NASA LEWIS RESEARCH CENTER

Space Station Freedom/ Lunar Transfer Vehicle Propellant Operation Hazard Analysis

Sam Dominick (Presenter)
Martin Marietta Corporation

Steven M. Stevenson
Advance Space Analysis Office
Lewis Research Center

Harvey Feingold
Science Applications
International Corporation

ADVANCED SPACE ANALYSIS OFFICE

SSF/LTV Propellant Operation Hazard Analysis

Space Station Freedom (SSF), as a transportation node for Space Exploration Initiative missions, would involve the assembly and refurbishing of lunar and Mars transfer vehicles. This includes operations involving cryogenic propellants (LH2 & LO2) such as storing and handling of loaded propellant tanks, assembly onto the vehicle, and propellant transfer. Cryogenic propellants dictate rigorous safety precautions and impose unique requirements to ensure safety to both personnel and SSF elements. The objective of this study is to identify potential hazards and risks associated with cryogenic propellants. This involves identification of pertinent system design features and operational procedures. Criticality of identified risks/hazards shall be assessed and those that fall in the catastrophic and critical categories shall include mitigating solutions.

SSF/LTV Propellant Operation Hazard Analysis

- Hazard Analysis Conducted To Define Hazards And Risks Of Storing, Handling And Transferring Cryogenic Propellants At SSF To Support LTV

- Objective:
  - Identify Hazard And Risk - Hardware, Operations, Human Error
  - Assess Criticality
  - Propose Mitigating Solutions

SSF/LTV Propellant Operation Hazard Analysis (Cont.)

Approach

The initial approach to the hazard analysis consisted of selecting a baseline Lunar Transfer Vehicle (LTV) design from previous LTV studies. This reference vehicle provided a point of departure concept and was used to generate a detailed operational scenario. Included in the operational scenario are activities such as propellant refueling, storage, mission refurbishment, safing and propellant topoff of the drop tanksets. Hazards identified from these activities are then analyzed to provide mitigating measures in order to either eliminate them or reduce the risks to an acceptable level.

SSF/LTV Propellant Operation Hazard Analysis (Cont.)

- **Approach:**
  - **Hazard Assessment Based On Selected Reference Scenario From LTV Design Studies**
  - **Assume Propellant Mini-Depot For Propellant Topoff And Contingency Supply**
  - **Develop/Assess Timelines And Scenarios For Propellant Refueling And Storage**
  - **Propose Measures To Mitigate Risks Of Identified Hazards - Assess Probability Of Occurrence For Hazards Without Suitable Solutions**

C-3

Task Plan

The SSF/LTV propellant operation hazard analysis is subdivided into four subtasks. The first subtask involves historical review of documentation pertinent to safety of cryogenic systems in space. The information derived from this effort provides an initial starting point and information base for the subsequent tasks. Subtask 2 examines risks and hazards associated with propellant refueling operations in reference to conditions producing the hazards and the severity of the impact on SSF. Subtask 3 is similar to subtask 2 except that it investigates vehicle operations other than refueling. These operations include vehicle turnaround operations, docking/storage, safing and various maintenance operations. Subtask 4 provides mitigating solutions to risk and hazards identified in both subtask 2 and 3.

Subtask milestones are listed below. The completion of the propellant operation hazard analysis is scheduled by August 9, 1991. The final report , written in "white paper" form, will be submitted by September 6, 1991.

SSF/LTV Propellant Operation Hazard Analysis

Task Plan

- Subtask 1 - Historical Review
- Subtask 2 - Cryogenic Transportation Refueling Risks
- Subtask 3 - Vehicle Operation Risks
- Subtask 4 - Mitigating Solutions

Schedule Milestone:

Subtask 1 - Ongoing

Subtask 2 - Completed 9 July 1991

Subtask 3 - Completed 2 August 1991

Subtask 4 - Underway -- Complete By 9 August 1991

Final Report - 6 September 1991

LTV Configuration

The LTV configuration baseline for the cryogenic propellant operation hazard study is shown below. This configuration provides a reference concept that is used as starting point for the analysis. Basic elements of the LTV are the crew & cargo modules, 6 drop tanksets and aerobrake assembly which are all attached to the common propulsion/avionics core. This vehicle can deliver 14.6 tonnes of cargo including a crew of 4 to the Lunar surface and return to the SSF using 174 tonnes of cryogenic propellant. Total vehicle dry mass is 27.5 tonnes.

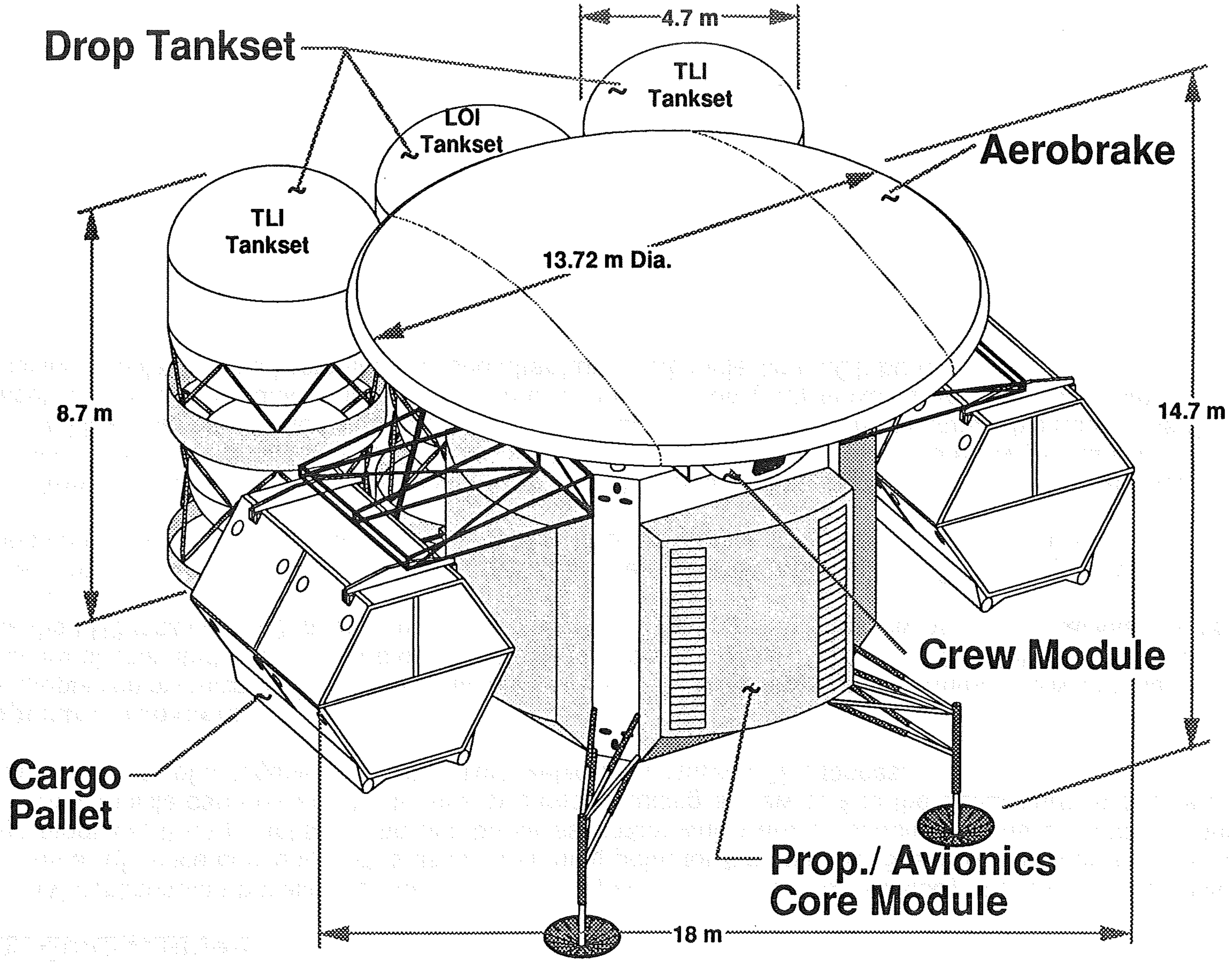
Propellant Tanksets

The propulsion/avionics core module contains 5 tanks -- 4 LH2 tanks spaced symmetrically around an LO2 tank. The tanks are all mounted to the lower cross beams of the core structure. The LO2 tank is 4.4 m long and 2.9 m in diameter while the LH2 tanks are 4.2 m long and 2.6 m diameter. Total propellant capacity of the core tanksets is 32.5 tonnes

The aerobrake assembly protects the crew during the aeroassisted return to the SSF. The system contains 2 return tank pallets consisting of 3 LH2 tanks and 2 LO2 tanks. Total aerobrake propellant load is 7.2 tonnes.

Each drop tankset consists of 1 LH2 and 1 LO2 tank. The propellant capacity of an individual tankset is approximately 28 tonnes. There are 3 tanksets (2 TLI and 1 LOI) per tank arrangement and there are two tankset arrangements per Lunar vehicle, placed on each side of the LTV. Each tankset has a support structure which connects it to the adjacent tankset as well as the tank vehicle. The Trans Lunar Injection (TLI) tanksets are jettisoned after the TLI burn. The remaining middle drop tanksets are released after Lunar Orbit Injection (LOI) burn.

Lunar Transfer Vehicle Configuration



Note: Front Drop Tankset Arrangement Not Shown

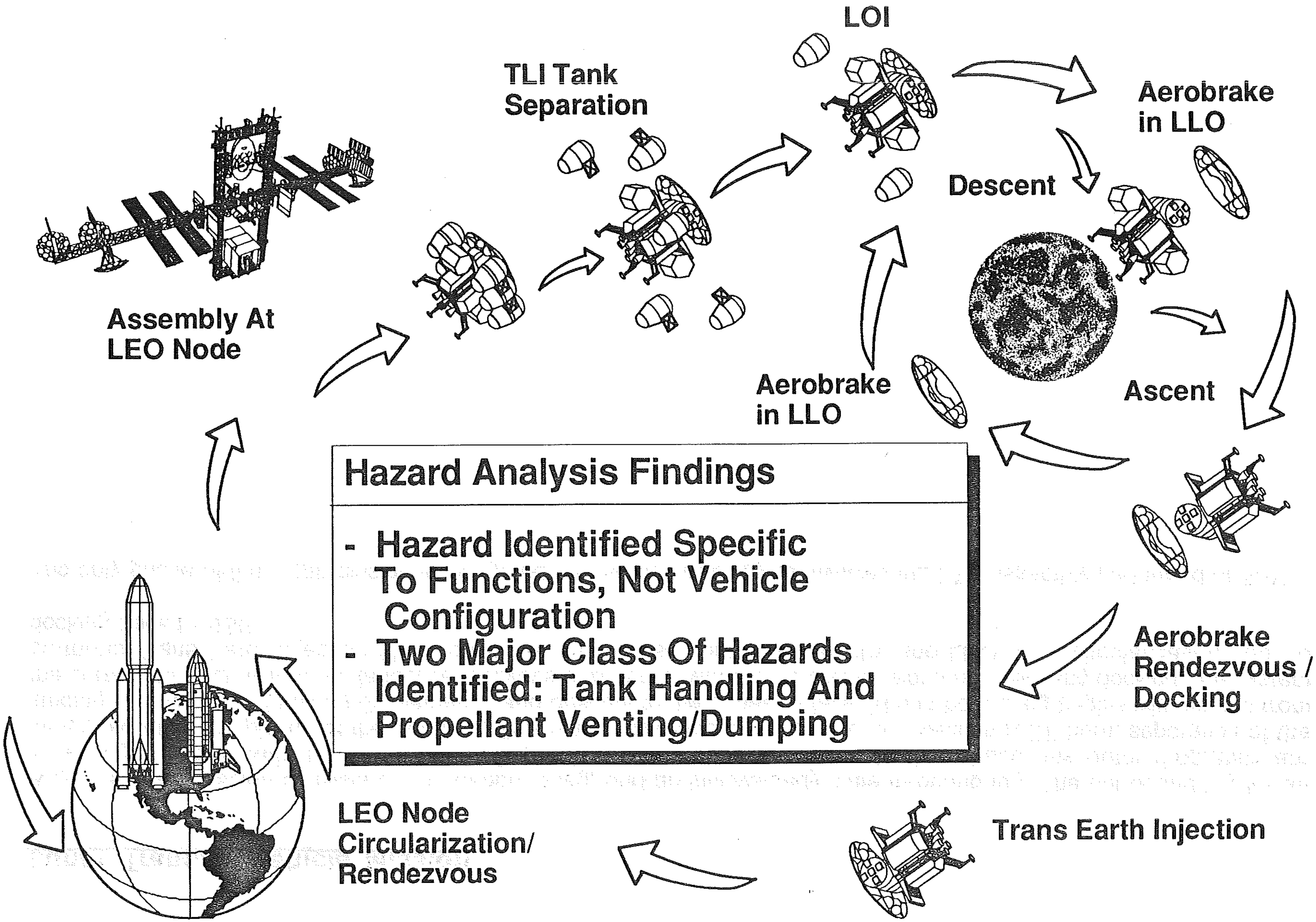
Lunar Transfer Vehicle Mission

A typical lunar mission consists of an out-bound leg, and an initial/steady state in-bound leg. The out-bound leg for an initial flight begins with the Trans Lunar Orbit (TLI) preparation and burn. In this phase, the outer droptanks are separated after completion of the TLI burn. This is then followed by a Lunar Orbit Injection (LOI) burn, separation of the landing & Low Lunar Orbit (LLO) elements, and descent to the Lunar surface. The in-bound leg begins with ascent from the surface to LLO, where the lander rendezvous and docks with the aerobrake element. Following docking, the system performs Trans Earth Injection (TEI), conducts mid-course correction, reentry and LEO node circularization prior to docking back to SSF.

The only phase of the lunar mission investigated for the hazard analysis involves the LTV assembly performed at SSF.

NASA LEWIS RESEARCH CENTER

Lunar Transfer Vehicle Mission



Hazard Analysis Findings

- Hazard Identified Specific To Functions, Not Vehicle Configuration
- Two Major Class Of Hazards Identified: Tank Handling And Propellant Venting/Dumping

ADVANCED SPACE ANALYSIS OFFICE

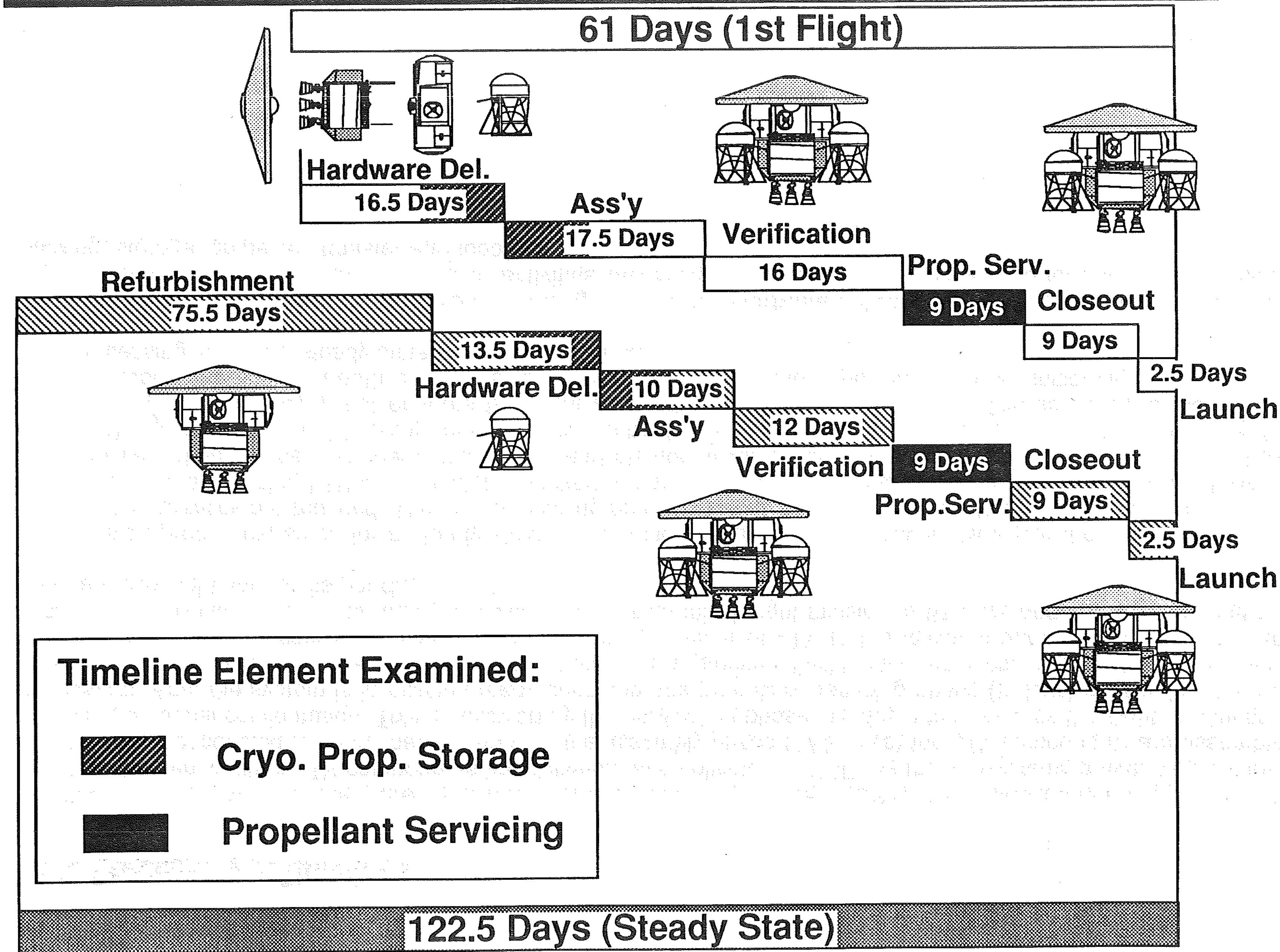
LEO Processing - Timelines

For the initial flight mission, there are six primary activities performed at LEO (SSF). The hardware delivery phase (16.5 days), is the period when LTV components are delivered and collected at SSF. As the subsystems arrive, element level checkouts are conducted to verify their integrity. In the assembly phase (17.5 days) the LTV components are assembled into an operational configuration. This is followed by the verification phase (16 days) that ensures the flight readiness of the system. After the system is in mission ready condition, the propellant servicing phase (9 days) assembles the drop tanks to the mission vehicle. The closeout phase (9 days days) provides final launch readiness status. The last activity is the launch phase. This consist of mission crew boarding, transfer of LTV to the injection burn area and initiating the Trans Lunar Injection (TLI). The total processing time for an initial flight mission is 61 days and it was assumed that there are two eight hour shifts per day.

The mission processing steps for a steady state mission increased from six to seven. However the times required for many of the activities are reduced. The first processing phase of a steady state mission is the refurbishment phase (75.5 days), where the returning LTV is completely checked out and refurbished. In the hardware delivery phase (13.5 days), the propellant drop tanksets are delivered at SSF and element level checkouts are conducted. In the assembly phase (10 days), the replaceable LTV components are assembled into an operational configuration. This is followed by the verification phase (12 days) that ensures the flight readiness condition of the system. The servicing, closeout, and launch phases are similar in both procedure and processing time to those performed for an initial flight mission. The total processing time for a steady state mission is 122.5 days

The time elements of interest during LEO processing occur in the hardware delivery, assembly,and propellant servicing phases. During portions of these phases, activities involving cryogenic propellants are performed. These include docking, storage, propellant transfer and topoff.

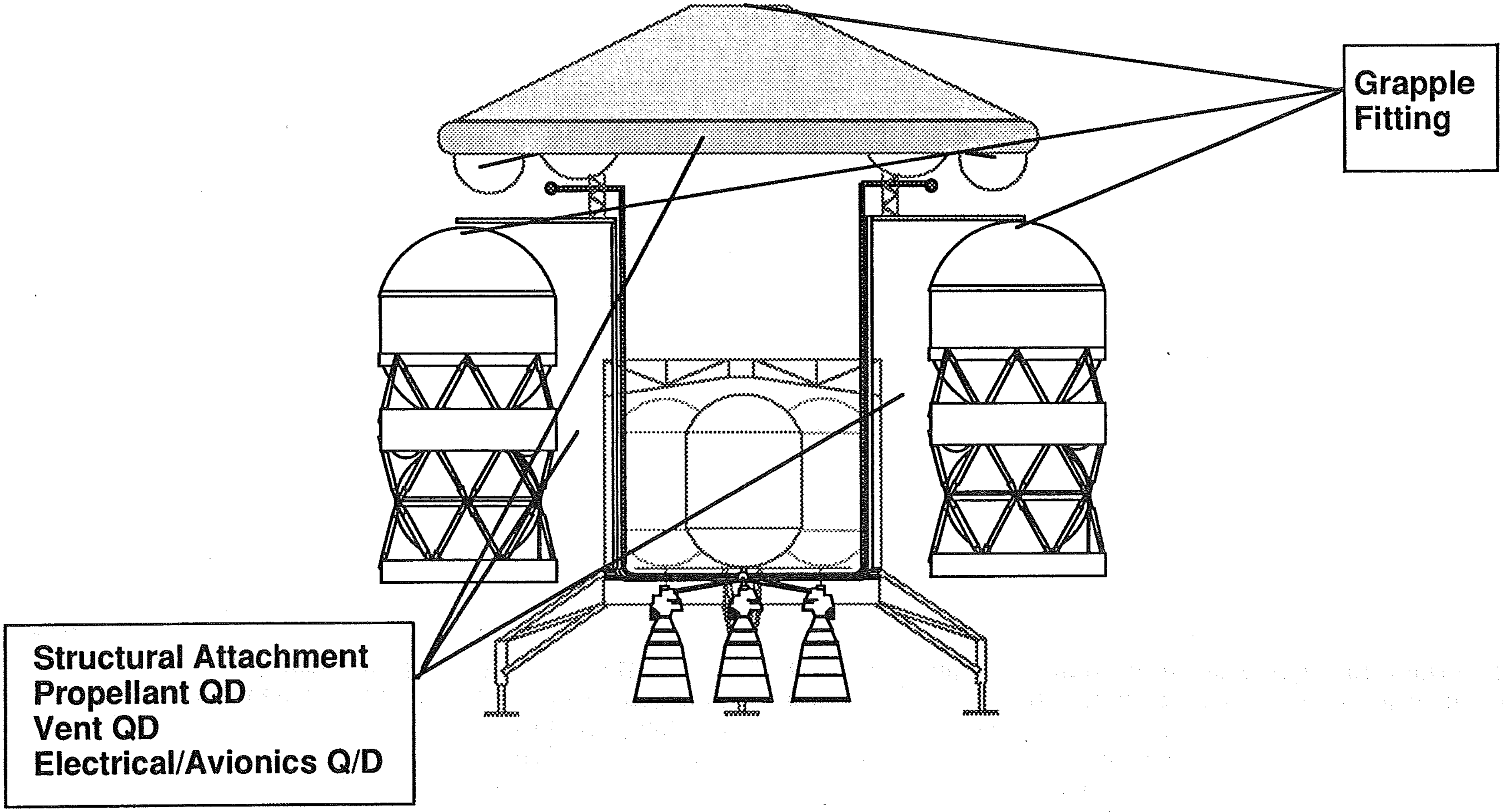
LEO Processing - Timelines



LTV - Typical Interfaces

The majority of the hazards identified in the study are failures that originate at the various vehicle/SSF interfaces. These interfaces include structural attachments, propellant line quick disconnect's (QD's), vent QD's, electrical/avionics QD's and grapple fittings used for RMS translation. Failure modes associated with these interfaces are a function of the components involved and are independent of vehicle configuration since these interfaces will be inherent in most vehicle designs. Changes in the LTV configuration would primarily result in differences in the number of interfaces required.

LTV - Typical Interfaces



LTV Refueling Activities

Subtask 2 examines cryogenic propellant refueling hazards. The refueling activities performed include drop tank changeout, drop tankset topoff, core tankset propellant loading and aerobrake tankset propellant loading. Droptank changeout consists of translation of the drop tanks using the RMS and attachment to the core LTV. Drop tankset topoff is performed using the mini-depot to replenish boiloff losses of 2%/month. Other refueling activities of concern involve the propellant loading of both the core and the aerobrake tanksets. Propellant for these tanksets is supplied from the drop tanks. Transfer line and tank chilldown are performed prior to the transfer process.

LTV Refueling Activities

- Drop Tank Change-Out
- Drop Tankset Topoff With Mini-Depot
- Core Tankset Propellant Loading
- Aerobrake Tankset Propellant Loading

LTV Refueling Functional Summary

This chart lists the major functions performed during the refueling activities. These functions are an inherent part of orbital cryogenic propellant resupply regardless of the tank size, geometry, or vehicle configuration.

LTV Refueling Functional Summary

- Leak Check/Mate/Demate Of Quick Disconnect
- Propellant Tank/Transfer Line Chilldown
- Tank Propellant Load In Low Gravity Environment
- Tank Venting/Dumping - Nominal And Emergency
- Transfer Line Purging/Safing
- Tank Transport/Handling

Functions Are Generic - Not Dependent On A Specific Vehicle Configuration

Representative Timeline/Hazard Tables

This chart shows a representative illustration of the tables generated during the hazard analysis. Under subtask 2, a total of four timeline operations corresponding to the number of refueling activities were created. The refueling activities have been broken down into detailed steps along with their respective operation times. These times were derived from a ground operations data base and adjusted for LEO operations. The timelines are consistent with previously derived numbers*.

Seven hazard tables were created using the refueling timelines. The hazard tables further break down the refueling operation into detailed steps and identify hazards associated with each. Potential effects on SSF elements are described and severity of impacts are established using the standard NASA hazard categories. These categories range from catastrophic to negligible. All potenital hazards, regardless of their probability of occurrence, were considered.

*Lunar Transfer Vehicle On Orbit Processing Study, Contract NAS10-11400; McDonnell Douglas Space Systems Company; December 1990

Representative Timeline/ Hazard Tables

Drop Tankset Propellant Top-off

Operation	Time (hrs / No. Of Shifts)
Prepare Mini-Depot For Propellant Transfer	
Mate Transfer Line Umbilicals	
Leak Test Conn	

Four Timelines Developed For Refueling Operations

Operation Drop Tankset Top-off	Hazard	SSF Element Affected	Potential Effect On SSF Element	Crit
1 Close Mini-Depot Vent Iso-Valve And Verify Shut	1a Iso-Valve Fails To Close 1b Unexpected High Propellant Pressure	Crew, Hangar Truss Assy, GN&C	1a Delay Of Drop Tank Topoff Operations 1b Overpressure Can Result	1a MA

Seven Hazard Tables Developed With 39 Operational Steps

Refueling Hazard Criticality Summary

The hazards identified in the refueling operation fall under two major categories. The first one involves collision of drop tanks during translation and the second category is the propulsive venting/dumping of propellants. Under the first category, the hazards identified are propellant slosh and remote manipulator system (RMS) failure resulting in loss or degraded control functions. Also included as potential hazards are interface hardware failures such as the grapple connection. The second category, propulsive venting/dumping, occurs from either two-phased venting or uncontrolled venting due to tank rupture.

Summary of identified hazards are shown below for the refueling scenario. The majority of the hazards are categorized as either catastrophic or critical and therefore require mitigating solutions.

Refueling Hazard Criticality Summary

Major Hazards Identified:

- Collision During RMS Transport Of Drop Tanks
  - Excessive Slosh, Exceeds RMS Control Capabilities
  - RMS Electr./Mech. Failure (Loss Of Control)
  - Structural Failure Of Interface Hardware
- Propulsive Venting/Dumping Of Propellants
  - Emergency Venting Due To Excessive Pressure Buildup (Thermal Control Degradation, Vent System Component Failure, Ventline Blockage Due To Frozen Propellants)
    - Two Phase (Liquid/Gas) Propulsive Venting

Refueling Hazard Criticality Summary (Cont.)

This page left intentionally blank.

Refueling Hazard Criticality Summary (Cont.)

- Venting Due To Tank Rupture
    - Uncontrolled Venting May Impart Excessive Loads To Truss Element Or Exceed GN&C Capabilities
    - Propellant Impingement On Crew And Equipment

Preliminary Criticality/Number

• Catastrophic	29
• Critical	14
• Marginal	8
• Negligible	None

Mitigating Solutions Have Been Identified To Eliminate Or Lessen The Severity Of The Majority Of Catastrophic And Critical Hazards

Preliminary Hazard Mitigating Solutions

Hazard and safety issues identified will be studied in detail to determine the range of measures which will either eliminate or reduce their probability or impact. These measures include hardware design changes, imposing additional requirements on the LTV and SSF, procedure modification, and redefining the Lunar mission scenario. For those hazards (identified as catastrophic or critical) without effective mitigating solutions, the risk involved with each hazard (determined by the probability of occurrence) will be evaluated. The evaluation of mitigating solutions has been initiated and some sample solutions are summarized in the chart. Many of the hazards can be addressed by incorporating adequate redundancy in key subsystems or components such as multiple vent lines. Other hazards involving those resulting from inadvertent collision can be lessened by incorporating measures to reduce damage to key subsystems such as the thermal protection system

Preliminary Hazard Mitigating Solutions

- Determine Measures To Either Eliminate Or Reduce The Probability Or Impact Of Identified Hazards Through:
  - Design Changes
  - Additional Requirements
  - Procedure Modifications
  - Different Mission Scenarios

- Sample Preliminary Solutions:
  - Increased Component Redundancy In SSF And LTV Subsystems
  - Multiple Vent Lines
  - Robust Thermal Protection System On Propellant Tank For Lower Susceptability To Damage

Preliminary Hazard Mitigating Solutions (Cont.)

There are ongoing or planned technical development efforts related to cryogenic fluid management that will demonstrate or validate technologies and processes to support solutions to the identified hazards. These include the ground test programs at NASA Lewis Research Center and Marshall Space Flight Center. These ground test activities are demonstrating techniques for low gravity cryogen transfer, active and passive tank pressure control, thermal insulation concepts, and advanced instrumentation. Flight experiments are underway or planned which would provide low-g validation of the ground test results.

Preliminary Hazard Mitigating Solutions (Cont.)

- Technical Development Effort Related To Cryogenic Propellants Are Ongoing Or Planned Which Will Demonstrate/Validate Mitigating Solutions
  - Cryogenic Ground Test Programs At NASA Lewis Research Center And Marshall Space Flight Center
    - Cryogenic Storage/Transfer/Pressure Control
  - Fluid Flight Experiments
    - Low-g Validation Of Ground Tests

Future Activity

Subtask 3 and 4 will complete the cryogenic propellant hazard analysis. Subtask 3, identification of hazards, risks and safety issues associated with vehicle operation other than refueling, have just been recently completed. Subtask 4, identification of mitigating measures to eliminate or reduce risk, will be completed by 9 August 1991.

Future Activity

- Subtask 3 - Vehicle Operations Risk/Hazards Evaluation
  - Drop Tankset Docking/Storage
  - Turnaround Operations, Vehicle Safing
  - Orbital Debris/ Micrometeoroid Effects
  - Long Term Thermal Control Degradation
- Subtask 4 - Identification Of Mitigating Solutions
  - Determine Measures To Reduce Or Eliminate Risk/Hazard Identified In Subtask 2 And 3
    - Mission Scenario Changes, Operations And/Or Design Solutions