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Volume II - Ground Operations Problems

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Prepared by
Glen S. Waldrop

Rocketdyne Study Managers: G. S. Wong/G. S. Waldrop
NASA, KSC Study Manager: R. E. Rhodes

Rocketdyne Division
Rockwell International
6633 Canoga Avenue
Canoga Park, CA 91303

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16. Abstract

This study was initiated to identify operations problems and cost drivers for current propulsion systems and to identify technology and design approaches to increase the operational efficiency and reduce operations costs for future propulsion systems. To provide readily usable data for the ALS program, the results of the OEPSS study have been organized into a series of OEPSS Data Books as follows: Volume I, Generic Ground Operations Data; Volume II, Ground Operations Problems; Volume III, Operations Technology; Volume IV, OEPSS Design Concepts; and Volume V, OEPSS Final Review Briefing, which summarizes the activities and results of the study. This volume presents a detailed description of 25 major problems encountered during launch processing of current expendable and reusable launch vehicles. A concise description of each problem and its operational impact on launch processing is presented, along with potential solutions and technology recommendation.

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FOREWORD

This document is part of the final report for the Operationally Efficient Propulsion System Study (OEPSS) conducted by Rocketdyne Division, Rockwell International for the AFSSD/NASA ALS Program. The study was conducted under NASA contract NAS10–11568 and the NASA Study Manager is Mr. R. E. Rhodes. The period of study was from 24 April 1989 to 24 April 1990.

ABSTRACT

This study was initiated to identify operations problems and cost drivers for current propulsion systems and to identify technology and design approaches to increase the operational efficiency and reduce operations cost for future propulsion systems. To provide readily useable data for the ALS program, the results of the OEPSS study have been organized into a series of OEPSS data books as follows: Volume I, Generic Ground Operations Data; Volume II, Ground Operations Problems; Volume III, Operations Technology; and Volume IV, OEPSS Design Concepts. This volume describes the major operational problems we have today and how they severely impact ground processing, launch operations, and facilities. Potential options for solving the problems are presented.

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INTRODUCTION

The operations cost of today's launch systems has become a large fraction of the vehicle recurring cost per flight, ranging from 20 to 40% for expendable and reusable vehicles, respectively. The complex operations requirements of current launch vehicles have also limited our ability to achieve routine access to space. Since the rocket engine/propulsion system represents one of the more complex and expensive systems in the launch vehicle, a study was made to identify operations problems (cause and effect concerns) that have driven operations costs to exorbitant levels. This volume describes the major operations problems encountered in today's launch vehicles and how these problems have adversely affected our ability to achieve serviceability, reliability, and operability. This volume emphasizes the need to recognize and understand the operations problems and the effort that must be made to avoid them in future designs; i.e., applying the "lessons learned."

CURRENT OPERATIONS PROBLEMS

Processing flight hardware for launch has been a very tedious and time–consuming task, requiring large numbers of people operating sophisticated ground support equipment (GSE) to verify flight system readiness. Each subsystem assembled for the major vehicle element requires total system checkout before flight certification.

This process is complex and involves numerous other systems during the checkout. For example, to support checkout of a main engine, the main propulsion system, electrical power distribution system, hydraulic system, instrumentation system, flight control system, avionics system, environmental system, and the purge, vent, and drain systems must all be activated to support the engine checkout. The checkout itself also requires highly trained and skilled personnel at the vehicle, in the firing room, and at the GSE to supply the required commodities like gases, hydraulics, power, etc. All these activities, in turn, depend on test conductors, quality control, safety, GSE engineering, etc., to accomplish a successful test. Many of these activities are "hands on" and serial in nature, which further complicates the checkout process. The ground support system providing services and commodities also must be verified to ensure that every system is available and certified to support the test. It is, therefore, not surprising that operations support for launch system checkout is complex, manpower intensive, time consuming, and costly, and a launch system that consists of many separate, independent systems simply exacerbates this problem.

A typical illustration of the technical disciplines and operations support required for flight system checkout is depicted in Figure 1–1. An illustration of the large infrastructure of logistics, supplies, equipment, and facilities to support the system checkout is shown in Figure 1–2. Every different commodity required on the vehicle adds another tentacle to the operations support structure. The requirement for Helium gas, no matter how small the amount, dictates the need for additional facilities, GSE, logistics, and transportation to ensure that the gas is at the vehicle processing site when needed.

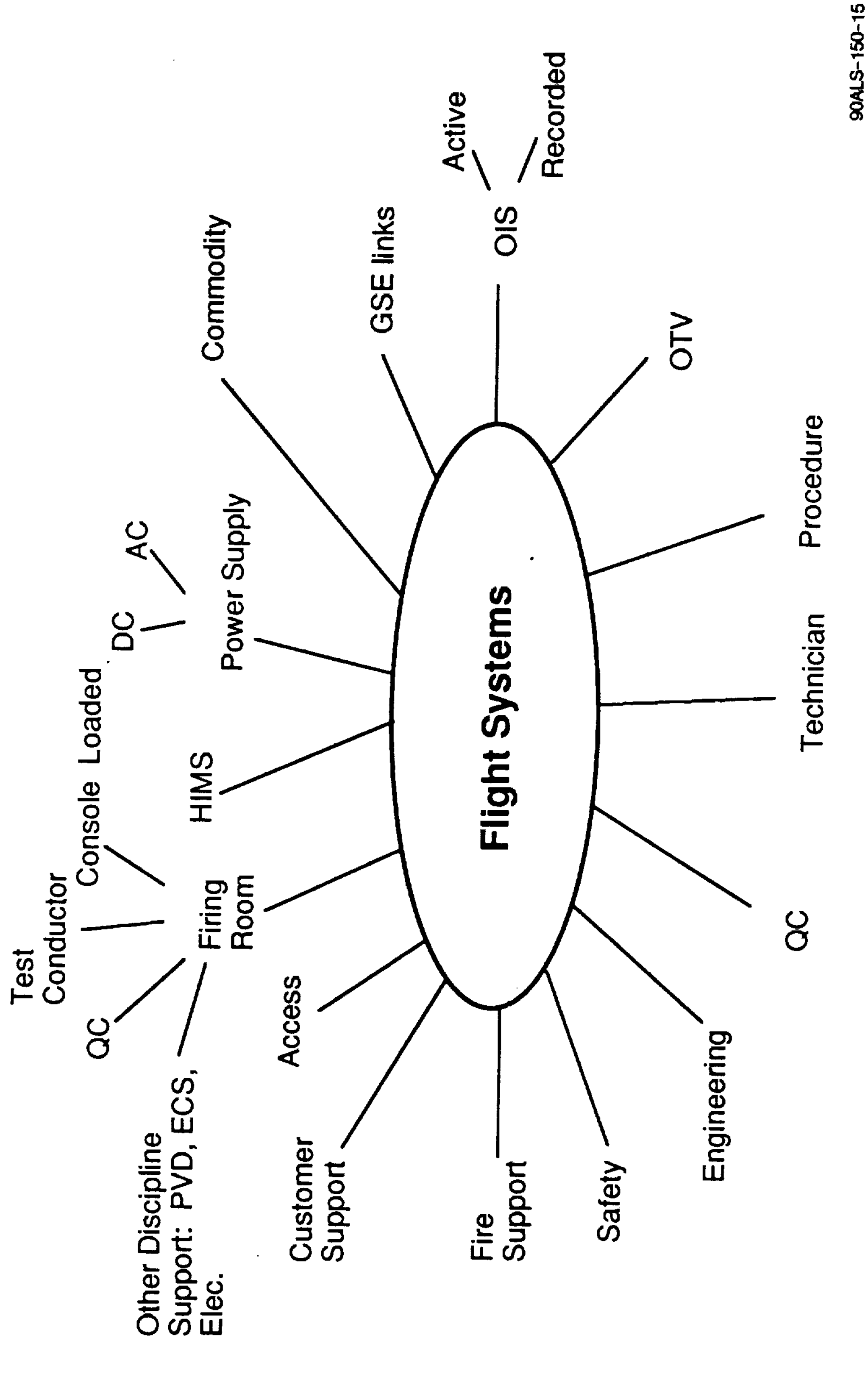

Figure 1. Launch System Operations Support

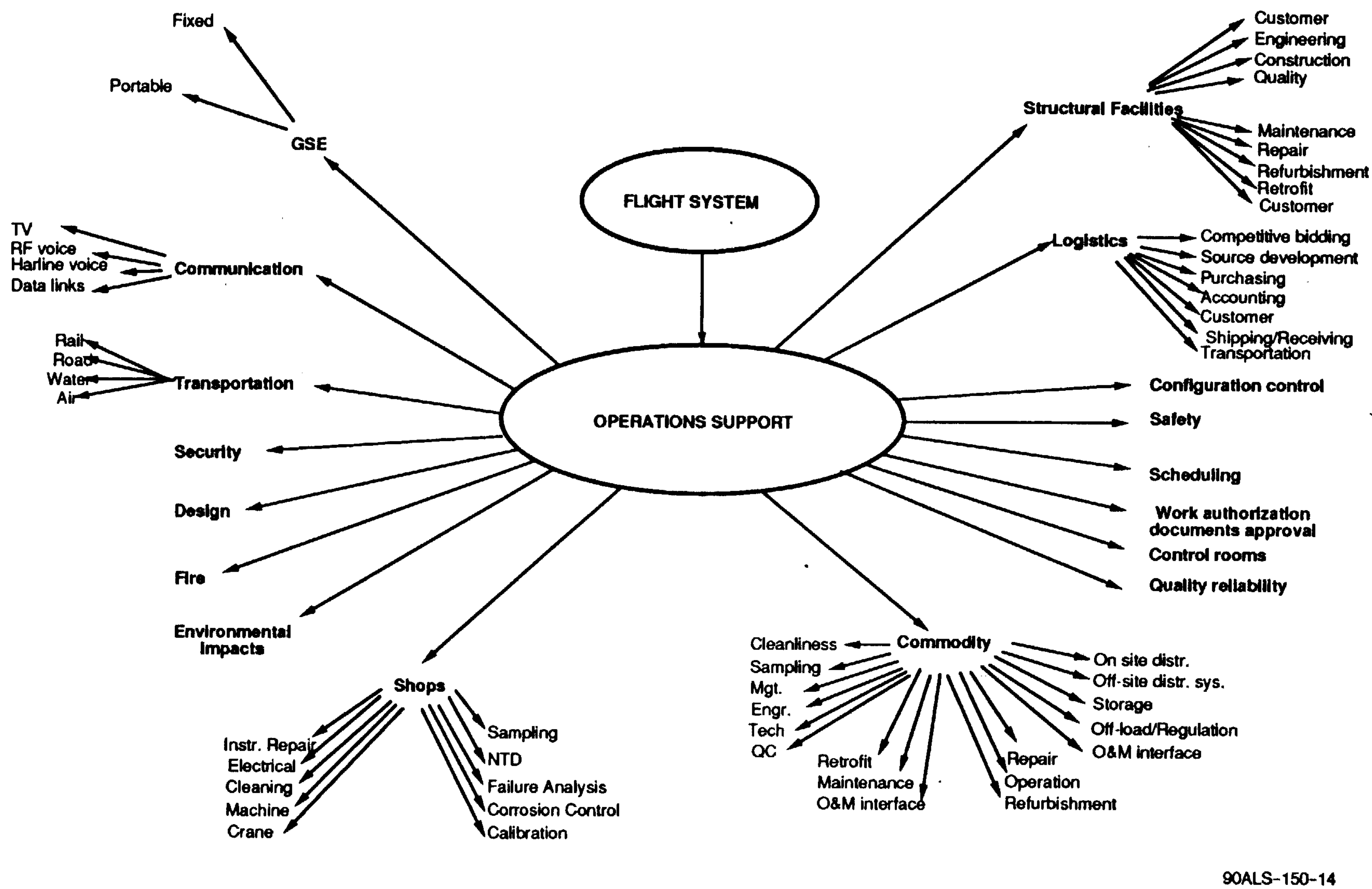

Figure 2. Launch Operations Support Structure

A recent SGOE/T study[1], conducted by Boeing Aerospace Operations for NASA Kennedy Space Center, found current operational requirements are driven by:

1. Systems that are not readily serviceable
2. Too many people are required
3. Too much time is needed for processing
4. Complex support facilities are needed
5. Serial operations are required
6. Hazardous operations are involved
7. Too many commodities and grades of commodity are used

The current OEPSS study has identified some serious major problems involving the propulsion system (which includes the propellant tankage, fluid system, and engine) that have plagued our operations requirements and compromised our launch capability. These operations problems, starting with the most pervasive, include the following:

1. Closed aft compartment
2. Hydraulic system
3. Ocean recovery/refurbishment
4. Separate OMS/RCS
5. Gimbal system
6. Sophisticated heat shield
7. GN_2/GHe purge
8. Excess interfaces

In view of current experience, it is manifestly clear that operational complexity stems from design. In order to achieve operational efficiency, operations must not simply support any design, it must drive the design at its conceptual beginning toward greater simplicity and operability. The following sections of this volume list 25 major operations problems, or concerns, that should be mitigated or eliminated in future propulsion design to achieve simplicity, reliability, and operability necessary to meet launch operations efficiency.

[1]Scholz, A.L., *Shuttle Ground Operations Efficiency/Technology Study (SGOE/T)*, NASA/KSC Contract NAS10-11344, Boeing Aerospace Company, May 4 1989.

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1.0 CLOSED AFT COMPARTMENTS, OEPSS CONCERN 1

1.1 OPERATIONAL IMPACT

The impact on ground operations caused by a propulsion system contained within a closed compartment is summarized in Figure 1-1.

1.2 REQUIREMENTS BACKGROUND

The need for structural efficiency is one of the factors leading to use of closed compartments in launch vehicles. Skin and stringer or monocoque type structures are strong and lightweight but, because their structural elements are large areas, tend to enclose volumes and form compartments. Where hazardous fluids exist within the enclosed volume, ground purging is usually required to preclude accumulation of these fluids as a result of possible leakage. This need for purging can then lead to further sealing of the compartment to control the purge process.

Closed compartments may also be used to protect components from main engine heat or other external environments. They also can be necessary to maintain pressure required for structural stability. The aft compartment of the STS Orbiter serves both functions as well as containing the inert purge.

1.3 SYSTEM DESCRIPTION

A typical ALS vehicle contains a closed engine compartment similar to that on the Orbiter for the same reasons. In addition, for the recoverable propulsion modules, the compartment protects the contained components and subsystems from sea water contamination. Closed compartments also are used in the intertank areas.

1.4 OPERATIONS PROBLEM DESCRIPTION

Closed compartments cause numerous ground operations problems because leakage of hazardous fluids is contained, because access is restricted, and because GSE requirements are made complex.

The fact that hazardous leakage can escape into a closed volume requires that volume be purged on the ground with an inert gas to preclude accumulation of hazardous fluids. A detection system is needed to ensure no dangerous buildup of gas. Both the purge and detection systems have vehicle hardware, ground interfaces, and ground support equipment. All necessitate maintenance, checkout, and servicing, which in turn demand a large staff of people to perform and support these functions. The inert purge leads to the very real possibility that personnel can inadvertently enter an environment that will not support life.

The restricted access caused by closed compartments also creates hazards for personnel. Injuries resulting from contact with hardware when working in tight areas are common, and the limited

- **Operational impacts**
  - Confinement of potential propellant leaks – criticality 1 failure
  - Requires inert purging during loading operations
  - Requires conditioned environment for personnel
  - Requires sophisticated hazardous gas detection system
  - Drives the requirement for sophisticated heat shielding
  - Inhibits proper access to components
  - Drives the requirement for specialized/dedicated GSE
  - Imposes manloading restrictions for confined space
    - Due to unnatural personnel passageways
    - Elevates potential for hardware damage
  - Additional interfaces required between vehicle and ground
  - Requires sophisticated ground support equipment
    - Environmental control system for personnel
    - Gaseous nitrogen regulation and distribution system
    - Must have redundant systems
    - Capable of local and remote operation
    - Requires an "army" for operation, maintenance, certification
    - Adds another function to the firing room operation
  - Tremendous risk to the safety of personnel and hardware
  - Drives many operations to be serial in flow
  - Drives need for LCC that could delay or scrub a launch
- **Potential options for consideration**
  - Aft area should be completely open – Ref. SII and SIVB vehicle configurations

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Figure 1-1. Operational Impact of Closed Aft Compartments

access can preclude rapid evacuation in case of an emergency. Tight working areas also cause hardware damage, require serial work, and complicate LRU replacement.

In addition to the GSE needed to provide compartment purging and hazardous gas detection, the closed compartment requires that complex and expensive GSE be developed to support personnel access and permit LRU handling. Installation of this equipment, such as access platforms, can be difficult and time consuming and must be done with extreme care to prevent flight hardware damage.

1.5 BRIEF PHYSICS OF PHENOMENON

N/A

1.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEMS

The aft or boat-tail of the launch vehicle must be as open as possible, allowing any small amount of propellant leakage to escape to the atmosphere. Free access to the engines and other systems must be provided. A truss-work thrust structure might be ideal. Shielding from engine heat must not restrict general access. Closing of other compartments must be avoided where possible. Small compartments should be combined to form larger volumes where practicable.

1.7 TECHNOLOGY RECOMMENDATION

Develop arrangements of engines and structure that do not form closed compartments.

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2.0 HYDRAULIC SYSTEMS FOR VALVE ACTUATORS AND TVC, OEPSS CONCERN 2

2.1 OPERATIONAL IMPACT

The impact on ground operations caused by hydraulic systems for a propulsion system is summarized in Figure 2-1.

2.2 REQUIREMENTS BACKGROUND

The use of hydraulic fluid as an operating medium for thrust vector control actuators and large rocket engine valve actuators has been common practice for most of our launch vehicles. Positive action, quick response, and relatively compact size for modulating control systems make hydraulic actuators very attractive, especially when there are large horsepower requirements for the actuator.

2.3 SYSTEM DESCRIPTION

The basic elements to provide the required hydraulic fluid pressure to the propulsion system components generally consist of a hydraulic pump, pump driver, hydraulic reservoir, hydraulic accumulator, hydraulic filters, control valves, and associated plumbing, instrumentation, and controls. Generally, the need to perform ground test and checkout dictates duplicate systems; therefore, a ground-based system as well as a flight system are needed. The requirements for redundancy in the hydraulic system essentially create the need for multiple and separate flight systems.

2.4 OPERATIONS PROBLEM DESCRIPTION

A hydraulic system represents another fluid distribution system that must be processed and maintained for flight operations. This involves distribution system leak checks, long periods of circulation for de-aeration/filtering, operations associated with fluid sampling and analysis, and functional checks of all control systems. In order to process the flight system, ground support equipment, generally consisting of all the basic hydraulic distribution system elements, must be duplicated to simulate pressure for the flight system checkout. The same operations and maintenance requirements are also required for the flight system. In the case of the Space Shuttle system, the operations problem is compounded by using hypergolic fueled auxiliary power units to drive the pumps. The use of a hypergolic fuel dictates that operations such as fueling the unit be conducted with only a limited number of personnel directly involved with the fueling operation and specially certified to work in self-contained atmospheric protective ensemble (SCAPE). This type of system dictates serial processing operations.

2.5 BRIEF PHYSICS OF PHENOMENON

Hydraulic actuation, whether for thrust vector control or valve control, requires that a nearly incompressible liquid be distributed from the area in which the liquid is stored and pressurized to the location of the actuator. The source of pressure, usually a positive displacement pump, may be powered by an electric motor from an engine-provided drive or by an auxiliary power unit. Actuators

- **Operational impacts**
  - Requires sophisticated ground support systems
    - Expensive pumping units/control systems
    - De–aerators/filters
    - High pressure piping systems
    - Both local and remote operating capability
    - "Army" to operate, maintain, sample, and calibrate system
  - Requires sophisticated flight hardware
    - Auxiliary power unit/pumping unit
    - Power units may demand lubrication equipment which may require cooling equipment
    - Control and filter systems
    - "Army" to operate, maintain, sample, and calibrate system
  - Requires long periods of circulation for de–aeration/filtering
  - Potential source of contamination for valve actuators
  - Another (2) fluid interfaces (minimum) between vehicle and ground
  - Depending on APU propellants, can force processing into periods of area clearing and serial operations
- **Potential options for consideration**
  - Electro–mechanical actuators

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Figure 2–1. Operational Impact of Hydraulic Systems for Valve Actuators and TVC

may be linear cylinders or rotary drives. Precise positioning of the actuator typically requires servo valves with position feedback for control. Because the servo valves have very small clearances between moving parts, careful control of fluid contamination is required.

2.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

To alleviate the problems associated with a hydraulic distribution system, the use of electro–mechanical actuators appears to offer the greatest potential for reducing operations cost associated with actuation systems. Electro–mechanical systems also offer the opportunity to automate completely the test, checkout, and verification of system integrity.

2.7 TECHNOLOGY RECOMMENDATION

Develop low cost, reliable, compact, electrical actuators for large cryogenic valves and thrust vector control devices that draw relatively low power.

D600–0011/sls

3.0 OCEAN RECOVERY AND REFURBISHMENT, OEPSS CONCERN 3

3.1 OPERATIONAL IMPACT

The impact on ground operations resulting from ocean recovery of a propulsion system is summarized in Figure 3-1.

3.2 REQUIREMENTS BACKGROUND

The need to reduce recurring launch operations costs drives the program to consider recovery, refurbishment, and reuse of certain flight hardware elements. The choice of water recovery would appear to be the preferred concept, taking into consideration the potential for high costs of developing a fly-back (for dry landing) system for the launch vehicle. The ALS program has been evaluating the concept of an ocean recovery of at least the propulsion and avionics (P/A) module.

3.3 SYSTEMS DESCRIPTION

Even though these are different concepts of effecting an ocean recovery of the P/A modules, the general approach is to:

- Separate the P/A module from the rest of the vehicle
- Deploy parachutes
- Land P/A module with engine thrust chambers up
- Attempt to protect critical hardware from water intrusion
- Bring the P/A module on board the ship
- Ferry the P/A module back to the launch site
- Refurbish
- Reuse

3.4 OPERATIONS PROBLEM DESCRIPTION

The economic justification for ocean recovery of a liquid propellant rocket propulsion system, based on observations made for the recovery of the relatively robust, spent space shuttle, solid rocket boosters (SRB), is questionable. The present operations associated with the recovery and refurbishment of the SRBs are time consuming and create the need for a unique infrastructure to support such operations. Support of an ALS type and size module recovery, in addition to anticipated frequency of recovery, could require a support system that is several orders of magnitude greater than that which exists today. Refurbishment of the SRBs has shown that sea water finds its way into everything, even into "sealed systems" such as the hydraulic system. "Sealed patches" on the structure have been re-

- **Operational impacts**
  - Vehicle stages and components recovered from performance–intensive operations require excessive refurbishment
    - STS orbiter requires approximately 2 months of intense 7–day week, three–shift operations to recycle for launch
    - SRBs require hazardous, tedious recovery from ocean impact, removal of 5,000 part–numbered components, cross–country shipment, and further intensive refurbishment prior to reload. Dynamic water impact and galvanic corrosion create highly significant component deterioration. Recycle time exceeds 6 months
- **Potential options for consideration**
  - Expendable low–cost vehicle elements
  - Recoverable elements that require only a bare minimum of refurbishment
    - Low–pressure, low–rpm engines and turbopumps with simple operational cycles and minimized support systems
    - Robust structures and components that operate at reduced performance levels to assure long life and minimum rebuilding; "caterpillar diesels" rather than "Indy 500 racers"

D600–0011

Figure 3–1. Operational Impact of Ocean Recovery and Refurbishment

moved only to find corrosion from sea water intrusion. Cleaning the hardware was originally conceived as being a "rinse-off" operation, but because of film left by the sea water, a labor-intensive scrubbing of the surfaces is required. Verification of hardware condition both as a result of sea water intrusion and impact load requires that all systems be disassembled for inspection.

3.5 BRIEF PHYSICS OF PHENOMENON

N/A

3.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The two potential options for eliminating the labor-intensive and costly operations and infrastructure associated with ocean recovery would be to develop either low-cost expendable systems or fly-back systems for the entire booster.

3.7 TECHNOLOGY RECOMMENDATION

Develop low-cost expendable or fly-back systems.

D600-0011/ljm

4.0 MULTIPLE PROPELLANTS, OEPSS CONCERN 4

4.1 OPERATIONAL IMPACT

The impact on ground operations and ground facilities resulting from the use of multiple propellants for the main propulsion system and auxiliary propulsion systems is described in Figure 4–1.

4.2 REQUIREMENTS BACKGROUND

Multiple propellants, or commodities, have been used on various launch vehicles. For example, one grade of liquid oxygen and liquid hydrogen is used for the main propulsion system, a higher grade of liquid oxygen is used for the fuel cell power plants, and storable propellants are used quite extensively for spacecraft propulsion system and attitude control systems. The Saturn V vehicle utilized many different propellants, including hydrocarbons, liquid hydrogen, liquid oxygen, hypergolic fuel and oxidizer, and high–grade liquid oxygen–liquid hydrogen for the fuel cells. Also coupled to these various multiple liquid propellant systems have been solid propellant devices, such as the current space shuttle solid rocket boosters, the stage–0 solids of the Titan, and the Castor motors of the Delta. In the case of the Titan and Delta vehicles, the solids evolved into the system as part of the propulsion system requirements to launch larger and heavier payloads.

4.3 SYSTEM DESCRIPTION

The launch site system required to support each of the different propellants is unique to handling each specific commodity. The liquid hydrogen loading system is a pressure–fed system using hydrogen vaporizers to pressurize the storage tank. The liquid oxygen system utilizes pumps to move the fluid. The storable propellants are generally transferred by a pressure system. Some systems utilize separate "loading carts" instead of the ground system. The solid propellants require their own unique facilities to enhance safety, prevent contamination, and maintain the grain in the proper environment. The hydrocarbons (RP–1) are generally transferred by pumps.

4.4 OPERATIONS PROBLEM DESCRIPTION

Each unique system for handling each commodity requires a separate "army" to operate that system. Generally, the maintenance requirement for each of the systems is different based on the specific hazards of the commodity. The highly toxic storable propellant must be handled by the "army" that is certified for working in a self–contained atmospheric protective ensemble (SCAPE). Operations involving storable propellant transfer require that the area be cleared of the "armies" operating the other systems, thus dictating lengthy serial processing operations. Because different grades of liquid oxygen and liquid hydrogen are used for the main propulsion system and fuel cells, each of these have separate storage and transfer systems on the ground, separate storage and transfer systems on the vehicle, and, therefore, separate vehicle–to–ground interfaces. Each of these systems has its own army to maintain the four systems, and the separate and multiple systems have requirements for separate gas purges and pressurization systems, both on the ground and on the vehicle.

- **Operational impacts**
  - Multiple commodities require:
    - Multiple facilities for storage and transfer
    - Multiple headcount and administrative support
    - Extra support for procurement/logistics
    - Vehicle complexity necessary for multiple systems requiring multiple propellants/commodities
- **Potential options for consideration**
  - Use LOX/LH_2 for all considerations:
    - Main propulsion
    - OMS
    - RCS
    - PRSD/propellant-grade fuel cell
    - APU

D600-0011

Figure 4-1. Operational Impact of Multiple Propellants

Multiple propellant usage for launch vehicles prevents system integration and, therefore, prevents reduction in multiple systems and interfaces, unique ground support equipment, and large number of personnel required to maintain and operate all the different systems. The stacking of the space shuttle SRBs also has created safety concerns for the Vehicle Assembly Building (VAB) and disrupts other ongoing system activities until the lifting operations are completed. Depending on the location of the SRB activity, at times the entire "low bay" of VAB is secured further hindering operation of the other space shuttle elements that work in the unprotected bays and move about in the transfer aisles.

4.5 BRIEF PHYSICS OF PHENOMENON

N/A

4.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The ALS has baselined a liquid oxygen–liquid hydrogen main propulsion system. Requirements for fuel cell power plants should be based on the same grade of propellant as the propulsion system. The requirements for the OMS/RCS systems and/or retro–propulsion system should also be based on the same propellants.

4.7 TECHNOLOGY RECOMMENDATION

Develop fuel cell power plants and OMS/RCS systems that can use propulsion system grade liquid oxygen. (See OEPSS Concern 10 for OMS/RCS systems.)

D600-0011/ljm

5.0 HYPERGOLIC PROPELLANTS, OEPSS CONCERN 5

5.1 OPERATIONAL IMPACT

The negative impact on ground operations resulting from loss of parallel processing capability is described in Figure 5-1.

5.2 REQUIREMENTS BACKGROUND

Hypergolic propellants (earth storable propellants) have been attractive for propulsion systems of spacecraft, especially when long-duration missions are involved. These propellants do not require special insulated tanks, no boil-off problems exist, and the need for a separate engine ignition system is eliminated. Essentially, this type of propellant can be loaded well in advance of intended use and lends itself to the quick deployment of a missile system by eliminating the time for tanking at notification of need.

5.3 SYSTEM DESCRIPTION

The present space shuttle orbiter OMS and RCS systems use earth storage hypergolic propellants. These systems are generally pressure-fed, require no special insulation for tankage or feed lines, and do not require a separate ignition system for each propulsive device. The ground distribution system is also a pressure-fed system located away from the launch pad. These highly toxic propellants create a major hazardous impact on ground operations.

5.4 OPERATIONS PROBLEM DESCRIPTION

The impact of using earth-storable hypergolic propellants on launch operations is directly related to their high level of toxicity. All operations involving any system maintenance or propellant transfer require special precautions to protect personnel from exposure to these propellants. Several mandatory safety measures are put into effect as follows:

- Only a limited number of personnel are allowed to support the operation on-site. All personnel must be self-contained atmospheric protective ensemble (SCAPE) certified.
- The operation area is cleared of all other personnel not directly associated with the task.

Essentially, this type of closed-area operation causes other work to stop and wait until the hypergolic task is completed. All to often, personnel have had to evacuate the area because one of the system components has developed a leak. On one occasion, a propellant leak reacted with adjacent noncompatible material and started to smolder. On another occasion, one of the quick disconnects in the propellant loading line disengaged from the vehicle fill port causing the propellant to spill over the sensitive heat shield tiles, thus causing the tiles to debond from the vehicle. Recovery from this mishap was a major unexpected cost for that launch. The closed-area operation thus becomes a

- **Operational impacts**
  - Loss of parallel processing caused by "area clear" evacuations required during hypergol operations
  - High cost in material and headcount for SCAPE–type operations
  - Disposal of contaminated materials and fluids is expensive
  - Separate, hazardous facilities required
  - Personnel safety constantly in jeopardy
- **Potential options for consideration**
  - Provide systems that use less hazardous storable propellants
    - RP–1/H_2O_4, etc.
  - Use existing prime propulsion propellants, i.e., eliminate hypergols (preferred option)
    - GOX/GH_2, etc.
  - Devise totally encapsulated system that is processed off–line and attached to vehicle late in process to absolutely minimize safety concerns and hazard duration (original goal of shuttle but design detail did not permit)

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Figure 5–1. Operational Impact of Hypergolic Propellants

serial impact to vehicle processing. When other test, checkout, and maintenance operations are interrupted, whether planned or realtime, additional time and cost are added to overall processing because other systems must constantly secure and reestablish their operations.

5.5 BRIEF PHYSICS PHENOMENON

N/A

5.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Some options for consideration would be to eliminate the use of toxic propellant in the launch vehicle, including the spacecraft, or to use encapsulated systems processed off–line and mated with the launch vehicle late in the processing flow. Discussions in OEPSS Concerns 4 and 10 are also applicable to this particular concern.

5.7 TECHNOLOGY RECOMMENDATION

See OEPSS Concerns 4 and 10.

D600–0011/ljm

6.0 POOR ACCESSIBILITY, OEPSS CONCERN 6

6.1 OPERATIONAL IMPACT

The impact on ground operations caused by propulsion system designs with inadequate access to components for checkout and maintenance is summarized in Figure 6–1.

6.2 REQUIREMENTS BACKGROUND

The sheer sophistication of space vehicle flight hardware, the necessity of verifying its operational integrity, and the ability to safely remove and replace defective components drives the need for proper access to all systems. This holds true not only for ground–based access structures, but for the launch vehicle as well. Proper access must be considered for every position in which the vehicle may reside when being processed for launch.

6.3 SYSTEM DESCRIPTION

The configuration of the flight vehicle and its components, the use of enclosed compartments ("aft skirts"), and the allotted access openings will dictate the shape and size of "internal" access platforms. These types of platforms will also have to be designed such that no more than two people (and in some cases only one person) can install and remove them safely. The space shuttle orbiter aft fuselage access platforms are an excellent example of supporting both horizontal and vertical processing of the vehicle. The ground–based access systems are generally not so sophisticated and are of a more robust design with more flexibility to allow access to the work area.

6.4 OPERATIONS PROBLEM DESCRIPTION

The use of enclosed compartments for the propulsion and other support systems is the largest contributor to the difficulty and complexity associated with accessibility at the launch site. The operations problem discussions in OEPSS Concern 1 are certainly relevant. The cost for replacing flight hardware that was damaged because technicians did not have proper access for servicing the systems located in the compartment has been extremely expensive. Replacement of avionics boxes on propulsion systems in the orbiter have taken at least five times longer than it would have been had the component been readily accessible. Improper accessibility adds costs to the operations by placing "man–loading" restrictions in the area with serial impacts to hardware processing. The inability of a person to remove himself rapidly from a work area because of poor accessibility is also a serious safety hazard. Ground–based systems for the most part have better access simply because the ground hardware designer is completely familiar with the ground hardware requirements at the launch site. The constant use of scaffolding, boards/ropes, etc., is good evidence that flight hardware designers are not completely familiar with access platform designs required for flight hardware. A good case in point is the profusion of boards/ropes needed around the SSMEs to service not only the propulsion system but other vehicle systems as well.

- **Operational impacts**
  - Restricted access can cause personnel hazard
  - Potential for hardware damage from personnel
  - Restricted access can force serial work
  - Increases complexity of GSE
- **Potential options for consideration**
  - Design for ample access for checkout and servicing
  - Provide provisions for easy removal of all LRU's

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Figure 6–1. Operational Impact of Poor Accessibility

6.5 BRIEF PHYSICS OF PHENOMENON

N/A

6.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The first order of business is to eliminate or drastically reduce the need for any type of enclosed compartment. High-risk components must be located in areas for quick access and safe removal/replacement. Close coordination among flight hardware designers and access platform designers is mandatory.

6.7 TECHNOLOGY RECOMMENDATION

More thorough investigation of heat shielding requirements in the aft portion of the vehicle to eliminate the need for enclosed compartments with poor accessibility.

D600-0011/ljm

7.0 SOPHISTICATED HEAT SHIELDING, OEPSS CONCERN 7

7.1 OPERATIONAL IMPACT

The impact on ground operations caused by sophisticated and complex heat shield designs is described in Figure 7-1.

7.2 REQUIREMENTS BACKGROUND

Protecting the aft portion of the launch vehicle, the propulsion system, and other support systems from overheating due to exposure to the rocket engine exhaust gases has been accomplished in a variety of ways. The type of propulsion system, configuration, location, mission profile, etc., are factors in determining the severity of heating by convection and/or radiation that may be experienced in the aft area of the vehicle.

7.3 SYSTEM DESCRIPTION

Most launch vehicles will have some type of thermal insulation on the aft base bulkhead. Depending on heat loads expected, these devices may be simple heat resistance panels and blankets or highly sophisticated fibrous refractory composite insulation (FRCI) as used on the space shuttle orbiter. Protective insulation for the engines might include "cocooning" the entire engine with lightweight, fiber-filled, inconel-foil batts as was done on the Saturn V, F-1 engines. Insulation used on the aft skirts of the SRBs is known as a Marshal spray-on ablative (MSA).

7.4 OPERATIONS PROBLEM DESCRIPTION

The installation of insulation, whether it be simple panels, blankets, engine cocooning, or sophisticated heat shielding, is a time-consuming and manpower-intensive operation. Generally, this heat shielding is installed late in the processing flow and represents closeout for flight. Any need to gain access to service a component after heat shielding installation can significantly impact vehicle processing at the most critical time in the vehicle flow.

The enclosed after compartment of the orbiter has created additional problems with heat shielding. In this configuration, the shielding is accomplished by having engine-mounted heat shields that move (when the engine gimbal) inside the dome heat shields (mounted to the base shield) with a sealing device to protect the aft end of the vehicle against intrusion of hot gases. These shields and their arrangement and movement are best illustrated as the way the human eyeball works with the open eye lid. The GSE to install and remove the domes is awkward; the domes are in two segments and weight approximately 200 lb each. A multitude of fasteners is used to attach these devices to the orbiter and engine and to secure splice lines of the segments. When major components of the SSME require replacement, this shield has to be removed. A relatively simple component replacement taking approximately one shift is stretched to approximately 3 to 5 days because of the accessibility and heat shield removal and reinstallation issues.

- **Operational impacts**
  - Manpower intensive due to weight and size
  - Means of fastening creates the need for "army" to accomplish
  - Generally a serial operation for closeout to launch
    - Time impacts to remove dedicated heat shielding to gain access to a component
  - Restricts ready access to components
  - Structure that is critical to combustion overpressure at engine start
  - Provides containment for cryo leaks or cryo condensate
- **Potential options for consideration**
  - Spray-on foam insulation
  - Insulation built into the component
  - Local shielding only for critical components
  - Relocate sensitive components

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Figure 7-1. Operational Impact of Sophisticated Heat Shielding

7.5 BRIEF PHYSICS OF PHENOMENON

N/A

7.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Several techniques should be considered to alleviate the problems associated with heat shielding. If a component is sensitive to elevated temperatures, then consideration should be given to relocating the component to a cooler location in the aft area. Local shielding and/or built–in insulation for critical components that cannot be relocated should be considered as an alternative to total isolation of the system from the heated environment. A thorough and realistic evaluation of the environment expected in the aft region should be made to determine whether the aft systems could be acceptably protected for the duration of the mission by using a spray–on foam insulation similar to that used on the space shuttle's external tank.

7.7 TECHNOLOGY RECOMMENDATION

Use thermal insulation or local heat shielding of selected components, or relocate components to lower–temperature areas.

D600-0011/ljm

8.0 EXCESSIVE COMPONENT/SUBSYSTEM INTERFACES, OEPSS CONCERN 8

8.1 OPERATIONAL IMPACT

The impact on ground operations caused by a complex propulsion system of many components and interfaces is described in Figure 8-1.

8.2 REQUIREMENTS BACKGROUND

Current launch vehicles are composed of numerous subsystems to accomplish the mission of the vehicle. The types and number of subsystems can be the result of whether a vehicle is to be recovered (space shuttle) or expendable (Atlas, Delta, etc.). In addition, the number of different components and subsystems is the direct result of the autonomy required to support the concurrent development of many subsystems. Since the engine is generally the long-lead time item, its development and design freeze is driven well in advance of the vehicle propellant management system and, therefore, drives the need for the engine to have its own avionics system, pneumatic system, instrumentation system, etc., separate from the vehicle propellant management system. The vehicle system will also require avionics, pneumatics, and instrumentation systems to support its development, which is usually done by a separate contractor and under the directión of a different design center. This practice has the potential to lead to numerous and duplicate components, which in turn leads to numerous and all-to-often artificial interfaces. The program requirement for developing standalone vehicle components will have a direct effect on duplication of hardware.

8.3 SYSTEM DESCRIPTION

There are many examples which describe this OEPSS concern; however, the one that is most recent, and represents this concern, would be the space shuttle orbiter propulsion systems. The orbiter has a standalone main propulsion system (MPS) that supports a standalone main engine. The orbiter also has an orbital maneuvering system/reaction control system that is completely separate from the main propulsion system and the standalone auxiliary power units that drive the hydraulic pumps. Each SSME is a standalone component that has all of the subsystems to support an engine test whether it is in an orbiter or on the test stand. This then, for instance, leads to three separate controllers and three separate pneumatic control assemblies. The standalone feature then produces the artificial interfaces where it is connected to the orbiter MPS. Likewise, the orbiter MPS has its own avionics devices, pneumatic system, and pneumatic distribution systems supplying each of the SSME pneumatic control assemblies. there is also duplication of instrumentation on both sides of the interfaces that supports standalone testing and checkout. The standalone OMS/RCS systems have their own pneumatic storage and distribution systems which are completely separate from the MPS/SSME pneumatic systems. Likewise, the standalone APU system has its own pneumatic storage and distribution system which is completely separate from the OMS/RCS pneumatic system and the MPS/SSME pneumatic system.

- **Operational impacts**
  - Every interface must be verified
    - Leak checks
    - Electrical checks
    - Mechanical integrity checks
- **Potential options for consideration**
  - Integrate subsystems into larger subsystems/systems
  - Develop modules to replace components

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Figure 8-1. Operational Impact of Excessive Component/Subsystem Interfaces

8.4 OPERATIONS PROBLEM DESCRIPTION

Standalone systems dictate the need for numerous and duplicate components (and support systems). This need, in turn, drives up the number of separate interfaces. Each standalone system promotes artificial interfaces just for the sake of being able to remove an entire subsystem. Each interface represents another "break point" in the system that must be verified should the connection be broken. Each fluid interface represents a potential leak point requiring special attention for disassembly, reassembly, and leak checks. Separating fluid connections leads to the potential for sealing surface damage, which, in turn, requires repair of the sealing surface and, depending on the severity, could even require a line changeout. Fluid connections also represent additional weight to the flight hardware in the form of bolts, flanges, fittings, and, most of all, sophisticated and expensive seals. It is not uncommon in a critical system containing helium, hydrogen, or oxygen to have to replace seals more than once to effect an acceptable leak-free joint.

Systems carrying fluids such as hydrogen and oxygen necessarily dictate the use of sophisticated, highly sensitive, and operations-intensive leak detection devices, such as mass spectrometers, to verify the integrity of the seal. The requirement to use mass spectrometers for leak detection can drive up the time to leak check a joint by several orders of magnitude when considering machine start-up, run-in, and calibration times. High helium content in the surrounding area can cause leak checks (using mass spectrometers) to be delayed until the background is reduced or add time to the operation by having to encapsulate each joint that is checked. Leak checking joints can lead and has led to time-consuming serial operations, impacting total system checkout.

The demating and mating of electrical connectors greatly increases the changes for damage to pins. Minor damage, such as a slightly bent pin, may be a simple operation to correct vs the more severe damage that could lead to a multipin connector replacement. In the case of the orbiter, several systems may have wires in the cable assembly with multipin connectors. The demating of this type of connector could impact the operations of other systems as well as requiring time-consuming retest of the functions passing through that connector when it is remated. (Replacing a single pin can be a 4-hr operation). Numerous standalone systems require numerous vehicle-to-ground interface to service and communicate with the system. Each system requires its own separate and unique quick disconnect with special installation and verification procedures, especially to support hazardous propellants.

8.5 BRIEF PHYSICS OF PHENOMENON

N/A

8.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The elimination of time-consuming operations associated with the presence of numerous interfaces is best addressed through hardware integration. Hardware integration could cross system lines such that a single system might support several activities. For instance, multiple-engine vehicle engine controllers might be integrated into a single unit (with built-in redundancy) located in the vehicle with the electrical interfaces located at the controller and controlled/monitored function. The artificial interface between standalone systems is eliminated as well as those eliminated or reduced by eliminating multiple units.

This approach would be applicable to pneumatic systems as well. For modularizing systems, such as an engine with, for example, a fuel module in which major items such as valving, pumps, etc., are packaged with sealed joint to reduce potential leak points, the module would be a line removal unit (LRU) and not a separate component. Using common fluid systems to support several different functions is another way to integrate hardware, reduce components, and drive down the number of interfaces. An example might be the selection of a common propellant set such as discussed in OEPSS Concern 4.

8.7 TECHNOLOGY RECOMMENDATION

Investigate and demonstrate integrated system designs wherein the same functions can be obtained with fewer components and subsystems.

9.0 LACK OF HARDWARE INTEGRATION, OEPSS CONCERN 9

9.1 OPERATIONAL IMPACT

The impact on ground operations caused by lack of hardware integration, which results in numerous components and interfaces requiring maintenance and checkout, is summarized in Figure 10–1.

9.2 REQUIREMENTS BACKGROUND

The discussion found in Section 8.0 for OEPSS Concern 8, Excessive Components and Interfaces, applies equally to OEPSS Concern 9.

9.3 SYSTEM DESCRIPTION

See OEPSS Concern 8.

9.4 OPERATIONS PROBLEM DESCRIPTION

See OEPSS Concern 8.

9.5 BRIEF PHYSICS OF PHENOMENON

N/A

9.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

See OEPSS Concern 8.

9.7 TECHNOLOGY RECOMMENDATION

See OEPSS Concern 8.

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- **Operational impacts**
  - Leads to numerous interfaces
    - Mechanical: adds weight; potential for leakage
    - Electrical: adds weight; potential for connector/pin damage
  - Increases number of components
    - Standalone engine — each has duplicate hardware
    - Drives vehicle to have a similar system to support the engine system
    - Increases probability of launch hold or scrub
  - Drives ground support equipment costs up
  - Increases requirements for replacement hardware
  - The more components, the more maintenance, checkout, operation, calibration operations required, which drives the size of the "army" up
  - Increased logistic support
  - Drive reliability down
  - Increases launch site flow time
- **Potential options for consideration**
  - Integrate hardware
    - (1) Avionics package, (1) pneumatic package, etc.
  - Minimize interfaces
    - Occurs when using minimum number of components
  - Multiple function hardware
    - Use LH_2 tank vent for the tank pressurization line in flight (if needed) and for "tank loaded overflow" (instead of tank loading sensors)

D600-0011

Figure 9-1. Operational Impact of Lack of Hardware Integration

10.0 SEPARATE OMS AND RCS, OEPSS CONCERN 10

10.1 OPERATIONAL IMPACT

The impact on ground operations caused by using separate propulsion systems and especially using different propellants, which is also hypergolic, is described in Figure 10–1.

10.2 REQUIREMENTS BACKGROUND

In many launch vehicles, propulsion systems used for attitude control or for small velocity changes (such as OMS) have been separate from the primary propulsion system. In many cases, three separate propulsion systems are used (primary, RCS, and OMS). This provides maximum flexibility and can allow one system to provide back–up to another.

10.3 SYSTEM DESCRIPTION

For those ALS type launch vehicles which are more than simple lower stage boosters, RCS and/or OMS type propulsion systems will be needed. Some utilize the shuttle approach with individual systems for each function. As on the shuttle, separate tankage for the RCS and OMS are used with propellants differing from those used in the primary propulsion system. Typically, the RCS and OMS propellants are earth storable hypergolics. The hypergolic propellants do not require tank and feed system insulation as do the cryogenic primary propellants and do not require an ignition system for each thruster. However, use of hypergolics has a major impact on ground operations.

10.4 OPERATIONS PROBLEM DESCRIPTION

Ground operations are complicated by the fact that with separate RCS, OMS, and primary or main propulsion systems (MPS), each vehicle subsystem has its own set of checkout and servicing requirements supported by separate groups of personnel and GSE. Duplication of actions necessitates added functions and leak checks. The different propellants necessitate multiple propellant facilities, each with its own support crew.

Ground operations are further complicated if hypergolic propellants are used. Their toxic characteristics require the use of special equipment and procedures for personnel protection. Overall vehicle processing time is increased because vehicle access is restricted during hypergolic servicing precluding concurrent work on other subsystems.

10.5 BRIEF PHYSICS OF PHENOMENON

N/A

10.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

As a minimum, all propulsion requirements, other than the MPS, should be combined into a single subsystem, with common tankage and propellant distribution. This single subsystem would

- **Operational impacts**
  - Maintenance and prelaunch checkout of multiple tankage and associated systems
    - Added functional component checks
    - Added leak check
  - Filling of separate tank systems
  - If earth storable propellants used
    - Hazards
    - Added serial processing time
- **Potential options for consideration**
  - Combine OMS and RCS with common tankage and propellant distribution
  - Integrate total propulsion system — MPS, OMS, and RCS

D600-0011

Figure 10–1. Operational Impact of Separate OMS and RCS

serve as both RCS and OMS. A more operationally efficient approach would combine all the propulsion requirements into a single integrated system. Common cryogenic tankage would provide propellants for MPS and RCS. The OMS function would be provided by the MPS.

10.7 TECHNOLOGY RECOMMENDATION

Continue development of an integrated propulsion system. Ref.: Integrated Hydrogen/Oxygen Technology (IHOT) study (NASA-LeRC contract to Rockwell).

D600-0011/ljm

11.0 PNEUMATIC SYSTEM FOR VALVE ACTUATION, OEPSS CONCERN 11

11.1 OPERATIONAL IMPACT

The impact on ground operations caused by service, checkout, and verification of the storage, regulation, and distribution systems is described in Figure 11-1.

11.2 REQUIREMENTS BACKGROUND

Pneumatic actuation of cryogenic valves is an effective method of isolating the electrical control system from the cryogenic environment. The pneumatic pressure acting on a cylinder can provide the force needed to actuate even large valves.

11.3 SYSTEM DESCRIPTION

A typical valve actuation system requires a central helium storage and regulation subsystem with pressure lines to each valve. One or more solenoid valves at each cryogenic valve responds to commands from the vehicle avionics system to control helium pressure to the cryogenic valve. The helium then pressurizes one or more pneumatic cylinders which open or close the valve. Therefore, the total control system for each valve consists of an electrical system and a pneumatics system.

11.4 OPERATIONS PROBLEM DESCRIPTION

Since cryogenic valves are distributed throughout the vehicle (tank vent valves, propellant fill and drain valves, engine control valves, etc.), a long network of high pressure helium lines is required throughout much of the vehicle. These lines, as well as the complete helium storage and control system, must be leak checked to assure the helium supply is not depleted during the mission. Functional verification is needed for all the regulators, isolation valves, and valve control solenoids in the pneumatic system. All the components in the pneumatic system have logistics and maintenance requirements in addition to this checkout. Prelaunch servicing of the pneumatic system involves charging the helium storage system to flight pressure from a complex, launch-critical, set of GSE, which must also be maintained and serviced.

In addition to the operations associated with the pneumatics system, a complete avionics system for each cryogenic valve also must be maintained, checked out, and serviced. This requires not only a separate and parallel set of vehicle hardware, but a separate set of GSE and a separate group of people to maintain, check out, and service both the vehicle and ground hardware.

11.5 BRIEF PHYSICS OF PHENOMENON

For small valves in ambient applications, a direct acting solenoid actuator is usually used. For larger sized valves, the electrical power required to drive the necessary large solenoid is high. For a cryogenic valve, the solenoid actuator should be isolated from exposure to the low temperature. The

- **Operational impacts**
  - Additional flight hardware requiring joint–to–joint checkout
  - Requires on–board storage tanks, regulation/distribution system
  - Requires redundant regulation/relief systems
  - Additional interfaces required between vehicle and ground
  - Multiplies instrumentation requirements
  - Requires sophisticated ground support equipment
    - Must have redundant regulation/distribution system
    - Capable of local and remote operation
    - Requires an "army" for operation, maintenance, certification
    - Adds another function to the firing room operation
    - Imposes labor–intensive cleanliness verification on system
- **Potential options for consideration**
  - Electromechanical actuators

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Figure 11–1. Operational Impact of Pneumatic System for Valve Actuation

typical pneumatically actuated valve avoids these problems, but with the described impact on ground operations.

11.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Duplication of control systems (electrical and pneumatic) for each valve must be avoided. Since the command signal from the computer is electrical and an electrical system is operationally much simpler than an equivalent pneumatic system, the choice is to electrically actuate all valves. Smaller valves can continue to be direct acting solenoids; others can use solenoid pilots operating with system fluid pressure or electromechanical actuators.

11.7 TECHNOLOGY RECOMMENDATION

Low-cost, reliable, electrical actuators for large cryogenic valves that draw relatively low power are needed.

D600-0011/ljm

12.0 GIMBAL SYSTEM REQUIREMENTS, OEPSS CONCERN 12

12.1 OPERATIONAL IMPACT

The impact on ground operations caused by the complexity of the gimbal system and its maintenance requirement is described in Figure 12-1.

12.2 REQUIREMENTS BACKGROUND

Because of unpredictable variations in factors (such as winds and engine thrust differences) that affect the flight path, active steering is needed during the powered portion of the flight. The traditional method of steering a high thrust rocket launch vehicle is to control the thrust vector by gimballing each of the main engines with hydraulic actuators.

12.3 SYSTEM DESCRIPTION

A typical thrust vector control system gimbals each main engine with two hydraulic cylinders operating in planes 90 deg apart. The pump that provides the necessary hydraulic pressure may be driven either from the main engine or another power source such as an electric motor or auxiliary power unit. High pressure supply and return lines carry the flow to and from the actuators. Flexible hoses in the lines accommodate engine gimbal motion.

12.4 OPERATIONS PROBLEM DESCRIPTION

The hydraulically driven thrust vector control system results in a number of operational impacts. The complex system of hydraulic pumps, pump drives, hydraulic lines and fittings, control valves, hydraulic cylinder actuators, gimbal bearings, and control system can be difficult to maintain, service, and checkout. See OEPSS Concern 2 for further discussion of hydraulic systems operations problems.

12.5 BRIEF PHYSICS OF PHENOMENON

See OEPSS Concern 2.

12.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

An operationally efficient approach to providing flight control should simplify the system by replacing the hydraulic cylinders with electromechanical actuators (EMA). Gimbal only those engines necessary for thrust vector control with the remaining engines stationary. If possible, hinge each engine in one plane with a single actuator. Alternate methods of thrust vector control such as differential throttling, gas generator exhaust vectoring, or vanes in the exhaust stream should be evaluated.

- **Operational impacts**
  - System complexity: actuator system, gimbal bearings, control system
    - Maintenance
    - Servicing
    - Prelaunch checkout
  - Hydraulics — addressed in OEPSS 2
- **Potential options for consideration**
  - Simplify system
    - EMAs replace hydraulic cylinders
    - Consider reducing number of engines gimballed
    - Hinge instead of gimbal
  - Consider alternate methods of TVC
    - Differential throttling
    - GG exhaust vectoring
    - Vanes

D600-0011

Figure 12-1. Operational Impact of Gimbal System Requirements

12.7 TECHNOLOGY RECOMMENDATION

Develop large EMAs and differential throttling for thrust vector control.

D600-0011/ljm

2ND SEC

13.0 HIGH MAINTENANCE TURBOPUMPS
OEPSS CONCERN 13

13.1 OPERATIONAL IMPACT

The impact on ground operations caused by stringent functional checkout required for a complex and sensitive component, especially if the component is recovered and qualified for reuse, is described in Figure 13-1.

13.2 REQUIREMENTS BACKGROUND

Rocket engine propellant pumps use turbine drives for their prime movers because of the high horsepower requirements, and their ability to be close coupled to result in a very compact size. These turbines are driven either by "hot gas" from hot gas generators or "cold gas" from expansion of heated hydrogen fuel. Extremely high rotating speeds and loads imposed on the hardware during operation require a thorough inspection of the unit prior to its next use.

"Breakaway" and "Running" torque measurements, along with shaft axial travel measurements, for turbomachinery is an accepted method of verifying its integrity to support the next test or mission requirement. Fiber optic inspection of bearings; impellers, turbine end hardware, and leak check of the pump/turbine internal seal package completes the general inspection/test/checkout for reusable turbopump machinery.

13.3 SYSTEM DESCRIPTION

N/A

13.4 OPERATIONS PROBLEM DESCRIPTION

The continual need to evaluate axial shaft travel and breakaway/running torque for turbomachinery has posed serial time constraints on ground operations in the past. Access to perform these operations requires that ports be opened to gain access to the end of the turbopump shaft. Special tooling is required to act as a guide and provide a support base for the measuring instruments. In some cases, multiple readings must be taken to insure that the data is representative of any small changes that may have occurred since the previous measurements. After the GSE is removed, the ports must be closed and leak checked to insure a leak-tight condition. Depending on access to these pumps, it is possible for the operation to consume a work shift or better depending on the type of pump and accessibility to perform the task.

Detailed inspections of the turbine end necessitate the disturbance of sealed joints to gain access. The use of fiber optic devices to perform the inspections is a time-consuming operation and requires special skills. When borescopes are used, extreme care must be exercised to prevent the "tip" from getting lodged in the crevices being inspected. These type of "hang-ups" have caused the turbopump to be removed so that the instrument and any associated debris could be retrieved. Depending on the type of pump, this operation could taken six to eight work shifts.

- **Operational impacts**
  - Requirements for repeated torque and shaft travel measurements
    - Final engine checkout/pump replacement
  - Disturbing critical fluid joints for above measurements
    - Potential for flange/seal damage
    - Potential for introducing a leak
    - Drives operation for repeated leak checks
    - Requires heat shielding to be removed for access
    - Potential for system contamination
  - Requirements for pump removal for turbine-end inspections
- **Potential options for consideration**
  - Use BIT/BITE for torque/shaft-travel measurements
  - Lower speed and turbine-end temperatures

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Figure 13-1. Operational Impact of High Maintenance Turbopumps

13.5 BRIEF PHYSICS OF PHENOMENON

N/A

13.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The use of built-in-test (BIT) and built-in-test-equipment (BITE) would offer solutions to most of the inspection issues.

13.7 TECHNOLOGY RECOMMENDATION

Develop nonintrusive devices that will continually monitor and provide information on demand on the health of the rotating machinery.

D600-0011/tab

14.0 ORDNANCE OPERATION, OEPSS CONCERN 14

14.1 OPERATIONAL IMPACT

Ordnance operation causes a severe and widespread impact on ground operations in that it poses a serial time constraint and suspends all other ground operations in the area because of safety requirements. See Figure 14–1.

14.2 REQUIREMENTS BACKGROUND

Ordnance devices are used on all launch vehicles as a means of destroying the vehicle should it deviate from its prescribed mission and pose a threat to the surrounding area. Explosive bolts are used when flight hardware needs to be separated from the external tanks, such as in the space shuttle orbiter. Explosive bolts are also used to separate the solid rocket boosters from the mobile launcher platform. Other ordnance devices are used to insure that critical functions occur both on the ground and with other flight hardware (such as ensuring proper and timely umbilical carrier plate retraction), to insure the orbiter landing gear deploys for landing, and for vehicle stage separation.

14.3 SYSTEMS DESCRIPTION

The pyrotechnic devices are basically a simple system when compared to other systems. An explosive device is fired by electrical signal sent through hardlines, in the case of ground systems, or by RF in the case of vehicle destruct systems. Of course, hardlines are used to activate these devices onboard the flight vehicle when the vehicle system is programmed to do so.

14.4 OPERATIONS PROBLEM DESCRIPTION

The major problem associated with using ordnance systems is that the installation, removal and checkout of these devices dictates clearing the area of all personnel not directly supporting ordnance operations. Other systems necessarily have to secure their work and then reestablish their operation when the ordnance work is completed. Ordnance operations thus become a serial impact to vehicle processing, and are a major cost driver.

14.5 BRIEF PHYSICS OF PHENOMENON

N/A

14.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Solving this problem at present launch sites might be immediately addressed with reassessing the need for area–wide evacuation for all ordnance operations. One other approach might be to consider the use of more “benign” initiators such as laser systems. The long range solution might be the substitution of laser type systems for all flight hardware ordnance.

- **Operational impacts**
  - Loss of parallel processing caused by "area clear" evacuations
  - Disposal of unused ordnance from recovered vehicle elements is hazardous and costly
  - Separate, hazardous storage facilities required
- **Potential options for consideration**
  - Eliminate explosive ignition devices; replace pyrotechnics with lasers
  - Eliminate explosive release and separation devices; replace with electromechanical and Nitinol shape-memory alloy components
  - Eliminate explosive range safety vehicle destruct devices; consider use of ground-to-air military weapons perhaps assisted by vehicle homing beacon

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Figure 14–1. Operational Impact of Ordnance Operations

14.7 TECHNOLOGY RECOMMENDATION

A program to develop other systems that eliminate the present hazards of using ordnance. Consider ground, airborne, and/or space laser systems for vehicle destruction.

The above describes the operational impact of small ordnance devices. Another big cost driver at John F. Kennedy Space Center is the ground operations of large solid rocket motors. The special precautions imposed have severe serial impact on other ground operations; it creates another unique and costly infrastructure and it is, at the present time, the "long pole in the tent" to restriction of launch rates (the issue stacking time vs facilities to accommodate the stacking). Safety precautions associated with the SRBs have severely curtailed the concurrent use of the vehicle assembly building for other purposes.

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15.0 RETRACTABLE UMBILICAL CARRIER PLATES, OEPSS CONCERN 15

15.1 OPERATIONAL IMPACT

The impact on ground operations caused by the complex carrier plate system that is used for connecting umbilical between the vehicle and ground is described in Figure 15-1.

15.2 REQUIREMENTS BACKGROUND

Maintaining "hardwire" communications with the flight vehicle, and the ability to service and deservice the vehicle with various commodities, is mandatory right up to the point of commit to launch. The criticality of maintaining "hardline" contact between the ground systems and the vehicle is to be able to abort the launch safely at the last moment of time and immediately begin to deservice the cryogenic propellants. Maintaining hardline contact with the vehicle gives the ground crew positive control of the vehicle systems prior to liftoff.

15.3 SYSTEM DESCRIPTION

Maintaining "hardline" contact between the ground distribution systems and the flight vehicle is accomplished through "umbilicals." The umbilicals include electrical wire systems as well as fluid transfer system. The interface between the ground system and the vehicle is by quick release disconnects. As the fluid lines are separated, the poppets in the flight half and ground half of the quick disconnect are spring-loaded to close to maintain integrity of the lines/vehicle from contaminates of the environment and prevent leaks outside of the system. The separation of these quick disconnects is most often accomplished by the ground portion of the disconnect being retracted (pulled away) from the vehicle. In the case of the space shuttle, the umbilicals are set in a single carrier plate (one plate for systems on the fuel side and one plate for systems on the oxidizer side). This carrier plate is retracted through a series of complicated moves to insure proper unlatching of the plate from the vehicle. An intricate mechanism of drop weights, cables, hinged-system-support frame, and closing blast shield, housed in an enclosure called the tail service mast (TSM), serve as the system to effect the umbilical retracting operation and protect the ground portion from the rocket exhausts.

15.4 OPERATIONS PROBLEM DESCRIPTION

The umbilical carrier plate installation on both the fuel and oxidizer side are labor-intensive and time-consuming operations. The original concept of "gang" mating quick disconnects never materialized with any great degree of confidence. In many instances, the plate is attached to the vehicle and then the disconnects are mated. The close arrangement of the disconnects to one another, passing through a relatively thick plate, presents access problems when a particular disconnect requires attention or inspection. The access problem is compounded when work has to be performed at elevated heights (on catwalks) and around the retract/support systems for the plate. If major problems exist with a vehicle side disconnect, it is possible that the entire plate; i.e., all the other disconnects, will have to be demated to gain proper access to the problem-disconnect.

- **Operational impacts**
  - Multiple systems sequenced for plate retract
    - Sequence initiation at commit
    - Pyrotechnic system for retract
    - Hinged vacuum jacketed lines
    - Drop–weight systems
    - Shock–absorber devices
    - Plate latching and unlatching from vehicle
  - Present "tail service masts" are enclosed
    - Confined space for personnel
    - Access to equipment is marginal
    - Working from ladders and narrow platforms
    - Requires inert purging
  - Depending on design of plate – may require inert gas purging of inner cavities
  - High maintenance equipment
- **Potential options for consideration**
  - Liftoff umbilicals, no retraction of plates, separation occurs as vehicle moves away
  - Consider simple design and low cost quick disconnect to justify discarding after launch vs expensive maintenance procedures

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Figure 15–1. Operational Impact of Retractable Umbilical Carrier Plates

The retract system is cumbersome. A combination of cables (positioned and tensioned to insure proper plate rotation to unlatch from the vehicle), drop weights, shock absorbers to stop the weights, ordnance system for sequence initiation, drop hood, safety latches, etc., are just some of the devices that make up an elaborate system to retract the umbilicals. The large number of fluid and electrical lines, along with the carrier plate, requires a large hinged-at-the-bottom support frame to carry the system weight and still be able to transition into the protective environment of the TSM. The rotation of the carrier plate plus the rotation of the support frame about its lower (bottom) end requires the fluid systems to incorporate flex lines both at the plate and the lower end of the frame.

Because the vehicle rocket motor/engine exhaust passes adjacent to the carrier plates, protective enclosures (tail service mast) are used to house the carrier plate once it is retracted. A drop shield sequenced to close as the plate is retracted basically seals the TSM. The TSM even with the shield represents a confined space and is a potential hazard to personnel entering the area. The compact enclosure gives rise to steep ladders and narrow catwalks compounding the safety problem of working in the TSM. The carrier plates and tail service mast systems to support umbilical retraction is time-consuming and requires an "army" to maintain.

15.5 BRIEF PHYSICS OF PHENOMENON

N/A

15.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Reducing or eliminating the ground support infrastructure that is required for retractable umbilical may best be addressed by using "flyaway" or "liftoff" umbilicals. These umbilicals are designed to separate from the vehicle as the vehicle moves away from its supports. The elimination of the "carrier plate" concept will provide needed access to mate the quick disconnect properly and to perform any disconnect servicing required with a minimum of effort.

15.7 TECHNOLOGY RECOMMENDATION

Investigate simpler "flyaway" or "liftoff" service umbilicals for vehicle to ground disconnect.

D600-0011/tab

16.0 PRESSURIZATION SYSTEM, OEPSS CONCERN 16

16.1 OPERATIONAL IMPACT

The impact on ground operation caused by long pressurization lines and valves that are difficult to access for checkout and service is described in Figure 16–1.

16.2 REQUIREMENTS BACKGROUND

Pressurization systems are needed to provide correct propellant conditions at the engine inlets and to ensure tank structural stability. Typically, the pressurant source is either a stored gas supply or vaporized propellant.

16.3 SYSTEM DESCRIPTION

Most current launch vehicles using hydrogen and oxygen propellants prepressurize both tanks from a ground supply and then utilize an autogenous system after main engine start. In the autogenous system, the engine provides high pressure gaseous hydrogen from the chamber coolant flow and high pressure liquid oxygen which is vaporized in an integral or external heat exchanger. Flow to each tank is controlled by a fixed orifice or a flow control valve. This system avoids the need for separate gas storage and control systems.

16.4 OPERATIONS PROBLEM DESCRIPTION

The autogenous system has long fluid lines from the engines to the top of each tank. Access to these lines for maintenance and leak checking is difficult. Because of tank pressure limitations, these lines cannot be checked at actual operating pressure without inserting a blanking flange. Included in this conventional system are flow control valves which historically have been a source of many problems, especially the oxidizer valve(s) because of the internal operating environment. A system of transducers, signal conditioners, and software, ensures control of the pressurant flow rate in response to tank pressure changes. All these systems require support personnel and ground support personnel for maintenance, checkout, and servicing.

16.5 BRIEF PHYSICS OF PHENOMENON

The ullage pressure of each tank must be controlled within an upper limit, usually a function of allowable pressure stress in the tank, and a lower limit, either based on minimum allowable engine NPSP or a minimum pressure for structural ability. These limits are not a single set of values, but can change as a function of mission phase.

16.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

As a minimum, flow control valves should be replaced with fixed orifices. This requires that the tanks be designed to accommodate the wider resultant pressure bands. Consideration should be given to the possibility of total elimination of the flight portion of the pressurization system by

- **Operational impacts**
  - Conventional system requires extensive maintenance and checkout
    - Long plumbing runs from engines and ground interfaces
      - Access for leak checks difficult
      - May not be possible to check at operating pressure
    - Flow control valves
      - Inherently subject to problems because of operating environments
    - Associated control system requires verification
      - Transducers, signal conditioners, software, etc.
- **Potential options for consideration**
  - Replace flow control valve(s) with fixed orifice where possible
  - Consider elimination of system by ground prepressurization only
    - Heavier tanks
    - NPSP concerns

D600-0011

Figure 16–1. Operational Impact of Pressurization Systems

pressurizing the ullage from the ground prior to liftoff and allowing the ullage pressure to decay during flight. An even simpler, and therefore, more operationally efficient approach, would require only the boil-off or vapor pressure to satisfy ullage pressure, therefore, totally eliminating a separate pressurization system.

16.7 TECHNOLOGY RECOMMENDATION

Investigate possibility of eliminating active tank ullage pressure control.

D600-0011/tab

17.0 INERT GAS PURGING REQUIREMENT, OEPSS CONCERN 17

17.1 OPERATIONAL IMPACT

The impact on ground operations caused by a sophisticated system of storage, distribution,and control required for providing inert gas purge is described in Figure 17-1.

17.2 REQUIREMENTS BACKGROUND

Inert gases, helium or nitrogen, are used to purge cavities and systems that might contain, or have contained, hazardous fluids. Nitrogen or helium is used to insure that propellant leakage past seal package(s) does not mix with each other. Engine shutdown purging of the propellant systems safely expels residual propellant from engine systems.

17.3 SYSTEM DESCRIPTION

A typical inert gas purge system requires a central storage and regulation subsystem with a distribution system to each component or system requiring purge. Typical engine purging is initiated during the cryogenic loading process through the use of electrical solenoids and may be continuous or intermittent as required. Purging of the propellant feed system is terminated prior to engine start, whereas turbopump seal package/cavity is purged continuously throughout engine operation. Purging of the propellant system is again initiated at engine shutdown for a short period of time to clear the system of residual propellants.

17.4 OPERATIONS PROBLEM DESCRIPTION

Inert gas purging systems require high pressure gas storage, regulation/control, and distribution system both on the ground and on the vehicle. The flight systems must be leak checked to insure that gas depletion does not occur during the flight mission. Ground systems must be validated, sampled, and verified, as ready to support the next vehicle/mission. The gas supply systems also represent another ground-to-vehicle interface that requires maintenance. Support systems to meet purge requirements also include electrical and avionics systems. Since mission success demands that both ground and flight systems have redundancy, a minimum of two of everything doubles the operational impact of a single system.

17.5 BRIEF PHYSICS OF PHENOMENON

N/A

17.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Design out of systems seal package cavities that must be purged to prevent mixing of propellants. Consider propellant gases for propulsion system shutdown purges.

- **Operational impacts**
  - Requires sophisticated ground distribution/control system
    - High pressure reduction/control system with redundancy
    - Requires both local and remote operation capability
    - Requires "army" to maintain, operate, sample, and calibrate
  - Requires storage/distribution/control systems onboard vehicle
    - Requires "army" to maintain, operate, sample and calibrate
    - Redundancy requirement also drives gas storage to be double or greater than what is needed
  - Additional interfaces between vehicle and ground
  - Firing room operations increased
    - Additional consoles, software development, and manpower required to operate system
    - Drives the need for launch commit criteria that could delay or scrub a launch
  - Commodities require expensive logistical support
- **Potential options for consideration**
  - Propellant turbopumps should be designed such as to eliminate the requirement for intermediate seal cavity purges; i.e., consider separating the pump from the turbine
  - Use propellant gases for propulsion system shutdown purge requirements

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Figure 17-1. Operational Impact of Inert Gas Purging Requirements

17.7 TECHNOLOGY RECOMMENDATION

Investigate cryogenic propellant seal package systems that do not require purge.

D600-0011/tab

18.0 NUMEROUS INTERFACES, OEPSS CONCERN 18

18.1 OPERATIONAL IMPACT

The operational impact on ground opeations by numerous interfaces, which increases the requirements for inspection, checkout and maintenance, is described in Figure 18-1. The excessive number of components used and the lack of hardware integration will lead to increase in interfaces, which are described in OEPSS Concern 8 and OEPSS Concern 9.

18.2 REQUIREMENTS BACKGROUND

See OEPSS 8 and 9.

18.3 SYSTEM DESCRIPTION

See OEPSS 8 and 9.

18.4 OPERATIONS PROBLEM DESCRIPTION

See OEPSS 8 and 9.

18.5 BRIEF PHYSICS OF PHENOMENON

N/A

18.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

See OEPSS 8 and 9.

18.7 TECHNOLOGY RECOMMENDATION

See OEPSS 8 and 9.

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- **Operational impacts**
  - Fluid systems — separable joints
    - Potential leak paths requiring leak checking
    - Torque — relaxing with time/vibration
    - Labor intensive for joint preparation, assembly, and leak checking
    - Increases hardware, drives logistics costs up
    - Adds weight to vehicle
    - Drives reliability down
    - Drives requirement for time–consuming and labor–intensive installation and removal of insulation on cryogenic fluid lines
  - Electrical systems
    - Potential for connector damage
    - Drives extensive end–to–end checkout
  - Artificial interfaces — just because of a nonintegrated component
- **Potential options for consideration**
  - Integrate hardware, minimize number of components
  - Make vehicle as autonomous as possible to eliminate stage–to–stage interfaces
  - Consider "seal welding" for mandatory separable joints to minimize potential leaks

D600-0011

Figure 18–1. Operational Impact of Numerous Interfaces

19.0 HELIUM SPIN START, OEPSS CONCERN 19

19.1 OPERATIONAL IMPACT

The impact on ground operations caused by checkout and maintenance of two duplicate storage, regulation, and distribution systems (vehicle and ground) is described in Figure 19-1.

19.2 REQUIREMENTS BACKGROUND

Engine systems utilizing a gas generator turbine drive have typically required some form of high pressure start assist fluid to provide adequate turbopump power to achieve sufficient pressures to ignite and maintain gas generator operation. This requirement is caused by the nature of the cycle since little energy is available at engine start command to initiate pumping of propellants. Previous engines have used solid propellant gas generators, hypergolic propellants, or high pressure hydrogen to achieve the required turbopump acceleration. These systems have required the addition of other systems to the engines to operate them.

Current design practice utilizes helium as the working fluid to provide initial power to the turbopumps. It was selected because existing engine systems already require helium for both the oxidizer turbopump intermediate seal and propellant valve actuation; therefore, it does not introduce additional fluid requirements to the system. This system is currently only applicable to gas generator cycle engines.

19.3 SYSTEM DESCRIPTION

The ALS gas generator cycle option utilizes the helium spin start. Helium is supplied to the engine from a source located at the launch pad, supplied to the vehicle through an umbilical. At the engine start command, the helium spin assist valve on the engine opens to provide turbine power for pressure buildup. Another option to this configuration is to utilize the same umbilical used to supply helium to the vehicle main propulsion system.

19.4 OPERATIONS PROBLEM DESCRIPTION

Since this is another use of pneumatics on board the vehicle, the same operations problems described in OEPSS Concerns 11 and 17 would apply. The additional major concern would be that the huge demand for helium to accomplish this start will significantly increase the onboard handling capability. The anticipated large size of the system (i.e., lines and components) to flow the required gas is expected to create additional processing and checkout problems in performing leak and flow checks. This system will necessarily create additional support systems such as electronics, instrumentation, and controls.

- **Operational impacts**
  - Additional flight hardware requiring joint–to–joint checkout
  - Requires on–board storage tanks, regulation/distribution system
  - Requires redundant regulation/relief systems
  - Additional interfaces required between vehicle and ground
  - Multiplies instrumentation requirements
  - Requires sophisticated ground support equipment
    - Must have redundant regulation/distribution system
    - Capable of local and remote operation
    - Requires an "army" for operation, maintenance, certification
    - Adds another function to the firing room operation
    - Imposes labor intensive cleanliness verification on system
- **Potential options for consideration**
  - Cryogen spin–up system: utilizing liquid hydrogen being tanked; diverted to holding bottle for pressure elevation and used at start sequence
  - Tank head start
  - SPGG start

D600-0011

Figure 19–1. Operational Impact of Helium Spin Starts

19.5 BRIEF PHYSICS OF PHENOMENON

Two considerations drive the gas generator cycle engine to require some form of turbine spin assist. First, this cycle utilizes high energy, high pressure ratio turbines since the gas generator exhaust gas can be dropped from a high pressure to ambient pressure levels unlike expander, staged combustion, or other topping cycle engines. At the low pressure start conditions, the turbines provide little power for the pumps.

This problem is compounded by the second consideration when the gas generator cycle configurations use tap–off propellants just downstream of the pumps to achieve the highest obtainable turbine inlet pressure. This close coupling provides little heat availability to the turbine drive fluid prior to gas generator ignition. This heat availability is key to tank head start even for engines with low–pressure ratio turbines.

High pressure fluid spin assist is used to provide the initial pump power during the early stages of the start sequence in gas generator cycles engines. This assist is removed when the gas generator ignites, thus enabling the engine to increase pressures to mainstage operating levels.

19.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

There are several options to eliminate the helium–assisted spin start for gas generator cycle engines. One is to utilize another working fluid such as hydrogen, similar to the J–2 engine used on the second and third stages of the Saturn V launch vehicle. This could be supplied in the form of either high pressure gas from a compressor or by the use of a pressure vessel which is filled to a low level with liquid hydrogen propellant and heated to increase the pressure of the vessel to the desired level.

Another option which has been used on the J–2S engine program is the use of a solid propellant gas generator. Such a system adds a canister to the engine which, when ignited, provides the necessary power early in the start sequence to allow ignition of the liquid gas generator and subsequent pressure buildup to mainstage levels.

19.7 TECHNOLOGY RECOMMENDATION

The only technique listed above which has not been adequately developed is the use of cryogenic propellants to pressurize the start bottle. This technology item could be easily validated in laboratory testing.

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20.0 LIQUID OXYGEN TANK FORWARD, OEPSS CONCERN 20

20.1 OPERATIONAL IMPACT

The impact on ground operations caused by long LOX feedlines with the LOX tank located forward in the vehicle, resulting in potential geysering and maintenance problems, is described in Figure 20-1.

20.2 REQUIREMENTS BACKGROUND

The positioning of the two propellant tanks in a hydrogen/oxygen launch system is generally dictated by vehicle mass properties requirements. Tank configuration is based on weight and manufacturing cost considerations.

20.3 SYSTEM DESCRIPTION

Proposed launch vehicles, such as ALS, typically have the liquid oxygen tank forward of the hydrogen tank. Both are of conventional configuration, with cylindrical center section and forward and aft domes. A cylindrical intertank structure joins the two tanks. One or more oxygen feed lines are routed from the aft end of the oxygen tank around the hydrogen tank and to the main engine area. This configuration locates the vehicle center of gravity forward for good control moment from engine gimballing and can minimize tank manufacturing costs.

20.4 OPERATIONS PROBLEM DESCRIPTION

The forward position of the main oxygen tank results in a number of operational problems. These include geysering and propellant conditioning concerns during prelaunch operations and the difficulty of checking and maintaining the required long, large-diameter feed lines. This arrangement of structure and engine feed system is more susceptible to pogo problems than if the oxygen tank were aft.

The high potential for geysering in the oxygen feed line is perhaps the most serious of these concerns, since catastrophic failure can result. An antigeyser line (in parallel with the oxygen feed line) into which a low flow rate of helium is injected prior to main engine start will provide a sustained circulation of the liquid which precludes geyser formation. In systems such as the shuttle, termination of the helium flow can demand an immediate and proper action to prevent a potential disaster. This requires a very reliable ground and vehicle helium system backed up by trained personnel to constantly monitor the system operation.

The long feed lines contribute to the problem of ensuring correct propellant conditions at the engine inlet. This is especially critical prior to engine start when heating of the long lines can warm the propellant so that engine start requirements are not satisfied. Continued bleeding of some of the

- **Operational impacts**
  - Potential for geysering — Criticality 1 failure
  - Time-critical operations required for on-pad abort
  - Skilled/experienced engineer required for console
  - Additional hardware and operations required
    - Gaseous helium injection system — flight
    - Requires checkout/maintenance
    - Requires ground-based regulation/distribution system
    - Additional personnel required for system maintenance
    - Additional interface between vehicle and ground
  - Long LOX lines: additional checkout and maintenance
  - Drives requirement for intertank structure
  - Forces propellant conditioning of engine systems
  - Pogo impacts
- **Potential options for consideration**
  - Concentric tank configuration — ref. SIB configuration
  - Antigeyser lines

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Figure 20–1. Operational Impact of Liquid Oxygen Tank Forward

propellant at the engine inlet is a solution to this problem, but introduces another subsystem which also requires maintenance, checkout, and servicing. In addition, the bleed is terminated prior to engine start, which limits countdown hold time after bleed termination.

Another operational problem results from the long oxygen feed lines. These lines, with their interface flanges and insulation, must be maintained and checked out. The difficulty in performing these operations is increased because of the large size of the lines and their location.

The oxygen tank forward vehicle configuration, because of the long oxygen feed lines, is susceptible to pogo. Any system needed to suppress pogo adds to the ground operations complexity.

20.5 BRIEF PHYSICS OF PHENOMENON

Locating the oxygen tank ahead of the hydrogen tank establishes a more forward location of the vehicle center of gravity than if the tank positions were reversed. The resulting longer moment arm from a gimballing engine provides more control moment for a given change in engine thrust vector.

The geysering phenomena results when heating of the lower portion of the cryogenic feed lines causes vaporization of some of the liquid. As the resulting bubbles rise, they expand, eventually coalescing into a single entity called a Taylor bubble which fills the complete diameter of the line. As the Taylor bubble rises, it expels the liquid ahead of it from the line into the tank. When the bubble enters the tank, it rises through the liquid into the ullage. Cold liquid at the bottom of the tank then rushes into the empty line propelled not only by gravity, but by the low pressure ahead of it created by condensation of the vapor in the line. This column of liquid impacts a closed valve or other obstruction at the bottom of the line with sufficiently high velocity to create a potentially destructive water hammer surge pressure.

20.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

In an effort to reduce the ground operations impacts of the oxygen tank forward configurations, alternate tank arrangements should be investigated. Options could include reversing the positions of the hydrogen and oxygen tanks to reduce geysering and pogo concerns. An even better solution from an operations standpoint would be to use long tanks in parallel, concentric tanks, or toroidal tanks so that the bottom of both tanks is near the engines.

20.7 TECHNOLOGY RECOMMENDATION

Low cost methods of manufacturing the alternate tank configurations described above should be developed.

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21.0 PRECONDITIONING SYSTEM, OEPSS CONCERN 21

21.1 OPERATIONAL IMPACT

The impact on ground operations caused by continuous monitoring and checkout of the propellant thermal conditioning system is described in Figure 21-1.

21.2 REQUIREMENTS BACKGROUND

Cryogenic propellants supplied to the engine inlet must be supplied at an NPSP level high enough to prevent pump cavitation. This is especially critical during the start sequence when stagnant fluid at the engine inlet has absorbed heat from the environment. The conventional means of providing acceptable propellants for engine start has been to circulate propellants through a portion of the engine prior to start.

21.3 SYSTEM DESCRIPTION

Although currently the ALS engine design requirement provides for engine start without engine bleeds, the operational impact of the conventional propellant conditioning system must be understood if return to these methods is to be avoided. The conventional propellant conditioning system requires a complex system of pumps, prevalves, recirculation valves, bleed valves, and lines for the hydrogen; and bleed valves, lines, and ground disconnect for the oxygen. In addition, control systems and additional ground systems are needed.

21.4 OPERATIONS PROBLEM DESCRIPTION

All elements of the conventional propellant conditioning system require maintenance, servicing, and checkout. The critical prelaunch propellant temperatures and pressures must be continuously monitored to satisfy engine start constraints. Anomalies in any part of the preconditioning system can cause launch delays.

21.5 BRIEF PHYSICS OF PHENOMENON

The propellant combined temperature and pressure at the engine pump inlet must result in subcooled liquid so that cavitation (local boiling) will not occur.

21.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The operational concerns associated with propellant preconditioning can be alleviated if the engine is carefully designed to allow natural percolation to maintain the propellants at the required prestart conditions. In addition, an extended start sequence can permit the engine to accept a wider range of propellant pressures and temperatures during start.

- **Operational impacts**
  - Added flight hardware
    - Hydrogen recirculation system: pumps, prevalves, lines, etc.
    - Oxygen bleed system: valves, lines, etc.
  - Added ground hardware
    - Disconnect, bleed line, etc.
    - Pump power supply, controls, etc.
  - Prelaunch operations
    - Preconditioning procedures
    - Engine start constraints
- **Potential options for consideration**
  - Design engines with natural percolation ability
  - Utilize slow start sequence to accommodate wider range of propellant inlet conditions

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Figure 21-1. Operational Impact of Preconditioning System

21.7 TECHNOLOGY RECOMMENDATION

Develop an integrated propulsion system that requires no bleed or prestart recirculation system and can accept a wide range of propellant pressures and temperatures during the start sequence.

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22.0 EXPENSIVE He COMMODITY USAGE, OEPSS CONCERN 22

22.1 OPERATIONAL IMPACT

The impact on ground operations caused by helium is the high cost of operations involved in shipping, handling, storage, regulation, and distribution of helium gas, and is described in Figure 22-1.

22.2 REQUIREMENTS BACKGROUND

Helium and other inert gases are used in rocket propulsion systems (including tankage) for pressurization, purging, inerting, and as fluid medium for valve actuation. Liquid hydrogen at -423°F drives the use of helium gas for its systems since helium (at -45°F) has a lower saturation temperature than hydrogen. If helium has to be used for the liquid hydrogen propellant system and is already mandated to be on board the vehicle, it stands to reason that it should also be used for the liquid oxygen propellant system (rather than adding another pneumatic distribution such as gaseous nitrogen for liquid oxygen).

22.3 SYSTEM DESCRIPTION

N/A

22.4 OPERATIONS PROBLEM DESCRIPTION

Helium is an expensive commodity when compared with other commodities used at the launch site. The cost is directly related to the logistics of getting the helium to the location where it is used. Helium is removed from the ground (from, for example, Amarillo, Texas), processed, and compressed for loading into railcars for shipment to the launch site. At the launch site, a unique system is required for handling, compressing, storing, and distributing the gas. The distribution system must be leak free to prevent any loss of this expensive commodity. Constant monitoring and maintenance of this system requires a dedicated crew. Major maintenance of system components is required, especially when high pressure helium flow can literally cut the seals apart. The presence of any inert gas is always a safety hazard to personnel, particularly in a confined area.

22.5 BRIEF PHYSICS OF PHENOMENON

N/A

22.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Use electromechanical actuators. Use propellant turbopumps that do not require He-purges for the seal package. The possible use of propellant gases for engine shutdown purge.

- **Operational impacts**
  - Logistics of getting helium to the user
    - Railcar shipment/transfer of gas to holding facility
    - Elaborate distribution/regulation systems required
    - Continual sampling for purity and particulate
    - Maintenance, operation, and calibration of the above systems
  - Maintenance, operation, and calibration of pressure reduction and regulation stations
  - Improper use of valving creates major maintenance requirements
- **Potential options for consideration**
  - Design for storage and use at ambient temperatures
  - Use SPGG or tank head start (eliminate tank prepressurization)
  - Eliminate turbopump "intermediate" seal cavities by physically separating turbine and pump
  - Use residual "propellant gases" for propulsion system shutdown purges
  - Explore the use of less expensive gas (gaseous nitrogen) for large tankage blanket pressures

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Figure 22–1. Operational Impact of Expensive He Commodity Usage

22.7 TECHNOLOGY RECOMMENDATION

Investigate EMA for actuators, purgeless pump designs, cryogen spin-up engine start, and purgeless engine shutdown to reduce dependency on helium.

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23.0 LACK OF HARDWARE COMMONALITY, OEPSS CONCERN 23

23.1 OPERATIONAL IMPACT

The impact on ground operations caused by lack of hardware commonality, producing serious logistic, spares, maintenance, and flight hardware support problem, is described in Figure 23-1.

23.2 REQUIREMENTS BACKGROUND

Hardware commonality has not been a requirement between and across the separate and different types of systems. Hardware commonality among separate system is necessarily an operationally and fiscally responsible requirement.

23.3 SYSTEM DESCRIPTION

N/A

23.4 OPERATIONS PROBLEM DESCRIPTION

The lack of hardware commonality creates a logistics nightmare when considering the number of different parts requiring huge inventory/staging areas. Cataloging, receiving, inspection, spares provisioning, maintaining integrity, shipping/receiving, part recall/restocking, shelf life verification, purchasing, dispositioning, etc., are just a few of the functions that create an entire "army" to support flight hardware processing at the launch site. Unique hardware necessarily creates "special run" manufacturing procedures, driving piece-part cost up and tends to create operational impacts through hardware shortages. The different types of hardware tend to promote one-of-a-kind procedures to refurbish the component along with unique system procedures to address the installation/removal/checkout of the special parts.

23.5 BRIEF PHYSICS OF PHENOMENON

N/A

23.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Systems should be designed to promote hardware commonality, especially in the propellant feedlines. Feedline design (size, shape, and material) should be made common for both fuel and oxidizer. Propellant feedline valving should be interchangeable between fuel or oxidizer. Modularizing pneumatic regulations and control systems should be considered to enhance hardware commonality.

23.7 TECHNOLOGY RECOMMENDATION

N/A

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- **Operational impacts**
  - Creates a logistic nightmare — gigantic inventory areas
  - Drives cost of hardware up
  - Tends to create hardware shortages
  - Increases number of procedures for operations
    - Installation/removal
    - Maintenance
    - Repair
  - Drives interchangeability possibilities down
  - Increased changeout time due to unique operations requirements
- **Potential options for consideration**
  - Design/arrange systems to maximize piping commonality
  - Select valving for interchangeability
  - Modularize fluid regulation/control systems

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Figure 23–1. Operational Impact of Lack of Hardware Commonality

24.0 CONTAMINATION, OEPSS CONCERN 24

24.1 OPERATIONAL IMPACT

The impact on ground operations caused by contamination, and the time consuming effort to identify and correct the problem, is described in Figure 24-1.

24.2 REQUIREMENTS BACKGROUND

Contamination in aerospace fluid systems is a major source of operational problems. Because dynamic components frequently have close fits between moving parts, control of particulate contamination is required. Incompatibility between fluids or with materials exposed to the fluids requires strict control of the chemical purity of the system fluids.

24.3 SYSTEM DESCRIPTION

The typical aerospace fluid system controls chemical purity and particulate contamination by sampling and analyzing fluids prior to introduction into the system. Systems are carefully isolated from the environment as much as possible. Interface filters guard against particles from ground fluid supplies.

24.4 OPERATIONS PROBLEM DESCRIPTION

Problems that are a direct result of contamination have had a major impact on ground operations. Rigorous cleanliness controls have been required to reduce the possibility of Criticality 1 failures due to contamination, particularly in oxygen systems. Component problems caused by contamination have resulted in time-consuming component replacement and checkout and have caused launch delays.

24.5 BRIEF PHYSICS OF PHENOMENON

N/A

24.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

The operationally efficient propulsion system must utilize adequate system and component filters. It should develop components less sensitive to contaminants using proper materials and adequate clearances.

24.7 TECHNOLOGY RECOMMENDATION

Investigate the development of contamination tolerant components.

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- **Operational impacts**
  - Potential for Criticality 1 failures
    - Particulate impact in oxygen systems
    - Requires rigorous controls
  - Component failures
    - Impacts launch schedule
    - Time–consuming replacement and checkout
- **Potential options for consideration**
  - Utilize system and component filters
  - Design components less sensitive to contaminants
    - Proper materials
    - Adequate clearances

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Figure 24–1. Operational Impact of Contamination

25.0 SIDE-MOUNTED BOOSTER LAUNCH VEHICLE, OEPSS CONCERN 25

25.1 OPERATIONAL IMPACT

The impact on ground operations caused by a side-mounted launch vehicle is quite substantial. Compared to a stage-and-a-half vehicle, the operational complexity, manpower, and flow time are more than doubled as described in Figure 25-1.

25.2 REQUIREMENTS BACKGROUND

Present practice of launching large payloads to orbit requires staging hardware during ascent. To avoid the use of critical ground systems (T-O swing arms), the vehicle has the booster element side-mounted. This technique is required to allow the design, development, and procurement of separately built booster elements.

25.3 SYSTEM DESCRIPTION

Side-mounted booster stages are designed to allow independent ground checkout, handling, and servicing at the launch site. The booster element contains propellant tanks, prepressurization, and engine feed systems; engines, pneumatics control, and purge systems; TVC and electrical engine instrumentation, and controls. The servicing requires flight umbilicals and supporting mechanical and fluid ground systems. The booster element must either be supported by a ground support and holddown/release system or be supported by the core element.

25.4 OPERATIONS PROBLEM DESCRIPTION

The separate booster element requires much manpower and time to perform checkout, handling, and mating to the core element. It also requires separate propellant tanking interface systems, along with distribution and fluid controls systems. If the booster element is supported and held down separately, the cryogenic shrinkage will impose very large pinch loads in both the core and booster elements, which will impose constraints on the servicing operation. If the booster is only supported by the core vehicle, the umbilicals will be required to take very large motions from cryogenic shrinkage and engine start-twang functions. Separate software will be required to load propellant into the booster because of its traditional unique requirements. Software and hardware will be required to perform ground pressurization and verify that engine start parameters are met. The booster engine will be canted, to allow reduced control angles, that will require engine removal GSE to be unique and difficult to use. The side drift at liftoff will impost additional ground systems to control the induced environment for both the flight vehicle and ground systems. The side-mounted booster element more than doubles the ground systems and functions and results in a very large impact on manpower and flow time at the launch site. The separate booster element also has this similar impact on operations in requiring development center support.

- **Operational impacts**
  - Doubles the tanking systems (at the vehicle)
  - Doubles the tanking systems distribution/control skids
  - Doubles the tank ground pressurization systems
  - Doubles the number of vehicle–to–ground interfaces
  - Drives booster engines to canted installation to reduce gimbal angle requirements
    - Increase complexity of engine R&R, GSE
  - Adds complexity to systems required for tanking operations to compensate for loads induced in connected fixed tanks due to shrinkage from cryogenics
  - Liftoff drags flame across platform and systems adding to refurbishment operations and costs
  - Increases propulsion flight hardware checkout, i.e., separate tanks, pressurization system, feed systems, control valves, instrumentation, etc.
  - Doubles ground control consoles and software
  - Adds complexity to holddown and release systems and clearance to prevent contact with facility systems
- **Potential options for consideration**
  - Stage–and–a–half vehicle with fall–away booster hardware — Atlas vehicle concept and possibly drop tanks if required

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Figure 25–1. Operational Impact of Side–Mounted Booster Launch Vehicles

25.5 BRIEF PHYSICS OF PHENOMENON

When the booster and core elements are both supported and tied down, the cryogenic conditioning causes the contraction of materials of the booster and core tanks and results in a reduction in their diameters. This reduction in tank diameters imposes lateral loads in the integrated stack or buckling of the tank aft bulkheads. Added pressure is then sometimes used to try and stabilize the structure.

25.6 POTENTIAL OPTIONS FOR SOLVING THE PROBLEM

Use only single stage or stage–and–a–half vehicle configurations. When more payload carrying capability is needed, build a larger vehicle and do not try to accommodate the higher payload by adding another side–mounted booster element.

25.7 TECHNOLOGY RECOMMENDATION

N/A

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