A Case Study of the STS Indirect and Support Costs

Lessons to be Learned for the Next Generation Launch System

Zachary C. Krevor
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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

ARC	Ames Research Center
CA	Contributing Analyses
CEV	Crew Exploration Vehicle
COTS	Commercial Off the Shelf
DOD	Department of Defense
ET	External Tank
EVA	Extravehicular Activity
FY	Fiscal Year
GAO	General Accounting Office
GEAE	General Electric Aircraft Engines
GFE	Ground Furnished Equipment
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HRST	Highly Reusable Space Transportation
ISS	International Space Station
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Life Cycle Cost
LEO	Low Earth Orbit
LEM	Lunar Excursion Module
LaRC	Langley Research Center
LRU	Line Replacement Unit
MAF	Michoud Assembly Facility
MCC	Mission Control Center
MOD	Mission Operations Directorate
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
NAA	North American Aviation

NASA	National Aeronautics and Space Administration
OMB	Office of Management and Budget
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
P & W	Pratt and Whitney
RCS	Reaction Control System
RFP	Request for Proposal
SFOC	Space Flight Operations Contract
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
S R & QA	Safety, Reliability and Quality Assurance
SSC	Stennis Space Center
SSMEs	Space Shuttle Main Engines
STG	Space Task Group
STS	Space Transportation System
STSOC	Space Transportation System Operations Contract
TPS	Thermal Protection System
VAB	Vehicle Assembly Building

1.0 Research Goal

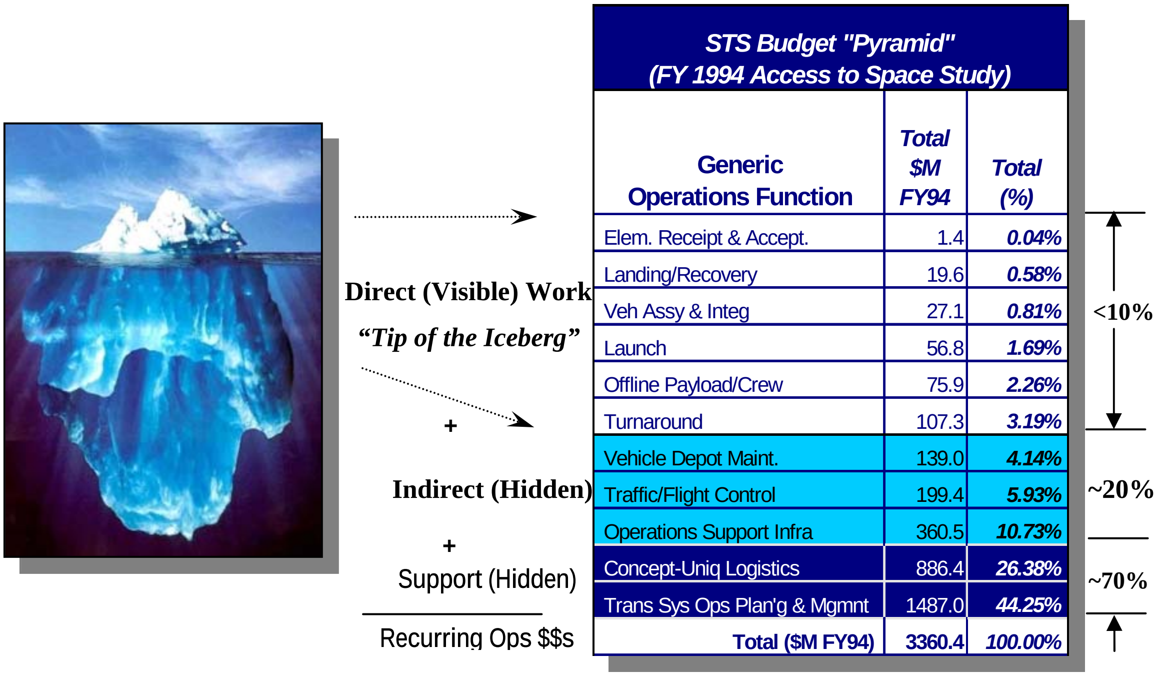
On January 14, 2004, President George W. Bush laid out an ambitious plan to return the United States to the moon. Additionally, he set a course for the future human exploration of the planet Mars. These plans give the National Aeronautics and Space Administration (NASA) a clear mission for its future. Within NASA's new initiative, plans were made to retire the current United States human launch vehicle. The current United States human launch vehicle, the Space Transportation System (STS), was not built to explore any region beyond a Low Earth Orbit (LEO). Therefore, to complete this exciting program, a new launch vehicle system for manned exploration must be developed. The STS program has provided a wealth of information for human launch systems. Knowledge gained from all areas of the STS program must be applied in developing the new human launch system.

For the new space initiative, the cost of the program will be one of the biggest influencing factors upon whether or not the mission plan is carried out. If the costs are deemed too high, the public and the current political climate will kill the initiative. Therefore, in order to achieve this stirring goal of planetary exploration, costs must be factored into every design decision. The effects of a design choice must not only be considered for the development cost, but also for effects on Life Cycle Cost (LCC). This includes any new launch vehicle system that may be developed.

In order to achieve the new initiative, access to space must become cheaper. The current STS program uses approximately one-third of NASA's available budget. In 1994, the year for which the most detailed cost data is available, the STS program budget was over $3.3 billion dollars (FY 1994)[1]. However, approximately 90% of these costs went to indirect and support costs. These areas include program management, logistics sections, and support groups for a wide range of work within the program. The direct operations aspect of the STS program has been studied in great detail. However, these indirect costs have not been examined, and therefore potential savings may exist within these areas. Also, investigating the indirect costs of the STS program will result in important knowledge about how to reduce these costs for the next generation launch system. The lessons learned from this examination will show how far various design choices go towards influencing LCC.

The main goal of this project is to examine the indirect costs of the STS program for cost savings. A more detailed examination of these indirect costs will lead to areas where inefficiency in the program is occurring. Additionally, another goal of this project is to show how design decisions greatly impact the LCC. In the short term, these choices may have aided vehicle performance, but they ended up costing the program more to perform its mission. Another goal of this project is to use the knowledge gained from examining the indirect and support costs to help influence the next generation launch vehicle. It is imperative that costs for this program are kept as low as possible, without compromising safety, in order to achieve the new space exploration initiative.

The inspiration for this project came directly from the work completed by Mr. Edgar Zapata and Mr. Carey McClesky at NASA KSC. They have provided the budget charts for which the main crux of this project is based upon. Figure 1 is the iceberg chart, describing the analogy between an iceberg and the shuttle program. Most of the structure of the iceberg is below water, while most of the shuttle program costs are below the support line. It has been said that for every person working directly on the shuttle, there are between 7 and 10 more employees supporting him or her.



STS Budget "Pyramid"
(FY 1994 Access to Space Study)

Generic Operations Function	*Total $M FY94*	*Total (%)*
Elem. Receipt & Accept.	1.4	*0.04%*
Landing/Recovery	19.6	*0.58%*
Veh Assy & Integ	27.1	*0.81%*
Launch	56.8	*1.69%*
Offline Payload/Crew	75.9	*2.26%*
Turnaround	107.3	*3.19%*
Vehicle Depot Maint.	139.0	*4.14%*
Traffic/Flight Control	199.4	*5.93%*
Operations Support Infra	360.5	*10.73%*
Concept-Uniq Logistics	886.4	*26.38%*
Trans Sys Ops Plan'g & Mgmnt	1487.0	*44.25%*
Total ($M FY94)	**3360.4**	***100.00%***

Figure 1: Iceberg Analogy for STS Program.

2.0 Introduction

The space shuttle program has been the launch vehicle for manned systems in the United States for the last 20 years. Throughout the shuttle's history, it has undergone many fluctuations in budget, various re-structuring efforts, and constant upgrades. The program has also seen large fluctuations in its workforce. These oscillations in the program are a result of the technical challenge of launching humans into space; this task has proved to be a very complex problem.

This paper will first look at the background of the STS program. The shuttle design will be examined to show how certain design choices resulted in its high LCC. Additionally, the role of each NASA center will be considered to show the complexity of the total launch vehicle system. By scrutinizing the role of each NASA field office, possible savings may be realized because of duplicity of roles and responsibilities. Finally, the choice of Johnson Space Center (JSC) as both the lead center for the shuttle program, and for mission control will be looked at to determine its effect upon the program LCC.

The next section of this paper will examine the contractor role within the STS program. The program uses many different contractors. While the main hardware contractors have stayed constant, with some slight changes, big changes throughout the program have been made in the area of operations. In using so many different contractors, there exists the possibility of overlap. This project will further detail the contractor involvement in the STS program, and reveal some areas where cost savings can be created. Additionally, future recommendations for the next launch system will be made based upon how contractors impact the current launch vehicle system.

By detailing the indirect and support costs, important information can be gleaned about how program decisions affect LCC. Five main areas have been identified within the STS program that are counted as indirect and support costs. Those five areas are:

- Systems Management, Operations and Planning
- Concept-Unique Logistics
- Operations Support Infrastructure
- Traffic and Flight Control
- Vehicle Depot Maintenance

This project will inspect these areas inside the STS program. In some areas there are inefficiencies occurring that could probably be reduced. These improvements would help with the LCC. In other areas, initial design choices for the STS program led to costs that cannot be reduced. Yet, with the program being retired by 2010, it is imperative to use all of the knowledge gained from examining these indirect costs for use in the next launch vehicle.

After suggesting improvements to reduce the indirect and support costs, recommendations will be made for future systems. These recommendations will hopefully aid future launch vehicle decisions. Historical trends will be examined to reveal more trends in the indirect and support costs. Finally, possible deviations from the historical method of accomplishing space access will be discussed. There areas include possible ideas such as the complete privatization of launch services, with NASA as strictly oversight organization. Different management ideas will be introduced and a different methodology for designing the next generation launch vehicle will be discussed.

The lessons learned from reviewing the indirect costs must be applied for future launch vehicle systems. The LCC of the program must be kept to a minimum in order to go back to the moon and beyond. To achieve this, the indirect and support costs must be reduced. NASA cannot afford to have its launch vehicle system use one-third of its budget on the way to further space exploration. Additionally, any potential next generation launch system cannot afford to have its indirect and support costs using ninety percent of the available budget. This paper will show where the indirect and support costs are occurring, what can be done to reduce them, and how the knowledge of these costs must be used for recommendations with the future launch system.

3.0 STS Background

In the late 1960s, even with the Apollo project in full swing, the NASA administration began to look towards the future. The success of the Apollo project, and the public support that NASA enjoyed led the administration to dream large. In 1969, the NASA administrator, Thomas Paine, met with then President Richard Nixon to push the expansion of the space frontiers. Paine envisioned a future with an orbiting space station for use as a stopover on the way to both lunar and Martian base stations[2]. The vehicle to accomplish these missions would be NASA's new, fully reusable space shuttle.

The Saturn launch vehicle was developed and used by the Apollo program. While this launch vehicle accomplished its mission with a high rate of success, the cost per launch was very expensive. Each Saturn launch cost $185M in 1970; this translates to a staggering cost of $734M[3] (FY 2004) in today's economy. Additionally, the Saturn was an expendable vehicle, and a new one was used for each Apollo launch. Many advocates of a reusable space program claimed this was akin to flying on a new airplane and throwing it away after each flight. Therefore, NASA decided that a new vehicle, fully reusable, would usher in the post-Apollo era.

Unfortunately, the decade of the 1970s was a turbulent one. The Vietnam War was dividing the country, inflation was soaring, and space began to fade from the public eye. Under budget constraints, the Office of Management and Budget (OMB) cut NASA's budget request by $1B (FY' 70). Plans for exploration bases immediately halted, and concentration was placed on a space station and the shuttle. As the budget reduced further, a transition began towards simplifying the shuttle design. Additionally, the increase of inflation caused NASA to choose between the space station and the shuttle. Since the space station could not be created without the shuttle, the space station program was put on hold. The shuttle program became the main thrust of NASA's effort.

The final orbiter design was created through the combination of NASA needs and the Air Force influence. NASA justified this system with economic estimates that it could capture the launch vehicle market using the shuttle. Initial estimates put the cost per shuttle launch at approximately $10M (FY 1970) [2]. Since current expendables then cost $12M, the shuttle would be used on virtually all space launches. Initially, the shuttle program was on the verge of being deemed to expensive. The OMB looked to cut the shuttle program entirely in 1971, and it was only with the aid of the Air Force that the shuttle program stayed. NASA appealed to the Air Force for support; in exchange, the Air Force would be able to help shape the design requirements. NASA convinced the Air Force that it could complete all future launches using the NASA vehicle. The Air Force had been having its own problems getting its space programs funded, and recognized that the shuttle could greatly aid their agenda. With the Air Force's support the shuttle requirements began to take shape. The Air Force wanted to be able to launch large military satellites into a polar orbit. These satellites could weigh upwards of 40,000 pounds. This requirement translated into a 65,000 pound requirement to LEO on a due East inclination launch. The payload bay would also have to be very large in order to accommodate such large satellites. Additionally, the Air Force wanted the shuttle to have abort capability after a single orbit, and the ability to land back at its launch site; thus, a large cross range requirement was imposed[4]. With the polar orbit requirement, a cross range of 1,000 miles was needed in order to land back at Vandenberg. The orbiter now needed a higher lift to drag ratio than previously designed, and would require greater thermal protection, which led to heavier wings. With the shuttle weight beginning to grow, the boosters also had to grow in size and capability.

Various different shuttle designs were considered. Initial designs from Lockheed included a two-stage, fully reusable shuttle built with all aluminum. With the Air Force influencing the shuttle program, it further recommended the use of aluminum. The Air Force had performed a study that showed the current aerospace industry did not have the tooling needed to fabricate large structures from titanium. NASA and contractors further studied the titanium versus aluminum consideration. These trade studies showed that a titanium shuttle would weigh 15% less than its aluminum counterpart. Titanium could withstand an additional 350°F, and would save in the amount of thermal protection required, in addition to being a lighter material. Yet, titanium carried a greater development risk, and therefore a greater development cost. The full revolution of LCC, and quality from initial design had not yet begun to take root in the United States. The focus during this period of design was on keeping the development costs down. Thus, aluminum was used for the shuttle structure. Many future decisions were also made with low development cost in mind; these decisions would have large impacts on the later phases of the shuttle program.

A new engine had to be developed to meet the requirements of the space shuttle; this engine would become the Space Shuttle Main Engine (SSME). The experience of using liquid hydrogen and liquid oxygen engines to achieve higher Isp levels led to a preference for this fuel. NASA designers wanted an engine to produce 415,000 pounds of thrust, and the Saturn J-2 could only provide 230,000 pounds of thrust. Pratt and Whitney (P & W), plus Rocketdyne emerged as the two competitors for this contract. P & W had working for many years on developing high performance liquid hydrogen and liquid oxygen engines. While P & W focused on developing the turbopumps, Rocketdyne decided to run tests that would demonstrate other features of the SSME design by building a complete thrust chamber: this included the required thrust levels, stable combustion, and the proper chamber pressure. NASA designers then increased the desired thrust to 550,000 pounds to match an increased payload capacity. Rocketdyne demonstrated an initial superior product, since its thrust levels reached 505,000 pounds while P & W only went to 350,000 pounds. Rocketdyne was eventually awarded the contract, although there was a contentious battle fought through auditors that concluded NASA had made a sound decision.

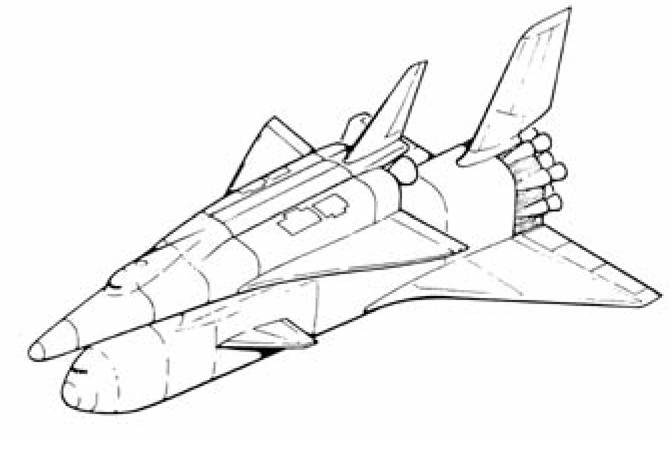


Figure 2: Rockwell Resuable Shuttle Design.

The initial 1st stage booster concepts for the shuttle were large winged vehicles that would fly back to Earth. Rockwell's initial design used 12 SSMEs', and 12 jet engines for use during flyback. However, under the tightening budget due to OMB cuts, the program could no longer fund a completely reusable vehicle. Again, an emphasis in the United States on LCC was nowhere near the levels where it is now; thus, the emphasis was placed on the development cost of the shuttle. Lockheed Martin had already been working on a partially reusable concept. This design would carry the hydrogen in an expendable, external tank. This tank could be aluminum, and would burn up upon entry. The development costs would be reduced, and the orbiter no longer had to carry the bulky hydrogen inside its structure. Additionally, the orbiter weight would be reduced since the hydrogen tanks no longer needed to be thermally protected to the levels required by re-entry. After reviewing this idea, NASA immediately directed Rockwell and McDonnell Douglas, who were also competing for the prime shuttle contract, to consider storing the liquid hydrogen in expendable tanks. The next progression was to realize that the oxygen fuel should also be stored in the expendable tank. Now the orbiter could be smaller and independent of the external tank designs, except for the structural interfaces. With a smaller orbiter, the staging point could occur lower in the trajectory, which would reduce the booster requirement, which would reduce the development cost.

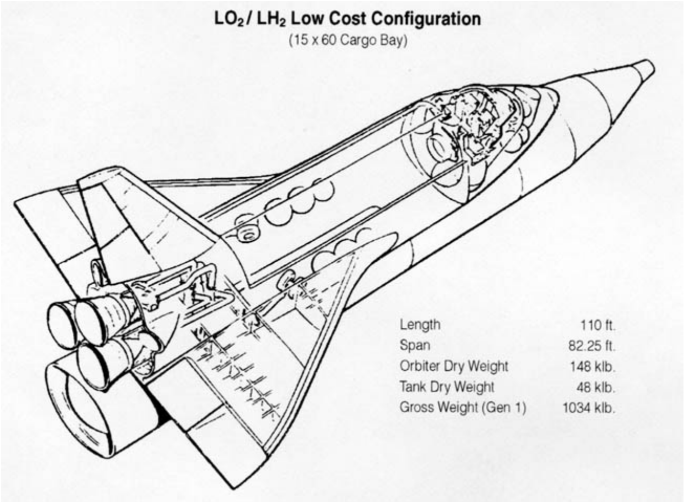


Figure 3: Rockwell Early External Tank Configuration.

While the external tank (ET) was taking shape, a debate was occurring over how to accomplish finishing the booster stage. Martin Marietta began to push its Titan rocket concept, where six solid rocket boosters would surround the external tank. Thiokol, Aerojet, and United Technology were pushing their own solid rocket booster designs. The NASA Marshall Space Flight Center entered with a desire for pressure-fed liquid boosters surrounding the core. However, the OMB continued to press NASA for lowering development costs, and therefore the solid booster design was chosen. The Air Force had experience in building large solid rocket motors with their work on the Titan III, and this further convinced the OMB that NASA should use solid boosters. Additionally, NASA conceded that some boosters may be lost at sea, and solids would be cheaper to replace. Therefore, the OMB appropriated NASA’s shuttle development accordingly for this option.

Once NASA had decided upon the design of the STS, requests for proposals (RFPs) went out on March 17, 1972. Four companies responded: Rockwell, McDonnell Douglas, Lockheed and Grumman. Lockheed had no experience with building piloted spacecraft, and their proposal for the orbiter was heavier than the other three. Additionally, Lockheed’s orbiter would cost $40M (FY ’72) more than Rockwell’s shuttle design. While McDonnell Douglas had built the Mercury and Gemini spacecraft, their review went poorly. They answered questions with vague, general answers, and did not leave NASA’s shuttle review team with a good impression. Grumman and Rockwell had worked together on building the maneuvering portion of Apollo. Yet, Rockwell won the proposal due to a lower orbiter dry weight and a lower development cost. Rockwell’s proposal included the least amount of “man-years” for the shuttle program, and NASA administration officials recognized that this is where true savings would be realized. Rockwell was contracted for the STS program.

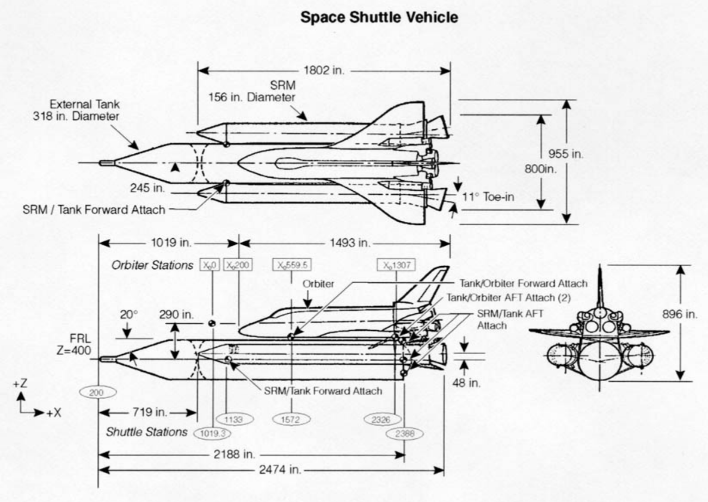


Figure 4: Rockwell's Final Shuttle Design.

4.0 NASA Shuttle Responsibilities

The STS program is split over many different parts of the United States. Six different field centers have some direct contribution to the shuttle program. Several other field centers and Department of Defense (DOD) facilities make contributions. Additionally, many private contractors work in the STS program. This section will explore the responsibilities of each field center, and examine why Johnson Space Center (JSC) was chosen as both the lead center for Shuttle, and the site for mission control.

4.1 Field Center Roles in the STS Program

NASA headquarters, which is located in Washington D.C., controls the various space flight centers and installations that constitute the total NASA program. It has responsibility for determining projects and their direction. Headquarters also shapes NASA policy decisions. They perform design reviews and evaluate the progress of all programs across NASA. Finally, the establishment of management structure, procedures and performance criteria are all completed at Headquarters. The STS program is one program that is monitored directly by this office[5].

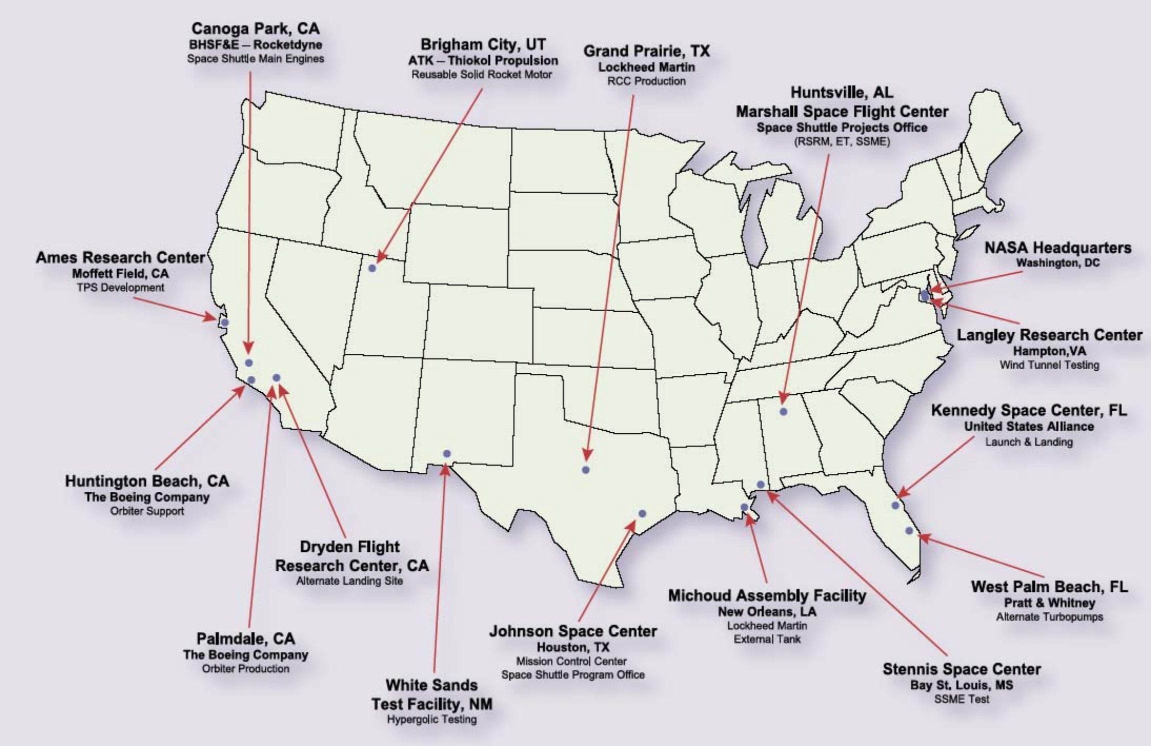


Figure 5: NASA Installations and Prime Contractor Locations.

JSC, located in Houston, Texas, is the lead center for the STS program and the program office for the STS resides here. JSC is NASA's main center for the design, development and testing of manned spacecraft systems. This center had a principal role in the shuttle design: this included the orbiter, payload integration and overall STS program integration. This center is currently "responsible for operational planning, astronaut selection, crew and console operator training, flight control, and control of experiments and payload aboard" the STS. The mission control center (MCC) at JSC runs the flight operations for the shuttle immediately after launch and until landing is completed. JSC also runs the White Sands testing facility, which is responsible for the hypergol propulsion testing.

Kennedy Space Center (KSC), located at Cape Canaveral, FL, is the launching pad for STS missions. KSC was developed in the late 1950s with the specific goal of launching manned spacecraft. Currently, it is the home to the shuttle fleet: Atlantis, Endeavor, and Discovery. KSC is the primary NASA center for test, checkout and launch of manned space vehicles. This center handles the post-processing of the shuttle once it has safely landed. All shuttle logistics, including items such as propellant storage, happen at KSC. Also, KSC operates the facilities which are used for mating the orbiter to the external tank (ET) and the solid rocket boosters (SRB).

Figure 6: STS at KSC Launch Complex.

Marshall Space Flight Center (MSFC), located in Huntsville, Alabama, is in charge of the propulsion aspects of the STS system. This center is known as "rocket city" due to its role in developing launch vehicles for use by NASA. Wernher von Braun, one of the pioneers of rocketry, was at one time director of this center. MSFC has the principal role for providing the ET, the SSMEs, and the SRBs. MSFC operates the Michoud Assembly Facility (MAF) where the ETs' are manufactured. This center also has a key role in the development of shuttle payloads. This includes Spacelab, which is a reusable "modular scientific research facility carried in the Shuttle cargo bay" [5].

Figure 7: Marshall Space Flight Center in Huntsville, AL.

Stennis Space Center (SSC), located near Bay St. Louis, Mississippi, is responsible for SSME and other orbiter propulsion testing. Its large test beds were used for developing the SSME, and continued to be used for developing upgrades. These test beds can accommodate full SSME testing and thus provide an important service to the STS program.

Figure 8: SSC SSME Test Bed.

Another NASA center that provides support for the STS program is the Goddard Space Flight Center (GSFC), in Greenbelt, Maryland. This is the primary facility for tracking and communicating with the Shuttle. Goddard is in charge of maintaining relations with the various tracking stations around the world that are used during a shuttle mission. GSFC also operates the Wallops Flight Facility, which is a small launching pad that performs a variety of research missions.

Both the Ames Research Center (ARC), located near San Jose, California, and the Langley Research Center (LaRC), provide support for the STS program. ARC provides support through wind tunnel testing and thermal protection system development. LaRC is the primary research facility for structures and materials. It is at LaRC that the landing gear for the shuttle is tested. In addition, LaRC also performs aerothermodynamics analysis for space vehicles and preliminary aerodynamics research.

The DOD is another agency that provides support for the STS program. This support is provided by the "Air Force Space Division" located in California. This division would be the primary "contingency support for the Space Shuttle in the event of an emergency landing". Additionally, the Space division designed a second launch complex at Vandenberg Air Force Base in California. Initially begun in 1966, but canceled three years later due to cost overruns, this shuttle complex never developed into the launch site foreseen by the Air Force. In 1979, $4B was injected to finish development, but following the Challenger accident, NASA and the Air Force decided to consolidate and focus launch operations solely at Cape Canaveral.

4.2 JSC as lead STS center

JSC has held the title of lead center for the STS program for virtually all of the program's lifetime. A break did occur after the Challenger accident, which will be discussed later, but JSC was eventually restored to lead status once again. Using this lead center style of management has wide ranging effects upon the STS program. There has been debate within NASA about whether the lead center arrangement is the most optimal for managing a large program. However, the tradition of lead center management dates all the way back to NASA's predecessor, the National Advisory Committee for Aeronautics (NACA)[6]. LaRC was typically the research lead in cross center projects, while Lewis Research Center and ARC took more of a secondary role. Thus, a precedent had been set to which the NASA administration was accustomed.

JSC was created in 1961 as the Manned Spacecraft Center (MSC). This was to be the new home for the Space Task Group (STG), which was the precursor to the official human spaceflight program at NASA. This group was initially formed at Langley in conjunction with the formation of NASA, which was a direct response to the Soviet launch of the satellite Sputnik. The United States administration could not believe that the country was now second to the USSR in terms of space technology. The U.S. also feared what kind of military capabilities the USSR might also be able to launch in space. Thus, NASA was created, and charged with the future of the U.S. space program. Once NASA began officially functioning on October 1, 1958, one of the first orders of business was to organize the Space Task Group.

This group was formed at Langley, and initially did not have a good course of action. The public and many officials in government did not believe that the American response to Sputnik should be to put an "American in space". However, under the effective leadership of former President Lyndon B. Johnson (for whom the Houston facility is named after), who was a senator at the time, the public and government was quickly convinced of the necessity for human space travel. During this period, the STG immediately began to come up with ideas for a manned launch. The group went to meet with Wernher von Braun and his associates at MSFC to discuss this plan further. After consulting with von Braun and his team of engineers, the preliminary designs for what would later become the Mercury project were completed. NASA administration quickly realized that the STG would need a new home.

While operating at LaRC, the STG reported directly to NASA headquarters. Some within LaRC wanted to keep the STG at LaRC, but make them operate within the center. NASA administrator James Webb believed that STG should be its own entity and thus began a study of where this group should work. Friction had begun between STG and other researchers at LaRC due to the fact that STG did not report directly to LaRC management. GSFC initially believed that they should receive the new group, but this transfer was quickly ruled out due to a lack of facilities. Others in the NASA administration believed that ARC should be the new home of STG. This would provide better contact with the eventual contractors for Mercury, and provide an easy way for both NASA and the contractors to help create the Mercury project. Webb eventually decided that a new facility should be created for this group. A task force was created to study possible sites for the new MSC. The initial location that was chosen was Tampa, Florida. The conditions for choosing a site included both flight test facilities, and large tracts of land. Tampa had both, with an Air Force base that was due to close. However, two months after the study was completed, but before a final decision had been made, the Air Force decided to keep the base in Tampa open. The second choice for the MSC was Houston, Texas. Houston also had an Air Force base, Ellington, but this base had not been used since World War II. Additionally, Rice University immediately recognized the benefits of having a science organization in their "backyard", and agreed to donate 1,000 acres of land. Finally, whether or not political pressure was truly applied, it definitely helped Texas that Senator Johnson, leading the charge for human space exploration, was also from Texas. The Representative in charge of Appropriations, and therefore NASA's "purse", was from the Houston district. All of these factors led to the creation of the MSC in Houston, Texas.

Figure 9: Original Area for JSC Development.[7]

While the MSC was being constructed, STG remained the lead center for the Mercury program. After the facilities were constructed, the center immediately became the lead for the Gemini, and Apollo missions. Development on these last two programs had begun before the finish of construction at MSC due to the push by President John F. Kennedy, who further defined NASA's mission when he declared that the United States would be headed to the Moon. All three manned programs operated out of JSC. Thus, when time came for the development of the STS program, it seemed only natural that JSC remain as the lead center. Headquarters also designated JSC as the lead for negotiations with the contractors, which further entrenched JSC in this role. Finally, the American public had become used to the astronauts as the face of NASA. The astronauts operated out of JSC, and thus the public viewed this facility as the proper center of manned spaceflight.

Figure 10: Aerial View of JSC.

As the budget in the 1970s began to dwindle, Headquarters wanted to keep staffing at their location to a minimum, probably due to the fact they were so visible to Washington. This further entrenched JSC as the lead center for shuttle operations. The lead center style of management was thought to be the most effective use of resources in this budget slashing era. Headquarters would still control the major milestones, but MSC had direct program management responsibility. Both KSC and MSFC would report to MSC (which did “rankle” a few employees at MSFC). Integration panels were created for each center, which all reported to the Systems Integration Office at JSC. MSFC was designated lead center for developing the propulsion systems, while KSC was in charge of designing and directing the launch and recovery facilities.

JSC would stay as the lead center for the STS program until the Challenger accident. It oversaw all the initial launches and successes of the program. However, the

Challenger accident led to internal reviews, which revealed flaws within this management structure. Headquarters took control of the STS program office, and reorganized the STS structure accordingly. JSC had lost some stature with headquarters and in the public eye due to the Challenger accident. Furthermore, crew systems and flight capsule development were transferred to MSFC. This structure was relatively constant until NASA administrator Dan Goldin shook up the NASA organization with the "faster, better, cheaper" mantra and style. Goldin, in 1996, decided that JSC should once again be the lead center for the STS program. In trying to cut costs from NASA's budget, he also believed that the lead center management style was the most cost effective for the STS program. This was part of a general move of all program management responsibilities to the NASA field centers[8]. Once again JSC would have authority over the funding and management of Shuttle activities. MSFC did not like the new arrangement, and others in the administration wondered why the shuttle should return to the flawed management structure of before. No mishaps had occurred while the STS program was under the watchful eye of Headquarters, but the transfer was completed nonetheless.

As will be seen later, the structure of the STS program has many influences upon the LCC of the program. While some benefits are realized from removing Headquarters from day to day operations of the Shuttle, a lead center with multiple other responsibilities outside of the STS program can result in overlap of responsibilities. JSC is also in charge of the International Space Station (ISS) program and must devote many of its resources to successful operation of that program. In addition, overlapping responsibilities can occur within the program if the center roles are not truly defined. One example is how both JSC and KSC operate flight operations. KSC is in charge of the launch operations until the shuttle clears the tower; then JSC is responsible for flight operations until the STS program is on the ground again. Yet, exactly where each of these centers takes over their role is not completely defined. Obviously, once in orbit, JSC has complete control of the shuttle; however, both KSC and JSC will monitor launch and landing operations. The choice of how this occurred, and why JSC was also designated the site for the MCC is the discussion of the next section.

4.3 Mission Control Center Development

For the first manned spaceflight program, the Mercury project, KSC had initial flight control operation with the flight monitoring systems located at GSFC. The Cape Canaveral launch facilities, which started with missile development and testing, were turned over to NASA by President Eisenhower in 1959. During the development of the Gemini and Apollo programs, the NASA administration quickly realized that a new, state-of-the-art MCC needed to be built. KSC immediately thought that this should be built at their site in Florida. They claimed intimate flight operation knowledge because they were already used to operating the flight controls for project Mercury; although this operation did not require much after the launch of the spacecraft since Mercury was a non-maneuvering vehicle. However, communications at the Cape were a source of controversy and politics. There was an ownership question about who controlled the current networking existing at the Cape. The DOD insisted that they owned the cabling inside the fences, while Radio Corporation of America said they carried the cable to the fence itself. Also, NASA employed three different telephone carriers that could not agree about how to construct new cable for the Cape. Meanwhile, both Gemini and Apollo program directors were clamoring that MCC should be at JSC. With MCC at JSC, it would put the flight controllers in direct contact with the design engineers of each program. NASA also realized that through the use of new networking technology, they could build a MCC virtually anywhere. JSC became the choice for a brand new MCC center. However, with the construction of new facilities for the Saturn launch vehicle at KSC, a new control center was also built for monitoring launches.

JSC has monitored flight operations since Gemini IV. Other center participation included KSC who provided backup services for launch and trajectory, and GSFC continued their involvement with vehicle tracking. The MCC was very busy throughout the Gemini and Apollo programs, with constant launches and monitoring. With the advent of the shuttle program, MCC would be the focal point of flight operations for that vehicle. There was no incentive to adjust, plus the STS program was worried about keeping itself afloat. However, as will be seen later, the choice of MCC at JSC has led to overlaps within the STS program that should be evaluated for the next generation launch vehicle.

Figure 11: MCC at JSC.

5.0 STS Contractors

Throughout the history of manned space flight, NASA has consistently used the help of private industry to accomplish its missions. From the project Mercury, to the ISS, private contractors have had a hand in developing human spaceflight. For the early projects, NASA engineers had most of the experience due to their research work for NACA. There was very little turnover in NASA during the early years, and thus a great deal of expertise existed at the organization. With their hands-on experience through previous research, NASA engineers were able to effectively manage and guide the contractors to the final design of the project. The NASA engineers were collaborators with the private contractors, rather than simply purchasing hardware. This situation changed as industry gained more experience, and dwindling budgets within NASA caused greater turnover. By the time of full scale development of the STS program, NASA had already undergone major personnel changes and losses. The relationship with contractors moved towards a more traditional role of buying hardware. However, with program management for STS in NASA hands, NASA engineers still played a major role in defining the hardware designs. This section will examine the use of contractors through history, and examine the contractor situation as it has changed for the STS program.

5.1 Contractor Use in Manned Spaceflight History

For the first human spaceflight, project Mercury, the competition for the prime contract came down to Grumman Aircraft and McDonnell Aircraft. This was the contract to build the capsule that the astronauts would fly in. At the time, Grumman had many Navy projects it was working on that were only in the conceptual phases of their design. NASA was worried about both scheduling conflicts and the priorities of Grumman, and awarded the prime contract for the capsules to McDonnell Aircraft. The initial contract for twelve space capsules was worth $18.3 M (FY ’59), with a fee of $1.15M (FY ’59)[9]. However, costs quickly spiraled up due to the combination of an optimistically low bid and more requirements that were added, such as a request for spare parts. Additionally, each of the capsules delivered was unique and tailored for the specific mission.

McDonnell eventually included some 4000 suppliers, 596 direct sub-contractors from 25 different states, and 1500 second-tier subcontractors. As alluded to earlier, NASA engineers and McDonnell worked closely together. STG drew up the original fifty page document for its ideas of what the final capsule design should look like. Included in this document was a great amount of detail and some fifteen different subsystems. Thus, it would be up to the McDonnell production engineers to expand on these preliminary specifications and flesh out the design. They made the blueprints, and also designed the tooling necessary to turn the capsule design into a piece of hardware. After much collaboration with STG, McDonnell delivered their first capsule on April 1, 1960. Though it was stripped of many of its subsystems, this delivery showed that the Mercury project was truly on its way toward launching a human into space. The final capsule cost for the delivered twenty vehicles was $45.6M (FY '59).

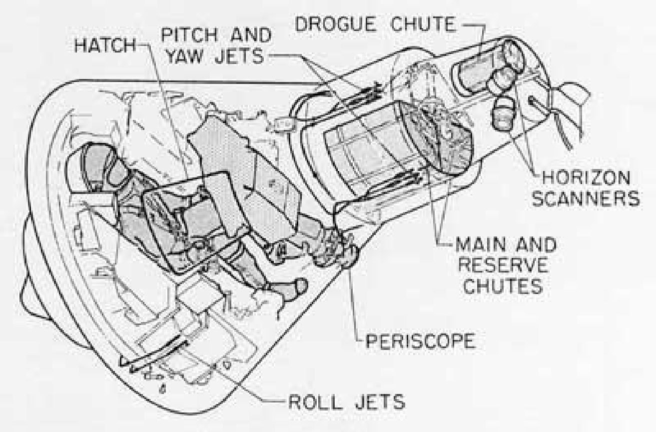


Figure 12: Mercury Capsule delivered by McDonnell.[10]

The next manned spacecraft, project Gemini, was originally seen as an extension of the Mercury program, except that the capsule would now carry two people. Since the project was to be the same concept as Mercury, NASA decided that no competitive bidding was required and the contract was awarded to McDonnell Aircraft again. With Mercury still going at the time, the initial parameters set the contract ceiling limit as $25M (FY '61) with further cost parameters to be determined later. In the initial contract, NASA told McDonnell to use equipment that had already been developed. This is an early example of engineers realizing the benefit of using commercial-off-the-shelf (COTS) parts[11].

For the launch vehicle, NASA decided that the Air Force should be included in some manner for this project. Therefore, they decided to "contract" the Air Force for the launch vehicle systems. The Air Force was to provide the fifteen Titan II launch vehicles and eleven Atlas-Agena target vehicles required for the program. The Air Force in turn contracted out Martin-Baltimore for the Titan and Lockheed Missiles and Space for the Atlas-Agena. The DOD was contracted out to provide launch and recovery support, plus aid in choosing the astronauts for the program. Including the Air Force added another layer of management to the program. MSC could only set guidelines for launch vehicle development; if they saw a problem, the procedure was for them to tell the Air Force, which would then tell the private contractors. Also, since MSFC had already been working on the Agena vehicle, NASA administration decided that MSFC should be in charge of those vehicles. Thus, for changes in that program, MSC had to first tell MSFC, which would then tell the Air Force, who would then tell Lockheed of the new business. MSC completed its first down payment for the Atlas-Agena vehicles in March of 1962, but the Air Force did not tell industry to begin work until a full two weeks later.

Many contractors, sub-contractors and vendors would be used for this program. Over 200 of them had contracts worth $100,000 (FY '1966) or more[12]. Even though this project was building upon Mercury, and was supposed to use COTS, the first system was delivered to the launch site over a year late. The project ran into budget, design and communication problems which caused this delay. The final spacecraft cost for the total Gemini capsules was $696M (FY '67).

Figure 13: Gemini Spacecraft.

The last manned spacecraft to launch from Earth before the STS launches began was the Apollo capsule. This program was large and very challenging technically. Many contractors and vendors would come together to work on this program. The prime contract was to build the command module, the service module, an adapter and the ground support equipment. Four contractors came back with proposals for the program. The final choice was not without controversy as the Martin Company came back with the highest rated overall score, which was a combination of three categories: technical approach, technical qualification, and business[13]. North American Aviation (NAA), which would later merge with Rockwell Corporation, had the highest technical qualification score. Additionally, NAA had worked with NASA/NACA before on projects such as the X-15 and Navajo. NASA administration chose NAA due to the fact that they had worked with them before. However, word had leaked out that Martin Co. had received the highest total score, and NASA administration had to answer before Congress about why NAA was chosen for the contract.

There were many other contracts to be awarded for this ambitious program. Grumman Aircraft was give prime contract for the Lunar Excursion Module (LEM). They in turn used six major subcontractors. The launch vehicle was to be developed from the Saturn program, for which MSFC would be in charge. Rocketdyne was the contractor for the new engine, while Douglas, P & W, Convair, Chrysler and others were used on the rest of the vehicle. The Saturn V, which would launch the Apollo astronauts, used three separate stages. The first stage was contracted to Boeing, while Rockwell received the second stage and Douglas the third. Apollo culminated with 15 manned launches, and six successful moon landings. The use of contractors throughout such a large program set the precedent for the STS vehicles.

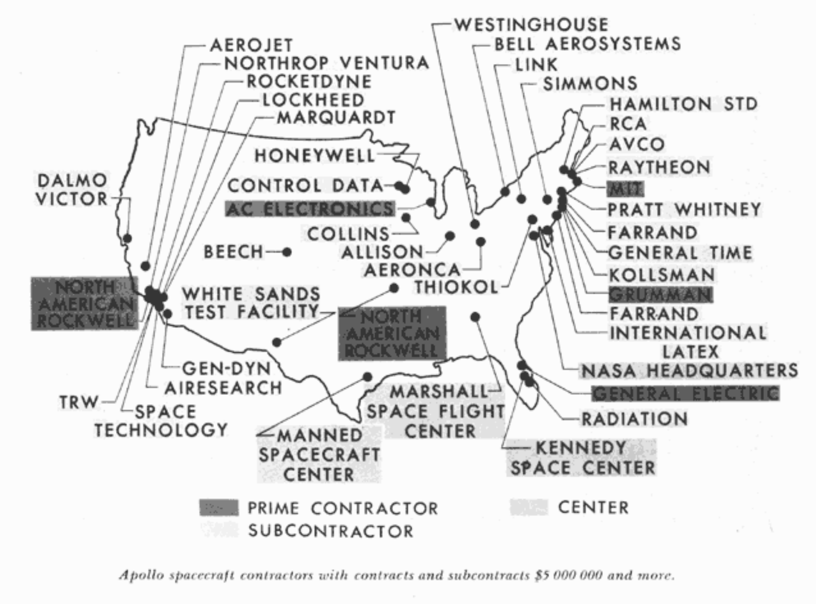


Figure 14: Apollo Contractors and Physical Locations.

5.2 The STS Contractors

The STS program uses many different contractors throughout its structure. As mentioned earlier, Rockwell, which eventually merged into Boeing, held the prime contract for developing the orbiter. Rocketdyne, which merged with Rockwell, was the prime contractor for the SSMEs. This section will further detail the prime contractors for the STS program, list a few subcontractors, and show a breakdown of the contractor structure in 1994. Again, 1994 is used because of the detail of the data that was found for this year. The dollar amount and private workforce of each contractor is listed in Table 1; this table lists the contractor full-time equivalent of an employee. Figure 15 illustrates the percentage of the STS program budget that goes to each contractor.

First, under the MSFC are the various hardware contractors. Rockwell Rocketdyne, in conjunction with P & W, is the developer in charge of the SSMEs. These engines are built and tested in various parts of California, Mississippi, and Florida. Two of the subcontractors involved with this project are Honeywell and Hydraulic Research. Lockheed Martin is in charge of the ET. They perform all designs and assemblies of the tank. This tank has almost half a million parts and is produced at the MAF. Some of the sub-contractors that work for Martin Marietta are Kaiser Aluminum, Reynolds Metals, GE, and Grumman. Thiokol and USBI perform the work required for the SRBs. Thiokol

Table 1: 1994 Prime Contractor Breakdowns.[14]

	Contractor	Function	$M (FY '94)	Contractor Workforce
MSFC	Rocketdyne	SSME	$287	2018
	P & W	SSME	$85	334
	Martin Marietta	External Tank	$372	2635
	Thiokol	Reusable Solid Rocket Motors	$404	2589
	USBI	Solid Rocket Boosters	$152	1024
KSC	Lockheed	Shuttle Processing Contract	$533	6309
	Rockwell	Orbiter Logistics	$199	1340
	EG & G	Base Operations	$38	520
JSC	Rockwell 1	Orbiter Production, Ops/Launch Support, Spares (Orbiter Project)	$288	1803
	Rockwell 2	System & Ops Integration (Program Office)	$151	699
	Rockwell 3	Space Operations Contract (Mission Operations)	$264	2214
	Loral 1	Flight Software Development	$35	280
	Loral 2	SR & QA	$20	251
	Loral 3	Mission Support Contract (MCC Dev)	$21	170
	Lockheed	Engineering, Test & Analysis	$39	490
	Krug	Medical Sciences	$4	39
	Kelsey Seybold	Medical Sciences	$1	13
	Johnson Eng.	Flight Crew Support	$12	120
	Ham Std.	EVA	$25	119
	SPAR	RMS	$13	60
	Boeing	Flight Equipment Processing	$35	333

is responsible for the design, manufacturing and testing of the solid rocket motors (SRM). They perform testing at their facilities in Utah. Thiokol is also a major sub-contractor for Lockheed Space Operations. They perform many portions of the Shuttle processing work, “including inspection, assembly and checkout of the [SRBs] and [ET]”. Additionally, Thiokol also aids in recovering, performing disassembly, cleaning,

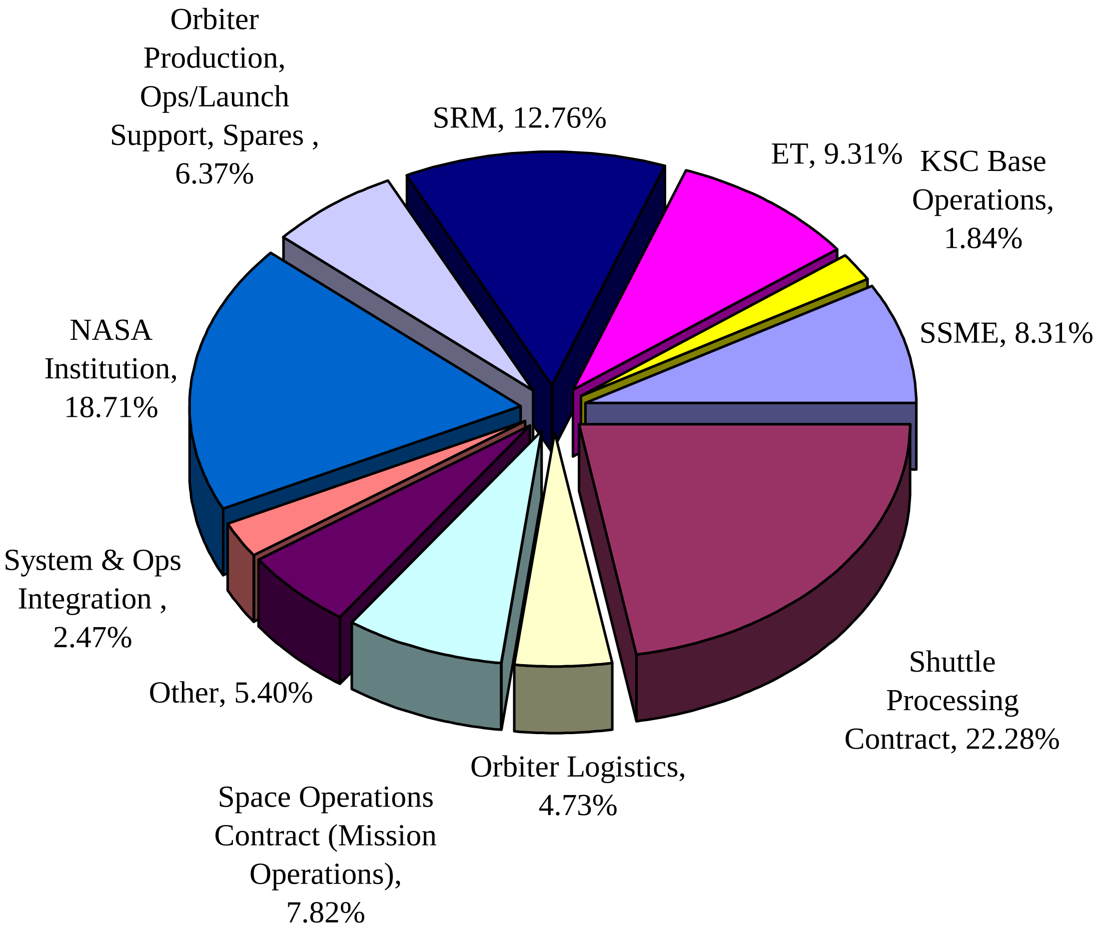


Figure 15: 1994 STS Contractor Percentage Breakdowns.[14]

Figure 16: Thiokol SRB Testing.

inspecting, and refurbishing the boosters. USBI is in charge of processing and refurbishing the non-motor segments of the SRBs. USBI directly refurbishes the frustum, plus the forward and aft skirt of the SRB. It also rebuilds the thrust vector control system. USBI has also developed an efficient logistics system that helps manage over 70,000 required parts; this system is also copied for use on the ISS. Furthermore, USBI performs many activities at the SRB Assembly and Refurbishment Facility at KSC. These functions include replacement of insulation on the booster components, installation of electronic and guidance systems, and installation of the parachutes.

At KSC in 1994, there were only three main contractors. However, the largest contractor, Lockheed, held the biggest single contract within the STS program. This Lockheed contract was for their Space Operations division. They were responsible for all ground processing of the shuttle fleet at KSC. Their overall responsibility for shuttle processing included operation of all the main facilities. These facilities include the Orbiter Processing Facility (OPF), the Vehicle Assembly Building (VAB), and the Orbiter Refurbishment and Maintenance Facility. Lockheed Space Operations also maintains both shuttle launch pads: Launch Complexes 39-A and 39-B. Two more facilities that are maintained within this contract are the logistics facility and the hypergolic maintenance facility. Lockheed also provides services in support of the shuttle at Vandenberg Air Force Base.   Among the sub-contractors supporting Lockheed are Thiokol, mentioned earlier, Grumman Technical Services, Johnson Controls, Rocketdyne, USI, and EG & G.

Another contract operating out of KSC is for orbiter logistics by Rockwell. Since Rockwell manufactured the orbiters', this contract is appropriate for the base. At KSC, Rockwell is involved with the integration of the Shuttle system, and helps to maintain the technical integrity and configuration of the orbiters. Rockwell also provides logistic support.

The last prime contractor shown above that operates out of KSC is E G & G Florida: they are NASA's base operations contractor for the Cape. They are responsible for the operation of the utilities, maintenance of the facilities, administrative services and technical operations. They are also the technical support for KSC computers and data processing. Finally, E G & G is responsible for fire protection and security.

With the program office at JSC, most of the contractors in the STS program are centered here. Rockwell occupies the largest amount due to its direct responsibility for building the orbiter. It is through the JSC office that Rockwell manages production of spares, and systems integration. Rockwell also helps support customer integration through JSC. The MCC is operated by Rockwell employees; they are responsible for the flight operations of the shuttle. Rockwell has numerous sub-contractors working for them including SAIC, Honeywell and Allied Signal.

Another contractor who supports the MCC is Loral systems. They are responsible for much of the software used by the STS program. Three separate contracts exist for Loral: one for upgrades and development for the MCC, one for software for the shuttle, and finally a contract for safety, reliability and quality assurance (S R & QA). Loral uses the sub-contracting team of IBM, Syscom Development, GHG, Cimarron Software, and Booz-Allen, in addition to others. Other direct contractors at JSC include Hamilton Standard for the space suits, SPAR for robotic arm development and support, and Johnson Engineering for flight crew support.

In 1994, there were many different contractors operating out of the three main field centers that worked on the STS program. JSC was managing 86 different contracts with over 56 direct contractors. With budget cuts looming, and the belief that overlapping responsibilities were plaguing the STS program, this region of NASA was seen as an area for which costs could be improved. Over 28,000 employees, including contractors and civil service workers, were charging to the shuttle. Various studies were performed on the STS program, including the "Functional Workforce Review", which suggested that NASA could reduce its STS workforce by 13% without compromising safety. In 1995, the "Kraft Report" was published that made various claims such as the STS as a mature system. This report advocated drastic changes within the STS program, such as consolidating "operations under a single entity" [8]. NASA's independent safety committee, the Aerospace Safety Advisory Panel, strongly disagreed with the Kraft conclusions and rebuked it sharply. Additionally, many engineers within NASA felt that the STS program was headed back towards the days of the pre-Challenger era and began to voice their concerns. However, during this time period under the Clinton administration, the government as a whole was looking for ways to reduce bureaucracy.

Goldin, the sitting NASA administrator, thought favorably upon the idea that NASA could lead the way towards implementing the President's vision. Thus, the Kraft report's recommendations were implemented, and NASA issued a contract for the prime Shuttle operations. This contract would be wide ranging, and worth a large sum of money per year. Rather than take their chances alone, both Lockheed and Rockwell teamed up to form a new company, with each having a 50% stake. This new company, United Space Alliance (USA), won the sole source contract in 1995, and a new era in Shuttle operations was ushered in.

5.3 United Space Alliance

USA was awarded the contract based upon their experience and wealth of knowledge. In actuality, it is doubtful that any other companies could have truly competed for this contract, which became known as the Space Flight Operations Contract (SFOC). The contract was split into two phases. Phase I duties included:

- Flight operations
- Mission design and planning
- Software development and integration
- Payload integration
- Logistics operations
- Astronaut and flight controller training
- Shuttle processing, launch and recovery

Figure 17: Dan Goldin announcing USA's Partnership with NASA.

Other companies submitting bids would know that if they won, they would have to purchase much of the infrastructure that was put into place by both Rockwell and Lockheed. Additionally, maintaining the orbiter would have become a big challenge to any outside company because of its technical complexity. Regardless, USA won the contract and became responsible for 61% of the shuttle operations. While some in Congress had reservations about safety integrity, the contract was pushed through and completed.

USA believed they could cut shuttle operating costs between $500M and $1B per year (FY '95). They would accomplish this through streamlining operations and reducing personnel even further. At the time of formation, once the organization had been completed, the number of employees in USA was 9,900. The total NASA STS workforce at this time was just under 20,000.

The complete savings under USA never fully materialized as initially estimated. Although exact savings for the program are difficult to ascertain, one estimate has put them at $167M per year. Unfortunately, these estimates have never been verified by the General Accounting Office (GAO)[15]. The full cost savings were supposed to be realized from the completion of Phase II responsibilities: these responsibilities included transferring the control of the MSFC contracts for the main shuttle hardware over to USA. Yet, MSFC managed to successfully resist this turnover and USA's complete streamlined approach would never be implemented.

5.4 Current Prime Contractor Breakdown

The STS program currently has about 92% of its total program budget earmarked for contractors. A breakdown of the contractors is shown in Figure 18. USA operates the largest part of the shuttle program. Boeing, which bought Rockwell, and therefore Rockwell's share of USA, is now responsible for the orbiter itself. Lockheed Martin purchased Martin Marietta, and is now responsible for the ET. Compared to 1994, NASA has been further removed from the STS program. MSFC is still in charge of the big hardware contracts for the shuttle, with the exception being the SRB non motor segment. That portion has been taken over by USA.

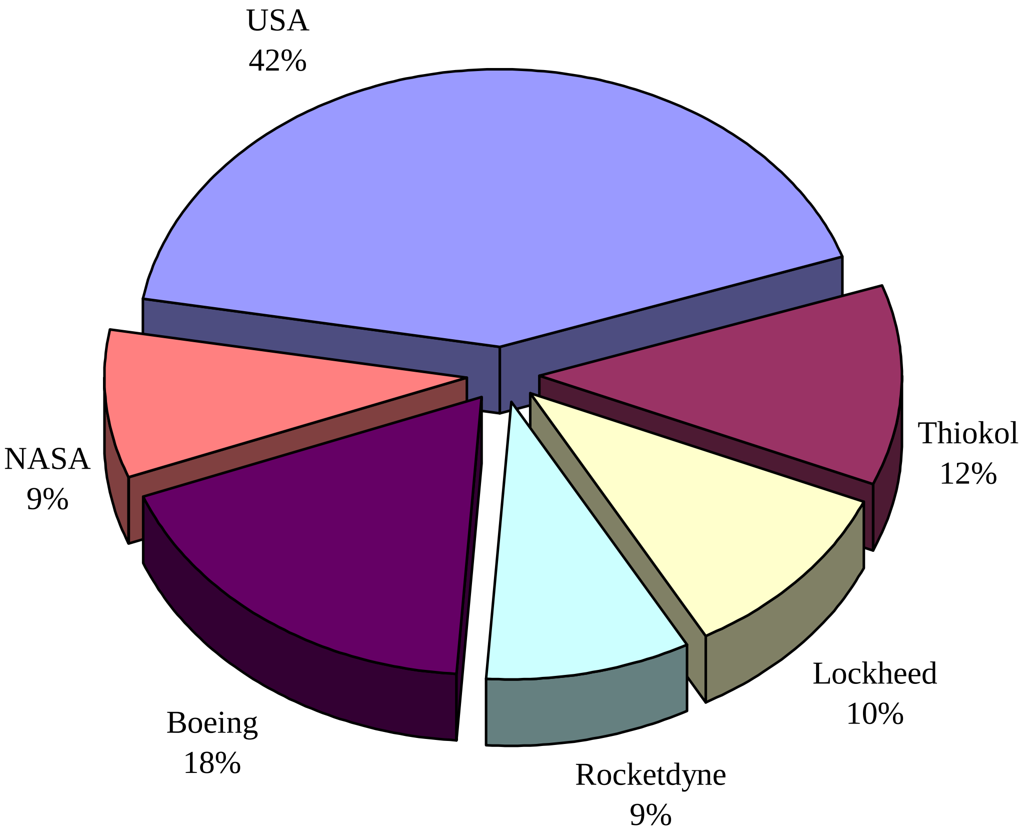


Figure 18: Current STS Breakdown.

While the move towards privatization has reduced costs of the STS program, there is still room for improvement. With MSFC resisting the transfer of contracts for further consolidation, cost savings may be missed. However, NASA admitted that they had not performed a true cost benefit analysis with regards to full consolidation of the contracts[16]. NASA simply believed that full consolidation of the contracts under a sole entity would produce savings. While this did agree with the Kraft report findings, that report was a source of controversy within NASA. Additionally, only one center, JSC was ever considered as the source for full consolidation. Without a true cost benefit analysis, that considered all options, NASA could not be entirely sure of how much the STS program could be further reduced by consolidating the contractors.

6.0 Breakdown of 1994 Shuttle Costs

In this report, the most detailed data about the workforce and cost was obtained from a 1994 study of the STS program. The program has changed quite a bit since that time, and the latter portions of this project will reflect that. However, this data will be used to lay a foundation for why the STS program has such a high cost. Examining the STS breakdown will also lead to ideas and plans that could result in cost savings to use for the current structure.

As mentioned earlier, five main areas were designated as indirect and support costs. These areas charge the STS program, yet do not work directly on the orbiter itself. Each segment will be broken down into various sub-sections to show which functions of the STS program are responsible for the high cost. Through an examination of each of these sections, this project will show why such a high cost occurs, and later reveal possible solutions for the current STS program and future manned spacecraft.

Each of the five areas of indirect and support cost can be broken down further into eleven sub-regions. These eleven sub-regions are as follows:

- Program Integration, Program Management, & NASA Institution
- Launch and Landing
- Solid Rocket Motor Project
- ET Project
- Orbiter Project and Logistics
- Mission Operations (JSC)
- SRB Project (MSFC)
- SSME Project (MSFC)
- Crew Operations and Training (JSC)
- Payload Support (KSC)
- Propellants (Cryogenics-KSC)

These sub-regions are mostly self-explanatory. The program integration category refers to NASA management, administration and indirect support people that aid the STS program in general. The propellants category only refers to the actual propellants and not any of the support or facility cost that may be associated with it. These eleven sub-regions will be used as an insight into the indirect and support costs of the STS program

6.1 Systems Management, Operations and Planning

This category of the STS program is responsible for a whopping 44% of the total program cost in 1994. Throughout the shuttle program, there is a lot of management and institution support that directly charges this area of NASA. Of the five indirect and support cost regions, this area has the most man-hours being utilized. The top-level functions of this area are defined below[17]:

- Customer relations
- Vehicle manifesting and scheduling
- Ground systems scheduling and management
- Software production (upgrades and mission unique)
- Personnel management
- Sustaining operations engineering (vehicle and facilities)
- Work control
- Public affairs
- Economic development
- Business management (contracts, procurement, legal, financial)
- Advanced planning
- S R & QA

Table 2 lists the breakdown of cost of each sub-region under the Systems planning and management category. Figure 19 provides the breakdown of this category into its eleven sub-regions using percentage values. As can be seen from both the table and the chart, NASA management and institution costs are the biggest region from this category. In the 1994 STS workforce breakdown[18], as can be seen in Appendix A, NASA institution has over 5000 employees who are charging the STS program under this category. All of these employees are civil servants who work directly for NASA. Within the institution heading, the workforce is further broken down into the field center and the number of employees that fit within one of three categories: direct labor and travel, indirect labor and travel, and operation of installation. With JSC as an example, the

Table 2: Systems Management Breakdown.

System Planning & Management: Sub-Regions	$M (FY '94)
Program Management & NASA Institution	860.8
Launch & Landing	192
Crew Operations & Training	71.8
External Tank	31.4
Orbiter Project & Logistics	25
Mission Operations	135.4
Solid Rocket Boosters	52.1
Solid Rocket Motors	67.2
SSME	51.3
KSC P/L	-
KSC Propellants	-
Total	**1487**

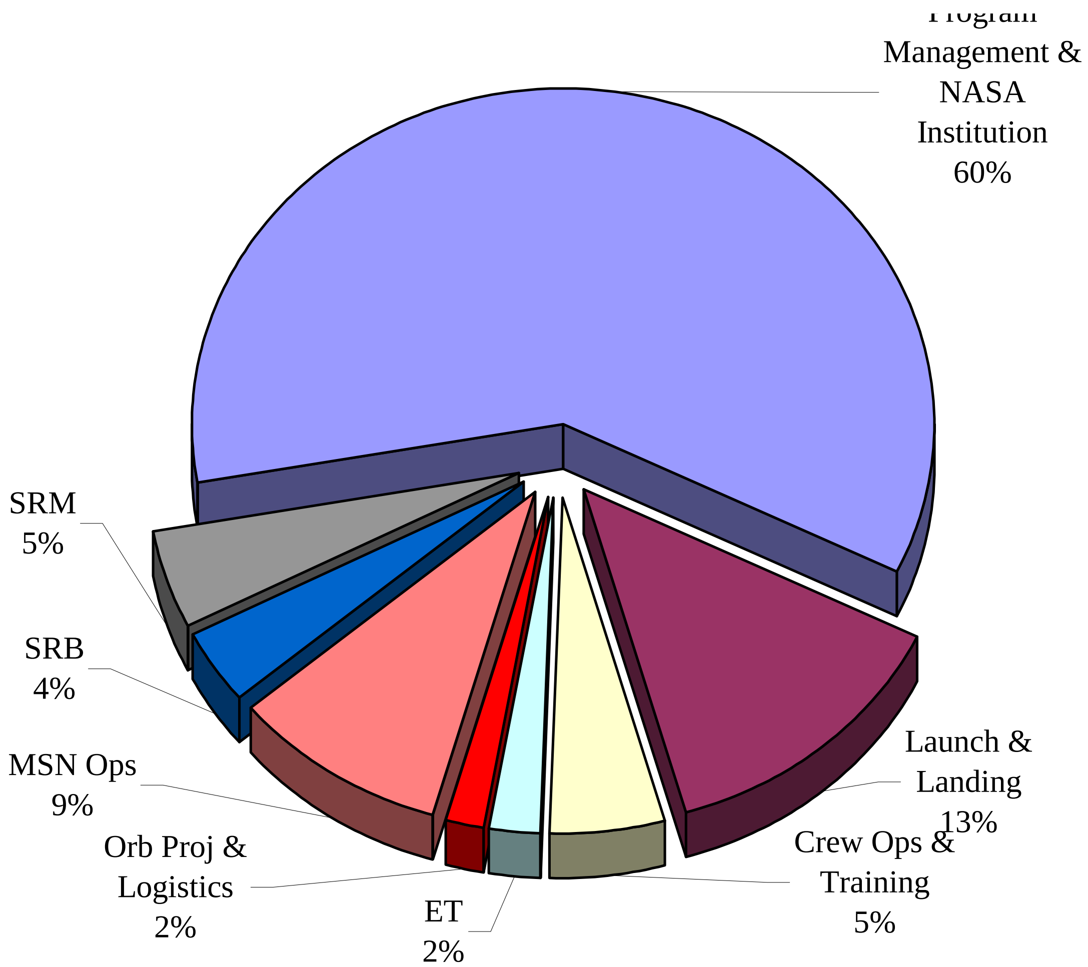


Figure 19: Systems Management Area broken into Sub-Functions.

institution has 1662 employees who charge this area. 798 are for direct labor and travel, 166 are for indirect labor and travel, and 698 are responsible for the operation of the installation. The direct labor employees are believed to be engineers and scientists who support the STS program, while the indirect labor employees are secretaries and other administrative employees who provide the overhead support to the engineers and scientists. The operation of the installation category most likely refers to employees who manage the utilities of the installation. The breakdown of this area is listed in Table 3. Also shown in this table are the numbers of program management at each field center.

Table 3: Breakdown of Program Management and NASA Institution Employees.

Program Management & NASA Institution			**Employees**		
Institution					5328
	JSC			1662	
		Direct Labor & Travel	798		
		Indirect Labor & Travel	166		
		Operation of Installation	698		
	KSC			2197	
		Direct Labor & Travel	974		
		Indirect Labor & Travel	188		
		Operation of Installation	1035		
	MSFC			749	
		Direct Labor & Travel	242		
		Indirect Labor & Travel	37		
		Operation of Installation	470		
	Hq			615	
		Operation of Installation	615		
	SSC			105	
		Operation of Installation	105		
Program Management					380
	JSC			165	
	KSC			100	
	MSFC			100	
	SSC			15	

The launch and landing sub-category is the next major area within the systems management area. Table 4 catalogs the major employee areas of this sub-category. All of these employees listed are working through KSC. As can be seen, the two largest areas are for support services: launch support and program support. Both of these areas are larger than the SR & QA group located at KSC.

Table 4: Launch and Landing Sub-Areas.

Launch and Landing	Employees
Program Operations Support	430
Launch Support Services	350
SR & QA	282
Operations Management	89

The third highest area within the systems management region is for mission operations. Mission operations are charges by JSC employees. This charge is only for support and sustaining engineering within mission operations, not for the actual flight controllers and operators who work during shuttle flights. Those charges are to a different area that will be explored later. However, mission planning is included within this region. Table 5 lists the major employee functions within this sub-category.

Table 5: Mission Operations Sub-Area.

Mission Operations		Employees	
Software Production & Development			208
Flight Design Division			424
Systems Division			184
Program & Doc. Support			644
	STSOC Support	554	
	Flight Software Support	31	
	Shuttle Data Support	29	
	MOD Directorate Office	30	

Only the three major regions of the systems management section will be explored in the main body of this paper. As seen above in the employee tables, a lot of support is used for the shuttle program. Additionally, there are many employees working directly on the STS program at each field center whose responsibilities are not entirely clear. Some other employee numbers that are listed in Appendix A include 632 for SRM support, 209 for ET support, and 196 for orbiter support. Additionally, another 327 are required for crew operations support and training.

6.2 Concept-Unique Logistics

This section is the next largest section charging to the shuttle. This area is responsible for 26% of the total STS program cost per year. Combined with the preceding section, nearly 70% of the STS program is charging to these two categories. The responsibilities of this category include:

- Propellants: acquisition, storage, distribution, conditioning, sampling and waste disposal management
- Other fluids, gasses and unique consumables: acquisition, storage, distribution, conditioning, sampling and waste disposal management
- Line Replacement Unit (LRU) hardware for both flight and ground systems

The LRU category is responsible for a wide variety of hardware and logistics duties. Responsibilities within this region include the acquisition, storage and preservation of LRUs. Also included are component repair and failure analysis, fabrication of tubing, and the thermal protection system. Table 6 lists this category broken into its sub-regions by cost, while Figure 20 shows the percent of this "concept-unique logistics" category for which each sub-region is responsible.

Table 6: Concept-Unique Logistics Cost Breakdown.

Concept-Uniq Logistics	**$M (FY '94)**
Program Management & NASA Institution	0.9
Launch & Landing	-
Crew Operations & Training	-
External Tank	263.2
Orbiter Project & Logistics	177.8
Mission Operations	-
Solid Rocket Boosters	46.2
Solid Rocket Motors	337
SSME	44.8
KSC P/L	-
KSC Propellants	
Total	**869.9**

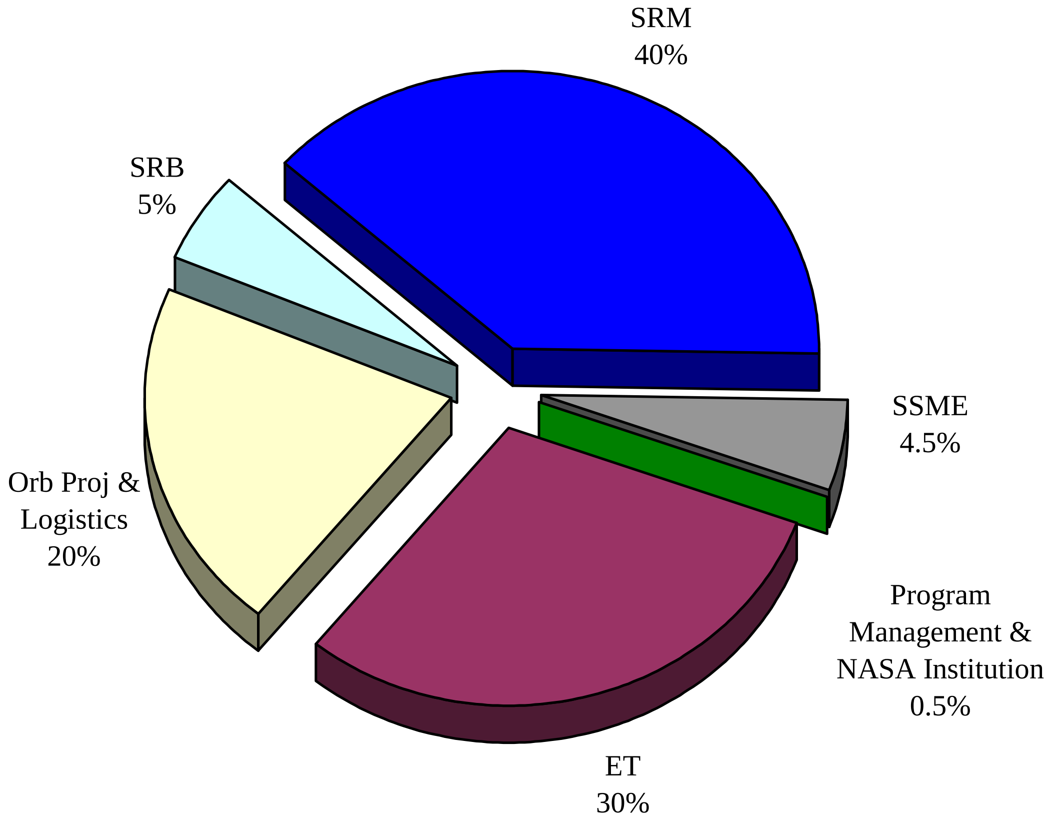


Figure 20: Concept-Unique Breakdown Percentages.

The largest categories within the concept-unique region are the main STS hardware pieces. The largest area, the SRM, also corresponds to one of the largest contractors, Thiokol. The next largest area, the ET, also corresponds to a large contractor, Martin Marietta. Table 7 lists the employee breakdowns within each major region shown in Figure 20.

Table 7: Major Employee Areas of Concept-Unique Logistics Section.

Function Area	Employees
SRM Manufacturing & Refurbishment Labor	2095
External Tank Production	2041
Orbiter & GFE (JSC)	1174
Orbiter Logistics & GSE (KSC)	1111
Solid Rocket Boosters	985
SSME Hardware Spares and Refurbishment	226

The hardware needed to support the STS program requires a large employee level. Additionally, a number of these employees must handle the true logistics area of using all this hardware. All the spares must be properly acquired and preserved, the propellants acquired and handled, and in general, a wide variety of equipment must be maintained. This category does not even include most of the general GSE, although the line between what constitutes as GSE for the orbiter and what's needed for the STS program as a whole can be blurry.

6.3 Operations Support Infrastructure

The third largest area under the STS cost breakdown umbrella is the operations support infrastructure region. This area includes all the facilities and equipment that is needed to support the shuttle program. A majority of this cost will be out of KSC, due to the number of facilities used to run the STS program. Over 500 facilities must be maintained to run the shuttle program. The responsibilities of "operations support infrastructure" are as follows:

- Maintaining all shops and labs
- Utilities
- Maintaining the roads and grounds
- Heavy equipment, such as cranes, and generators
- Communication and information services
- Environmental compatibility management
- Pyrotechnic storage and handling
- Personal environmental protection equipment

This category is the support behind the STS operation. To maintain all the necessary facilities, a large number of employees and equipment is required. Table 8 provides the cost breakdown of this category, while Figure 21 illustrates the percentage for which each sub-region is responsible.

The largest category for this STS region is for launch and landing. For launch operations, a large number of facilities and equipment is required. Thus, a large employee base is required to operate these facilities. The three largest employee regions within launch and landing are the operations and maintenance of various facilities,

Table 8: Breakdown of Operations Support Infrastructure Cost.

Operations Support Infrastructure	**$M (FY '94)**
Program Management & NASA Institution	0.2
Launch & Landing	136.1
Crew Operations & Training	-
External Tank	76.8
Orbiter Project & Logistics	-
Mission Operations	93.7
Solid Rocket Boosters	53.7
Solid Rocket Motors	-
SSME	-
KSC P/L	-
KSC Propellants	
Total	**360.5**

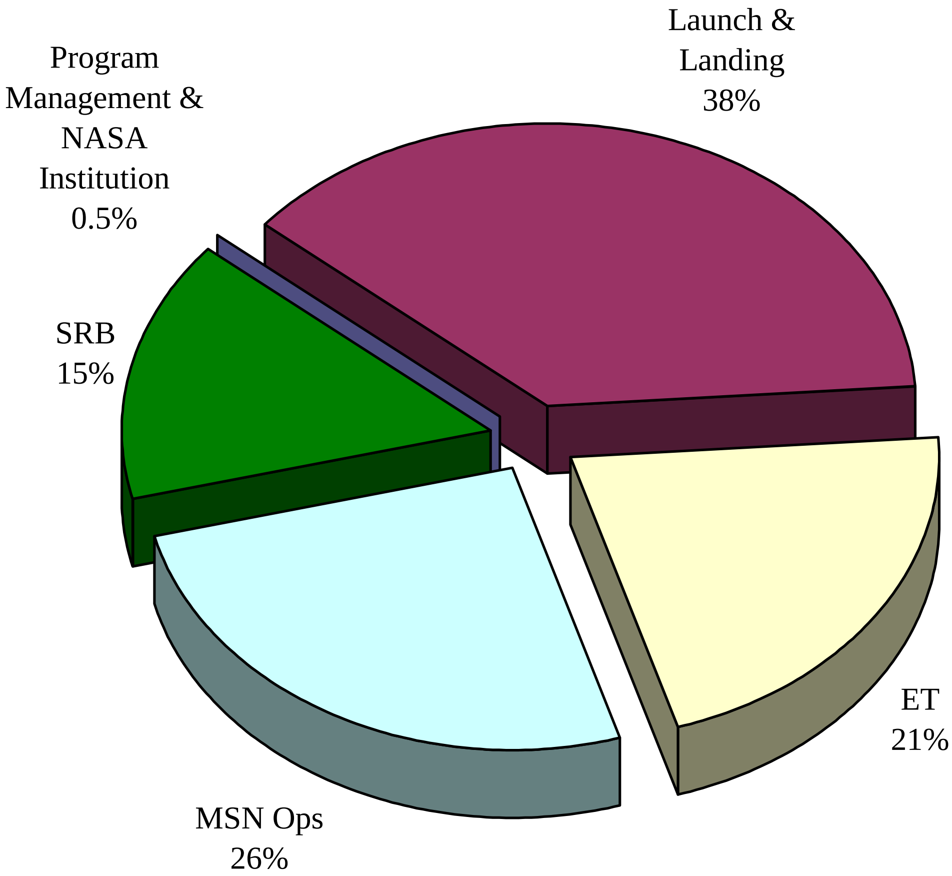


Figure 21: Percentage Breakdown of Operations Support Infrastructure Cost.

maintaining the system equipment and providing for communications. The employee numbers are listed in Table 9.

Table 9: Largest Employee Regions within Launch and Landing Operations.

Launch and Landing	Employees
Facility Operations & Maintenance	1301
Communications	437
System Equipment Maintenance	209

The mission operations area is the next largest sub-category within operations support infrastructure. This sub-category is also large because of the support necessary for maintaining JSC's training facilities. These include maintaining and supporting the flight operations trainer, and the shuttle avionics integration laboratory. The next largest categories within this indirect cost region are the ET and the SRBs. The ET requires over 400 employees for maintaining the facilities and providing project support. The SRB uses 350 employees for support labor. In order to support the employees needed for the many STS systems in the concept unique logistics area, an additional number are required to provide support for them.

6.4 Traffic and Flight Control

This section of the indirect and support costs is responsible for almost 6% of the STS program cost. The duties within this category include:

- Landing facilities traffic control
- Launch facilities traffic control
- Ground and flight vehicle communications systems management
- Weather advisory for launch, landing and ground operations
- Ascent flight safety monitor and control
- Audio and visual monitoring of ground launch operations

There are only three sub-categories within this region: program management, launch and landing, and mission operations. The cost breakdown is listed in Table 10, and the graph of the percentage values are shown in Figure 22.

Table 10: Cost Breakdown of Traffic and Flight Control.

Traffic/Flight Control	$M (FY '94)
Program Management & NASA Institution	72.3
Launch & Landing	49.4
Crew Operations & Training	-
External Tank	-
Orbiter Project & Logistics	-
Mission Operations	77.7
Solid Rocket Boosters	-
Solid Rocket Motors	-
SSME	-
KSC P/L	-
KSC Propellants	-
Total	**199.4**

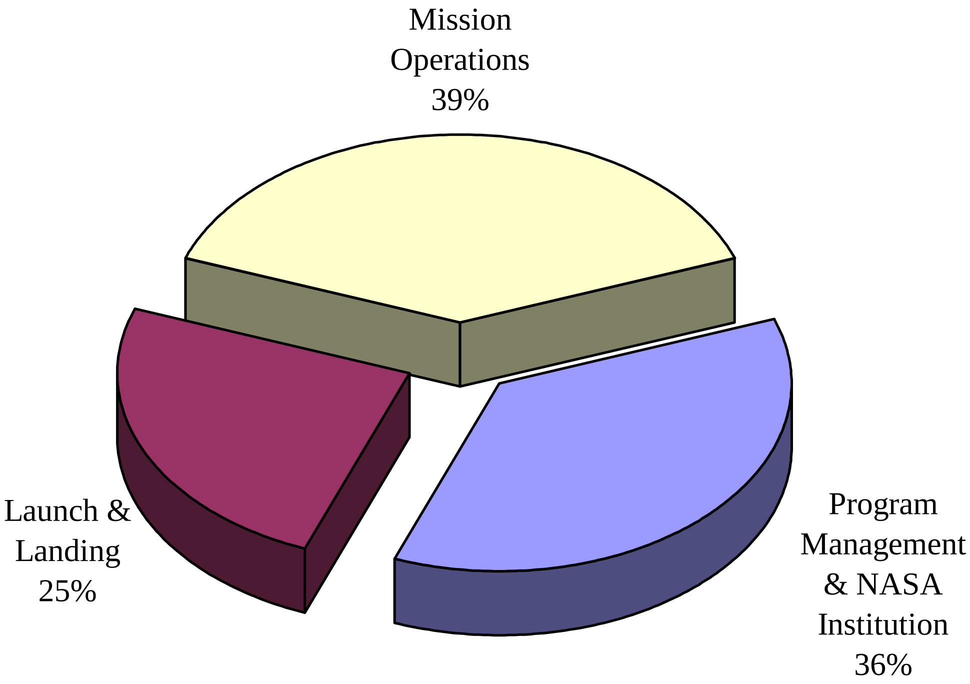


Figure 22: Percentage Breakdown of Traffic and Flight Control.

Within mission operations, the largest category is for the MCC center. 667 employees operate this facility during STS missions. Another 161 support the launch control at KSC. For weather advisories, over 100 employees are used across the various centers.

6.5 Vehicle Depot Maintenance

The last indirect and support cost area is for vehicle depot maintenance. This category includes all of the maintenance activities required every three years for refurbishment at the facilities in Palmdale. These maintenance activities are not the normal turnaround maintenance required every time the shuttle flies a mission. All of these maintenance activities are either unplanned maintenance or for refurbishment. The responsibilities for this category are:

- Vehicle overhaul and modifications (structural, flight controls, etc.)
- Modular element overhaul, including OMS-RCS pods, SSME
- Hot test propulsion hardware
- Space software upgrades (non-flight)

Within this area of indirect cost, there are only three different sub-regions that charge to this area. They are launching and landing, the orbiter, and the SSME project. Table 11 lists the cost breakdown of the vehicle depot maintenance category, while Figure 23 shows the percentages.

Table 11: Vehicle Depot Maintenance Cost Breakdown.

Vehicle Depot Maintenance	($M FY '94)
Program Management & NASA Institution	-
Launch & Landing	1.5
Crew Operations & Training	-
External Tank	-
Orbiter Project & Logistics	108.3
Mission Operations	-
Solid Rocket Boosters	-
Solid Rocket Motors	-
SSME	29.2
KSC P/L	-
KSC Propellants	-
Total	**139**

The largest cost goes to the orbiter refurbishment. Each orbiter is taken out of service every three years for major overhaul. The orbiter is transported using a specially fitted Boeing 747 that takes the orbiter to the (now) Boeing facility in Palmdale, California. Over 200 employees work at the orbiter facility in Palmdale. In addition to the schedule repair, some unplanned maintenance will usually occur for an orbiter. These repairs are performed at KSC, and require another 400 employees. However, many of these employees are also used for helping with turnaround of the shuttle. The bulk of the SSME hot testing will occur at SSC, and over 140 employees will charge to this area. Some of these employees will operate out of Marshall where the SSME program is located.

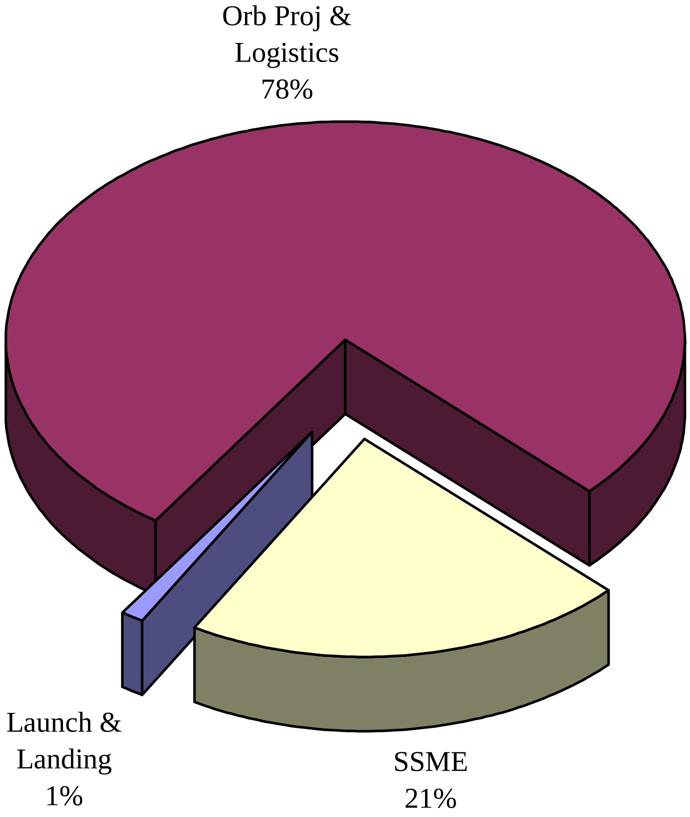


Figure 23: Vehicle Depot Percentage Breakdown.

These are the indirect and support costs of the STS program. Again, they do apply to the 1994 shuttle project, but are used as basis for which to make recommendations. The exact duties of many personnel in the shuttle blur across various boundaries within the program. Examples of this are the employees who support the shuttle maintenance for both turnaround and true depot maintenance. Table 12 and Table 13 list a summary of the main information presented in this section. In the next section, this project will analyze the total indirect and support cost areas to show some inefficiencies and generate some possible solutions to reducing the STS program cost.

Table 12: Summary of Indirect Costs by category in $M FY 1994

	PGM Ingrtn, PMS, NASA	Launch & Landing	SRM Proj	ET	Orb Prob & Logistics	MSN Ops	SRB Proj	SSME Proj	Crew Ops & Training	KSC P/L	KSC Propellants
Sys Plan'g & Mgmnt	860.8	192	67.2	31.4	25	135.4	52.1	51.3	71.8		
Concept-Uniq Logistics	0.9		337	263.2	177.8		46.2	44.8			16.5
Operations Support Infra	0.2	136.1		76.8		93.7	53.7				
Traffic/Flight Control	72.3	49.4				77.7					
Vehicle Depot Maint.		1.5			108.3			29.2			

Table 13: Indirect Cost Summary broken down into Employee Numbers

	PGM Ingrtn, PMS, NASA	Launch & Landing	SRM Proj	ET	Orb Prob & Logistics	MSN Ops	SRB Proj	SSME Proj	Crew Ops & Training	KSC P/L	KSC Propellants
Sys Plan'g & Mgmnt	5708	1381	632	209	196	1493	347	230	327		
Concept-Uniq Logistics	66		2095	1710	1100		290	226			159
Operations Support Infra	30	1628		557		894	350				
Traffic/Flight Control	642	259				731					
Vehicle Depot Maint.		83			707			143			

7.0 Analysis and Improvement Ideas for the STS Program

The high launch cost of shuttle is a large problem for NASA. By reducing these costs, NASA could move funds to different areas, such as work on the President's new initiative. The shuttle budget for FY 2005 will be $4.232B. With a reduction of 20%, over $800M could be saved and used towards the President's initiative. Both the U.S. public and Congress would most likely look favorably on such a decrease within the program, and therefore boost support for the goal of a manned Mars mission.

The 1994 STS breakdown will be the basis for analysis and to determine how such reductions could take place. The program has obviously undergone large changes since that time, but this report will take those changes into account. The goal of these improvements within the STS program will be for "freeing" up funds to use for the new exploration proposal.

7.1 Systems Management Restructuring

As seen from section 6, this area was responsible for 44% of the total program cost. A first idea is to examine the structure of this division. Within such a large program, there exists a possibility that responsibilities are overlapping. Management has been restructured at least twice since the 1994 program. Below, Figure 24, is the current structure of the STS program. All offices are located at JSC unless specified otherwise. The red lines denote sub-branches of an office. For example, the Space Shuttle Processing group that works out of KSC is responsible to the Space Shuttle Systems Integration office. Unless a box is denoted by red, this group will report to the Space Shuttle Program Office directly. The structure from the program office to the NASA administrator was not included, but it can be found in Reference 7. By examining the responsibilities of the various program offices, overlap and inefficiency can be determined.

There is overlap of responsibilities occurring within the management structure. Within the STS program office are six different managers who oversee the various departments. The groups below them all report to these managers in some manner. However, there is a lot of cross-information that needs to flow between various groups in order for the STS program to function. For example, the shuttle systems integration office has some responsibilities for determining the environmental impact of some

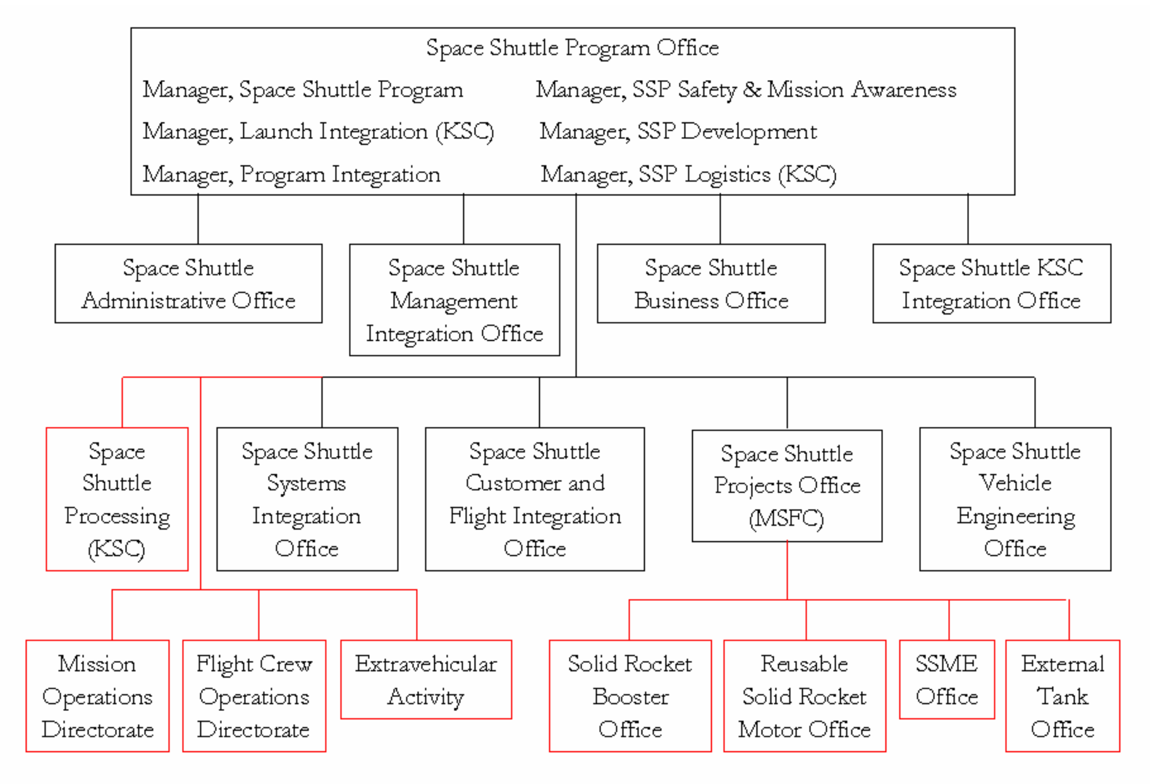


Figure 24: STS Program Management.

materials, and how to properly dispose of them. Yet, they must coordinate with the vehicle engineering office because the engineering office is constantly using new materials for any type of upgrades. The engineering office is also responsible for the environmental compliance required for any new hardware upgrades.

A further instance of cross-flow is that the engineering office is responsible for the upgrades that are needed to install at the Palmdale refurbishing facility. However, any SSME upgrades, for example the Advanced Health Monitoring System, are developed by the SSME Office out of the projects office located at MSFC. The same applies for any hardware developed for the SRBs or the ET: the engineering office is in charge of implementing these upgrades, but an entirely different branch is in charge of developing them. However, the decision for hardware upgrades, another example being the new lightweight aluminum-lithium ET, and how to develop these upgrades must result from a consensus of the two offices[19].

Another case of iteration between various branches of the STS program is when the projects office must confer with the systems integration office, the KSC integration office, and KSC processing regarding the logistics of the main shuttle hardware. These four offices must all work out the varying schedules of areas such as delivery, testing, and maintenance of the hardware. The projects office will need to know of any new problems with the hardware that occurs during flight, while the both the systems integration office and KSC integration office must be kept abreast of new procurements of the ET and SRBs. Additionally, this will all affect the KSC processing branch, since they will perform the physical work that needs to be done in order to turn the orbiter around for another flight.

Finally, one more occurrence of the necessary cross-flow of information occurs on for the mission and crew operations of the shuttle. The MOD is in charge of planning the mission while in space, and to help provide the proper training for the people involved. They also help maintain the training laboratories that are needed[20], but the Flight Crew Directorate works with the astronauts who require the training. The astronauts will then use systems from the Extravehicular Activity (EVA) office, for this office provides the space suits. However, this office must go back and coordinate with the MOD because the EVA is also in charge of planning the spacewalks.

Other examples of this iteration of information exist in the STS program. However, rather than use more explanation, Figure 25 shows the current iteration between the program offices. Figure 25 is borrowing from an idea in the optimization field of work. This figure is an illustration known as a design structure matrix (DSM) that shows where information needs to be passed in order for the top body to operate. The lower boxes are known as Contributing Analyses (CA) that perform their function and report back to the head level. The analogy being drawn here is that the STS program office represents this top body, and all the secondary offices are the CA's. Only one "sub-sub-category" is represented in the graph: the Space Shuttle Processing Office out of KSC. This is the only sub-sub-level included because this office needs to coordinate with other offices that are not within its directly higher level office. The DSM of the "sub-sub-levels" is included in Appendix C.

In keeping with the optimization analogy, a DSM will represent the best system when there are as few feedfoward and feedback loops within each of CAs'. Ideally, the top level function will dictate to each of the CA's only the information that is needed for the singular CA to run its analysis. The responsibility of determining the best system optimization falls directly upon the top level function. Using this method, no internal optimizations within the CAs' that can affect another CA will occur. Otherwise, while a particular CA may be optimized, the system as a whole will be sub-optimized.

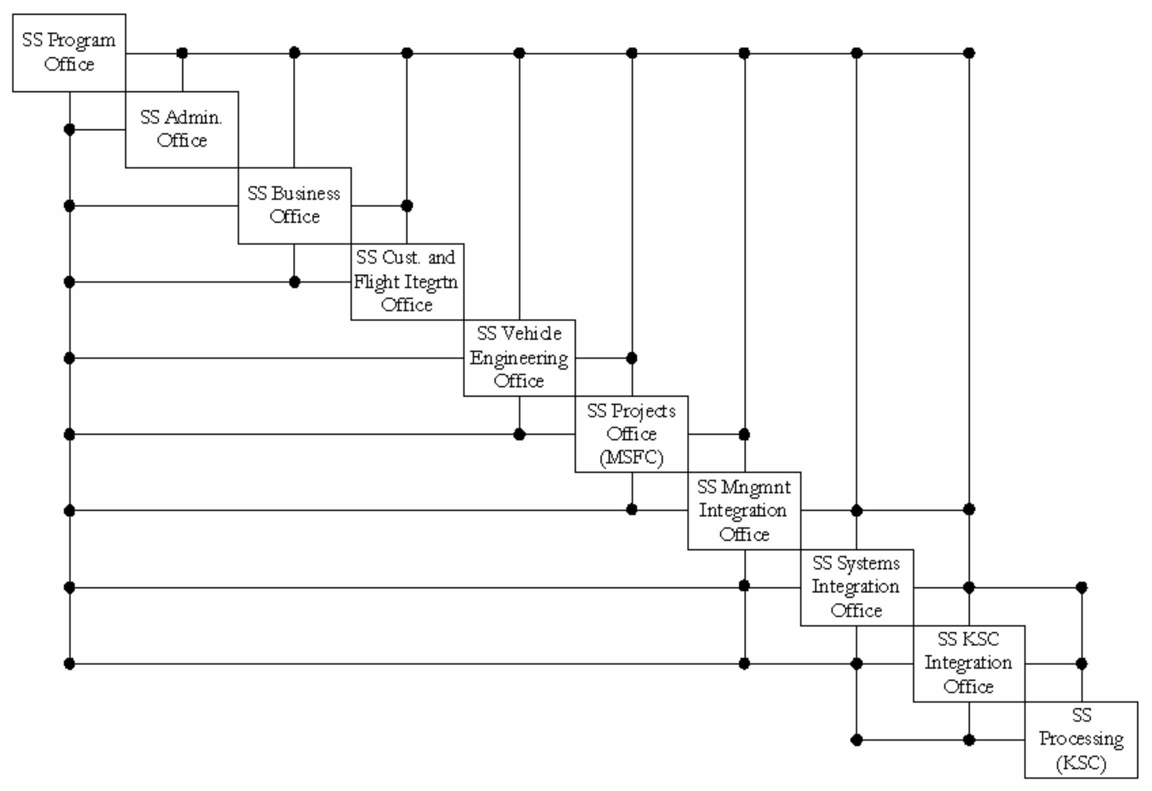


Figure 25: STS Management DSM.

Illustrated in Figure 25 is an example of a bad DSM. There are many feedforward and feedbackward loops of information between the various shuttle offices. These secondary level offices not only rely on the program office, but also on each other. Thus, multiple iterations must occur within each of the lower offices in order to pass back the information required by the overall program office to make an appropriate decision. In optimization, the number of function calls is used as a measure of the efficiency of the program. Figure 25 shows an expensive system due to the required number of function calls that will be needed before the information is passed back to the system office.

The highly respected statistician, W. Edwards Deming, teaches that large programs like STS must be thought of as a system[21]. The goal must be total system optimization. Anything less than this goal will cause losses for the program. Therefore, to increase efficiency, many of these loops within the program offices must be eliminated. This is one idea for reducing the system management cost.

Figure 26 is a new solution for the STS management structure. As will be seen in the DSM, many of the feedforward and feedbackward links were eliminated. This management structure was created with only optimization in mind. Therefore, a dramatic reorganization has taken place. Additionally, some of the changes in structure were done due to logistics concerns and management.

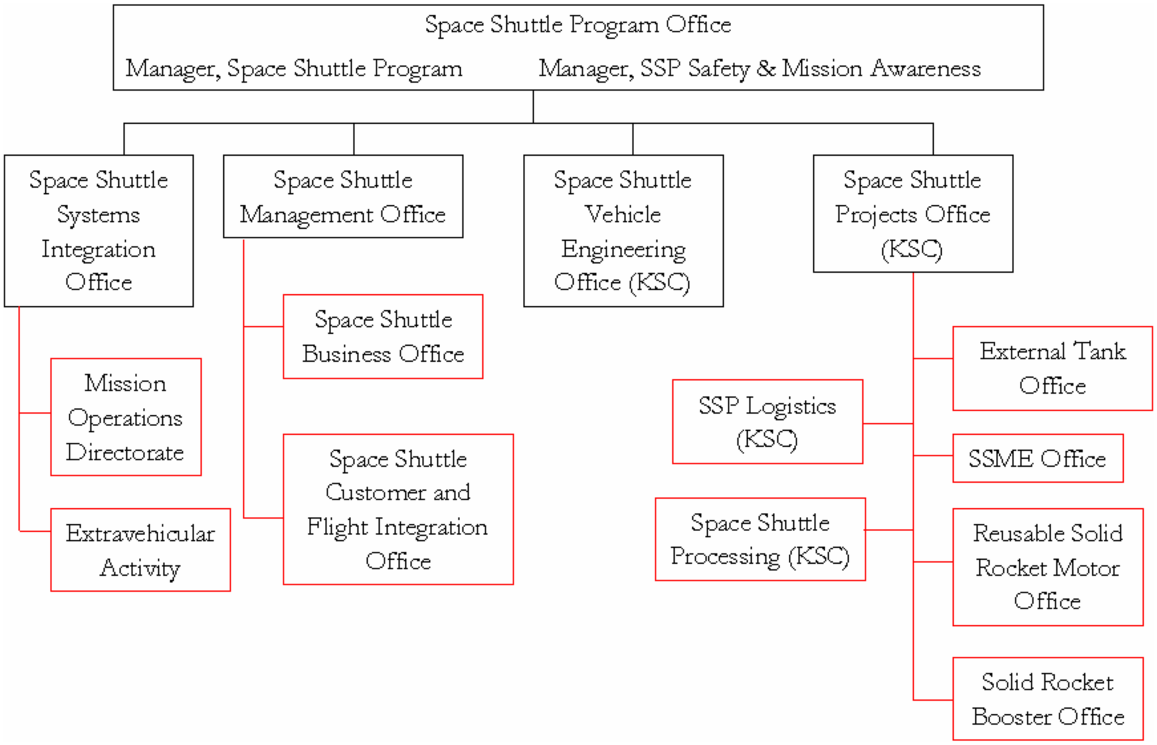


Figure 26: Proposed STS Management Structure.

The largest secondary office will now be the Space Shuttle Projects Office that is located out of KSC. In both the Kraft report and USA's initial contract bid, the end result for cost optimization was that the projects office should be taken out of MSFC and located at JSC. However, with logistics concerns (that are discussed more in-depth in the next section) factored into restructuring, this office would now be located at KSC. Logistics would be able to work directly with Space Shuttle Processing, as well as all the hardware offices in order to coordinate any matters related to schedule and maintenance. Yet, by locating these offices together, they will constantly have access to each other in order to work together to achieve the overall system goal. Unfortunately, as will be seen in the new DSM, some iteration will have to occur between the Vehicle Engineering Office and the Projects Office in order to mesh the upgrades for hardware properly. However, with the Vehicle Engineering Office also located at KSC, this iteration will be able to occur more smoothly and efficiently. Another of Deming's teachings is that physical communication greatly aids the program in all cases. Thus, the overall STS program will gain because coordination across three different NASA centers for processing and logistics will no longer be required. The launch integration manager from the STS program office has been moved into the Space Shuttle Processing Office so that they can work at the same field center.

The program integration officer from the STS office has been moved into the management office along with the administrative office. Many of their tasks will be related, and thus should be consolidated into one branch. Both the business office and the customer and flight integration office have been moved; they are now sub-levels to the management office. Using this structure, all customer integration responsibilities can be handled within the same group.

The flight crew operations directorate has been consolidated into two parts: half will go into the MOD, and the other half will enter the EVA group. The MOD and EVA groups will still need to work together, but eliminating an overlapping branch can help streamline the structure. The MOD will then be able to plan the in-space missions, while the EVA can provide the details for supporting the astronauts. Both of these branches will fall under the systems integration office, which will now mainly be responsible for the human portion of the STS program.

The DSM for this new structure is shown in Figure 27. Now there is only one set of feedforward and feedback loops through the structure. System optimization will occur more quickly and become less cumbersome. The number of "function calls" will be less, and therefore the structure will be more efficient when compared to the current STS structure. In examining cases through history, various businesses have undergone management restructuring in order to streamline costs. General Mills was able to boost their profit by 12% over the previous year by streamlining management[22]. Another example is Federal Express, which was able to increase profit by 10% through management restructuring[23]. Profit does not directly apply to NASA since it is a government institution, but with profit being a measure services sold subtracted by the cost to provide those services, the cost reduction can be seen. The services provided by these companies were done at a lower cost in order to increase profit.

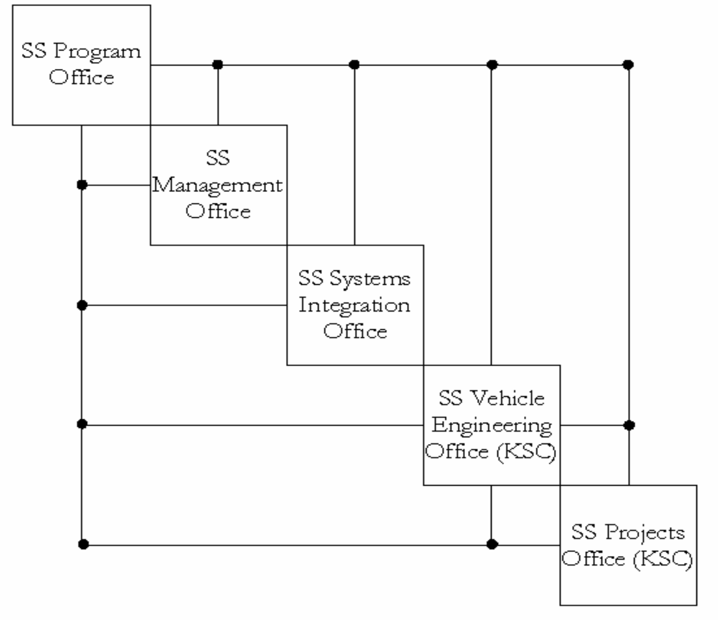


Figure 27: New Management DSM.

Another idea for reducing cost within this area is to eliminate the duplicity of responsibilities that appears to be occurring. Included in Appendix B is the STS workforce breakdown over the last ten years. There are some slight differences between the 1994 figures of the STS breakdown used earlier in this report and the numbers listed in Appendix B for the year 1994. However, from examining the workforce from 1993 to 1994, the number of employees was in a state of flux during this time, and therefore the differences between these two sources can be explained by this flux. The chart in Appendix B shows that some reduction in employee levels has occurred. However, the flight rate of the STS program has also gone down, which made it even easier (and more necessary) to reduce employee levels.

Regardless, the 1994 figures showed that overlapping responsibility was occurring. In section 6.1, many responsibilities were overlapping. The biggest example is for the institution costs. The exact nature of the employees' responsibilities within this area must be determined, but there is a category for the operation of the installation. 1035 employees are used for this category at KSC, but KSC also has its own base operations contract which utilizes 208 employees. Another concern is that the operation of an installation is being charged to the STS program. This whole category must be investigated further to see if workforce reductions have decreased, and what responsibilities the employees currently have. Additionally, the program management category should also be evaluated. The number of managers at each installation appears disproportionate. For example, in 1994, the total workforce, including contractors and employees, was higher at KSC than at JSC, but JSC had more management.

Through deeper investigation by a thorough audit of the STS program, inefficiencies could be rooted out. A restructuring of the STS program management would be greatly beneficial towards reducing the overall STS cost. An initial estimate, based upon business cases and a reduction in management levels suggests that between 5 and 20% of management costs could be reduced. This could result in savings over $350M per year (FY '94). With the budget levels for FY 2005 already surpassing the 1994 budget levels, but with launch levels reaching only slightly more than half the number of launches for 1994, the shuttle cost per flight will dramatically increase. Therefore, STS program changes should be implemented, with management restructuring as one example.

7.2 Reducing Costs in the Concept-Unique Systems Area

The logistics of this area are very challenging, and thus result in the large cost for this section of the STS program. Many different parts and shuttle hardware must be transported from places all over the country to supply the STS program. Unfortunately, most of this hardware is a one of a kind type system; therefore, the workforce that produces the hardware must be kept on the payroll in case the need arises for a replacement part. This is the main area of STS indirect costs for which the "standing army" of STS program workers has a direct influence. As mentioned above, 2000 employees are needed to produce the ET, and another 2000 are required to manufacture the RSRMs. These pieces of hardware are two examples of items that need to produced every year; undesirably, whether the STS program is flying 4 launches a year or 8 launches a year, or no launches a year, these employees must remain on the payroll.

Figure 28 illustrates the STS logistics structure. The orbiter must undergo maintenance in the OPF, or be transported to the Palmdale facility in California if it is time for refurbishment. However, the Palmdale facility is now closing, and the effects of this will be discussed shortly. The SSMEs undergo maintenance in the VAB shop, unless they require overhaul and are then transported to Rocketdyne in California. Then they must undergo testing at SSC and are trucked back to KSC. Each ET is manufactured at MAF, and then brought by barge to KSC. This trip takes roughly five days, and the ship used to pull the barge is one of the fleet of SRB recovery ships. The SRBs are recovered after each flight by one of these ships, and then undergo disassembly at KSC. The motor segments are then transported back to Thiokol by rail, while the aft and forward skirts continue to undergo refurbishment at KSC. After Thiokol processes the RSRMs, they are then moved back to KSC by rail once more.

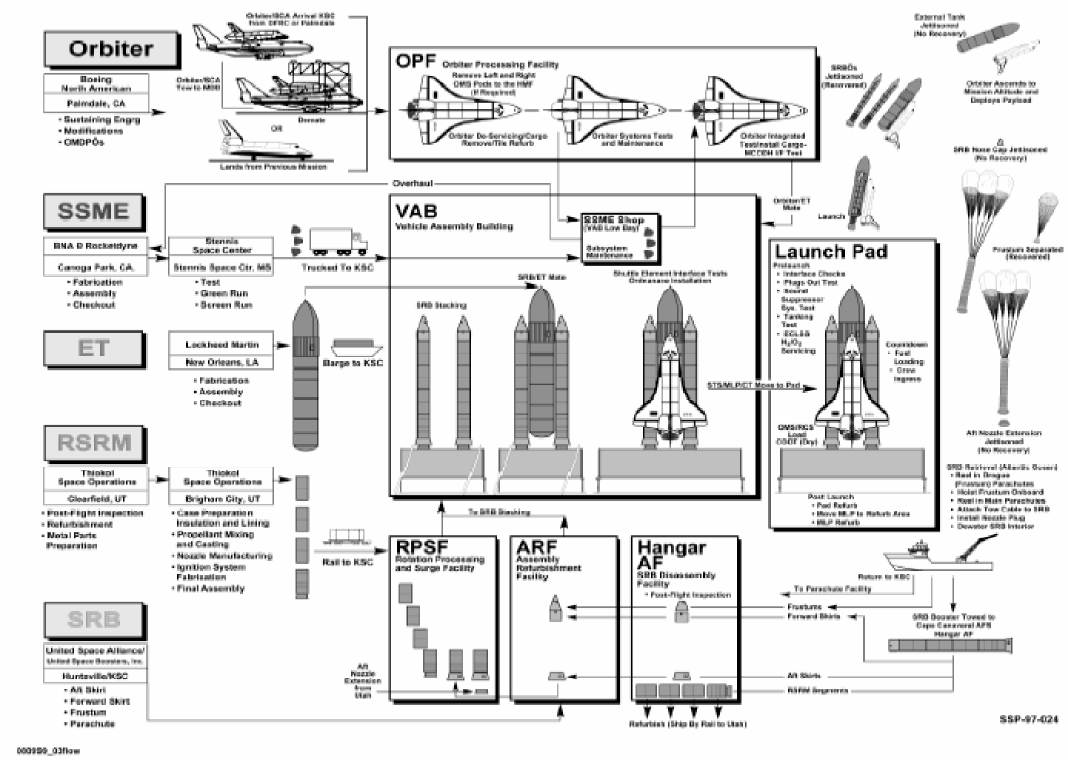


Figure 28: STS Program Hardware Flow.

Even using the main STS hardware as examples, the logistics of planning for these pieces to come together for a shuttle launch is challenging. However, considering that MSFC controls these main hardware pieces, but KSC is where they are assembled together, inefficiency is created. This is one reason that the MSFC projects should be moved to KSC. The logistics will be much easier to handle when the projects office can work directly with the logistics and processing office at all times. When the complete STS program is considered from a logistics point of view, with all the parts that need to come from various suppliers all over the country, the complete system is very challenging to manage. The logistics facility at KSC handles 190,000 space shuttle parts alone. For a program of this magnitude, the entity controlling the hardware should be working directly with those responsible for managing the logistics of that hardware.

Another of Deming's philosophies is that consolidating the suppliers is always better for quality, and will result in cost savings. The current STS situation makes it challenging to accomplish this task. As shown in the earlier sections of this project, the STS method of obtaining parts and hardware is derived from the earlier programs of Mercury, Gemini and Apollo. Those programs had the philosophy that the equipment should be of the best design and materials, with little regard for cost. This is no longer an acceptable way of thinking, and this ideology has hurt the STS program. Too many unique parts are used, and thus consolidating suppliers is very challenging. An example of an orbiter subsystem that trades high performance over the logistics concerns is the hypergolic propellants that are used for the shuttle Orbital Maneuvering System (OMS) and RCS engines. The first concern with using these propellants is the fuel and oxidizer immediately ignite upon contact. Thus, the storage facilities must be maintained at considerable distances from each other. Also, when loading these propellants, they cannot be loaded in parallel; serial loading must occur before launch. The next concern is for the handling of these propellants. Workers must be specially trained in order to load these propellants into the shuttle before launch. They must also work on purging these systems after launch for orbiter processing. Cumbersome suits, known as a self-contained atmosphere protective ensemble (SCAPE) must be worn when handling these toxic propellants[24]. Thus, the lack of concern for the logistics of the STS program has had a large impact on the total cost of the system.

Some consolidation has already been performed at the Cape. In 1994, 25 vendor stores were consolidated and $1.8M was immediately saved[25]. It has been suggested that further consolidation at the Cape could reduce between 30-70% more in logistics costs. However, within the STS program, there is no standard method for operating logistics. In order to treat the STS program as a system and achieve optimization, each field center should have the same, standard logistics method. This will help save logistics costs, even if STS offices are not consolidated, simply due to the fact that each field center will know how logistics are being handled across NASA. Thus, the employees at the different centers who are in charge of various parts will know how to track these parts in the supply chain. Those responsible for physical logistics will also know where they can find the necessary information regarding hardware in order to better mange the acquisition of parts and propellants.

Further investigation should be completed to see if there is different equipment that uses the same type of materials. This is one method in which the suppliers can be consolidated. Another of Deming's teachings is that to achieve high quality through the system, the system must stop relying on inspection. The STS program requires a lot of inspection on its hardware all the way through processing. For example, inspections are completed on the orbiter before and after processing, the ET after it arrives by barge, and the RSRMs. Under Deming's theory, if quality is built into the process for this hardware and variability is reduced, inspection will no longer be needed. However, due to the complex technology that a launch vehicle requires, and its unique nature, this theory does not appear applicable. Using the SSME as an example, this engine is manufactured in low numbers, and with a high level of technology. This engine has not reached full maturity and many inspections are required for each one. However, Deming's idea for inspection is one that should be considered. The steps needed in order for the SSME to reach full maturity should be determined and reached. General Electric Aircraft Engines (GEAE) is a good example of a company that builds sophisticated hardware, but has introduced quality into the process in order to reduce the amount of inspection required[26]. GEAE also builds a low number of engines that incorporate a high amount of technology, yet they do not rely on the amount of inspection that the SSME requires. Determining the current maturity levels of the main hardware and the steps required to reach full maturity should be considered and implemented to help reduce the costs of this area.

With a large, constant employee workforce, non-standard logistics practices, and many suppliers producing equipment all over the United States, the indirect cost of concept-unique logistics is high. However, using the estimates of consolidation and standardization, it may be possible to reduce this area by $200M (FY '94). New practices would have to be implemented, and the facilities at KSC evaluated further to see if true consolidation could be handled, but the resultant savings could greatly aid the STS program and NASA. Additionally, if the system could stop relying on as much inspection, then even more savings could be realized. With the STS program to continue until 2010, these ideas should be evaluated for their implementation in the program.

7.3 Other Areas for Costs Reduction

The next largest category within the indirect and support costs of the STS program is the operations and support infrastructure. As seen earlier, a lot of employees must be used to maintain all of the facilities used throughout the STS program. Much of this is a result of such unique systems being used. A lot of upkeep must be performed, and with each facility tailored to a unique portion of the STS program, there is a lack of standardization within this area. For example, the VAB sits on 8 acres of land, and is 525 feet tall. For comparison, the height of the Statue of Liberty is 305 feet tall. While this is the largest building at the Cape, over 500 more facilities require constant maintenance[27]. This adds up to over 6 Mfeet^2 of facilities that require attention.

Additionally, all of the ground support equipment must be maintained. Much of this equipment is dated and therefore requires more maintenance than usual. Estimates of updating this equipment have reached as high as $800M. These examples were looking at the facilities on the Cape alone. When the training labs at JSC and the testing facilities for the SSME and hypergolic propellants are also considered, the huge costs of the operations and support infrastructure region becomes clear. Unfortunately, there appears to be little possibility for cost savings. All of these facilities and ground equipment must be properly maintained in order to ensure the safety and integrity of the STS program. There can be no simple reduction in this area of indirect costs if every employee is performing a different job. The only possibility for cost reduction would come from an audit of the support services provided in order to ensure that there are no overlapping responsibilities. This audit should also show that there are enough employees to cover all the facilities, since a typical overtime pay rate costs 50% more than normal working hours.

For the traffic and flight control portion of the indirect costs, some duplicity may be occurring. The decision to build the MCC at JSC has had a large influence of program costs throughout NASA's history. Even though networking provided a solution for keeping communications flowing between the NASA field centers, a different MCC from the actual launch site has resulted in inefficiencies. KSC provides direct launch support to JSC and helps monitor the launches. Additionally, when landing occurs, both JSC and KSC must be working. When MCC was placed at JSC to help the Gemini and Apollo programs little thought was given to the processing required. At the time, neither of these programs was reusable, so not much of a difference was made. However, with the STS program, and all the processing required for the orbiter, having flight operations and ground operations at different facilities is hindering possible cost reductions.

Moving MCC to KSC could help reduce costs by combining flight operations with ground operations. The flight operations employees would constantly be kept abreast of schedule changes that need to be made, and can plan accordingly. Also, with this combination, the ground operations can properly prepare for what the mission is trying to accomplish, and tailor their work accordingly. The flight controllers in MCC would have a good idea of how the orbiter was prepared for the mission, and thus could tailor their planning even more. During launch operations KSC monitors the shuttle until the tower is cleared, and then JSC takes over. KSC will also monitor the shuttle during landing, since the Cape is the only landing facility for the shuttle now that Edwards has ceased operation. With JSC also monitoring these operations, overlapping responsibilities are occurring. Using figures from the workforce, between $25M and $50M can be saved by eliminating these overlapping responsibilities. Also, further costs could be reduced due to eliminating the operation of virtually the same type of facility during launch and landing operations. With the flight controllers working with the ground operations employees, each STS mission could be streamlined even more.

The last indirect cost area of the STS program to be examined for reductions is in the vehicle depot maintenance area. Most of the costs can be directly attributed to the Palmdale facility. Operating the Palmdale facility to perform major refurbishing requires another facility with virtually the same capabilities as the KSC processing facilities. KSC can perform major overhauls already, and the only concern would be handling multiple orbiters at the same time. Two orbiters can be handled in parallel, but major refurbishing requires twelve months of service[28]. However, with the current flight rates of the shuttle program, the Palmdale facility will be closed with refurbishment now being handled by the Cape. Refurbishment can take place in one bay of the OPF, while normal post processing can take place in the other.

Figure 29: Shuttle at the Palmdale Facility.

The roundtrip transfer of the shuttle to Palmdale facility costs \$5.6M. It has been estimated that between \$16M and \$70M could be saved each year by transferring the refurbishment responsibilities from Palmdale to KSC. The orbiter Columbia was the last shuttle to undergo refurbishment at Palmdale. The project had cost overruns and eventually required seventeen months after an initial estimate of seven months. The cost of this refurbishment jumped from \$70M to \$145M. After the Columbia was returned to KSC, an additional three months of work were required before this orbiter could finally return to service. In 1992, NASA performed studies that showed at least \$30M could be saved by moving the Palmdale facilities to KSC. However, politics prevented this transfer to KSC due to the loss of jobs within California. In order to truly reduce the STS indirect costs, politics must be ignored and what is best for the program must be implemented.

True consolidation of the contractors would also help reduce the indirect costs of the STS program. Original estimates by USA had pegged cost savings of $500M per year by transferring the MSFC projects to USA's control. As mentioned earlier, these results were never verified by the General Accounting Office. In fact, NASA admitted that they had not performed a true cost benefit analysis of these phase II activities and merely assumed that transferring the contracts would produce cost savings[29]. While this assumption that consolidation would help reduce costs is most likely correct, a cost benefit analysis should be completed. Yet, this analysis should also include the scenario of consolidating the contractors at KSC. It is the logistics and processing offices at KSC that physically work with the hardware and therefore must know exactly what is happening with it in the supply chain. They must be kept abreast of schedule and upgrade developments so they can plan accordingly. In addition, with all of the physical work occurring at KSC, the further consolidation of contractors and movement to KSC would help the program. With this change, all of the manufacturers of hardware and the offices dealing with system integration would be able to physically interact on a daily basis. Again, changes in schedule, processing or in other areas could be met by all the teams working on the STS program together. With the current system, the lack of physical interaction results in less cooperation. Deming stresses that to achieve quality within a system, there must be a high level of cooperation throughout the program. In 1981 review of various publications, over 122 studies were collected that examined the benefits of cooperation. In an "overwhelming number of cases cooperation was found to improve higher achievement than competition or independent work".[30]

7.4 Complete STS Privatization

In September of 2001, Space Shuttle program manager Ron Dittemore argued for a virtual complete transfer of shuttle services to private industry[31]. He discussed how privatization would reduce shuttle program costs. Dittemore suggested that a company should be created whose responsibility is to maintain the shuttle while also building experience in space launch operations for the next generation reusable launch fleet.

Ideally, this company would also manage the ISS program. All civil service employees who currently work in program management, ground operations, mission operations and the astronauts would be transferred to this private company.

One rationale for this privatization has been the erosion of the civil service workforce in the STS program. The article says that the loss of NASA workforce to private industry is robbing the STS program of the necessary experience to be able to perform the proper checks and balances. These checks and balances are the inspections of procedures and processes that must be used in order to ensure the safety of human space flight. Another motive for privatization is the current contract structure. Most of the current contracts are created in such a way that short-term, profit motivated decisions are made. There is little regard to the long term health of the STS program. This contract structure is in direct opposition to Deming's philosophy about long term vision. Deming stresses that for a successful company, long term planning must always be factored into decision making. Dittemore also suggests that vehicle operations and processing employees should be kept separate from hardware design. He argues that healthy tension is needed between these groups in order to ensure that the process of checks and balances is kept intact. There needs to be tension so that these groups will question each others' processes and methodology on vehicle design.

The idea of privatization appears to be a good one, because it will eliminate unnecessary waste within the system. The STS program is obviously inefficient and private industry should be able to rectify this situation through its drive for profit. However, there are a couple of areas for concern within this idea. First and foremost is safety. The question arises about whether or not a private company can truly make decisions that will reduce their "bottom line" in order to ensure safety. Even when a design or process decision is not on the magnitude of life threatening, will the company be able to mitigate risk properly in the face of decreasing profits or even losses. While Dittemore did discuss an independent safety organization at NASA for oversight, this organization must be given incredible authority to be effective. The oversight committee must be able to stop a launch and also review many of the design and process decisions that the private company makes. Whether a private company would accept such an arrangement is also another question. Another concern involves the long term health and goals of this private company. With the current structure of U.S. business and Wall Street, where earnings' reports are made each quarter, there is a question of whether long-term decisions can be made to ensure the health and safety of the system. Regardless, Dittemore does draw attention to the fact that the STS program is inefficient and changes should be made.

One last point of disagreement with Dittemore's article regards his separation of the vehicle operations employees from the hardware designers. While the acknowledgement is made that he has a very unique perspective on the shuttle program, the idea of not using concurrent engineering does not appear strong. He argues that the separation is needed for the checks and balances required within the STS program. However concurrent engineering has resulted in many cost reductions across a whole range of businesses. Part of Deming's teachings to the Japanese auto makers was the involvement of process and manufacturing engineers with the vehicle designers. The operations employees are the people who work directly on the shuttle and therefore the vehicle designers must be concerned with how they complete their work. If processing the vehicle requires an employee to wear a huge cumbersome suit after undergoing an extensive hazardous materials training course, then the vehicle designer needs to know that using this material will result in a higher LCC. Concurrent engineering helped the Japanese automakers reach the top of their industry. GEAE is another example; they have applied the six sigma quality control processes with very good results. Vehicle designers make decisions considering both manufacturability and maintainability. The checks and balances will occur when the manufacturing engineers inform the vehicle designers that making a certain design choice will raise the LCC versus another choice. This is another reason for why the move of the projects office to KSC would be beneficial. The projects office could discuss directly with the processing and operations employees about the effects of implementing new developments in the hardware. Throughout history, concurrent engineering has only benefited the system for which it has been applied.

7.5 Total Cost Savings

System management is the largest cost to the STS program. Restructuring could lead to savings as large as $350M. When combining this with other changes that can be made across the system, there is the possibility for large savings within the STS program. Using the estimates regarding logistics, another $200M could be reduced through consolidation of stores and enhancing the logistics process. Consolidation of the contractors would also help by moving the management of the main STS program hardware to the same location as the managers responsible for logistics. Additionally, the closing of the Palmdale facility should lead to savings of at least $30M per year. By combining flight and ground operations, another $50M could possibly be saved through reductions of overlapping responsibilities. While immediate cost savings are not realized within the operations infrastructure area, it is believed that the possibility exists for cost reductions. An audit to make sure that the right numbers of employees are working in this area should be completed in order to determine possible cost reductions. Thus, there is the possibility that $600M could be saved through management restructuring, reducing overlapping responsibilities, consolidating contractors, combining flight and ground operations, and moving the major refurbishment site to KSC.

A Monte Carlo simulation was performed using these estimates to show the large possible savings. Each of the five indirect cost areas was given triangular distributions; the ranges are listed in Table 14. For the first two areas, the minimum values used were not as low as estimates from the previous paragraph. Additionally, the mean of these two indirect cost areas were chosen in a conservative manner. These values were picked using a conservative approach in order to reinforce how much money can truly be saved in the STS program. While the true amount that can be saved from these indirect cost areas may be disputed, by choosing conservative values, the results will not be in-doubt.

The results of the simulation are illustrated in Figure 30. Additional statistics are listed in Table 15. While $600M is an aggressive estimate, the simulation shows that this number may be possible, even with conservative assumptions. The mean is very close to $600M, and the standard deviation is not very large. Finally, upon examination of the 80% confidence interval, a minimum of $548M can be saved from the STS program.

Table 14: Input Distributions for Monte Carlo Simulation

	FY 1994 $M			
	Minimum	**Mean**	**Maximum**	**1994 True Value**
System Mngmnt	1287	1387	1400	1486
Concept-Uniq Logistics	730	800	840	886.4
Operations Support Infrastructure	320	345	360	360.5
Traffic/Flight Control	150	170	185	199.4
Vehicle Depot Maint.	90	110	125	139

Table 15: Statistics from the Monte Carlo Simulation

$M FY '94		
Mean	**Standard Deviation**	**80% Confidence Range**
594	36.28	548-642

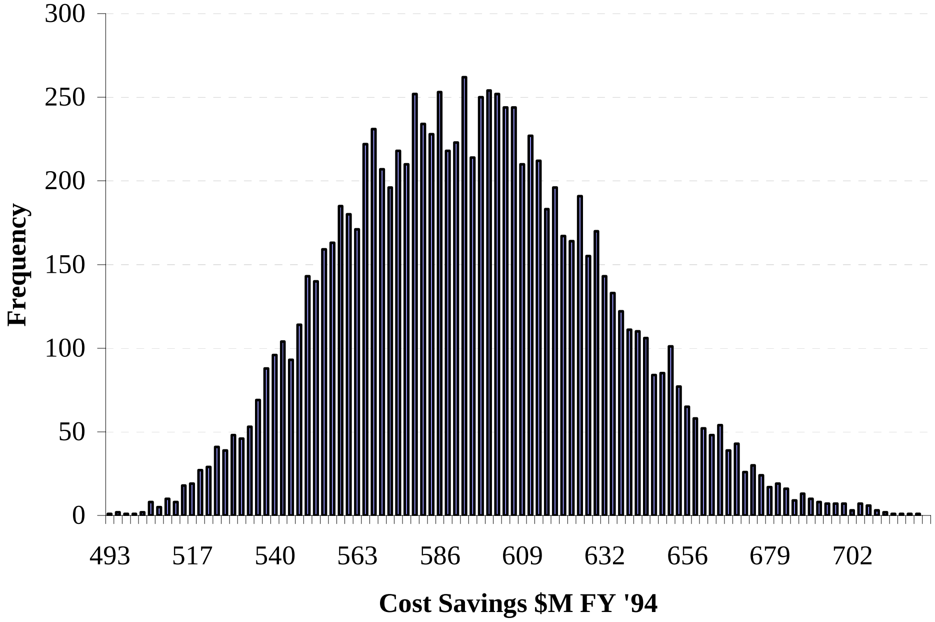


Figure 30: Monte Carlo Simulation for Cost Savings.

The STS program has been able to reduce program costs during the last 10 years, and therefore a study into exactly where these cost savings occurred should be performed to determine what implementations can still be made. The reductions have not been as large as predicted here, and therefore some areas could still be improved for efficiency and reduced cost.

8.0 Future Design Recommendations

For the next generation launch vehicle, the designers must learn from the past. The lessons learned about LCC from the manned spaceflight program must be utilized in order to achieve the new exploration initiative. Vehicle designers can no longer simply use the best performance design. By striving for the highest possible performance, LCC will go up due to the use of technology that is not fully mature. This will drive up costs due to the massive inspections needed to operate this design. Using the best technology available for hardware will also lead to the standing army that the STS program has now. By using high technology, skilled workers who are specially trained must be kept on the payroll, or else new workers must constantly be trained. However, these new workers would not have the experience and thus are prone to more errors which drive up costs.

The vehicle designers must also design for manufacturability and maintainability (in the case of a reusable vehicle). This will lower the cost of production and aid the launch processing team. If the launch processing team can spend fewer hours performing pre-launch operations, additional savings can be achieved. An excellent example of this is the use of hypergolic propellants for the OMS and RCS. If another propellant could be used that is easier to handle and requires less training, immediate cost savings can be accomplished. For a reusable system, maintainability is the key parameter. As Deming points out, inspection is a total loss for the system. Therefore, building a new launch system that is easier to maintain, with less inspections, will result in a lower LCC. This can be achieved by using more COTS or hardware that has reached full maturity.

One of the most important lessons that should be learned from the STS program design is how the OMB must not influence the final decision. Deming's teachings have proven many times that reductions in development cost can hurt the LCC of the program. For this next generation vehicle, LCC will be one of the most important parameters. Vehicle designers must take it upon themselves to strive for achieving the lowest LCC possible. An example from the STS program was the use of an aluminum structure for the orbiter instead of titanium. Since titanium could have resisted temperatures at least another 350°F, the thermal protection system (TPS) would not have needed to be so heavy. This would have resulted in weight savings on the orbiter, in addition to using fewer TPS tiles. The tiles themselves are hard to manufacture and require constant inspection and refurbishment. Thus, the initial savings in development of the orbiter by using aluminum has increased the LCC of the orbiter. This kind of tradeoff must be considered by vehicle designers for whom it is imperative to strive for a low LCC.

One more recommendation for the next generation launch system involves the use of contractors. Deming has taught that single suppliers are always better, but this will be hard to achieve in a system as complex as launch vehicles. Thus, the number of contracts and contractors should be kept to a minimum where possible. An example from the STS program is how Lockheed now operates Martin Marietta, and is also part of USA, which manages the ground operations. Ideally, the logistics manager for the ET is able to accomplish his work quickly and effectively due to the use of a single supplier. However, the space industry as a whole is small, and this hurts the community. There are not enough private contractors with the experience required of the launch vehicle industry to be able to infuse new ideas. Many of the contractors in the future will most likely be the major contractors used in the STS program today: Lockheed, Boeing, Thiokol, etc. Thus, the cheapest way of doing business for them will result in heritage designs. While this will help the LCC, a lack of innovation will always hurt the community.

The structure of the contracts awarded should also be altered slightly. Even though there is a low production of parts, quality control should be built into the contracts. Penalties should be assessed for requiring many inspections, and having to order many spare parts. A program that GEAE now uses is to rent the aircraft engines to airframe manufacturers. Using this approach, GEAE is now required to pay the bill for maintenance, and they no longer make their money on spare parts. This could be used if the next launch system is reusable; ideally, higher quality will be achieved since the manufacturer of the reusable equipment would be in charge of maintenance. There is the safety versus profit argument once again, but for this case, airplanes all over the world have flown with minimal loss of vehicle due to engine failure. By building quality into the contract, manufacturers would be pushed to use the suppliers that have the highest quality. Deming has pointed out that if a company knows there will be lots of inspection for which there is no cost to the company, then the lowest bid on parts may win the supplier contract. Using quality will eliminate this practice and require contractors to use the suppliers that will lower the LCC. One last idea for contract structure is to reward the contractors for the ease of maintainability. If the vehicle design can be processed quickly without large degradations in performance, then this should be rewarded. All future contracts should have clauses that can reward for helping to reduce the LCC of the system.

8.1 A Future Launch Vehicle System

With the goal of reducing LCC, one idea for the next generation launch system is to use expendable launch vehicles. Currently, two launch vehicles that would suffice are almost reaching the test phase. In addition, they are already being developed with human cargo in mind[32]. These launch vehicles are the Atlas V heavy configuration (although Lockheed claims there non-heavy configuration would work), and the Delta IV heavy configuration. The Delta IV could be used for launching both payload and human cargo. An initial estimate of the Delta IV heavy is $170M (FY '98)[33]. The cargo capacity of this launch vehicle to the ISS is 51,000 [lb]. The space shuttle can only carry 35,400 [lb]. The Delta can therefore launch more payload for much less money than it costs the STS program.

Figure 31: Delta IV Heavy Preparing to be Loaded Vertically onto the Launch Pad.

If future launch human launch rates hold, then approximately four human launches will occur per year. An assumption is made that the Delta IV heavy would not be able to carry both cargo and a human crew. Therefore, three cargo launches and four human launches of the Delta IV would need to occur to match STS capability. This results in a launch cost of $1.2B per year. However, development will be needed in order to ensure that human space flights can take place on the Delta IV heavy. This will drive up the price of a man-rated version. Another assumption is made that a man version of the Delta IV heavy may cost $300M. Now the launch cost would reach $1.7B. This is still much cheaper than the current STS program. However, the crew exploration vehicle (CEV) must still be developed. The orbiter development costs are not included in the current program budget since they have already been paid for. Thus, only the recurring CEV cost will be considered. The cost of an Apollo command service module was $277M (FY '03)[34]. If the new launch system was an Apollo type architecture, then an additional $1.1B for the service modules must be added in. However, the launch cost per year is still only $3.2B, which is over $0.5B less than the current STS program. There will be additional recurring costs that must be included, such as the operation support infrastructure, and the cost for oversight inherit in any manned space mission. Also, the launch pad situation at KSC must be evaluated to determine if the launch rate can be accommodated. However, it is highly doubtful that the next generation Apollo capsule would cost so much with the knowledge the community has gained. Thus, even this quick estimate on a new architecture has provided a lower program cost per year, and that was using very high cost estimates.

This Apollo style architecture was a simple estimate of the costs of an idea for the next generation launch vehicle. If further cost controls can be implemented in this style of architecture, such as building quality into the future CEV, then the total LCC will be lower than the current STS program. If the CEV is chosen to be a reusable vehicle, then it must truly be a reusable vehicle. While the STS is technically a reusable vehicle, since the airframe is flown over and over again into space, the processing and refurbishing that must take place after each mission makes the orbiter turnaround complex. A turnaround time of three months will not be acceptable for the next generation launch vehicle. The requirement of such a large skilled workforce is also unacceptable in order to achieve the space initiative. The launch system must be streamlined with as little inefficiency as possible in order to achieve low LCC for access to space.

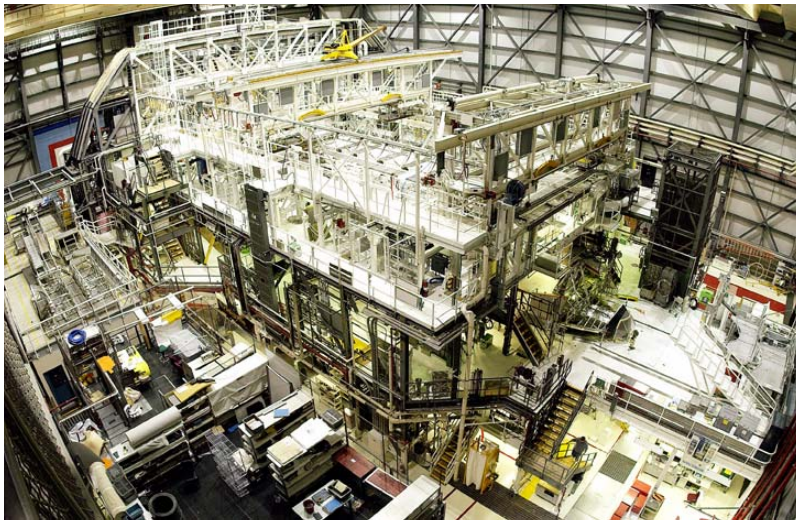


Figure 32: Shuttle Undergoing Routine Processing in the OPF.

9.0 Conclusions and Future Work

9.1 Conclusions

There are inefficiencies occurring in the STS program. These inefficiencies cannot be tolerated; the LCC of this program must be continually reduced so that the new space initiative can proceed. Ideas for rooting out the inefficiency include:

- Restructure management across the STS organization. The systems management area represented 44% of the total STS program cost in 1994.
- Consolidating the contractors and logistics is another way to rid the STS program of cost wastefulness. Better supply chain management would result in more savings to the STS program.
- Combine flight and ground operations at KSC. With the dual launch operations centers at KSC and JSC, duplicity is occurring within the program that can be removed.
- Continue with closing the Palmdale facility. All future refurbishment will take place at KSC.

Figure 33 illustrates a summary of the cost savings resulting from the ideas presented in this paper. The first bar is the baseline 1994 STS program, while the next bars show results from reducing cost in that indirect area. Moving to the right reduces the program cost further until each area has been considered. This chart is meant to be read as a Pareto chart, showing in order where the largest cost reductions can be achieved.

The Monte Carlo simulation further validated these results. Using conservative estimates a mean savings of $594 M (FY ’94) was achieved. The 80 percent confidence bands showed that a minimum of $548 M could be saved in the STS program. Again, this analysis was completed using the 1994 STS program figures. There have been some reductions in cost as well as manpower, and therefore more work must be done to determine the exactly where additional savings can be achieved. With the return to flight scheduled by fiscal year 2005, and the budget for that year easily exceeding the 1994 budget with a lowered flight rate, there are still cost reductions can and should be made.

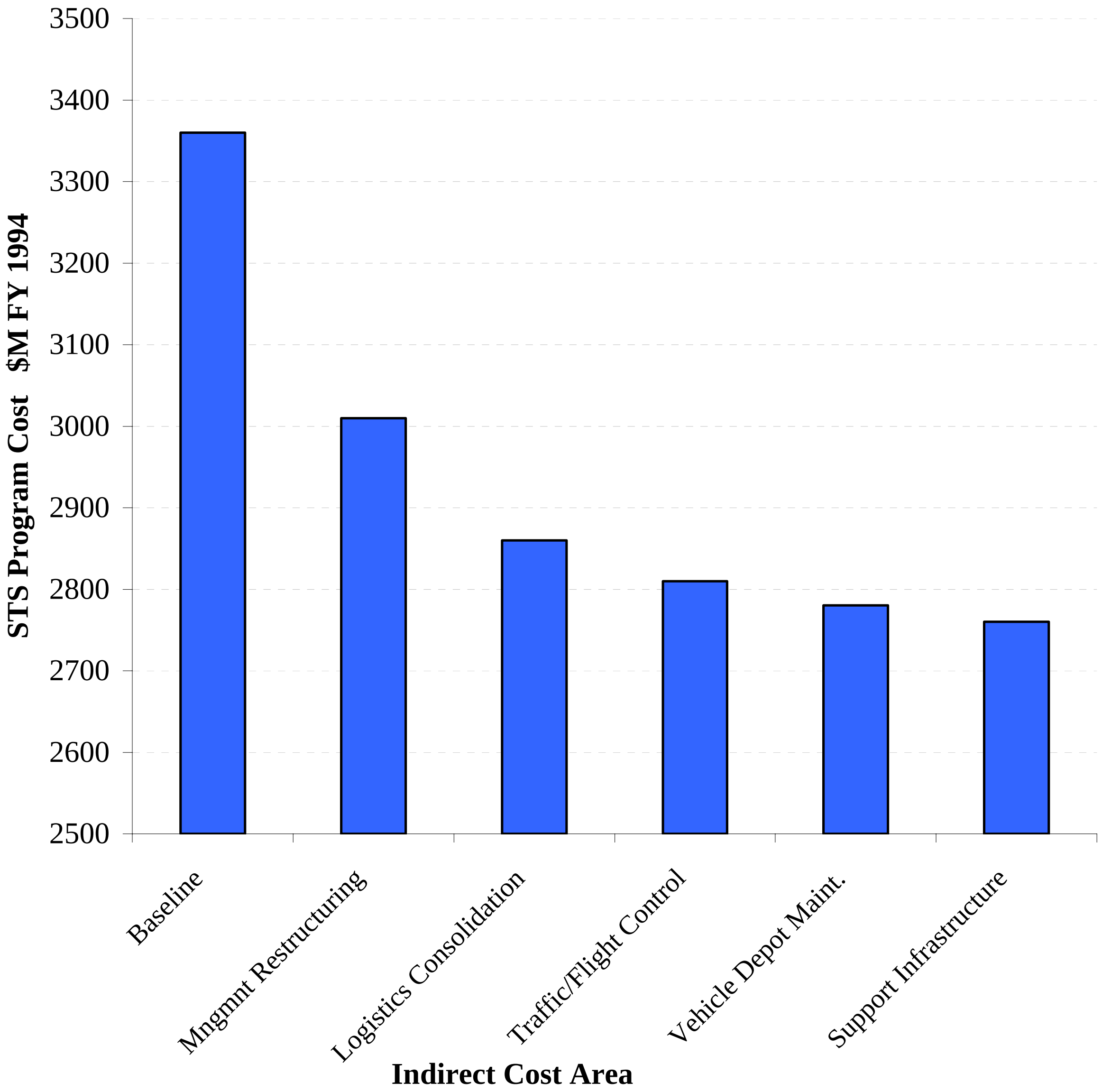


Figure 33: Summary of Indirect Cost Region Reduction

Drawing on an idea from the field of optimization, a DSM was used to illustrate the inefficiency of the current management structure. A new structure was proposed that had less iteration loops so that the overall efficiency of the structure can be increased. Another solution within the systems management division was to eliminate duplicate roles. The workforce has dropped by over 10,000 since the 1994 STS employee breakdown, so this may not result in a high amount of savings. However, the possibility still exists that by determining overlapping responsibilities within management, cost reductions can be made.

Finally, by changing the method of working with contractors, further cost reductions may be available. The number of contractors should be kept to a minimum; system optimization will be much easier to achieve with a reduction in the number of different companies. Additionally, by altering the contract structure a reduction in the LCC could be achieved. The goal would be to try to build quality into the contract, and making the contractors responsible for the usage of spare parts. These ideas should be explored because the STS program will be operating until 2010; therefore, any reductions in cost can be used on the new and exciting space initiative.

The future launch vehicle system must learn from the past about LCC. The idea of reduced development costs in favor of higher costs down the road is no longer tolerable. The public will be wary of a high cost of the new space initiative, so reducing the LCC of the next generation launch vehicle is crucial. If this requires a higher development cost than another option, then the effect of LCC must be explained to the public and Congress. The overall LCC must be shown to be lower in order to receive support. Then NASA must act upon its promise and prove that the LCC will be lower. This will occur as long as the vehicle designers are focused on a low LCC objective, while also achieving safe, human spaceflight. By focusing on LCC, the need for a large standing army of workers should be reduced substantially. The logistics of planning the manufacturing and acquisition schedule will also be considered. The method of storing spares and the use of COTS should further reduce the LCC. Finally, by creating a system that is superior in its maintainability than the current launch system, a reduction will occur in both the possibility of failure and LCC.

NASA has a challenging mission in the years ahead. The goal will be to balance the support of the public and Congress with the requirements to carry out the new exploration initiative. By focusing on LCC, both objectives can be achieved. This is an exciting time to be an aerospace engineer working the in the space community. The opportunity is at hand for innovation and fresh thinking to lead the U.S. into a new space era. This cannot happen without learning from the past, and using those lessons to make our space future even brighter. The future of the U.S. involvement in space is being decided right now, by the selections we make, and therefore we cannot afford to choose incorrectly. By learning from our previous experience in human space flight, these decisions will be made properly in order to lead us to destinations never before conceivable.

9.2 Future Work

This project has barely scratched the surface of a whole host of topics that can be studied to further reduce LCC. The first area for future work is to perform the cost benefit analysis of moving the MSFC projects office to JSC as previously planned. The next step would be to examine what would happen if the office is moved to KSC instead. Another step for the cost-benefit analysis is to examine the effects of moving MCC to KSC. The duplicity of roles between the two installations in the area of launch operation should be further scrutinized. Additionally, more investigation into the roles of the institution and operation of installation employees should be completed. This inquiry should delve into the exact responsibilities of these employees. Another query should be performed to determine where the reduction in STS workforce from 1994 to now has occurred. The STS breakdown in 1994 is extremely insightful, but having a current version would be better.

The supply chain and logistics concerns of the STS program should also be studied more carefully. There are most likely many suppliers of parts to this program, so the goal will be to look for further consolidation. It would not be surprising to learn that varying field centers used different suppliers for the same type of service. Furthermore, the effects of design decisions on logistics planning should be studied. An example is the use of a certain propellant or material. Possibly choosing one type of material would result in less of a logistics challenge versus a different type of material. The performance effect between these two choices could be slight, so the one that results in a lower LCC should be chosen. Even more interesting would be if there was a definite difference between the performances of selecting one design over another. How they match up in LCC, whether this savings is truly worth the degradation in performance, and how exactly to determine this tradeoff would be an intriguing topic for study. Many more STS program decisions could be investigated in this manner. One example would be the use of hypergolic propellants on the orbiter and what ramifications this choice had later on in the orbiter's life.

A very interesting area for study is to further Deming's idea that inspection causes loss to the system. Launching people to space is one of the most technologically challenging activities that the human race has performed. However, the reason for the high number of inspections should be investigated. There may be a way to root out variability in many of the hardware parts so that they can be expected to function with"six sigma" reliability. GEAE has honed their practice to reduce many defects and result in better maintainability. While launch vehicles are obviously more complex, there must be better processes that can be used in order to reduce inspections and maintenance. One thing that would help the STS program is using fully matured technology. Constantly upgrading the system without reaching a freeze of design will continually cause the need for high inspections and maintenance. The benefits of using technology that is not fully mature should be evaluated, along with the benefits of upgrading this technology. While upgrades are nice to have, the effect they have on the LCC must be determined. If the LCC goes higher, then the true benefit of the system must be re-evaluated. Safety upgrades are very hard to quantify, and therefore make the decision of upgrading even tougher. Also, the hardware within the STS program should be evaluated to determine what effort will be required to reach full maturity. Once this maturity is reached, standardization of practices can occur, which will result in a lower LCC. However, if reaching full maturity will outweigh the savings in LCC, then there will be no benefit in accomplishing this task. This is important for the STS program, which has a finite life span.

A large problem with Deming's teachings is that they were made for the manufacturing sector. It is much tougher to implement his ideas in an area where production rates are low. However, there must be a point, using a frozen design, where enough hardware can be produced so that the process is refined to reduce the variability, and therefore the need for inspection. This point may possibly be unrealistic because the manufacturing process cannot root out variation until the 500th unit is produced. However, if this point can be reached at much lower levels, for example the 100th unit, then the cost of producing these units versus the savings they will create in LCC should be studied. This idea would require the standardization within a new launch vehicle so that there is no difference between the first piece of sub-hardware and the 20th piece of sub-hardware. However, in order to achieve low LCC, this must be the case. By rooting out variation, and being able to know with high degrees of accuracy the reliability of the hardware, the need for inspections should be reduced.

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Appendix A: STS 1994 Workforce Breakdown

ID	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

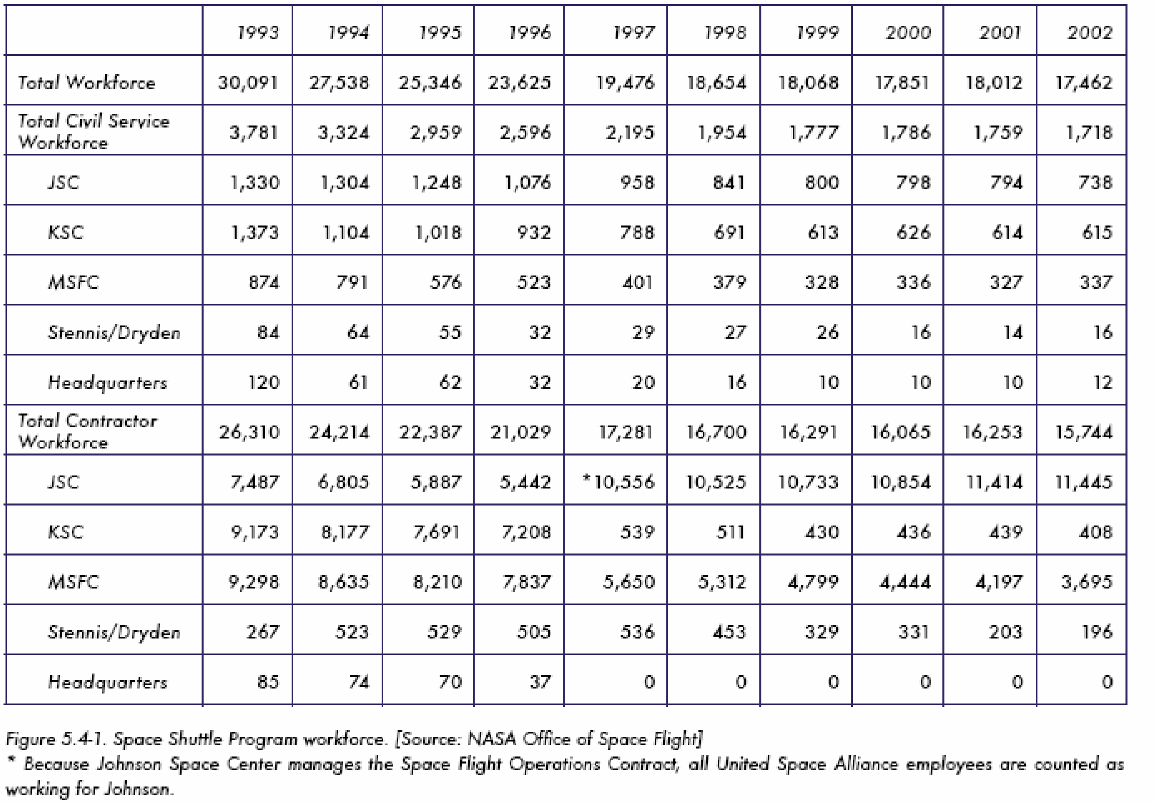
	TOTAL PROGRAM OFFICE/HEADQUARTERS	1046
	Program Office	1012
STS01	Management, SE&I, Flight Analysis	494
STS02	Payload Integration	257
STS03	STSOC Mission Integration Support	56
STS04	Other Support	11
STS05	Landing Site Support	5
STS06	Config Mgmt, Mission Verif, & PRCB	54
STS07	ADP Facility & Ops, MIC 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 B: STS Workforce Breakdown from 1993-2003

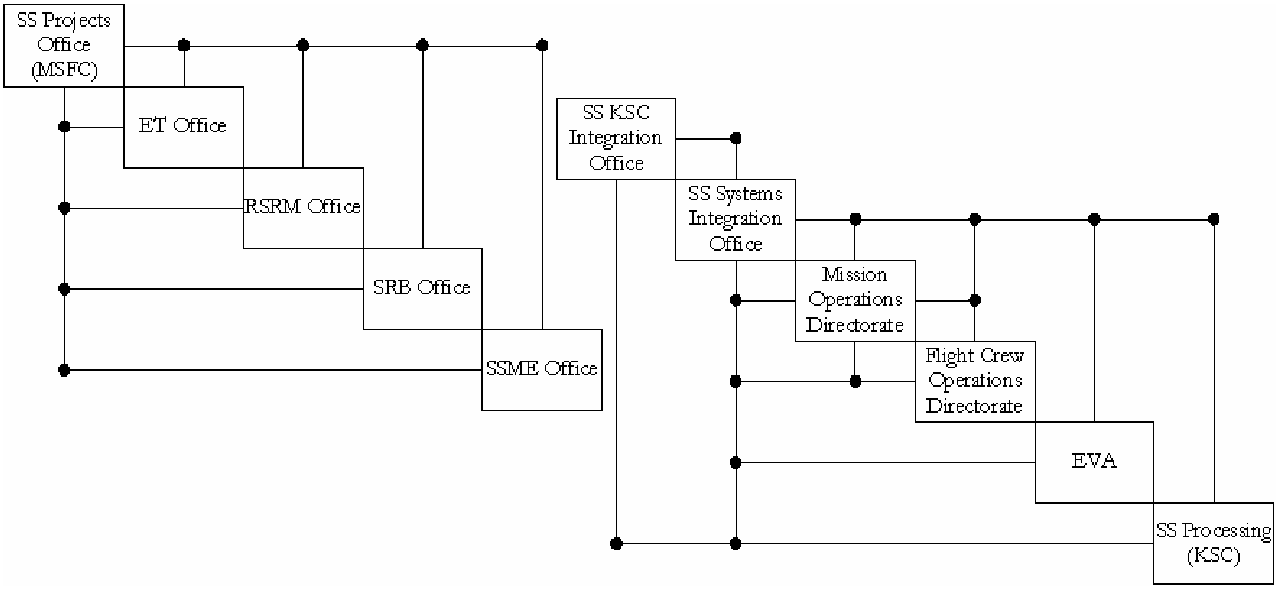


	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total Workforce	30,091	27,538	25,346	23,625	19,476	18,654	18,068	17,851	18,012	17,462
Total Civil Service Workforce	3,781	3,324	2,959	2,596	2,195	1,954	1,777	1,786	1,759	1,718
JSC	1,330	1,304	1,248	1,076	958	841	800	798	794	738
KSC	1,373	1,104	1,018	932	788	691	613	626	614	615
MSFC	874	791	576	523	401	379	328	336	327	337
Stennis/Dryden	84	64	55	32	29	27	26	16	14	16
Headquarters	120	61	62	32	20	16	10	10	10	12
Total Contractor Workforce	26,310	24,214	22,387	21,029	17,281	16,700	16,291	16,065	16,253	15,744
JSC	7,487	6,805	5,887	5,442	*10,556	10,525	10,733	10,854	11,414	11,445
KSC	9,173	8,177	7,691	7,208	539	511	430	436	439	408
MSFC	9,298	8,635	8,210	7,837	5,650	5,312	4,799	4,444	4,197	3,695
Stennis/Dryden	267	523	529	505	536	453	329	331	203	196
Headquarters	85	74	70	37	0	0	0	0	0	0

Figure 5.4-1. Space Shuttle Program workforce. [Source: NASA Office of Space Flight]

** Because Johnson Space Center manages the Space Flight Operations Contract, all United Space Alliance employees are counted as working for Johnson.*

Appendix C: Second-Level DSM



Appendix D: Endnotes

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