, skin, and engines. However, before work can begin on these three areas an important operation must be completed. After the orbiter is towed into the OPF, the first step is to complete the safeing operations. This requires the removal of hazardous materials and any payload. The cryogenics reactants are removed and the hypergolic OPM/RCS systems are checked for leaks. The supply tanks and lines for the OMS/RCS thrusters are not drained. If they indicate a leak or if there needs to be removal of the system for repairs, the OPF is evacuated and SCAPE suits are worn throughout the process.[xix]

Payload Reconfiguration

The shuttle was designed to support a wide range of operations including launching satellites, conducting scientific experiments, repair work on satellites in orbit, and supporting a space station. Such a wide range of missions has resulted in the shuttle having to carry a wide range of payloads. The processing of the shuttle payload is done in parallel with the processing of the shuttle, and is completed at other sites at KSC and around the country. While work is being completed on the payload, work must also be done on getting the payload bay reconfigured to meet both the power and payload demands of the satellite

To accept a new payload, the orbiter's mid body is reconfigured using mechanical adapters. These devices include the longeron beams installed on the sides, and keel beams installed at the bottom of the mid body. These beams are mainly for the support of the payload. Many more specialized attachments needed for each payload require extensive fitting and checkout. Because of their unique character, the reconfiguration procedures must be well planned and efficiently coordinated to be completed in the normal processing cycle.[xx] In addition to structural elements that are added to the mid body of the orbiter, there are electrical and fluid interfaces that are needed, and with each of these systems come additional structural support requirements. The process of reconfiguring the shuttle's payload bay doesn't end with structural reconfiguration. The reconfiguration of the payload is the equivalent of making a major design change in the vehicle. This means that each change much be tested. As with the reconfiguration itself, no two tests are the same since each shuttle is slightly different from each other, and the payloads and requirements of the payloads are different. This means that an entirely new process has to be developed for reconfiguring and testing of the payload bay. And, all of this is done before the payload is ever loaded into the shuttle.

Compared to the airline industry, the process of reconfiguring the payload bay is extremely inefficient, and is costly both monetarily and in terms of man-hours. To streamline this process, the airlines and cargo carriers have implemented a generic cargo container. A cargo container can be loaded with a variety of cargo and then sealed before being loaded into an aircraft. A similar process, if adopted for the shuttle program, would greatly decrease the time and money consumed in reconfiguring the shuttle's payload bay. The idea of the generic cargo container for the shuttle will be discussed in greater detail later in this report.

Thermal Protection System

The TPS is one of the critical systems onboard the shuttle that requires an enormous amount of time during the inspection and replacement of the tiles. The TPS system contains several different types of material for different parts of the vehicle. The temperatures experienced by some of the tiles can range from –250° F to 3000° F. The tiles that cover the aerodynamic leading edges and the bottom surface of the orbiter experience the highest temperature during reentry, and thus require the most work of all the tiles. These tiles are an integral part of the shuttle and a critical component to the safety of the orbiter, and must been maintained at optimum effectiveness.

Figure 3.7: Heat Lamps Drying the Shuttle Tiles[xxi]

An example of how sensitive the TPS tiles are to not only temperature, but also the elements can be seen with a problem that the orbiter Atlantis experienced in 2001. Prior to the launch of Atlantis in June of 2001, the orbiter was forced to make a landing at Edwards Air Force Base in California at the end of its previous mission, and was then ferried back to KSC. During the return trip, Atlantis and the shuttle carrier encountered a significant rainstorm that caused a moisture problem for the tiles. The tiles absorbed some of the moisture and had to be completely dried with the use of 200-300 watt heat lamps before Atlantis could be transferred to the VAB to be mated to the stack. If the tiles had been left moist, it is possible that when in orbit, water trapped in the tiles might have frozen, expanding the tile as the water froze, and in the process, damaging or destroying some of the tiles. Such a result would have disastrous effects for the shuttle during landing. This is why such detail and precision is required when dealing with the TPS tiles.

The first step in processing the tiles is the evaluation phase. This phase begins as soon as it is safe to approach the shuttle after landing. It is here that an initial inspection is made of the lower tiles as workers complete a walkover. This process is continued once the orbiter has been towed into the OPF. Due to the importance of the tiles effectiveness, each tile must be carefully examined looking for any slight clue that might indicate a damaged tile. This process can take more than two weeks depending on the amount of damage to the tiles.

Once the tiles have been inspected, the next step is to remove the damage tiles and replace them. This operation entails exacting measurement and fitting; generally less than 0.005” on the edges with a 0.045” ± 0.02 gap between tiles.[xxii] Such precision is required to maintain the vehicles safety during reentry. Complicating the removal and replacement of the tiles is the fact that no two tiles are exactly alike. This means that each replacement is specifically made for the one removed. This part of the process is done in the Tile Facility located near the OPF. Once the replacement tile has been made it must be hand fitted, installed, tested, and the results recorded carefully for current use and future reference. The replacement of the blankets that cover the area of the vehicle that does not experience extreme temperatures is a simpler process since they are larger and easier to remove and replace than the tiles.

The process of inspecting the TPS tiles, removing them, making the replacements, and installing the new ones is tedious and requires a large amount of time, but is extremely important to the survival of the shuttle. Aircraft do not have the same problems with their exterior as the shuttle. The flight regime that aircraft fly through does not generate the amount of heat that a ballistic style reentry does. However important the integrity of an aircraft's skin is, (and it is very important), it is looked at only during its time in an overhaul facility, not at a terminal gate.

Space Shuttle Main Engines

Imagine that every time an aircraft landed and taxied to its gate the engines had to be taken off, taken to a special facility where they would be torn down, inspected and then rebuilt, and finally reinstalled on the aircraft. If this were one of the operational requirements of an aircraft, the airline business would have gone under before it ever got off the ground. This is exactly what is done with each of the main engines of the shuttle. The shuttle engines were rated for 7.5 hours (the SSMEs operate just over 8 minutes per flight) and 55 starts before requiring a major overhaul, yet after each flight a major overhaul is what they get.

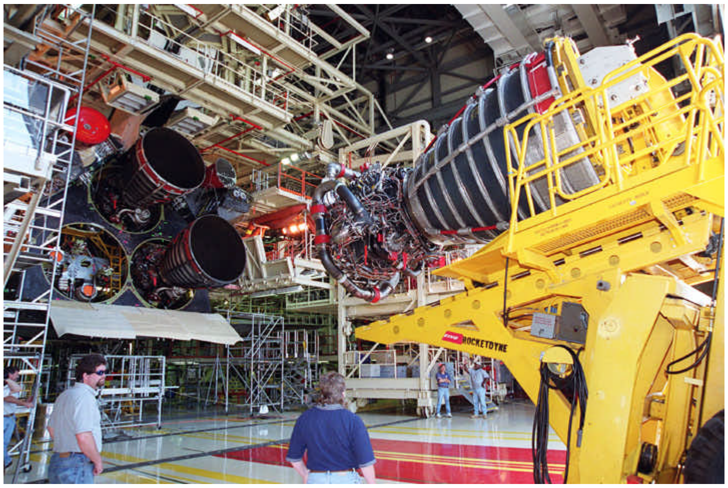


Figure 3.8: Removal of SSME[xxiii]

One of the reasons for the detailed inspection of the SSMEs is the conditions that the engines experience. Like the TPS tiles, the engines encounter a wide range of temperature. The temperature range experienced by the SSMEs is -400° F to 6000° F. In addition to temperature, the engines encounter a pressure change from one atmosphere to vacuum. During the SSMEs brief operation time, 8 min, its time in orbit, and reentry, the engines are exposed to intense vibration that can cause internal damage that would not be detected without a detailed inspection after each flight. Such internal damage could cause disaster for the shuttle if it were to go unnoticed.

Like most of the ground operations for the orbiter, the SSMEs processing starts when the orbiter lands and is parked on the runway. Here the SSMEs are visually inspected for any visible damage, and the external aft section for any loose hardware. Once the orbiter has been towed into the OPF, the next stage of SSMEs processing begins. Before the SSMEs may be removed, several steps must be completed. They are:

1) High Pressure Turbine Pump drying with heated GN2 (within 48 hours of landing)
2) Visual inspection of interior and exterior
3) Low Pressure Turbopump turbine torque check
4) Hydraulic activation of actuators to move engines into correct alignment for removal
5) Aft heat shield removal
6) Engines heat shield removal[xxiv]

After these steps have been completed, the SSMEs are ready for removal and transport to the SSME Processing Facility located within the VAB. At the SSME Processing Facility the engines are placed in test stands for post flight inspection. These tests are done before the process of breaking them down begins. During the break down process every component of the engines is tested for structural integrity. Many of the parts are subjected to leak tests in which a gas is passed through the Main Combustion Chamber (MCC), Nozzle/Chamber joints, liquid Oxygen (LOX) and liquid Hydrogen lines. If a leak is present, the damaged component is replaced. Once all of the components of the engines have been tested, they are reassembled at which time the engine as a whole is tested for leaks or other damage that may have occurred during reassembly. Once the engines have been reassembled and tested to insure their integrity, they are ready for reinstallation on the orbiter. Once reinstalled, the engines and orbiter go through another series of tests to check for interface leaks, gimball nozzle clearance, hydraulic actuator check and a final walk down inspection.[xxv]

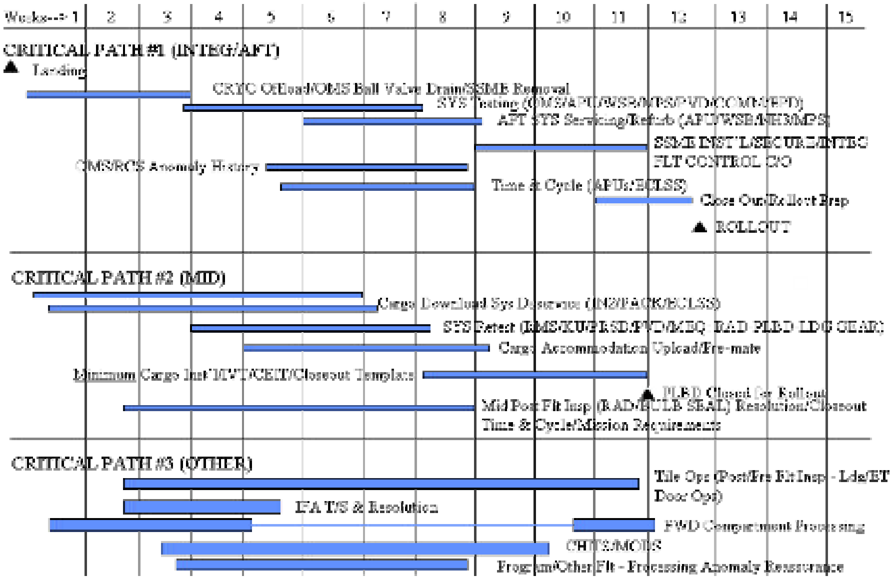
Like the engines onboard an aircraft, the SSMEs are in integral part of the shuttle. They not only provide the means for launch, but also provide power for many onboard systems just as aircraft engines do. For this reason, the SSMEs require an enormous amount of inspection and detail to make sure they are fully operational. Still, the cost and time associated with removing and dismantling the engines after each flight is extensive. Integrated Vehicle Health Maintenance (IVHM) would allow a quicker inspection of the engines allowing the IVHM to tell ground operation personnel what, if anything, is wrong with the engines. This could result in a shuttle being turned around without any of the engines having to be removed or possibly only one instead of all three engines. The possibilities of IVHM will be discussed later in this paper.

It is important to note here that the payload reconfiguration, TPS, and SSME inspection are not the only operations that are performed on the orbiter while in the OPF. However, they are consistently the most time consuming That does not mean that by simply addressing the operational problems associated with these three systems the turnaround time wouldl drop from three months to one week. Every aspect of operations, from time-consuming processes (like the SSME processing), to small details must be looked at as a whole including the ground operations that take place in the VAB and on the launch pad.

3.2.3 OPF Turnaround Time Schedule

For shuttle processing in the OPF, there are three critical paths. These are the procedures that take place in the aft compartment of the shuttle, (SSMEs, RCS, and OMS), the mid-body (payload reconfiguration), and the third path, which contains the rest of the operations including TPS tiles. Table 3.2 shows the time schedule for these three paths, which occur in parallel, and how long it takes to complete certain processes, (SSME, payload reconfiguration and TPS being the most time consuming).

Table 3.3: Shuttle Turnaround Schedule[xxvi]



3.2.4 Vehicle Assembly Building

Aircraft are completely autonomous from take-off to landing, requiring no additional assistance from any other vehicle. The Shuttle, being a two stage to orbit (TSTO) vehicle, requires additional assistance reaching orbit. This is achieved through the use of the ET and SRBs. This in turns requires an infrastructure in which to assemble the three components. The VAB is where this is done. Work begins in the VAB prior to the arrival of the orbiter from the OPF. First, the SRBs must be stacked, then the ET is lowered into position between the two SRBs, and finally the orbiter can be mated to the stack. Before discussing the mating of the orbiter and continuing operations onboard the orbiter, it is important to take a look at the assembly of the stack.

Solid Rocket Boosters

The SRBs are considered to be a reusable component of the shuttle, but being reusable, require a lot of time to get ready for another launch, not the next shuttle launch. The SRBs, like the shuttle, require an extensive infrastructure. Two days before launch, the SRB recovery ships head out into the Atlantic Ocean so that they will be in position to recover the SRBs after splashdown. After the SRBs are recovered they are returned to KSC where they are dismantled, loaded onto train cars, and shipped to Utah where they are refurbished, and made ready for shipment back to KSC. Once the SRB components are returned to KSC they are sent to the Rotation Processing facility for inspection and preparation for stacking. A critical and careful inspection is made of the SRB components to make sure they meet the required specifications. The tests and preparation of the SRB components can take approximately 50 days per vehicle flow and include the following major items.[xxvii]

1) Attach aft booster assembly
2) Attach hold down post (HDP) hardware
3) Joint assembly and clevis operations
4) SRB joint heater umbilical installation
5) Attach aft center segment
6) Joint Assembly
7) Forward center segment attachment
8) Joint assembly
9) Forward segment attachment
10) Joint assembly
11) SRB alignment to ensure proper ET attachment
12) Segment leak testing
13) Igniter installation & lead test
14) ER/SRB attachment completion
15) Separation motor installation (fore & aft skirt)
16) SRB pyro installation

17) Range safety system installation
18) Forward skirt assembly
19) Fustrum assembly
20) Nose cone installation
21) SRB pyro and ordinance installation
22) Assembly closeout and inspection

The stacking and alignment of the SRBs is an important procedure that requires precision, and alone can take up to twenty days. In addition to the precise work required to ensure correct alignment, work on the SRBs must be done with care since they are the only component of the stack that is loaded with fuel. This increases the risks in stacking the SRBs since a mistake could accidentally ignite the solid fuel. For this reason, the number of personnel present in the VAB during stacking is kept to a minimum.

Figure 3.9: SRB Stacking[xxviii]

External Tank

The external tank is the only component of the STS that is not reusable. Once the fuel and oxidizer in the ET has been expended the tank is jettisoned and allowed to return to Earth. Most of it burns up in the atmosphere. The concept of throwing away a component of a vehicle once it has served its purpose is unheard of in the aircraft industry. This is one of the reasons why a primary NASA initiative has been the development of a Single Stage to Orbit (SSTO) vehicle, such as the X-33.

The ET is manufactured in Michoud, Louisiana and transported to KSC by barge. Upon arrival at KSC, the ET is transported into the VAB where it is inspected and tested for conformity to specifications, then the required hardware is attached and the insulation material on the outer surface of the ET is applied. The total time for ET checkout and preparation is nearly 70 days.[xxix] Once the ET has been thoroughly examined, it is lifted into vertical position and mated to the SRBs.

Figure 3.10: Lifting of the ET[xxx]

Shuttle

The shuttle operation is only partially completed in the OPF. The next step in the shuttle operation process takes place in the VAB. It should be noted, that the majority of the work required by the orbiter does take place in the OPF, since accessibility is much greater in the OPF than in the VAB where the shuttle is mated to the stack and in a vertical position. Of the three areas of ground operations that require a large amount of time, payload reconfiguration, SSME, and TPS, the payload reconfiguration is the only component that is completed in the OPF. The loading of the payload can take place either in the OPF, if it needs to be loaded horizontally, or at the pad if a vertical loading procedure is desired. Crew reconfigurations, structure and mechanism check, which were not discussed, are also completed before the orbiter rolls out of the OPF. The rest of the ground operations that take place in the OPF continue in the VAB, on the launch pad or both. This section will again focus on the time consuming operations of the TPS and SSMEs.

Figure 3.11: Mating of Atlantis and the STS Stack[xxxi]

The majority of the TPS work is completed in the OPF except for the tiles located around the connection points between the orbiter and ET. During the mating of these two components, the loads experienced by the orbiter’s structure can create a misalignment of the tiles and the thermal barrier which must be corrected to ensure the integrity of the system. For this reason, the final nose gear doorstep and gap evaluation takes place after the orbiter has been mated with the stack.[xxxii] This process occurs because the current

STS is a TSTO vehicle. A SSTO vehicle would circumvent this step completely by eliminating the mating process that results in misalignment of the TPS tiles.

As with the TPS, some of the additional work on the SSMEs is the result of mating the orbiter with the ET. One of the first operations that are done after mating is checking the orbiter/ET interface for any leaks. A leak, if present, could result in disaster during launch if fuel or oxidizer were to leak and ignite. The SSMEs also go through another round of leak tests with gaseous nitrogen in addition to being purged to remove humidity and contaminated air from the engines.[xxxiii]

Once all the components of the STS have been mated together and all the operational procedures have been completed, the shuttle is ready to be moved out to the launch pad at one mile an hour. While the processes of transporting the shuttle to the launch pad is in no way the most time consuming process, it is a delicate process that requires constant watch and preparation. In order to transport the shuttle the crawler must be kept in good working condition. The shuttle must be constantly watched to ensure that it remains level, within 5 degrees in either direction, so that it does not tip over. Also, the crawlerway that is used by the crawler must be constantly maintained between shuttle launches to prevent any unforeseen accident as the shuttle is being transported. The crawlerway consists of four layers to support the weight of the stack. The crawlerway is approximately eight feet thick. Edwards Air Force base, the proposed west coast launch site of the shuttle, used a different method for assembly and transportation of the shuttle. At KSC, they combined the two into one site. Edwards VAB was actually built on the launch pad. The shuttle stack would have been assembled inside, and at launch the VAB structure would split and move back from the launch pad. Unfortunately, there was never a shuttle launch from Edwards, so this VAB/Launch system was never fully tested to ascertain whether it is more efficient than the system used at KSC.

3.2.5 Launch Pad

The final step on the ground-processing track takes place once the shuttle is in place at the launch pad. Here is where the shuttle undergoes the last minute detail checks before launch. The shuttle was originally designed to require no work at the pad other than the possible loading or change out of the payload, in which case the Rotating Service Structure (RSS) would be used. However, over the years, the RSS has been used to complete ground operation procedures in addition to providing protection to TPS tileswhich were found to be susceptible to weather. The RSS has become a constant present, enclosing the shuttle for the days or weeks that it sits on the pad before launch.

As with the VAB, several of the operational procedures that began in the OPF continue in the VAB and on the pad. Of the three areas that demand the most time, only one, the SSME's, is worked on at the pad. Most of the work done on the SSME's are not as much operational as they are launch readiness procedures. The SSME's are subjected to flight readiness testing, final leak checks, purges, and electrical system checkout.[xxxiv] It is also on the launch pad that the ET is filled with LOX, and LH2. This is done hours before launch, and if for any reason the launch is delayed, the ET must be emptied after a certain amount of time.

Figure 3.12: Shuttle Stack at the Pad[xxxv]

3.2.6: Shuttle Overhaul

Like aircraft, each of the shuttles has a time line for scheduled overhaul. It is during this overhaul that the shuttle is inspected thoroughly for any unseen damage in systems or structure. This is also the time when the shuttle receives updates or modifications that are required. However, unlike aircraft, shuttles are rotated to overhaul once every three years of operation, which is equivalent to about four to eight flights between overhaul. Aircraft sustain several flights a day for years before requiring an overhaul.

Orbiter Vehicle-104 (OV-104), Atlantis, is currently in Palmdale, California for its Orbiter Maintenance and Down Period (OMDP). Each shuttle is ferried there aboard the Space Shuttle Carrier (SSC), a modified Boeing 747. The shuttle will remain at the Palmdale facility for about 14 months before overhaul is completed and it is reintroduced into the launch sequence. At this time, another shuttle is removed for overhaul. Due to the complexity of shuttle ground operations, the overhaul process introduces an anomaly into the operation process. This means that there are at any given time three operational shuttles. Each of these shuttles are different in some respects due to when they were fabricated. For just over a year, the ground crew works on the three shuttles maybe once, then, once every 14 months one of those shuttles is removed and replaced by another that none of the ground crew has worked on for 14 months. What occurs here is a lack of routine in operations. In airline manufacturing or automotive manufacturing, workers become efficient in their jobs because they are doing the same thing repeatedly. For shuttle operations this does not occur. This is because there is variation between shuttles in addition to the anomalies that are introduced due to the flight regime in which the shuttle operates. This inconsistency bogs down the operational efficiency of the shuttles.

4.0: Spaceport Driven verses Vehicle Driven Design

How does one design a spaceport and RLV? In many ways they are two parts of a single entity. Without a vehicle there is no reason to have a spaceport, and without a spaceport there is no place for a vehicle to operate from. At the time of the race to the moon, an enormous infrastructure was built to support the Apollo program. The goal of the space race was to be the first to land a man on the moon and return him safely back to Earth. Not much emphasis was placed on making sure the Apollo program was efficiently run in terms of operations. In fact, there was not one reusable component on the entire vehicle. Everything was tossed away, so there wasn't much to be operationally efficient about at that time as there is with the shuttle now. The end of the Apollo program and the development of the space shuttle, America's first reusable space plane, would mean that the infrastructure already in place at KSC would be inherited by the shuttle program. Every piece of equipment already in place or built specifically for the shuttle was designed or modified for the shuttle and the shuttle alone. The spaceport known as Kennedy Space Center was designed to meet the needs of the space shuttle.

Is designing a spaceport to meet the needs of a single vehicle wrong? As the space program exists now, having a spaceport that only meets the needs of a single vehicle is not the wrong way, it is the only way. In the future, as more vehicle configurations are developed, it will become important for a spaceport to support more than one vehicle configuration. This type of generic spaceport raises the question of what should drive the design process. Should the spaceport drive the design of the vehicle that will use it or should it be the other way around? A starting place for looking at this question is to find, in industry, a model that closely resembles what the future spaceport may look like, the airport system.

In the airline industry, one thing is certain, and of great importance, time. The longer a plane sits on the ground, the less time it is making money. To achieve maximum profitability, decreasing ground operations turnaround time is of utmost importance. This is approached from two directions, the first being the airlines, and the second being the aircraft manufacturer. This chapter will concentrate on these two directions, and discuss how airlines operate in terms of operational personnel, turnaround time, and maintenance time, and how manufacturers have taken into account the impact of operations on their design decisions.

4.1 Operational Personnel

Turnaround time is of concern to both the aircraft and spacecraft industries. The economical viability of each depends on having their vehicles in flight where they are making money, not sitting on the ground. This has to do with the maintainability of a vehicle. In other words, how much time is required to turn the vehicle around. The aircraft industry has decreased turnaround time to maximize the time the aircraft is in flight. An aircraft turn around time can range from less then an hour to a few hours, depending on the vehicle. A Boeing 747 for example may have a relatively short turnaround time if refueling and system checks were the only concerns. Yet, an aircraft the size of the 747 requires time to unload the passengers and cargo, clean the cabin and then board the new passengers and load cargo. The processes dealing with the passengers, cargo, and cabin are the driving factor for turnaround time of an aircraft. For the shuttle, the driving factors are the SSMEs, the TPS tiles and payload bay reconfiguration. Time on the ground, in addition to the number of vehicles in operation, has a direct effect on the number of operational personnel required to operate the fleet.

Using the number of operational personnel required to support a certain flight rate for an airport or airline as a guideline for their efficiency, it is possible to gain an over view of airport efficiency. There are several ways in which this can be accomplished. One can perform an airport-to-airport comparison, or an airline-to-airline comparison, or an even more detailed comparison by specific personnel, for example, mechanics, in an airline-to-airline or airport-to-airport comparison. A database of aircraft operational personnel can then be used as a guideline for determining the number of personnel required for the next generation spaceport. The creation of an operational personnel database for airlines and airports is a several step process with the first step being a comparison of airports to airports. To achieve this, statistics on the total number of operational personnel and flight rates for twenty-four airports across the United States were chosen. The information used was for the year 2000, and is shown in Appendix A. The graphical results are shown in Figure 4.1.

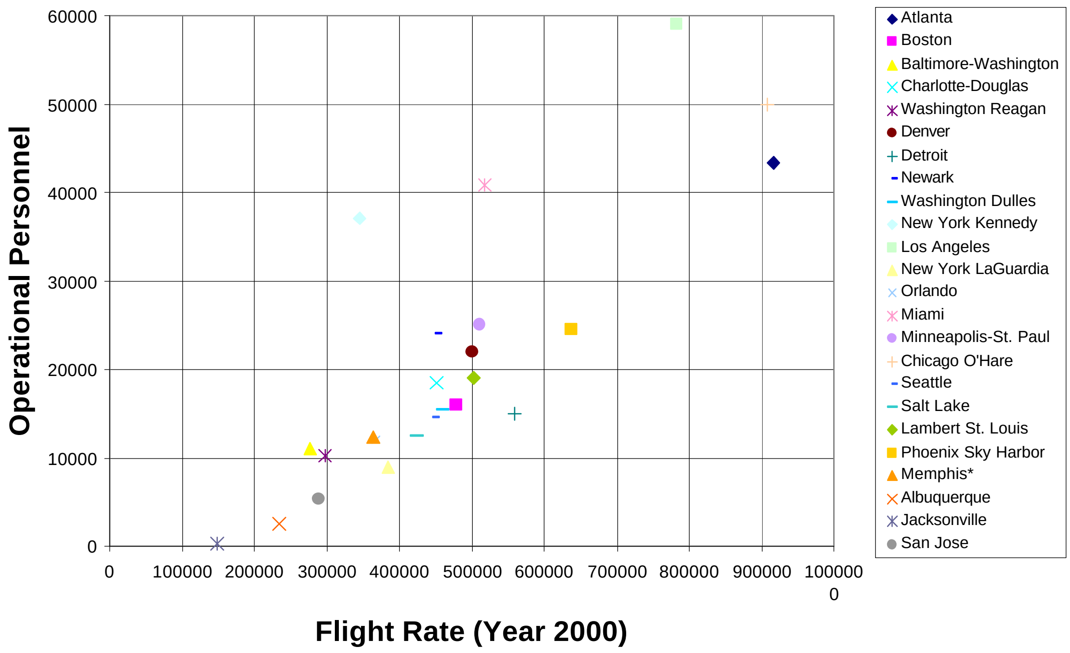


Figure 4.1: Operational Personnel vs. Flight Rate

With this data, a trend can be seen that relates the number of operational personnel to the flight rate per year. Such a trend could then be used to determine, for a spaceport, what the number of operational personnel should be for a given flight rate, to make that spaceport as operationally efficient as an airport. The first step in developing the trend linking personnel with flight rate was the use of a linear trend line fitted to the data points. However, a linear trend line indicates that as the flight rate drops below 100,000 flights per year the number of operational personnel becomes negative. Since the results from a linear fit of the data points create infeasible results, a quadratic trend line was fitted to the data points with the specification that the trend line pass through the point where zero flight rates equal zero operational personnel. Figure 4.1 shows the results of the linear and quadratic trend lines. It is important to note here that the data points for Los Angeles, Miami and New York Kennedy were not included when fitting the trend lines. These three airports fell outside the normal trend and greatly skewed the results of the trend line fit. All three of the airports are part of a port authority, and the additional personnel required may be a reason for the unusually high number of operational personnel.

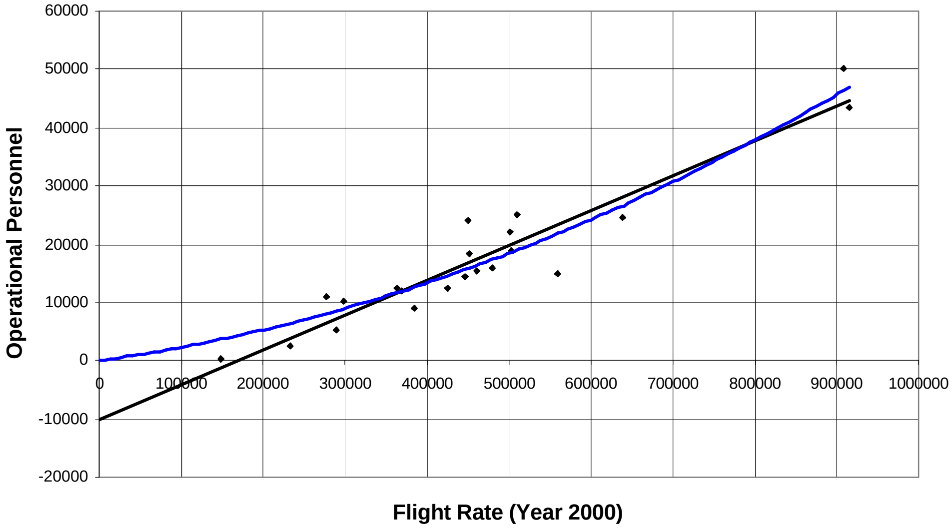


Figure 4.2: Linear and Quadratic Trend Line Fits

The next step in generating a table that could be used to estimate spaceport operational need as it relates to flight rate was to generate an upper and lower bound. For this, a second trend line was fitted to that data point above the quadratic trend line and a third trend line was fitted to the data points below. The mean, upper bound, and lower bound trend lines are shown in Figure 4.3.

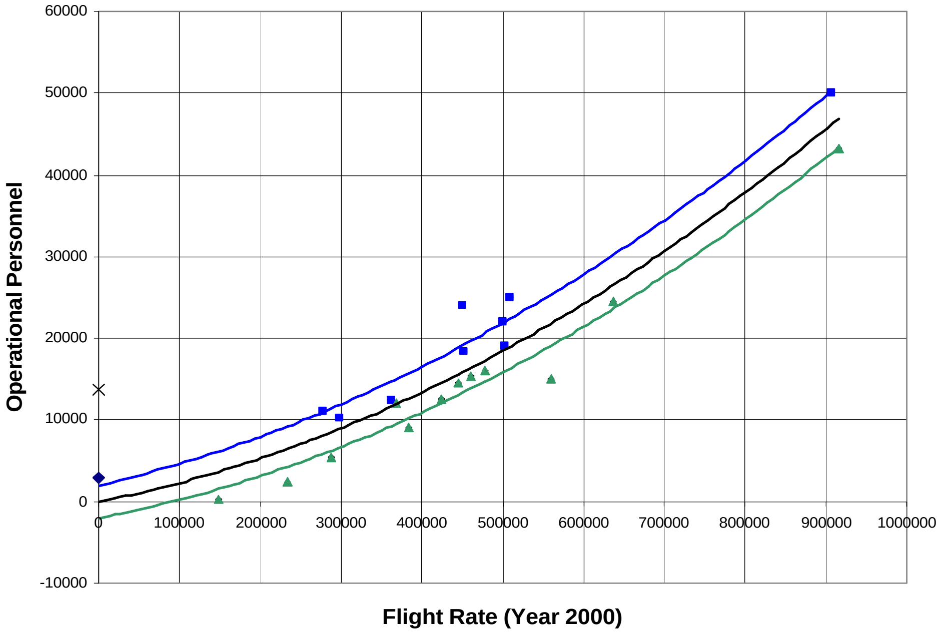


Figure 4.3: Mean, Upper Bound, and Lower Bound Trend Fits

The significance of Figure 4.3 is that it sets up an initial guideline on operational efficiency that the next generation spaceport should work to achieve. An example of this would be if a vehicle, or fleet of vehicles were designed to have a total flight rate of 100,000, the number of personnel required to meet airport efficiency standards would be between 200 and 4600 personnel. This would then give the designer an idea of the workforce that would need to be present to turn the vehicle around. This thought process would help designers keep in mind that their decisions, while they may benefit the performance of the vehicle, may, in fact, require additional personnel possibility pushing the number of operational personnel above the operational bound of airport efficiency. With the addition of each additional personnel, there is an associated cost and time required to complete an action, all having the effect of increasing cost and turnaround time, thus decreasing the vehicle economic viability.

The results shown in Figure 4.3 are just the initial results. By breaking down the personnel working at each airport into airlines, and then into specific jobs, a greater understanding of airport/airline efficiency would emerge. This greater understanding of airport/airline operations would allow for more direct comparisons between airports and spaceports and show where spaceports, such as KSC, are already efficient as airports and where the greatest improvements are needed.

However, even at this level where the operational personnel working for an airport is known, it is possible to gain a low level understanding of how personnel would be divided up among different jobs in a spaceport setting. This is done using existing shuttle data. Table B1 in Appendix B shows the operational breakdown for the shuttle and all of its support systems.[xxxvi] Table C1 in Appendix C shows a similar operational breakdown table, generated from the STS Work Breakdown Structure, consisting of only the shuttle operations as they pertained to KSC. The operational information associated with the Johnson Space Center (JSC) was included with that of KSC, based on the assumption that any next generation spaceport would consolidate the operations performed at both KSC and JSC into one facility. Table C1 lists the number of operational personnel having direct interaction with preparing the shuttle for its next launch, the engineering support team, and the personnel required for facility maintenance and facility modifications. Table C1 also shows the head count as a percentage of the total number of operational personnel or as a percentage of a specific group. For example, orbiter tile operations is shown as a percentage of the total head count for the orbiter operations, while the head count for the orbiter operations is shown as a percentage of the total number of operational personnel. Knowing these percentages it is possible to scale the head count for the shuttle based on the flight rate and corresponding operational personnel required to meet airport efficiency.

Table 4.1: Operational Personnel Scaling

Personnel Drivers	
Number of personnel as a % of Shuttle Ops.	50 %
Number of personnel	2006 Persons

Summary		
	Head Count By %	Head Count By #
Shuttle Processing	899	264
Vehicle Assembly	159	47
Launch Operations	530	156
Launch Control	334	98
Payload Processing	263	78
Maintenance (Facilities)	1313	386
Maintenance (Others)	140	41
Engineering Support	1461	429
Mission/Flight Operations	1519	446
Management	215	64
Total	6833	2009

Table 4.1 shows the first level of information that can be calculated by combining the information about the shuttle personnel head count and the operational efficiency of airports. It is possible to calculate the number of people required in ten areas of spaceport operations from shuttle processing to facility maintenance based on a given number of personnel or as a percentage of the shuttle workforce. Table 4.1 can be used in two ways. First, by inputting a scale down factor, such as 50%, the operation head count is scaled down accordingly resulting in the total number of operational personnel. The total operational personnel number can be used in conjunction with Figure 4.3 to determine a flight rate of approximately 170,000 per year. This means to meet airport efficiency a spaceport operating at 50% of the shuttle’s workforce should be able to sustain 170,000 flights per year. The second way that Table 4.1 can be used is to input the number of personnel. For a flight rate of 300 flights per year the operations

requirement based on airport efficiency is 2006. The right hand column under the summary shows the corresponding breakdown of the 2006 persons.

It becomes possible with a knowledge of airport operational efficiency and the shuttle workforce to obtain more detail. This is done by creating a strong database on airport operational personnel at all levels, from airports as a whole to individual jobs, such as electricians and mechanics and then comparing this data with that of the shuttle to get an initial prediction of what the workforce will look like.

4.2: Operational Inefficiencies

Nearly one hundred years of experience has allowed for the emergence of airports that are efficiently run and aircraft that are designed with how they will be operated, both on the ground and in the air, in mind. Because of this, the aircraft industry can be used not only to estimate the number of people required to operate the next generation spaceport, but also as a vast source of information on how to design for operability and not just performance. This section will deal with looking to the aircraft industry for examples of operability efficiencies that could be applied to the next generation launch vehicle or even to the space shuttle.

4.2.1 Payload Reconfiguration vs. Standard Payload

When the Shuttle is in the OPF there are three processes that have the largest effect on the turnaround time, they are the SSME, TPS, and payload reconfiguration. For this example, this section will look at the process of payload reconfiguration. As stated in Section 3.2 the shuttle payload bay goes through an extensive reconfiguration process in which the bay is dismantled and reconstructed using mechanical adapters, and additional longeron beams on the side and keel beams are installed at the bottom of the payload bay. Beyond structural reconfiguration, the bay must also be rewired to supply power and cooling to the payload. For airliners and especially air cargo carrier/delivery services, such a method of reconfiguration would be a non-viable solution. Aircraft manufacturers and air cargo carriers such as United Parcel Service (UPS) have approached the problem of cargo carrying from a different angle. As with the shuttle, air cargo carriers carry a variety of payloads, different sizes and different weights. However, instead of reconfiguring the cargo hold of an aircraft each time, the aircraft industry came up with a standard cargo container that can simply slide into an aircraft.

Figure 4.4: Standard Aircraft Cargo Containers[xxxvii]

Figure 4.4 shows a UPS aircraft being loaded with a standard cargo container that enters the aircraft through a loading door and is then moved along the length of the cargo hold to a predetermined position. Each containers weight and placement is controlled with precision to sustain an acceptable center of gravity (C.G.) range for the aircraft as designed by the manufacturer.

The aircraft industry, and how it operates cargo carriers, sets up a guideline that could be applied to the shuttle and future launch vehicles. Like an aircraft, a RLV would have a standard size cargo bay and a required C.G. range in which it operates. A standard cargo container could be designed to slide into a RLV payload bay, already loaded so that when it is placed in the RLV the entire vehicle will achieve the required C.G. range. Such a container could either house a self-contained power supply to provide power and cooling to the payload, or it could have a standard plug that could connect directly to the RLV for power.

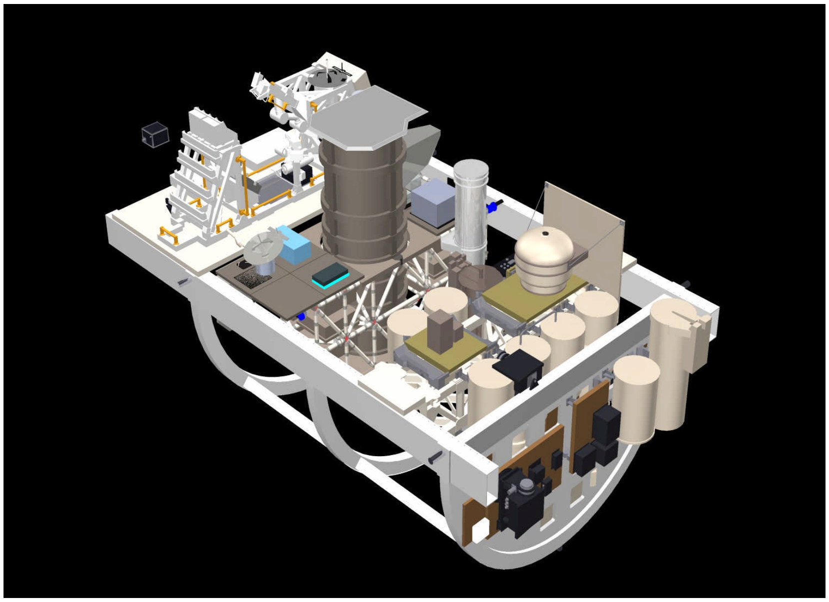
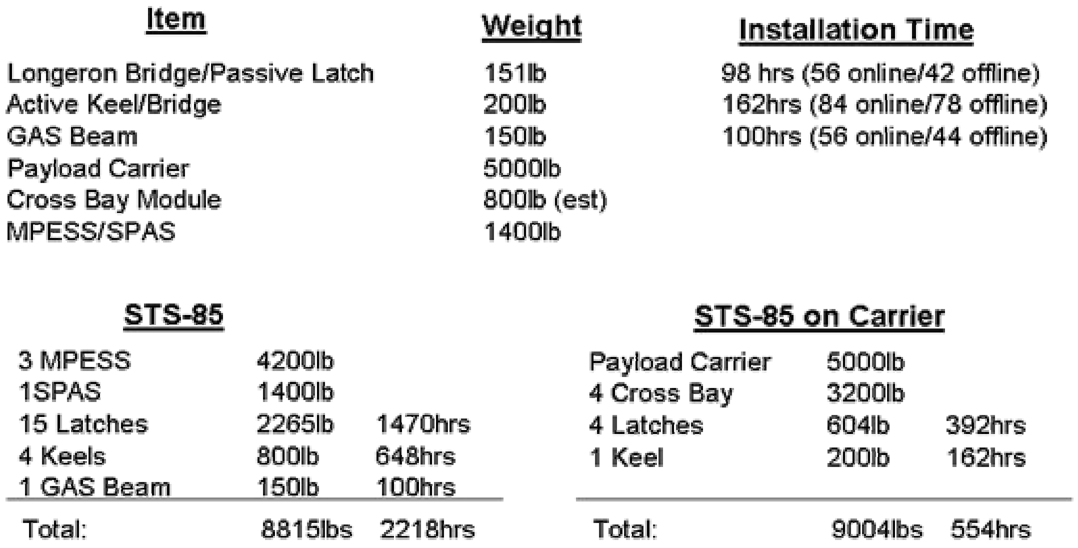


Figure 4.5: Standard Shuttle Payload Carrier[xxxviii]

Figure 4.5 shows a standard payload carrier packed with a satellite that is proposed for use onboard the shuttle. Such a system would require little modification to the shuttle payload bay.

Table 4.2: Standard Payload Carrier Savings[xxxix]



Item	Weight	Installation Time
Longeron Bridge/Passive Latch	151lb	98 hrs (56 online/42 offline)
Active Keel/Bridge	200lb	162hrs (84 online/78 offline)
GAS Beam	150lb	100hrs (56 online/44 offline)
Payload Carrier	5000lb	
Cross Bay Module	800lb (est)	
MPESS/SPAS	1400lb	

STS-85		
3 MPESS	4200lb	
1SPAS	1400lb	
15 Latches	2265lb	1470hrs
4 Keels	800lb	648hrs
1 GAS Beam	150lb	100hrs
Total:	8815lbs	2218hrs

STS-85 on Carrier		
Payload Carrier	5000lb	
4 Cross Bay	3200lb	
4 Latches	604lb	392hrs
1 Keel	200lb	162hrs
Total:	9004lbs	554hrs

Table 4.2 shows the installation time and weight of the items used in reconfiguring the shuttle bay. Table 4.2 uses as example STS-85 and shows the number of hours and additional weight added to the shuttle by reconfiguring the payload bay and by using the payload carrier. While the carrier increased the weight by approximately

200 lbs (200 lbs of payload that could not be put into orbit) the overall installation time decreased by over 1600 hours.

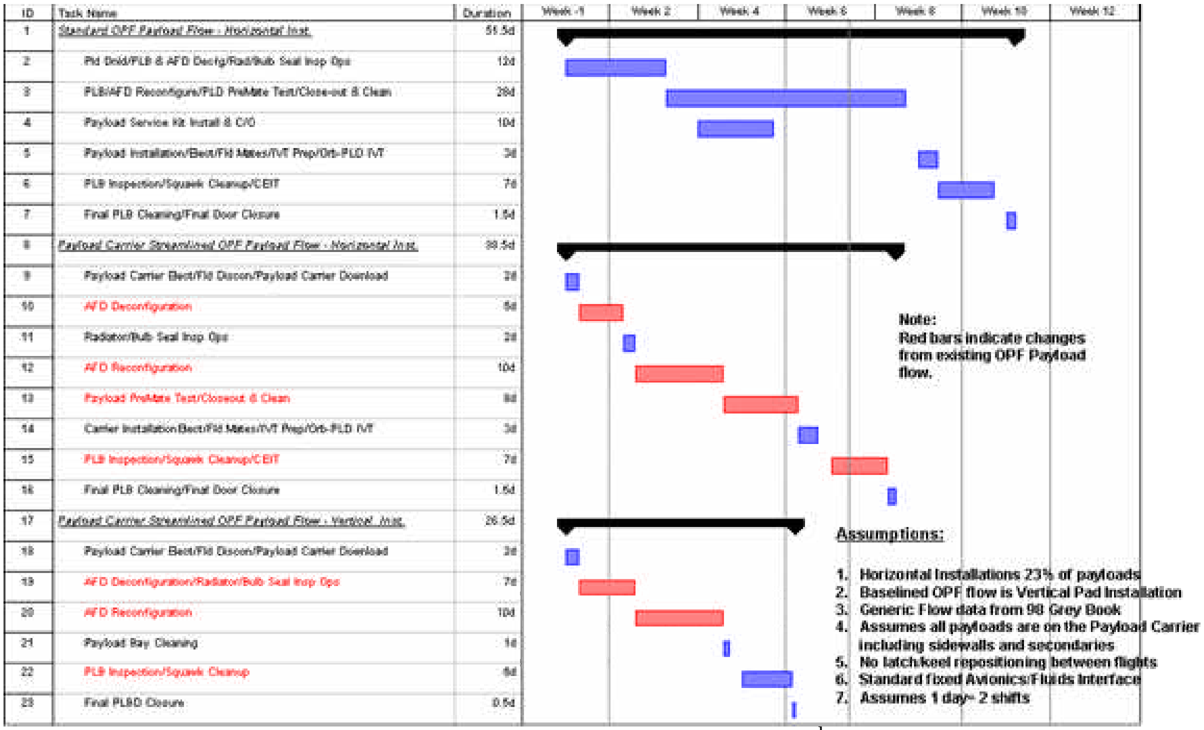


Figure 4.6: Payload Carrier Time Saving[xl]

Figure 4.6 represents the time saved by use of the payload carrier. Completing a horizontal installation in the OPF the payload carrier would save approximately three weeks, while a vertical installation completed at the pad would generate a saving of nearly 6 weeks achieving over a 50% reduction in turnaround time simply due to the payload. This significant reduction in turnaround time would allow for a greater number of flights per year increasing the number of payloads launched to orbit and decreasing the cost per payload helping make the shuttle or any RLV economically more viable than the current system of payload bay reconfiguration. For the shuttle, the turnaround time would still be dictated by the TPS and SSME. But, it would be the first step in decreasing the overall turnaround time, while at the same time decreasing the cost associated with payload reconfiguration.

4.2.2 Integrated Vehicle Health Management

Preparing the shuttle for its next launch is an extensive and some times invasive process. For example each tile on the shuttle must be visually inspected for the slightest indication of damage while the SSME are removed from the vehicle, tested and carefully inspected. A simple and ideal solution would be to have the vehicle tell the ground personnel what needs to be worked on and replaced. Such a concept is recognized as an Integrated Vehicle Health Management (IVHM) system. IVHM has three basic objectives, first, it is a more autonomous operation in flight and on the ground which translates to a reduced work load on the ground controller team through reduction of raw vehicle data into "health summary information." Next is reduced ground processing of reusable vehicles due to more performance of system health checks in flight rather than back on the ground, as well as more automated ground servicing and checkout. Last is enhanced vehicle safety and reliability due to increased capability to monitor system health using modern sensing systems inside even the harsh environment of an engine combustion chamber as well as through prediction of pending failures.[xli]

While the airline industry has not fully incorporated the full use of IVHM, military aircraft, such as the F-111 and F-22, which incorporate significant use of computers to fly the aircraft, use the concept of a IVHM, where the computer can inform the pilot of damage onboard, then once on the ground, that information can be accessed by a ground crew to determine what damage has occurred and what systems if any require work.

The impact of an IVHM system on ground operations would be in the area of safety, reliability and maintainability. Safety is increased for the astronauts, public, ground crews, and property. IVHM would allow a forewarning of failures and predicted failures of highly critical systems allowing for an increased response time. Reliability and robustness would also be improved through the use of a fully implemented IVHM system resulting in aircraft-like maintenance through in situ vehicle checkout during operations and robust on-board fault isolation and prediction. Ground maintenance would be performed on an exception only basis and would be pre-planned and automatically adjusted prior to vehicle return. Operations in flight and on the ground would be enhanced through more autonomous operations allowing faster responses with fewer personnel.

An IVHM system would have a large impact on the ground operations of the TPS and SSME. If ground crews knew by the use of an IVHM which tiles required replacement and what on the SSME's, if anything, required repair, the ground turnaround time could be greatly decreased. In conjunction with a payload carrier, (previously discussed), the total turnaround time for the shuttle could be decreased, making the shuttle economically more viable.

4.3 Design By…

How do you design the next generation spaceport? Do you design a spaceport to service a single vehicle, or multiple vehicles? How do you design an airport? Do you design an airport for a particular aircraft or does the design of an airport partially dictate the design of an aircraft? Over the course of one hundred years the aircraft industry has found a balance between the design of aircraft and airports. When travel by way of air was just beginning, airports were designed to accommodate the aircraft that used them. However, over time, airports have become more standardized placing constraints on the aircraft designers. For example, the gates at airports are spaced equal distances apart, to accommodate the largest aircraft. Over the years, aircraft designers have consistently designed aircraft with greater capacity, resulting in increased weight, increased lift required, and thus increased wing span. Currently, most airports are designed with the Boeing 747 in mind concerning the spacing of the gates. However, when Boeing developed the stretched version of the 747 the wing span initially increased beyond the capability of airports. Since it was unreasonable for the airports to change all their gates to accommodate one aircraft the 747 was redesigned with winglets to provide the additional lift required while still maintaining the required wing span for the airport gates. This means that airports have a degree of control over the design of an aircraft. In addition to affecting wingspan, airport operations have a large effect on how aircraft are designed.

An aircraft designer must take into account how their design will be manufactured, built, and then operated. The aircraft industry has taken this ideology, also know as Integrated Product and Process Development (IPPD), to heart and have begun using virtual reality simulations to simulate an aircraft and a worker to test that everything on board the vehicle is accessible to the worker. If it is not, the part or parts can be redesigned and tested all before a single component is actually manufactured.

Along with this understanding comes an understanding of how the aircraft will be maintained and supported while on the ground at an airport. The consideration of how an aircraft will be manufactured and operated has an impact on the over all design process.

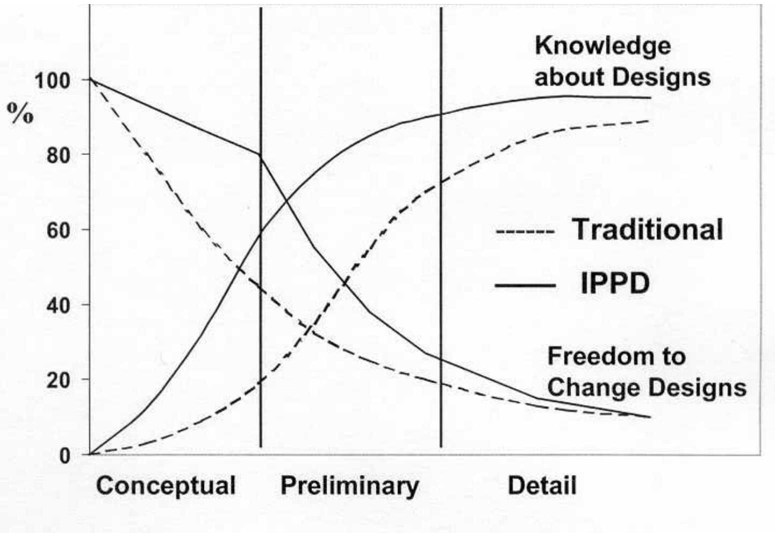


Figure 4.7: Advantages of IPPD[xlii]

By considering how an aircraft will be manufactured, assembled and operated early on in the design, designers have greater knowledge about the design and greater freedom to make changes early in the design process instead of later where the cost of such a change would be great. This type of design is done, and preserves the traditional notion of designing for performance. In addition to the use of IPPD design simulation, virtual reality has been used in designing for manufacturability and operability. Figure 4.8 depicts a virtual reality simulation in which a person can enter the simulation and interact with an aircraft or collection of components. This allows a designer to interact with an aircraft to see if a part that has been designed was designed in such a way that it is inaccessible and thus needs to be redesigned. All of this would take place before the first part was ever manufactured. Problems that would have occurred during the actual processing and construction can be discovered while the aircraft is still in the design phase. The same can be true for test the operability of an aircraft, how easy is it to change out a component if the aircraft was on the apron, is the part so inaccessible that it requires a maintenance facility? These operational questions can be dealt with much earlier in the design process instead of discovering them after the aircraft has been built and having to make a difficult modification at that time.

Figure 4.8: Virtual Reality Simulation[xliii]

The launch community has worked from a different frame of mind where what the vehicle was designed for, performance and pounds of payload to orbit, dictated design. Operations, in terms of safety, reliability, and turnaround time have been an issue and one of the goals from the beginning, but as the design progresses and design changes are made, their impact on operations is not taken into consideration. A prime example of this is the space shuttle. The initial designs did not indicate a turnaround time of three months nor an infrastructure as complex as what was required.

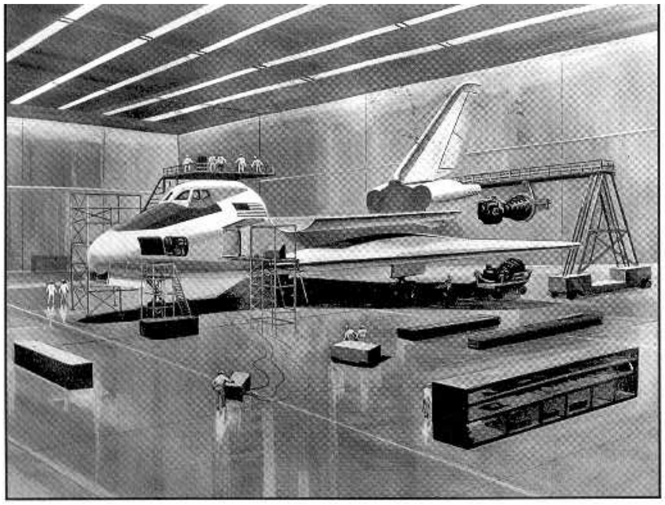


Figure 4.9: Shuttle Operation Concept[xliv]

Figure 4.9 depicts the shuttle operation to be aircraft-like and simple, when, in fact, the shuttle turnaround process is quite complex. The use of IPPD and virtual reality simulations would help designers to grasp some of the operational concepts. Like most processes, it is best to learn the mistakes of the past and not repeat them in launch vehicles that would replace the space shuttle. By truly examining the ground operations of the space shuttle, designers could get a grasp of how complex shuttle operations are and how their decisions have enormous impact on operations. A vehicle cannot be designed by isolated components, where one group works on a single component like the engines and never considers how it fits in with the overall design. The design of the next generation spaceport and launch vehicle must be done in balance. The spaceport must be designed to meet the needs of the next generation launch vehicle, while at the same time the launch vehicle must be designed with the needs of the spaceport in mind, such as quick turnaround times, simply maintenance that requires a minimum of infrastructure, and an increase in safety and reliability.

5.0 Safety and Reliability

There is another relationship between designing an aircraft/airport and RLV/spaceport,and that is the role of safety and reliability. Airports are able to operate in an efficient manner not only because operations considerations are designed into an aircraft, but also because the aircraft is designed to have a high safety and reliability factor. Because the engines are designed to operate a certain number of hours before needing maintenance, an aircraft engine does not require removal and inspection after each flight as is required with the shuttle. Safety and reliability that is designed into an aircraft also protects passengers and the ground crew. On the shuttle, safety and reliability are important issues but they take on a slightly different look.

5.1: Safety

For the operation of any vehicle, whether it is an aircraft or a launch vehicle, safety is an issue for the ground crew. Ground personnel safety can range from ensuring the proper equipment is used when removing a component from a vehicle so that is not accidentally dropped damaging the component or injuring ground personnel, to protecting ground crew from fire/explosions. For Shuttle ground processing there are a series of risks involved from the time the shuttle lands to take off.

Many of the hazardous conditions that pose safety risks to the ground personnel are the fuels used for the RCS and OMS, and gases and liquids used for cleaning systems onboard the shuttle. When the shuttle first lands the air around the vehicle must be tested to determine if any hypergols used in the RCS and OMS are leaking. Hypergols are an extremely toxic gas that could easily kill the ground personnel if they were not to check for leakage before proceeding with the ground operations. If, any toxic gases are detected, large fans must be moved into place to blow the gases down wind of the vehicle so that it may be accessed. Some of the hazardous operations that take place in the OPF are listed below:[xlv]

1) Controlled T-0 Venting
2) Jack and Leveling
3) PRSD Horizontal Drain
4) Ordnance Safing

5) Thruster R&R
6) SSME Removal/Install
7) NH3 Servicing
8) DMES Waterproofing
9) Ordnance Install
10) Ball Valve/Cavity Drain
11) APU Catch Bottle Drain
12) OMS Pod Removal
13) Hypergol Offload
14) Horizontal Payload Operations

Each of these operations poses dangers to the ground crew. The removal of the SSME requires precise movement of the lift that pulls the SSME from the aft section of the shuttle. A wrong move or a faulty connection could result in serious damage to the SSME and personnel. Again, the hypergols play a role in the OPF. When the OMS engines and RCS jets are serviced, careful attention must be paid to the remaining hypergol in the tanks and fuel lines. The OPF is equipped with sensors in the event that a leak of a toxic fuel occurs. When this happens, an alarm sounds and all personnel are required to immediately evacuate the facility.

The VAB like the OPF has its share of hazardous operations. One of the most hazardous operations is the stacking of the SRBs. When the VAB was first constructed for the Apollo missions and the Saturn V, designers were aware that the Saturn V would be assembled and transported to the launch pad un-fueled. The SRBs, on the other hand, are fueled when stacked. Over the years, offices and support teams that were located within the VAB have been moved off site due to the potential for accidents stemming from the SRBs. When the SRBs are stacked, a minimum number of personnel are present in the off chance that a spark or something else would prematurely ignite the solid fuel in the SRBs.

From the OPF, to the VAB and finally out to the pad, the shuttle and the RCS engines are constantly monitored for any leakage of hypergols that might pose a danger to personnel. Also, in all three areas, OPF, VAB, and pad, there is the concern of an oxygen deficient atmosphere due to tests and purges. In certain cases gaseous nitrogen is used to purge vent lines and test for exterior leaks of the shuttle body. During the process the gaseous nitrogen displaces the oxygen atmosphere creating a potentially dangerous situation if a person were to enter an area where gaseous nitrogen had displaced the oxygen.

At the launch pad there is great care taken when the ET is loaded with LOX and LH2. There is always the possibility of a Hydrogen fire/leak during cryogenic loading/draining. The launch of Atlantis, STS-110, was delayed due to work that was focused on the Mobile Launcher Platform 16-inch hydrogen vent line that began to leak during external tank loading operations for the launch attempt on April 4th, 2002.[xlvi] If such a leak were to have gone unchecked, a possible fire could have resulted endangering the launch vehicle, crew, and ground personnel.

These examples of safety issues along with others represented in the shuttle ground procedure indicate a design philosophy of designing for performance. Moving to a design philosophy based on operations and performance would attack these issues of safety, and bring with it a realization that with each hazardous operation come equipment, procedures, and additional personnel required to deal with these hazardous conditions, each of which cost money, and consumes time.

5.2 Reliability

Reliability, like safety, is dealt with significantly differently between aircraft and the shuttle. To start with, the aircraft industry is regulated by the FAA and is required to meet certain standards stated in the Federal Aviation Requirements (FAR). These requirements state minimum reliability standards that must be met by the aircraft manufacturer in order to obtain certification for their aircraft. The launch vehicle industry has no such regulations. It is left up to the industry to set the standards. This does not mean that the design of the space shuttle or future RLV completely ignore the reliability of the vehicle, because reliability is very important. However, with reliability comes a certain amount of distrust. The space shuttle is the first of its kind, thus the effects of flying into space on hardware, such as the SSME, is not fully understood. While the SSMEs are designed for 55 starts, the engines are continually removed, tested, and checked out after each flight. This has nothing to do with reliability, but it does have something to do with not knowing what all of the effects of a space flight might entail. IVHM would help in this area by allowing ground personnel a look into the engine by having the computer relay what, if anything, has been damaged. This, in conjunction with data on the effects of space flight on the SSMEs over the last 110 flights, would give designers added information for designing the engines for the next generation launch vehicle.

Table 5.1 shows system failure rates for Worldwide and United States launch vehicles and general aviation aircraft. For structures and engines, critical components in both launch vehicles and aircraft, the aircraft have achieved a low failure rate compared to that of launch vehicles. This is anther reason why the shuttle engines must be inspected after each flight and aircraft engines are not.

Table 5.1: Reliability Comparison of Worldwide, US Launch Vehicles to GA Aircraft[xlvii]

	Worldwide Database	**Failure rate**	**US Database**	**Failure rate**	**Complex General Aviation**	**Failure rate**
1	▪ PFS	0.0195	▪ Engine	0.0191	▪ cockpit instrument	0.02400
2	▪ Engine	0.0169	▪ PFS ▪ Avionics/FC	0.0144	▪ flight control	0.01525
3	▪ Avionics/FC	0.0116	▪ Electrical ▪ Hydraulic	0.0096	▪ ground control	0.00402
4	▪ Electrical	0.0080	▪ Payload Fairing	0.0064	▪ structures	0.00060
5	▪ Hydraulic	0.0054	▪ ACS	0.0048	▪ non-engine propulsion	0.00012
6	▪ Payload Fairing ▪ ACS	0.0045	▪ Software ▪ Design	0.0032	▪ engine ▪ electrical	0.00003
7	▪ Software ▪ Propellant Storage	0.0036	▪ Propellant Storage ▪ Structure	0.0016		
8	▪ Structure ▪ Design	0.0027				

6.0 Conclusion and Future Work

6.1 Conclusion

The process of designing the next generation spaceport and launch vehicle is a complex task, but must be done in order to meet the requirements of the Space Launch Initiative. As the SLI indicates, the long-term goal of the launch vehicle industry is the development of an RLV that operates much like that of an aircraft. Figure 6.1 and 6.2 depict the future look of the next generation spaceport as developed by the Kennedy Space Center.

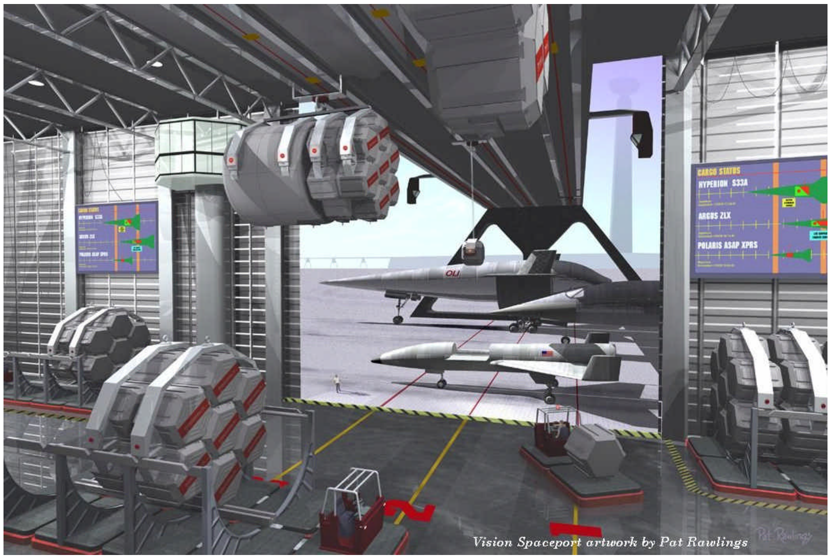


Figure 6.1: Vision Spaceport Offline Cargo Processing[xlviii]

Figure 6.2: Vision Spaceport Terminal Concept[xlix]

While the concept of the Vision Spaceport creates an airport like atmosphere, the next generation spaceport and launch vehicle will fall somewhere in between KSC and Vision Spaceport. The ultimate goal of launch vehicle and spaceport designs is not necessarily to match what the aircraft industry has been able to accomplish, but to use the aircraft industry as a guide to improving the operational efficiency of launch vehicles in the direction of aircraft and airport efficiency. There will always be fundamental differences between aircraft and launch vehicles. The greatest difference, of course, being the flight regime. Due to the severe flight regime that launch vehicles experience they are bound to be more complex than aircraft and thus require more time to turn around. Will an hour turnaround time for a launch vehicle ever to be achieved? Is a day or week turnaround time more likely? At this point in time it is hard to say, but there are steps that can be taken to achieve quicker turnaround times. Taking the shuttle for example, if the SSMEs could be redesigned with a large enough safety factor that they would only have to be removed for inspection once every 3 flights, if the payload reconfiguration were to implement a standard cargo container, and if a TPS system were developed such that the TPS could simply be sprayed on for each mission (having to be completely removed once every 3 flights) it becomes possible to decrease the shuttle turnaround time possibly by as much as 6 weeks. What was a turn around time of 3 months could be decreased to 1-½ months, making the shuttle cheaper and more efficient to operate.

In order to achieve the goals put forth for the next generation launch vehicle and spaceport, a detailed understanding of how airport and aircraft operation, along with how the space shuttle and Kennedy Space Center operate is needed. By gaining knowledge of these two operations and obtaining a grasp on the processes that drive turnaround time, a method for designing a RLV that eliminates, or decreases the time required for those processed, such as TPS, SSMEs, and payload reconfiguration, can be developed. Understanding these critical processes and designing a new method requires an understanding of how aircraft and airports operate, and how over the last one hundred years aircraft manufacturers have found feasible solutions. Again, there will always be difference between the operations of aircraft and launch vehicles, (the flight regime that both vehicles fly through are dramatically different and thus require different operations). A aircraft do not require the use of TPS tiles to expel heat generated by flying through the atmosphere as the shuttle does, but even with this difference, there are a lot of similarities that exist between airport operations and spaceport operations.

6.2 Future Work

This report represents the first step in creating a guideline for developing and designing the next generation spaceport and RLV. The research completed for this paper gives a top-level perspective on how airports and spaceports operate. What is required now is to take the next step and gain a greater amount of knowledge of how these facilities operate. The next step would be to continue to accumulate more operational data for both systems, including a more detail breakdown of the personnel requirements for specific tasks. This type of detailed knowledge is required to fully understand the operations of both systems. If the amount of time required by the TPS, SSMEs, and payload configuration could be reduces to the point that they are no longer the determining factor in turnaround time, which would mean that another system becomes the determining factor. A comprehensive understanding of the operational procedure would allow designers to understanding at what point does a new process become the determining factor, and when should time and money be spent on decreasing its operation time. Finally, once all of this information has been assembled, comparisons can be made between airports and spaceports on a detailed level allowing designers to understand the inner workings of an airport and what key processes have a major effect on turnaround time and efficiency, and then, how to cross apply those lessons learned in the aircraft industry to the design of the next generation spaceport and launch vehicle.

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Appendix A: Airport Personnel and Flight Rate

Table A1: Airport Personnel and Annual Flight Rate (FY2000) Data

Airports	Total Flight Rate	Grand Total
Atlanta	915454	43300
Boston	478873	16001
Baltimore-Washington	277765	11000
Charlotte-Douglas	452009	18430
Washington Reagan	297879	10200
Denver	500415	22000
Detroit	559375	15000
Newark	450187	24000
Washington Dulles	460000	15400
New York Kennedy	345093	37000
Los Angeles	783433	59000
New York LaGuardia	384064	9000
Orlando	368172	12000
Memphis*	363448	12360
Miami	517440	40822
Minneapolis-St. Paul	510421	25000
Chicago O'Hare	908080	50000
Phoenix Sky Harbor	637779	24516
Seattle	445677	14500
Salt Lake	424608	12511
Albuquerque	233491	2500
Jacksonville	148797	220
San Jose	288360	5364
Lambert St. Louis	502865	19000

Appendix B: STS Work Breakdown

Table B1: Breakdown of Shuttle Workforce[1]

	1994 STS WBS	*8 Flt/Year Baseline Headcount*
	Shuttle Operations	**28,311**
	TOTAL EXTERNAL TANK	**2,376**
	Mission Analysis	**209**
ET01	Launch Support Services	49
ET02	Flight Support	128
ET03	Technical Directives	32
	Production	**2041**
ET04	Build and Support	1710
ET05	Facilities Self-Sustaining	331
	Project Support	**126**
	Plant Operations	0
ET06	*Replacement Equipment*	*0*
ET07	*Utilities*	*0*
ET08	*Rehab Equipment*	*0*
ET09	*Special Studies*	*0*
	Logistics	0
ET10	*Refurbishment*	*0*
ET11	*ET Transportation*	*0*
ET12	*Government Bills of Lading*	*0*
ET13	*Pressurants*	*0*
	MAF Communications	14
ET14	*Labor*	*14*
ET15	*GSA FTS*	*0*
ET16	*Maintenance*	*0*
ET16	*Equipment/Supplies/Materials*	*0*
ET17	*Local Phone Service*	*0*
	Slidell Computer Complex	106
ET18	*ADPE Purchases*	*0*
ET19	*Labor*	*106*
ET20	*ADPE Lease/Maintenance*	*0*
	Technical Evaluation and Analysis	6
ET21	*Science and Engineering*	*0*
ET22	*Rockwell Support*	*0*
ET23	*Computer Labor Support*	*6*
	TOTAL SOLID ROCKET MOTOR (SRM)	**2,727**
SRM01	**Sustaining Engineering**	**632**
SRM02	**Touch & Support for Manufacturing & Refurbishment Labor**	**2095**
SRM03	**SRM Propellant**	**0**

SRM04	**Expendable/Reusable Hardware**		**0**
SRM05	**Tooling Maintenance & Computer Support**		**0**
SRM06	**Freight**		**0**
SRM07	**Institutional Support**		**0**
	TOTAL SOLID ROCKET BOOSTER (SRB)	**985**	
SRB01	**Touch & Support Labor**		**440**
SRB02	**Expendable/Reusable Hardware**		**0**
SRB03	**Sustaining Engineering & Management**		**489**
SRB04	**Vendor Refurbishment of Reusable H/W**		**0**
SRB05	**Travel, Computer & ODC**		**0**
SRB06	**KSC Support, Comm. & Sys Analysis**		**56**
	TOTAL ENGINE (Sustaining Engineering)	**599**	
SME01	**Flight Support**		**186**
SME02	**Anomaly Resolution**		**143**
SME03	**Inventory Management & Warehousing**		**44**
SME04	**Hardware Rerfurbishment**		**98**
SME05	**New Hardware Spares**		**128**
SME06	**Transportation**		**0**
	TOTAL ORBITER & GFE (JSC)	**1174**	
ORB01	**Sustaining Engineering & Launch Spt**		**693**
	Orbiter Support		**408**
ORB02	PICS		2
ORB03	NASA Std Initiators (NSI)		3
ORB04	Pyros, Standard Operations		13
ORB05	RMS-Ops & Support		26
ORB06	RMS-Sustaining Engineering		38
ORB07	RMS-Program Management		14
ORB08	FCE Operations Management		4
ORB09	EMU/EVA Field Support/O&R		10
ORB10	EMU Logistics		10
ORB11	FEPC Tasks		283
ORB12	SSA Provisions (FEPC)		3
ORB13	Parachute Maintenance		2
ORB14	**Flight Data Support**		**42**
ORB15	**Orbiter /ET Disconnects**		**31**
	TOTAL ORBITER LOGISTICS & GSE (KSC)	**1111**	
LOG01	**Spares**		**222**
LOG02	**Overhaul & Repair**		**431**
LOG03	**Manpower to Support Logistics, Procurement, Engineering**		**276**
LOG04	**Tile Spares & Maintenance**		**153**
LOG05	**GSE Sustaining Engineering**		**29**
	TOTAL PROPELLANT (KSC Launch Ops)	**0**	
PROP	**Propellant**		**0**

	TOTAL LAUNCH OPERATIONS (KSC)	**7552**
	Shuttle Processing	**2864**
	Orbiter Operations	1797
KSC01	*Orbiter Maintenance*	*807*
KSC02	*Orbiter Shop Operations*	*117*
KSC03	*Orbiter Modifications*	*89*
KSC04	*Orbiter Landing Operations*	*107*
KSC05	*Orbiter Processing Support*	*398*
KSC06	*Orbiter Tile Operations*	*279*
	SRB Operations	251
KSC07	*SRB Processing Operations*	*75*
KSC08	*SRB Stacking*	*74*
KSC09	*SRB Retrieval & Disassembly Operations*	*51*
KSC10	*SRB Shop Operations*	*25*
KSC11	*SRB Modifications*	*1*
KSC12	*SRB Processing Support*	*25*
	ET Operations	67
KSC13	*ET Processing Operations*	*45*
KSC14	*ET Shop Operations*	*5*
KSC15	*ET Modifications*	*2*
KSC16	*ET Processing Support*	*15*
	Launch Operations	601
KSC17	*Integrated Vehicle Servicing*	*181*
KSC18	*Integrated Vehicle Test & Launch Ops*	*259*
KSC19	*Launch Operations Support*	*161*
	Payload Operations	148
KSC20	*Payload Integration and Support Services*	*148*
KSC21	*Payload Operations Support*	*0*
	Systems Engineering/Support	**171**
KSC22	Engineering Services	62
KSC23	Systems Engineeering	109
	Facility Operations & Maintenance	**1301**
KSC24	Facility O&M Support Operations	235
	Facility Maintenance	684
KSC25	*OPF Maintenance*	*70*
KSC26	*HMF Maintenance*	*21*
KSC27	*VAB Maintenance*	*62*
KSC28	*LCC Maintenance*	*8*
KSC29	*MLP Maintenance*	*95*
KSC30	*Transporter Maintenance*	*26*
KSC31	*PAD A Maintenance*	*135*
KSC32	*PAD B Maintenance*	*147*
KSC33	*SLS Maintenance*	*7*
KSC34	*CLS Maintenance*	*1*
KSC35	*Logistics Facilities Maintenance*	*10*
KSC36	*RPSF Maintenance*	*10*
KSC37	*SRB Retrieval Vessel Maintenance*	*16*
KSC38	*Miscellaneous Facility Maintenance*	*66*
KSC39	*Dredging Operations*	*0*
KSC40	*Processing Control Center Maintenance*	*6*

KSC41	*OSB Maintenance*	*4*
	Launch Equipment Shops (LES)	109
KSC42	*Launch Equipment Shops (LES)*	*76*
KSC43	*Decontamination/Cleaning/Refurb/Shops*	*2*
KSC44	*Janitorial Services*	*1*
KSC45	*Corrosion Control*	*30*
KSC46	Facility Systems	56
KSC47	Maintenance Service Contracts	0
KSC48	Inventory Spares and Repair	8
	System Equipment	$209.0
KSC49	*SE Maintenance*	*209*
KSC50	*SE Acquisition*	*0*
KSC50.1	*Capital Equipment Procurements*	*0*
	LPS/Instrumentation & Calibration (I&C)	**696**
	LPS Engineering and Software	158
KSC51	*LPS Engineering*	*40*
KSC52	*LPS S/W Development & Maintenance*	*69*
KSC53	*LPS Software Production*	*49*
	LPS O&M	397
KSC54	*Checkout, Control & Monitor Subsystem*	*168*
KSC55	*CDS Operations*	*66*
KSC56	*Record & Playback System O&M*	*48*
KSC57	*LPS Maintenance/Support Engineering*	*115*
	Instrumentation & Calibration	141
KSC58	*Instrumentation*	*101*
KSC59	*Calibration*	*40*
	Modifications	**157**
KSC60	OPF Modifications	19
KSC61	HMF Modifications	2
KSC62	VAB Modifications	6
KSC63	LCC Modifications	1
KSC64	MLP Modifications	4
KSC65	Transporter Modifications	0
KSC66	PAD A Modifications	5
KSC67	PAD B Modifications	4
KSC68	SLS Modifications	0
KSC69	CLS Modifications	0
KSC70	RPSF Modifications	1
KSC71	Miscellaneous Facility Modifications	10
KSC72	SE Modifications	6
KSC73	LPS Hardware Modifications	99
KSC74	Istrumentation & Calibration Modifications	0
KSC75	Communication Modifications	0
KSC76	PAD B Block Modification	0
	Technical Operations Support	**1019**
	Safety, Reliability, Maintainability & Quality	282
KSC77	*Safety*	*108*
KSC78	*Reliability*	*32*
KSC79	*Quality Assurance*	*142*
	Logistics	218

KSC80	*Logistics Engineering*		*48*
KSC81	*Systems & Audit*		*13*
KSC82	*Receiving Service Center*		*0*
KSC83	*Supply*		*117*
KSC84	*Transportation*		*40*
KSC85	*Procurement Service Center*		*0*
	Facility/SE Engineering		233
KSC86	*Systems Integration/Design Engineering*		*165*
KSC87	*Special Engineering Projects*		*35*
KSC88	*Ground Systems Change Control*		*33*
KSC89	*Technical Data/Documentations Service*		*0*
	Operations Management		89
KSC90	*Manifest Planning*		*46*
KSC91	*Flt Element/Mission-Related Change Ctl*		*25*
KSC92	*Configuration Management Office*		*18*
KSC93	Non-IWCS H/W, S/W and Maintenance		6
KSC94	Launch Team Training System (LTTS) Pgm		22
	Integ Work Ctl System (IWCS) Development		169
KSC95	*IWCS Shop Floor Control Project*		*26*
KSC96	*IWCS Work Preparation Support System*		*17*
KSC97	*IWCS Automated Reqments Management*		*11*
KSC98	*IWCS Computer Aided Schedule & Planning*		*19*
KSC99	*IWCS Project Integration*		*10*
KSC100	*IWCS Operations, Management & Support*		*86*
	Program Operations Support		**430**
	Program Administration		158
KSC101	*Contract/Financial Management*		*69*
KSC102	*Management Planning & Procedures*		*14*
KSC103	*Team Member Management/Administration*		*75*
KSC104	Training		204
	Human Resources		68
KSC105	*Security*		*67*
KSC106	*Human Resources Service Center*		*1*
	Communications		**327**
KSC107	Voice Communications O&M		120
KSC108	Wideband Transmission & Navaids O&M		97
KSC109	Cable and Wire O&M		45
KSC110	Communications Support		49
KSC111	OIS-D Implementation		16
KSC112	**Base Operations Contract (BOC)**		**208**
KSC113	**Launch Support Services**		**350**
KSC114	**Weather Support**		**29**
	TOTAL PAYLOAD OPERATIONS (KSC)	**378**	
KSC115	**P/L Transportation & Interface Verification**		**318**
KSC116	**P/L Processing GSE Sustaining Engrg**		**60**
	TOTAL MISSION OPERATIONS (JSC)	**3118**	
	Mission Operations Facilities		**1546**
JSC01	Control Center Operations		667

JSC02	Integrated Training Facility Operations		285
JSC03	Integrated Planning System Operations		71
JSC04	Shuttle Avionics Integration Lab (SAIL)		228
JSC05	Flight Operations Trainer		42
JSC06	Software Production/Software Dev. Facility		208
JSC07	Mockup & Integration Lab		12
JSC08	Control Center Systems Division		21
JSC09	Integrated Planning System Office		8
JSC10	Simulator and Traininbg Systems Division		4
JSC11	STSOC Material		0
	Mission Planning & Operations		**928**
JSC12	Systems Division		184
JSC13	Ops Division		131
JSC14	Training Divivion		125
JSC15	Flight Design Division		424
JSC16	Recon Division		64
	Program & Doc. Support/Management		**644**
JSC17	STSOC Support		554
JSC18	Flight Software Support		31
JSC19	Shuttle Data Support		29
JSC20	MOD Directorate Office		30
	TOTAL CREW OPERATIONS (JSC)	**327**	
	Aircraft Maintenance & Ops		**$279.0**
JSC21	T-38 Training Aircraft		159
JSC22	Shuttle Training Aircraft		111
JSC23	Shuttle Carrier Aircraft		9
JSC24	Heavy Aircraft Training		0
JSC25	Astronaut Support		0
JSC26	**STSOC Flt Crew Ops Directorate Support**		**48**
JSC27	**TOTAL CREW TRAINING & MEDICAL OPS (JSC)**	**191**	
	TOTAL PROGRAM OFFICE/HEADQUARTERS	**1046**	
	Program Office		**1012**
STS01	Management, SE&I, Flight Analysis		494
STS02	Payload Integration		257
STS03	STSOC Mission Integration Support		56
STS04	Other Support		11
STS05	Landing Site Support		5
STS06	Config Mgmt, Mission Verif, & PRCB		54
STS07	ADP Facility & Ops, MIC Support, Publications		123
STS08	ADP Equipment		0
STS09	Program Office Support		12
	Headquarters		**$34.0**
HQ01	Systems Engineering & Integration Support		34
HQ02	Auditing Services Tax		0
HQ03	EEE Parts Program		0
	TOTAL INSTITUTION	**5328**	

	Institution JSC		**1662**
CS01	CS Direct Labor & Travel		798
CS02	CS Indirect Labor & Travel		166
CS03	Operation of Installation		698
	Institution MSFC		**749**
CS04	CS Direct Labor & Travel		242
CS05	CS Indirect Labor & Travel		37
CS06	Operation of Installation		470
	Institution KSC		**2197**
CS07	CS Direct Labor & Travel		974
CS08	CS Indirect Labor & Travel		188
CS09	Operation of Installation		1035
	Institution Headquarters		**615**
CS10	Operation of Installation		615
	Institution SSC		**105**
CS11	Operation of Installation		105
	TOTAL PMS	**380**	
PMS01	**MSFC**		**100**
PMS02	**JSC**		**165**
PMS03	**KSC**		**100**
PMS04	**SSC**		**15**
	TOTAL NETWORK SUPPORT	**0**	
NET01	**Tracking, Telemetry, Comm. & Data Processing**		
	TOTAL SYSTEMS ENGINEERING	**1019**	
	MSFC Propulsion Systems Engineering		**248**
	Institutional Program Support		97
SYS01	*Computer/SPO*		*27*
SYS02	*Data Reduction*		*40*
SYS03	*Information Servvices/HOSC*		*24*
SYS04	*Information Services Direct*		*5*
SYS05	*Facilities*		*1*
	Science & Engineering		59
SYS06	*Technical Tasks*		*7*
SYS07	*Mission Operations (EO) HOSC*		*52*
SYS08	Weather Support		4
	General Shuttle Support (Integ. Contractor)		88
SYS09	*Rockwell Prime*		*68*
SYS10	*Administrative Operations Support*		*9*
SYS11	*Small Business (Facility & HOSC Equip)*		*11*
	JSC Engineering Directorate		**545**
SYS12	Engineering Analysis		143
SYS13	Flight Software Support		402
SYS14	**White Sands Test Facility**		**108**
SYS15	**JSC Center Ops**		**67**
SYS16	**Ames**		**51**

Appendix C: Shuttle Operational Data

Table C1: Shuttle Operational Data

Shuttle Operations			Shuttle	
			Head Count	Head Count (%)
Shuttle Processing			**2864**	**20.97%**
Shuttle Processing		Orbiter Operations	1797	62.74%
	Y	*Orbiter Maintenance*	*807*	*44.91%*
	Y	*Orbiter Shop Operations*	*117*	*6.51%*
	Y	*Orbiter Modifications*	*89*	*4.95%*
	Y	*Orbiter Landing Operations*	*107*	*5.95%*
	Y	*Orbiter Processing Support*	*398*	*22.15%*
	Y	*Orbiter Tile Operations*	*279*	*15.53%*
Vehicle Assembly		SRB Operations	251	8.76%
	Y	*SRB Processing Operations*	*75*	*29.88%*
	Y	*SRB Stacking*	*74*	*29.48%*
	Y	*SRB Retrieval & Disassembly Operations*	*51*	*20.32%*
	Y	*SRB Shop Operations*	*25*	*9.96%*
	Y	*SRB Modifications*	*1*	*0.40%*
	Y	*SRB Processing Support*	*25*	*9.96%*
Vehicle Assembly		ET Operations	67	2.34%
	Y	*ET Processing Operations*	*45*	*67.16%*
	Y	*ET Shop Operations*	*5*	*7.46%*
	Y	*ET Modifications*	*2*	*2.99%*
	Y	*ET Processing Support*	*15*	*22.39%*
Launch Operations		Launch Operations	601	20.98%
	Y	*Integrated Vehicle Servicing*	*181*	*30.12%*
	Y	*Integrated Vehicle Test & Launch Ops*	*259*	*43.09%*
	Y	*Launch Operations Support*	*161*	*26.79%*
Payload Processing		Payload Operations	148	5.17%
	Y	*Payload Integration and Support Services*	*148*	*100.00%*
	Y	*Payload Operations Support*	*0*	*0.00%*
Systems Engineering/Support			**171**	**1.25%**
Engineering Support	Y	Engineering Services	62	36.26%
	Y	Systems Engineering	109	63.74%
Facility Operations & Maintenance			**1301**	**9.52%**
Facility Maintenance	Y	Facility O&M Support Operations	235	18.06%
		Facility Maintenance	684	52.57%
	Y	*OPF Maintenance*	*70*	*10.23%*
	Y	*HMF Maintenance*	*21*	*3.07%*
	Y	*VAB Maintenance*	*62*	*9.06%*
	Y	*LCC Maintenance*	*8*	*1.17%*
	Y	*MLP Maintenance*	*95*	*13.89%*
	Y	*Transporter Maintenance*	*26*	*3.80%*
	Y	*PAD A Maintenance*	*135*	*19.74%*
	Y	*PAD B Maintenance*	*147*	*21.49%*
	Y	*SLS Maintenance*	*7*	*1.02%*

	Y	*CLS Maintenance*	*1*	*0.15%*
	Y	*Logistics Facilities Maintenance*	*10*	*1.46%*
	Y	*RPSF Maintenance*	*10*	*1.46%*
	Y	*SRB Retrieval Vessel Maintenance*	*16*	*2.34%*
	Y	*Miscellaneous Facility Maintenance*	*66*	*9.65%*
	Y	*Dredging Operations*	*0*	*0.00%*
	Y	*Processing Control Center Maintenance*	*6*	*0.88%*
	Y	*OSB Maintenance*	*4*	*0.58%*
Launch Operations		Launch Equipment Shops (LES)	109	8.38%
	Y	*Launch Equipment Shops (LES)*	*76*	*69.72%*
	Y	*Decontamination/Cleaning/Refurb/Shops*	*2*	*1.83%*
	Y	*Janitorial Services*	*1*	*0.92%*
	Y	*Corrosion Control*	*30*	*27.52%*
Facility Maintenance	Y	Facility Systems	56	4.30%
	Y	Maintenance Service Contracts	*0*	*0.00%*
	Y	Inventory Spares and Repair	*8*	*0.61%*
		System Equipment	*209*	*16.06%*
	Y	*SE Maintenance*	*209*	*100.00%*
	Y	*SE Acquisition*	*0*	*0.00%*
	Y	*Capital Equipment Procurements*	*0*	*0.00%*
LPS/Instrumentation & Calibration (I&C)			**696**	**5.10%**
Engineering Support		LPS Engineering and Software	158	22.70%
	Y	*LPS Engineering*	*40*	*25.32%*
	Y	*LPS S/W Development & Maintenance*	*69*	*43.67%*
	Y	*LPS Software Production*	*49*	*31.01%*
		LPS O&M	397	57.04%
	Y	*Checkout, Control & Monitor Subsystem*	*168*	*42.32%*
	Y	*CDS Operations*	*66*	*16.62%*
	Y	*Record & Playback System O&M*	*48*	*12.09%*
	Y	*LPS Maintenance/Support Engineering*	*115*	*28.97%*
		Instrumentation & Calibration	141	20.26%
	Y	*Instrumentation*	*101*	*71.63%*
	Y	*Calibration*	*40*	*28.37%*
Modifications			**157**	**1.15%**
Facility Maintenance	Y	OPF Modifications	19	12.10%
	Y	HMF Modifications	2	1.27%
	Y	VAB Modifications	6	3.82%
	Y	LCC Modifications	1	0.64%
	Y	MLP Modifications	4	2.55%
	Y	Transporter Modifications	0	0.00%
	Y	PAD A Modifications	5	3.18%
	Y	PAD B Modifications	4	2.55%
	Y	SLS Modifications	0	0.00%
	Y	CLS Modifications	0	0.00%
	Y	RPSF Modifications	1	0.64%
	Y	Miscellaneous Facility Modifications	10	6.37%
	Y	SE Modifications	6	3.82%

	Y	LPS Hardware Modifications	99	63.06%
	Y	Instrumentation & Calibration Modifications	0	0.00%
	Y	Communication Modifications	0	0.00%
	Y	PAD B Block Modification	0	0.00%
Technical Operations Support			**1019**	**7.46%**
Engineering Support		Safety, Reliability, Maintainability & Quality	282	27.67%
	Y	*Safety*	*108*	*38.30%*
	Y	*Reliability*	*32*	*11.35%*
	Y	*Quality Assurance*	*142*	*50.35%*
		Logistics	218	21.39%
	Y	*Logistics Engineering*	*48*	*22.02%*
	Y	*Systems & Audit*	*13*	*5.96%*
	Y	*Receiving Service Center*	*0*	*0.00%*
	Y	*Supply*	*117*	*53.67%*
	Y	*Transportation*	*40*	*18.35%*
	Y	*Procurement Service Center*	*0*	*0.00%*
Facility Maintenance		Facility/SE Engineering	233	22.87%
	Y	*Systems Integration/Design Engineering*	*165*	*70.82%*
	Y	*Special Engineering Projects*	*35*	*15.02%*
	Y	*Ground Systems Change Control*	*33*	*14.16%*
	Y	*Technical Data/Documentations Service*	*0*	*0.00%*
Flight/Mission Operations		Operations Management	89	8.73%
	Y	*Manifest Planning*	*46*	*51.69%*
	Y	*Flt Element/Mission-Related Change Ctl*	*25*	*28.09%*
	Y	*Configuration Management Office*	*18*	*20.22%*
Engineering Support	Y	Non-IWCS H/W, S/W and Maintenance	6	0.59%
	Y	Launch Team Training System (LTTS) Pgm	22	2.16%
		Integ Work Ctl System (IWCS) Development	169	16.58%
	Y	*IWCS Shop Floor Control Project*	*26*	*15.38%*
	Y	*IWCS Work Preparation Support System*	*17*	*10.06%*
	Y	*IWCS Automated Requirements Management*	*11*	*6.51%*
	Y	*IWCS Computer Aided Schedule & Planning*	*19*	*11.24%*
	Y	*IWCS Project Integration*	*10*	*5.92%*
	Y	*IWCS Operations, Management & Support*	*86*	*50.89%*
Program Operations Support			**430**	**3.15%**
Management		Program Administration	158	36.74%
	Y	*Contract/Financial Management*	*69*	*43.67%*
	Y	*Management Planning & Procedures*	*14*	*8.86%*
	Y	*Team Member Management/Administration*	*75*	*47.47%*
	Y	Training	204	47.44%
		Human Resources	68	15.81%
	Y	*Security*	*67*	*98.53%*
	Y	*Human Resources Service Center*	*1*	*1.47%*
Communications			**327**	**2.39%**
Flight/Mission Operations	Y	Voice Communications O&M	120	36.70%
	Y	Wideband Transmission & Navaids O&M	97	29.66%
	Y	Cable and Wire O&M	45	13.76%

	Y	Communications Support	49	14.98%
	Y	OIS-D Implementation	16	4.89%
Facility Maintenance	Y	**Base Operations Contract (BOC)**	**208**	**1.52%**
Launch Operations	Y	**Launch Support Services**	**350**	**2.56%**
Facility Maintenance	Y	**Weather Support**	**29**	**0.21%**
Payload Processing	Y	**P/L Transportation & Interface Verification**	**318**	**2.33%**
Payload Processing	Y	**P/L Processing GSE Sustaining Engrg**	**60**	**0.44%**
Facility Maintenance	Y	**Spares**	**222**	**1.63%**
Facility Maintenance	Y	**Overhaul & Repair**	**431**	**3.16%**
Engineering Support	Y	**Manpower to Support Logistics, Procurement, Eng.**	**276**	**2.02%**
Facility Maintenance	Y	**Tile Spares & Maintenance**	**153**	**1.12%**
Engineering Support	Y	**GSE Sustaining Engineering**	**29**	**0.21%**
Flight/Mission Operations	Y	**Sustaining Engineering & Launch Spt**	**693**	**5.07%**
Orbiter Support			**408**	**2.99%**
Engineering Support	Y	PICS	2	**0.49%**
	Y	NASA Std Initiators (NSI)	3	**0.74%**
	Y	Pyros, Standard Operations	13	**3.19%**
	Y	RMS-Ops & Support	26	**6.37%**
	Y	RMS-Sustaining Engineering	38	**9.31%**
	Y	RMS-Program Management	14	**3.43%**
	Y	FCE Operations Management	4	**0.98%**
	Y	EMU/EVA Field Support/O&R	10	**2.45%**
	Y	EMU Logistics	10	**2.45%**
	Y	FEPC Tasks	283	**69.36%**
	Y	SSA Provisions (FEPC)	3	**0.74%**
	Y	Parachute Maintenance	2	**0.49%**
Flight/Mission Operations	Y	**Flight Data Support**	**42**	**0.31%**
Flight/Mission Operations	Y	**Orbiter /ET Disconnects**	**31**	**0.23%**
Mission Operations Facilities			**1546**	**11.32%**
Launch Control	Y	Control Center Operations	667	**43.14%**
Flight/Mission Operations	Y	Integrated Training Facility Operations	285	**18.43%**
	Y	Integrated Planning System Operations	71	**4.59%**

	Y	Shuttle Avionics Integration Lab (SAIL)	228	**14.75%**
	Y	Flight Operations Trainer	42	**2.72%**
	Y	Software Production/Software Dev. Facility	208	**13.45%**
	Y	Mockup & Integration Lab	12	**0.78%**
	Y	Control Center Systems Division	21	**1.36%**
	Y	Integrated Planning System Office	8	**0.52%**
	Y	Simulator and Training Systems Division	4	**0.26%**
	Y	STSOC Material	0	**0.00%**
Mission Planning & Operations			**928**	**6.79%**
Flight/Mission Operations	Y	Systems Division	184	**19.83%**
	Y	Ops Division	131	**14.12%**
	Y	Training Division	125	**13.47%**
	Y	Flight Design Division	424	**45.69%**
	Y	Recon Division	64	**6.90%**
Program & Doc. Support/Management			**644**	**4.71%**
Engineering Support	Y	STSOC Support	554	**86.02%**
	Y	Flight Software Support	31	**4.81%**
	Y	Shuttle Data Support	29	**4.50%**
	Y	MOD Directorate Office	30	**4.66%**
Aircraft Maintenance & Ops			**279**	**2.04%**
Maintenance (Other)	Y	T-38 Training Aircraft	159	**56.99%**
	Y	Shuttle Training Aircraft	111	**39.78%**
	Y	Shuttle Carrier Aircraft	9	**3.23%**
	Y	Heavy Aircraft Training	0	**0.00%**
	Y	Astronaut Support	0	**0.00%**
Flight/Mission Operations	Y	**STSOC Flt Crew Ops Directorate Support**	**48**	**0.35%**

Totals	13660	100%

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