RI/RD90-149-5

p-153

# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS) DATA BOOK

## Volume V - OEPSS Final Briefing for 1st Year Study

Prepared for
Kennedy Space Center
NAS 10-11568

14 August 1990

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

Rockwell International, Rocketdyne Division
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Contract Technical Monitor: Russel E. Rhodes
Co-author Organizations: Raymond J. Byrd, Boeing Aerospace Operations; James M. Ziese, Space Systems Division, Rockwell International

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 contains the final briefing on the OEPSS first-year effort. This briefing was presented to NASA, MSFC Huntsville, Alabama, as part of an effort to promote greater interaction between the design community and the launch site operator.

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Rockwell International
Rocketdyne Division

# 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 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; and Volume IV, OEPSS Design Concepts.

Volume V contains the OEPSS Final Briefing, summarizing the first year study, and is hereby made part of the OEPSS Data books. The final briefing was presented at NASA, MSFC, Huntsville, AL, 14 August 1990.

# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS)

## Agenda
14 August 1990

√ • Introduction ---------------------------------------- R. Rhodes

• Operationally Efficient Integrated P/M ------------- G. Wong

• Operations Problems ---------------------------- G. Waldrop

• Operations Technology ------------------------- G. Wong

• Operations Database

# PROPULSION DEVELOPMENT

## Where are we headed?

- **First 30 years focused on space effort**
  - All criteria based on performance: $I_S$, GLOW, T/W, mass fraction
  - Engine development based on establishing artificial interfaces for design and operational control
    - Engine CEI and ICD - ease of procurement and development test
    - Vehicle assumed weight burden of all systems demanded by the engine
    - Mission use determined number of engines required by vehicle
  - Cost and launch rate were not a Big concern
    - Reusability was answer to cost reduction
  - Where are we falling short in vision
    - Experience identified many generic operations concerns that cause status quo
    - OEPSS Study identified alternate concepts that offer major reduction in complexity and manpower intensive operations

# PROPULSION DEVELOPMENT

- **Next 30 years focused on ambitious space exploration**
  - By applying the principles of TQM to Advanced Planning; Conceptual Design; Development of Requirements; and Design Development Processes provides
    - Low cost, reliable, timely access to space
    - Low cost, reliable, operationally flexible space transfer system
  - Develop a simple, reliable, operationally efficient, integrated propulsion system concept to be used and sized for different missions/vehicles
    - Fully integrated to achieve major reduction in propulsion components
    - Major reduction in traditional vehicle support systems
    - Concentrate on $LOX/LH_2$ for all vehicle fluid needs
      - Providing environmentally clean and totally integrated propulsion and vehicle power requirements, i.e.
      - MPS, OMS, RCS, fuel cells, cooling/thermal management and life support systems

# PROPULSION DEVELOPMENT

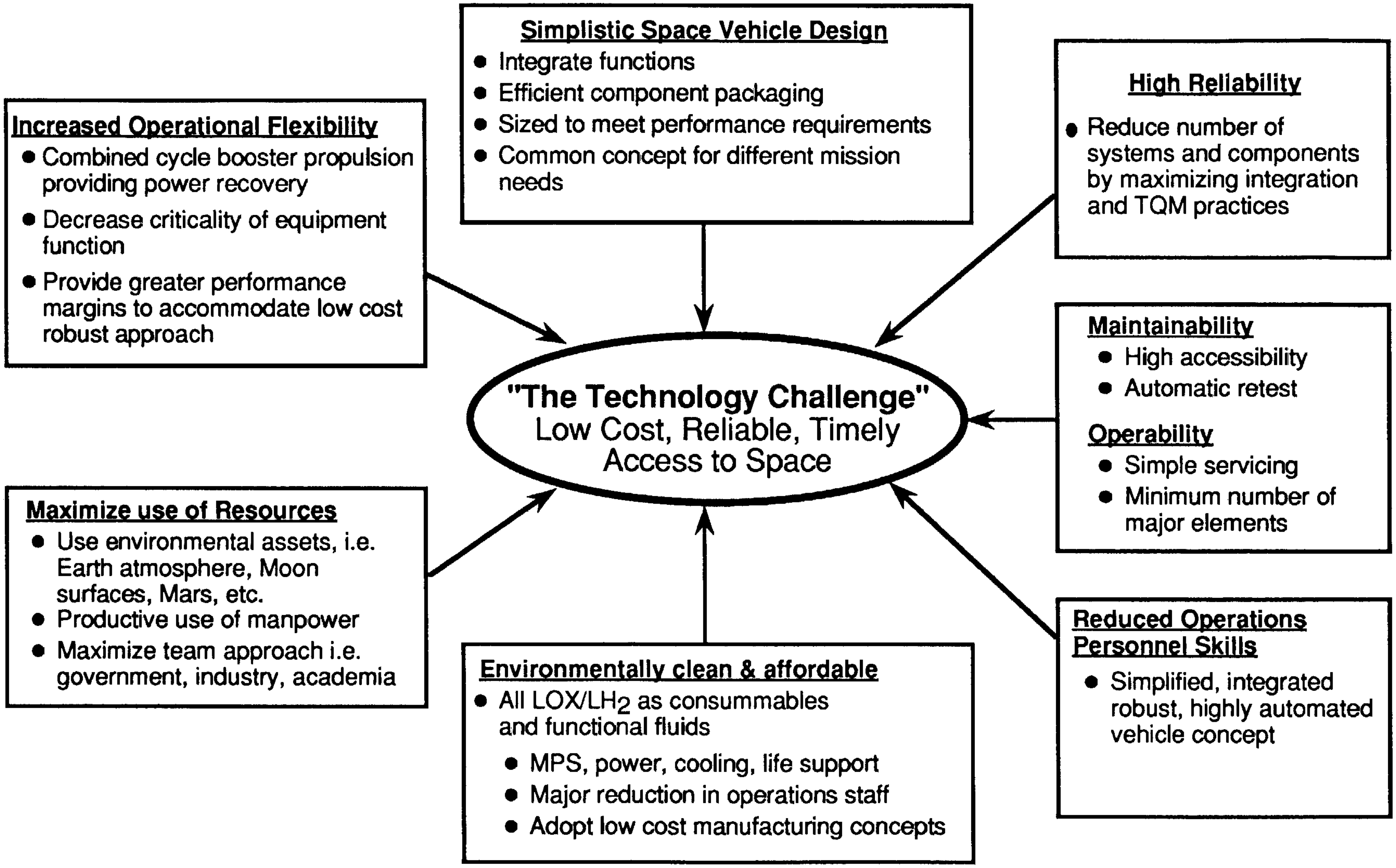
- **Surface the necessary technology needs to allow this ambitious space exploration program to occur**
  - Develop these technology items into projects and follow them through maturity for use
- **Maximize the use of manpower and facilities**
  - Realign our government and industry teams and procurement practices to perform productive work and increase operational flexibility
- **Let us accept this challenge for the future**
  - Let us not build a new 1990 model

**But**

  - Let us provide real measurable progress, allowing us to achieve the next frontier

**"Routine access to Space"**

# PROPULSION DEVELOPMENT

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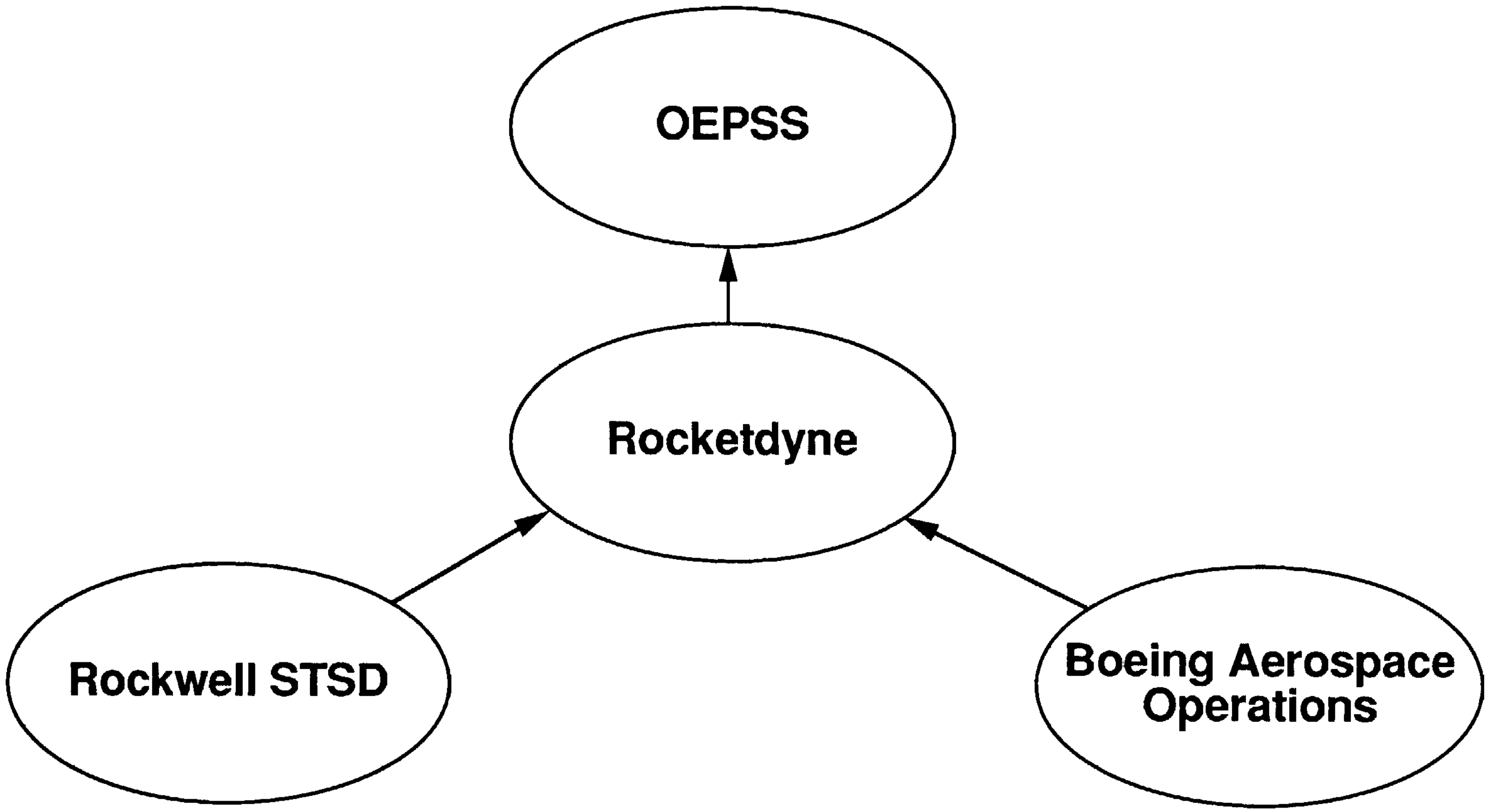
# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS)

## Agenda

14 August 1990

- Introduction ---------------------------------------- R. Rhodes
- √ Operationally Efficient Integrated P/M ------------ G. Wong
- Operations Problems ------------------------------ G. Waldrop
- Operations Technology ---------------------------- G. Wong
- Operations Database

# THE OEPSS TEAM



# OEPSS PROGRAM STATUS

**May 1989-February 1990**

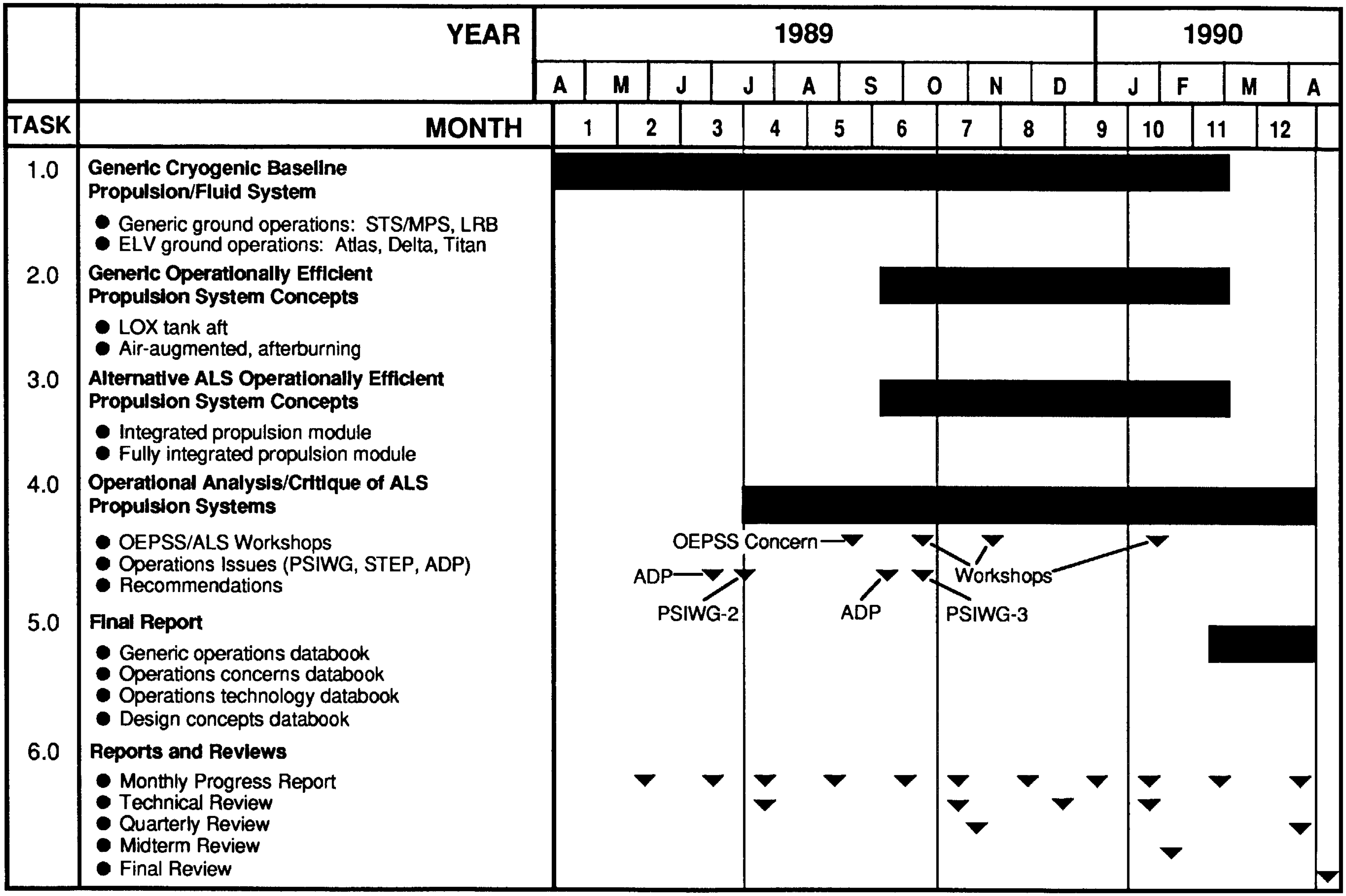
- **Developed generic, cryogenic launch operations database**
- **Developed propulsion system Operations Concerns list**
- **Conducted on-site visit to STS, Atlas, Delta and Titan launch sites**
- **Completed OEPSS/ALS Operations Workshops with ALS vehicle contractors:**
  - Boeing Aerospace
  - Martin Marietta
  - General Dynamics
- **Completed OEPSS/ALS Operations Workshops with ALS engine contractors**
  - Pratt and Whitney
  - Rocketdyne
  - Aerojet Techsystems
- **Participated in 2nd and 3rd ALS, PSIWG meetings (L.A., San Diego)**

# OEPSS PROGRAM STATUS

## May 1989-March 1990

- **Completed quarterly reviews**
  - NASA, KSC — 8 November 1989
  - ALS/JPO — 9 November 1989
  - ALS/JPO Col. Wormington — 6 December 1989
  - NASA, MSFC — 19 December 1989
- **Completed midterm reviews**
  - NASA, headquarters — 13 February 1990
  - NASA LeRC — 14 February 1990
  - ALS/JPO — 27 February 1990
  - NASA, SSC — 13 March 1990

# OEPSS STUDY SCHEDULE

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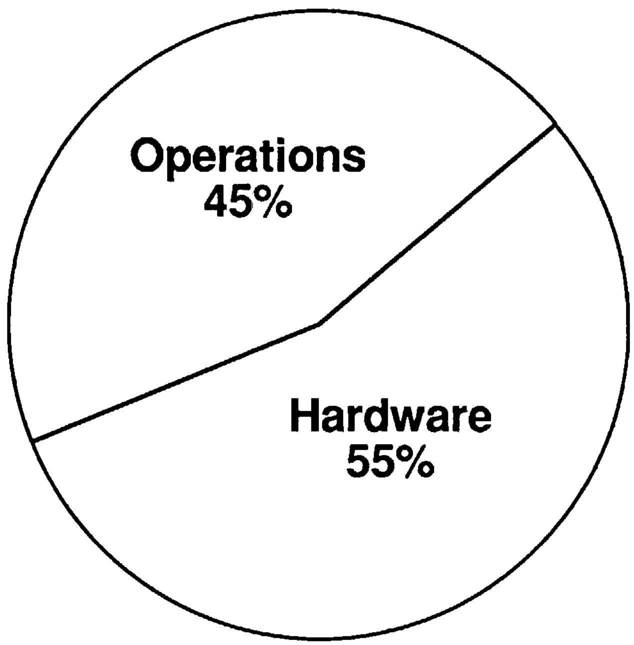
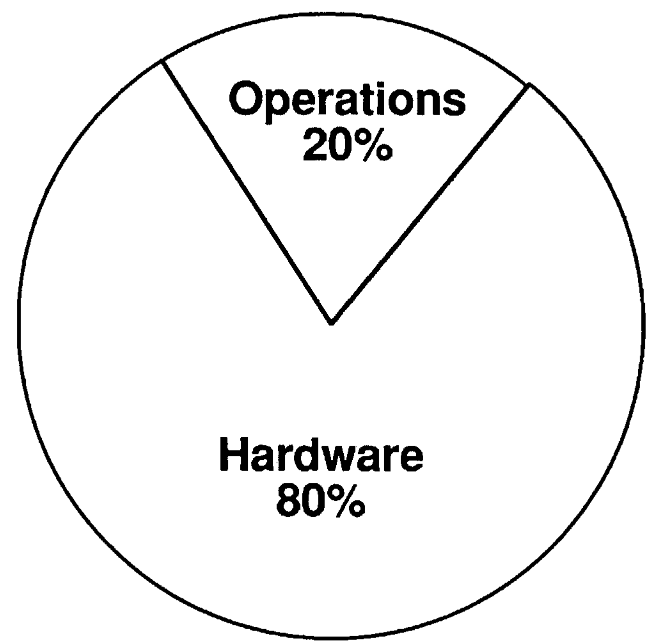
# LAUNCH OPERATIONS COST PER FLIGHT

## % of Total Recurring Cost




STS




Titan IV

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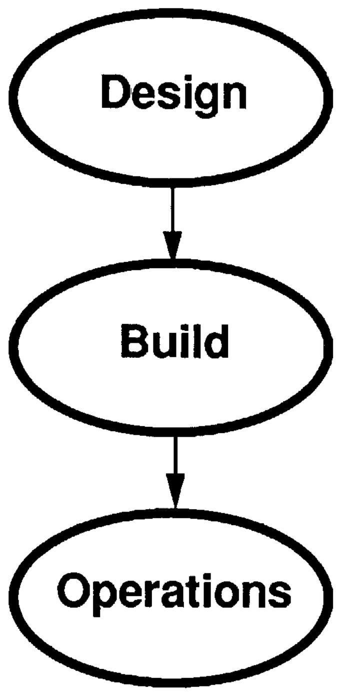
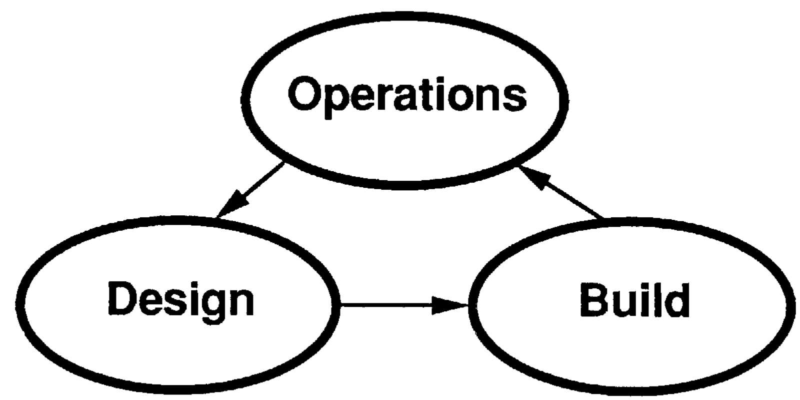
# OPERATIONS PROBLEMS RESULTS IN HIGH COST

- Operations problems largely ignored
- Operations is a major cost driver
- Operations must play interactive role with propulsion system design

# OPERATIONS AND DESIGN MUST BE INTERACTIVE



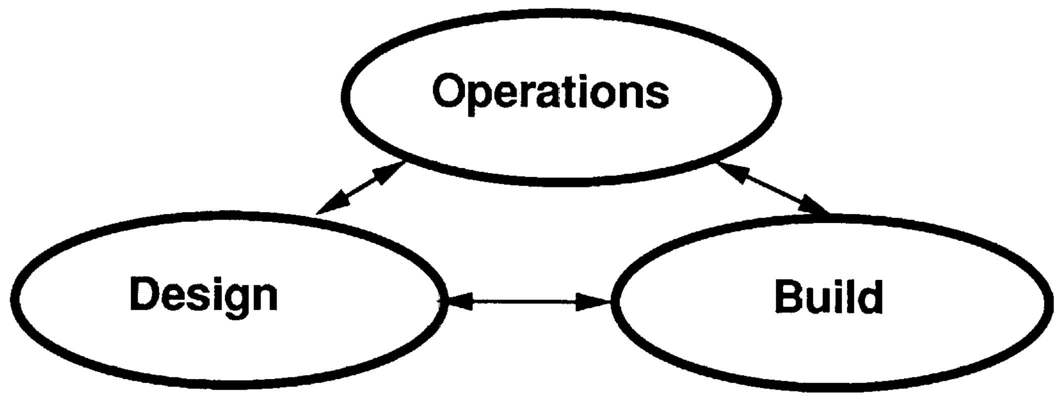

Traditional




OEPSS

# TOTAL QUALITY MANAGEMENT (TQM) FOR OPERATIONS

## Total Propulsion System




OEPSS

# CURRENT OPERATIONS IS SERIAL, TIME CONSUMING AND MANPOWER INTENSIVE

- **Some major operations problems**
  - Closed boat-tail compartment
  - Hydraulic and gimbaling systems
  - Multiple propellants/commodities ($LO_2$, $LH_2$, hypergols, He, $N_2$, freon, etc)
  - Excessive components and interfaces

- **Reduce operations problems by integrating engine components and subsystems**
  - Integrated propellant feed and engine system
  - Integrated engine supports systems
    - Helium
    - Pressurization
    - Control avionics
  - Common $O_2/H_2$ systems
    - MPS
    - OMS/RCS
    - Fuel cells
    - ECLSS

# OEPSS IDENTIFIES OPERATIONS PROBLEMS

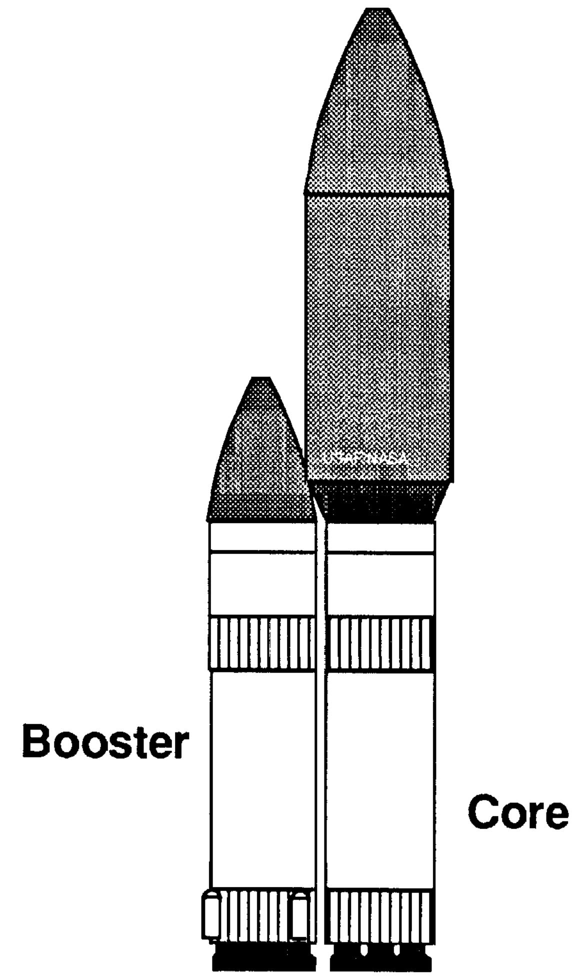
## Causes and Effects

| No. | | No. | |
|---|---|---|---|
| 1 | Closed aft compartments | 14 | Ordnance Operations |
| 2 | Hydraulic system (valve actuators and TVC) | 15 | Retractable T-O umbilical carrier plates |
| 3 | Ocean recovery/refurbishment | 16 | Pressurization system |
| 4 | Multiple propellants | 17 | Inert gas purge |
| 5 | Hypergolic propellants (safety) | 18 | Excessive interfaces |
| 6 | Accessibility | 19 | Helium spin start |
| 7 | Sophisticated heat shielding | 20 | Conditioning/geysering ($LO_2$ tank forward) |
| 8 | Excessive components/subsystems | 21 | Preconditioning system |
| 9 | Lack hardware integration | 22 | Expensive helium usage - helium |
| 10 | Separate OMS/RCS | 23 | Lack hardware commonality |
| 11 | Pneumatic system (valve actuators) | 24 | Propellant contamination |
| 12 | Gimbal system | 25 | Side-mounted booster vehicles (multiple stage propulsion systems) |
| 13 | High maintenance turbopumps | | |

# PROPULSION SYSTEM FOR ALS

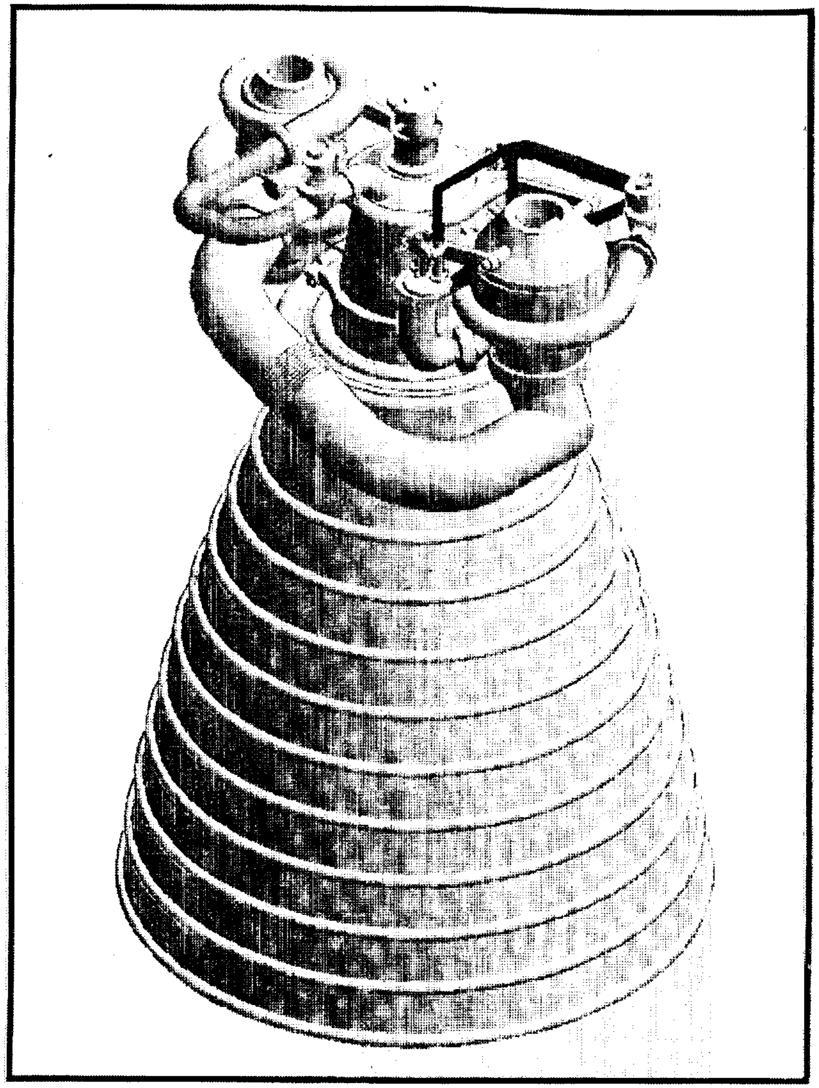
- **Defined as a totally "integrated" system of components and subsystems to provide vehicle thrust and control**
  - Tankage
  - Fluid Systems
  - Structure
  - Thrust Chamber(s)
  - Turbopump(s)
  - Controls
- **Use a "minimum" of components and subsystems to meet the functions of the propulsion system**
  - Simple
  - Reliable
  - Robust
  - Operationally efficient
- **Achieve lowest possible cost by applying TQM to propulsion system development process**
  - Design/Build/Operate

# BASELINE ALS VEHICLE




| | |
|---|---|
| • Payload | 120,000 lbs (LEO) |
| • GLOW | 3,500,000 lbs |
| • Thrust/weight | 1.30 |
| • Booster vehicle | 150' x 30' dia. |
| • Core vehicle | 280' x 30' dia. |
| • Booster engines | 7 |
| • Core engines | 3 |
| • Engine thrust (vac) | 580,000 lbs (STME) |

# SPACE TRANSPORTATION MAIN ENGINE



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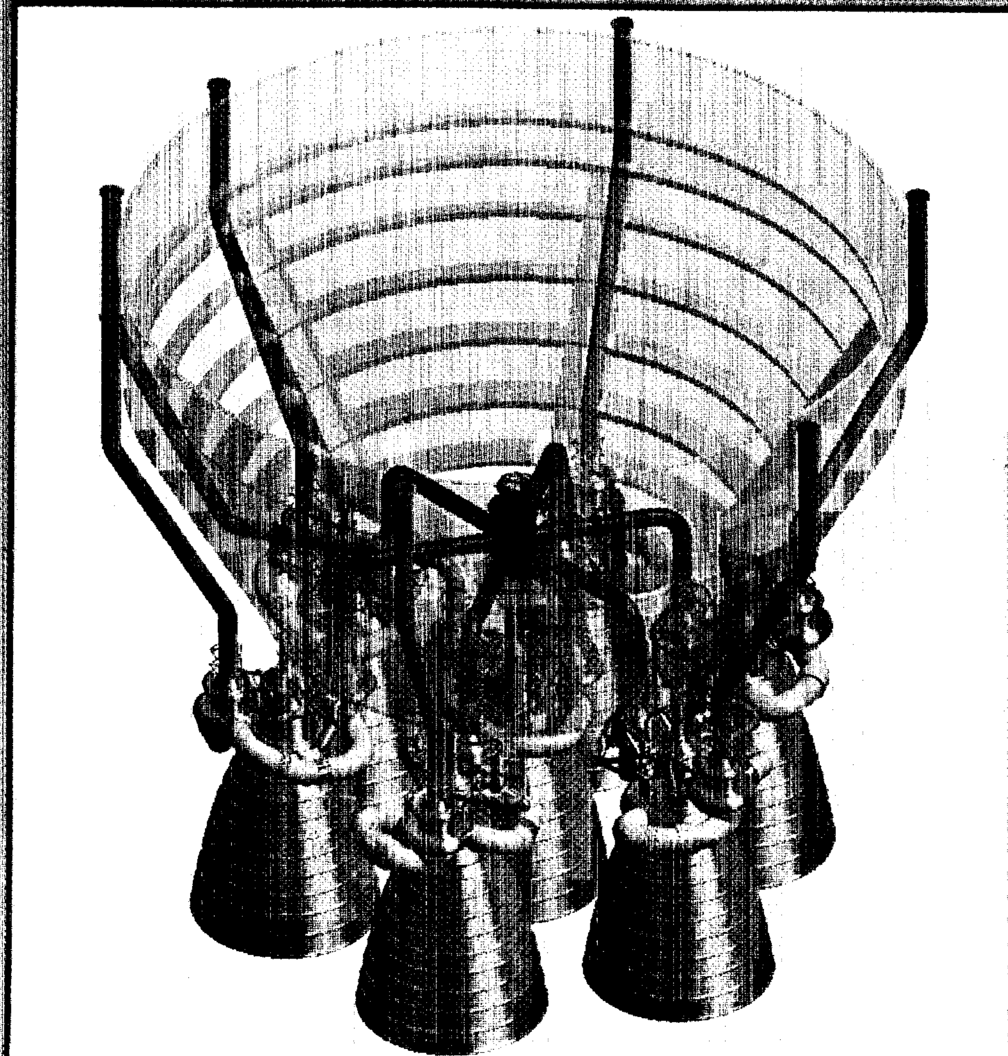
443

# CONVENTIONAL BOOSTER PROPULSION SYSTEM
## 7 - ENGINE



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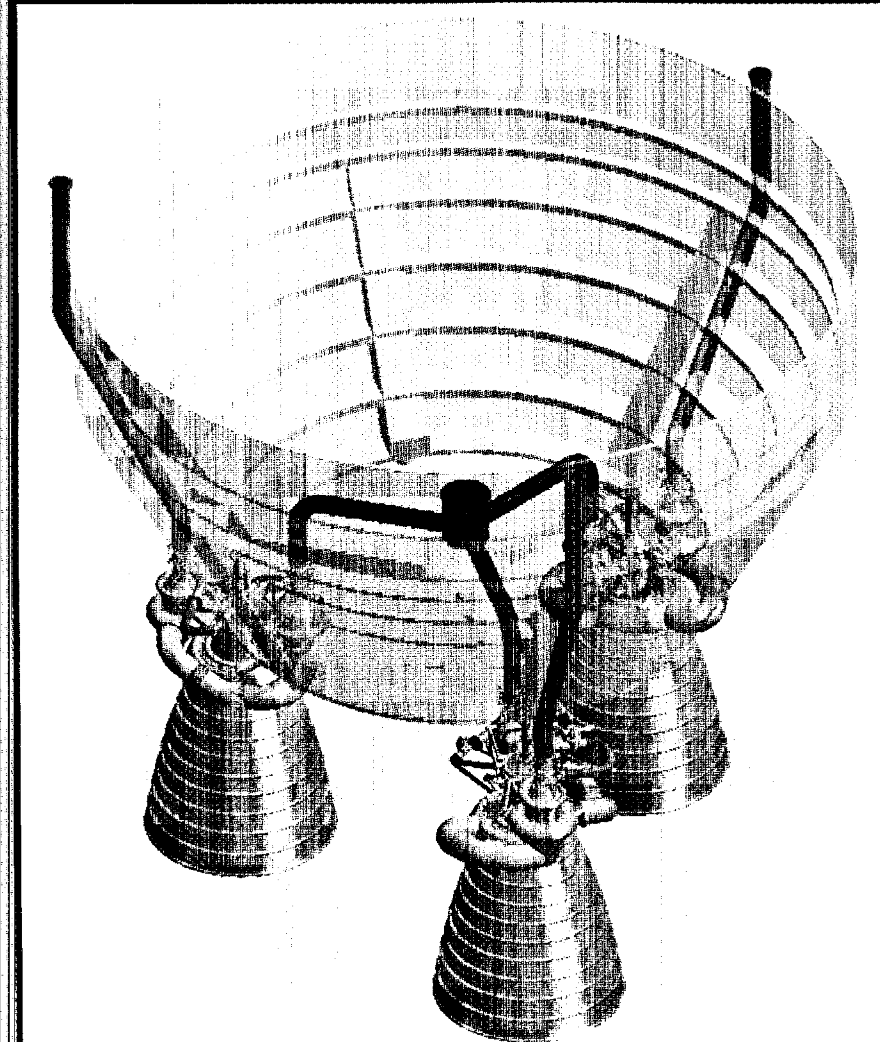
# CONVENTIONAL CORE PROPULSION SYSTEM
## 3-ENGINE



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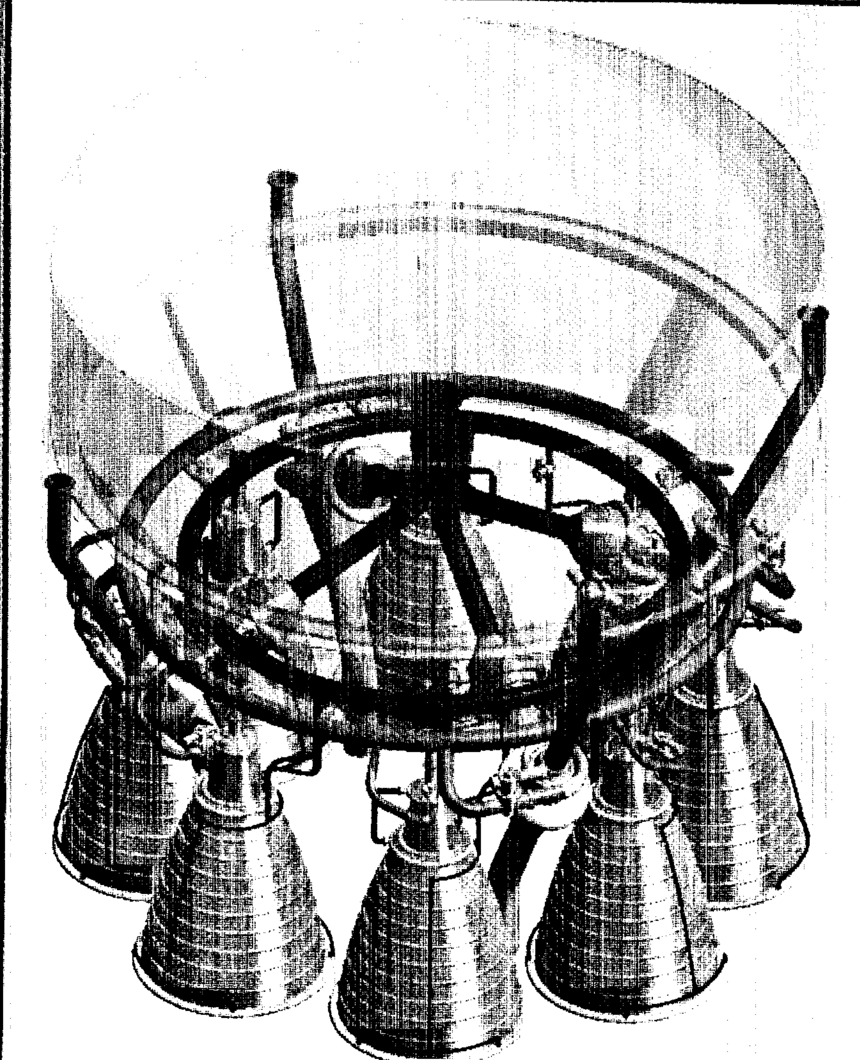
# FULLY INTEGRATED PROPULSION MODULE

# "INTEGRATED" DESIGN INCREASES OPERABILITY

- Single He-pressurization System *
- Single LOX-pressurization System * (HX)
- Single Control System *
- No flexible propellant lines
- No gimbal actuators

* Redundancy provided in propulsion module

# INTEGRATED BOOSTER PROPULSION MODULE – ENGINE
## 8 – THRUST CHAMBERS



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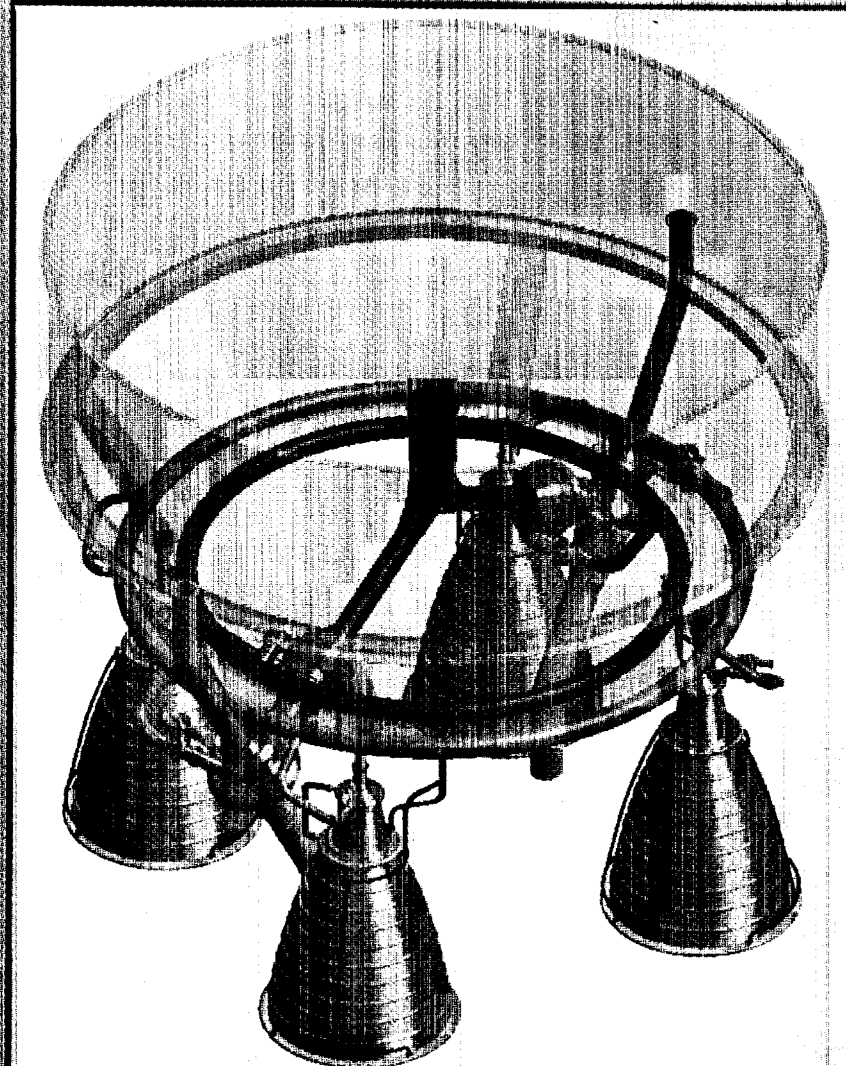
SC89c-30-153A
M803

# INTEGRATED CORE PROPULSION MODULE – ENGINE
## 4 – THRUST CHAMBERS



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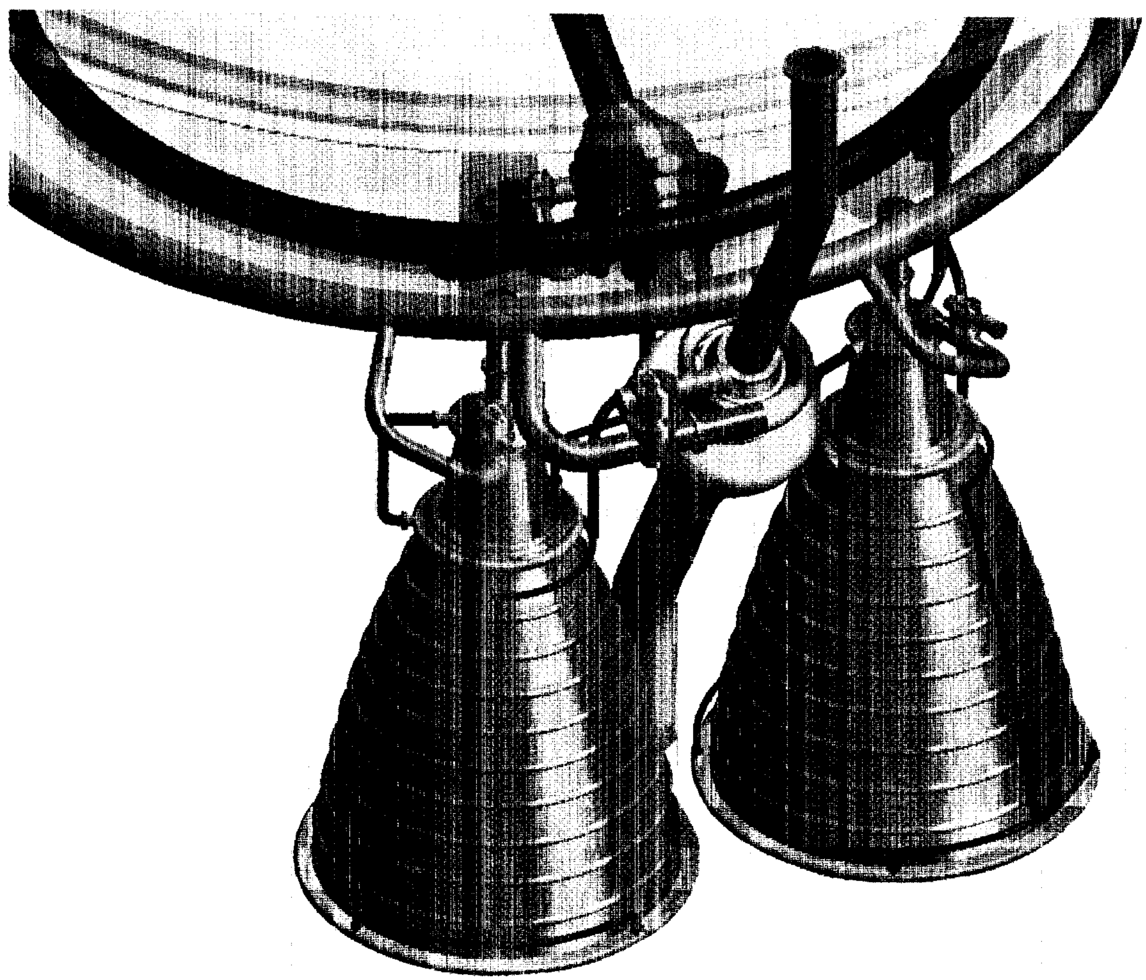
# INTEGRATED PROPULSION MODULE - ENGINE ELEMENT



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# INTEGRATED DESIGN ELIMINATES COMPONENTS AND INTERFACES

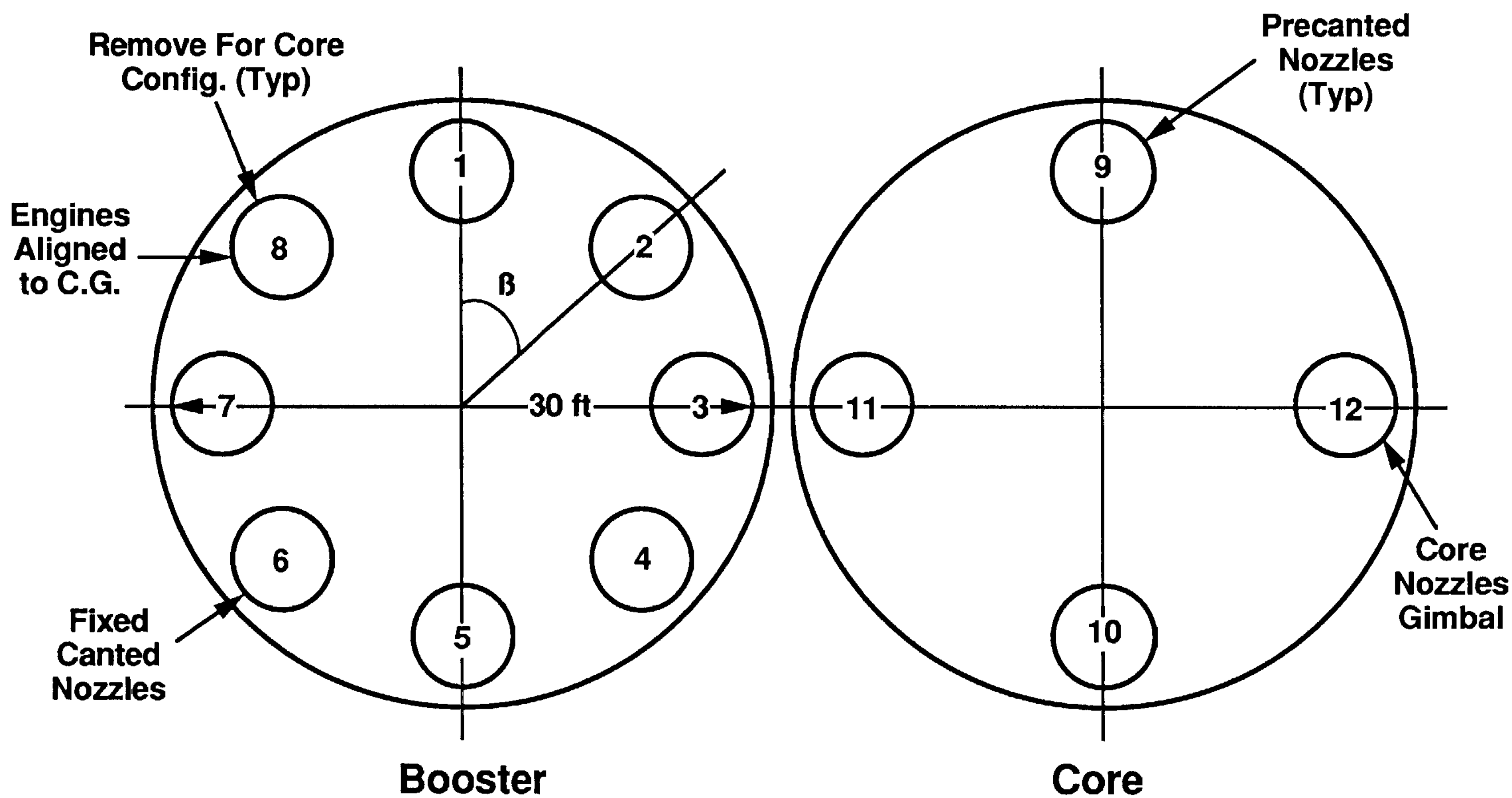
- **Torus propellant manifold allows 50% reduction of**
  - Propellant inlet lines
  - Turbopumps
  - Gas generators

- **Torus manifold provides "engine-out" capability**
  - Thrust chamber-out
  - Turbopump-out

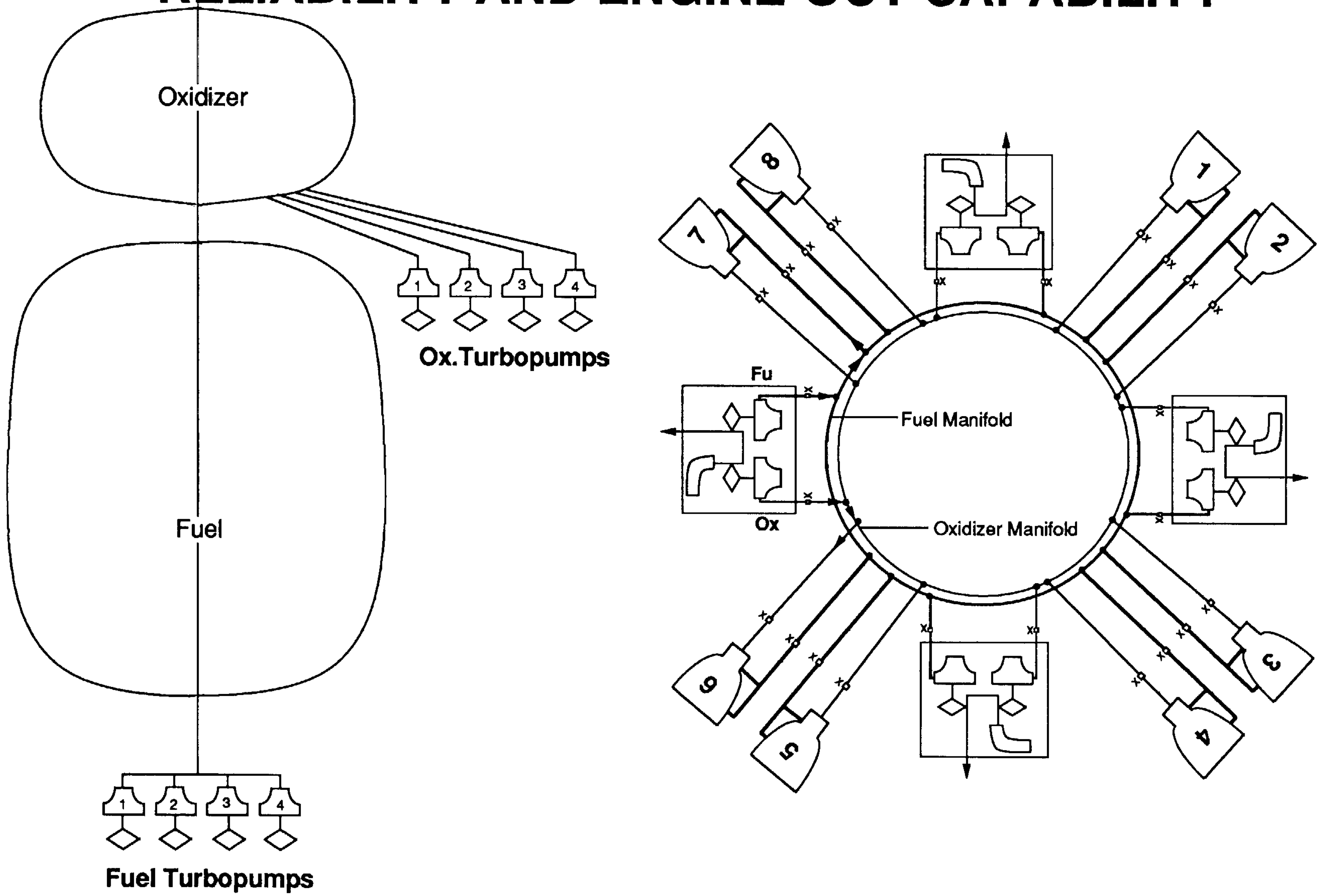
# INTEGRATED DESIGN INCREASES ROBUSTNESS AND COMMONALITY

- **Normal engine operation at 85% nominal thrust**
- **Engine operates at 100% thrust with "engine-out" (1-T/C, 1-T/P)**
- **Outer thrust chamber arrangement maximizes maintainability**
- **Booster-core configuration achieves maximum commonality**
  - Identical module thrust structure
  - Identical feedlines and valves
  - Identical thrust chambers
  - Identical turbopumps

# 8/4 BOOSTER-CORE CONFIGURATION ACHIEVES MAXIMUM COMMONALITY



# INTEGRATED CONCEPT INCREASES RELIABILITY AND ENGINE-OUT CAPABILITY

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# INTEGRATED DESIGN HAS OPERATING MARGIN AND "COMPONENT-OUT" CAPABILITY

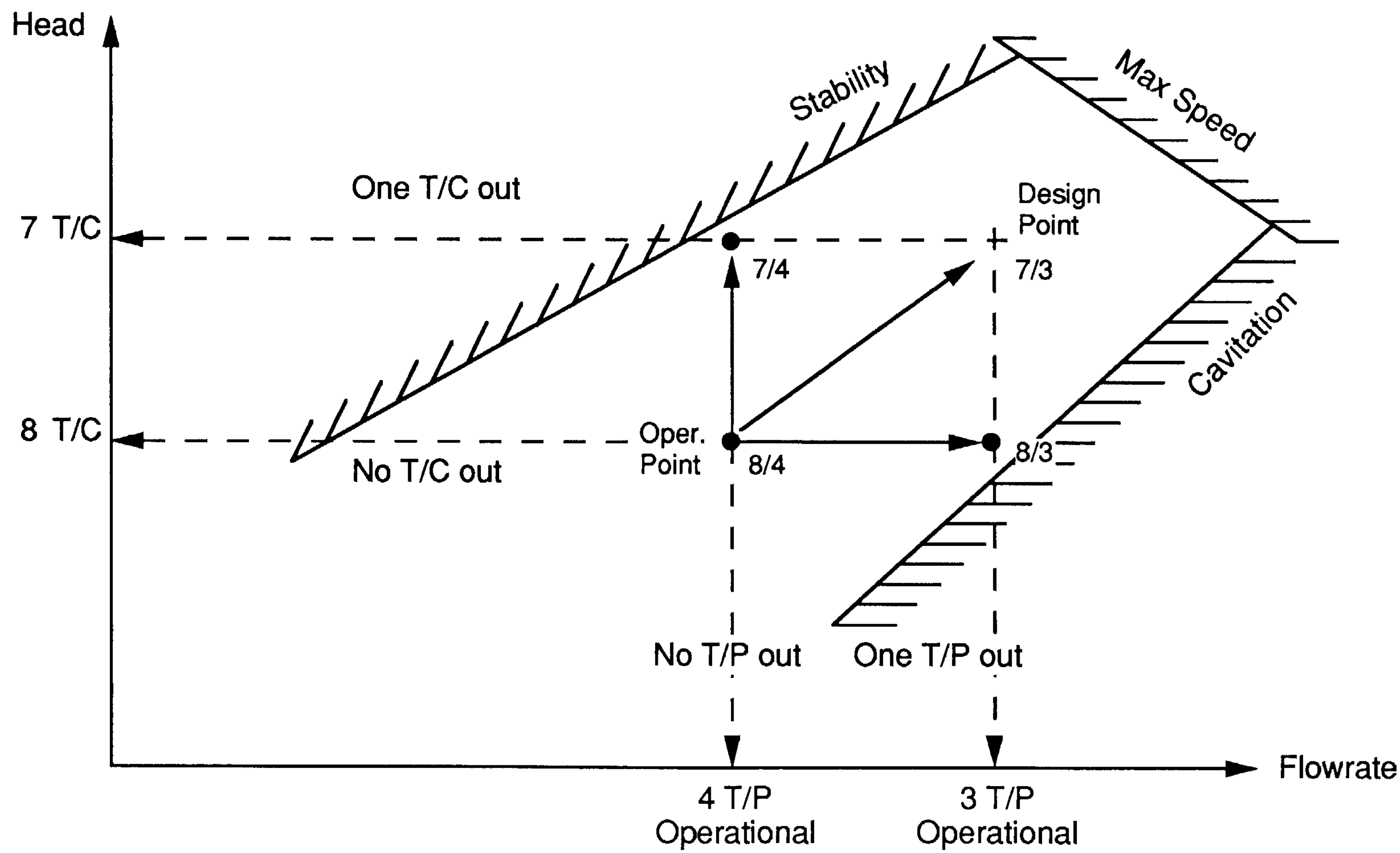
| Engine Operation | Thrust Chamber (T/C) % Rated Thrust | Turbopumps (T/P) % Rated Speed |
|---|---|---|
| Nominal | 85 | 90 |
| T/C - Out | 100 | 97 |
| T/P - Out | 85 | 93 |
| T/C and T/P-Out | 100 | 100 |

# ROBUST TURBOPUMP DESIGN

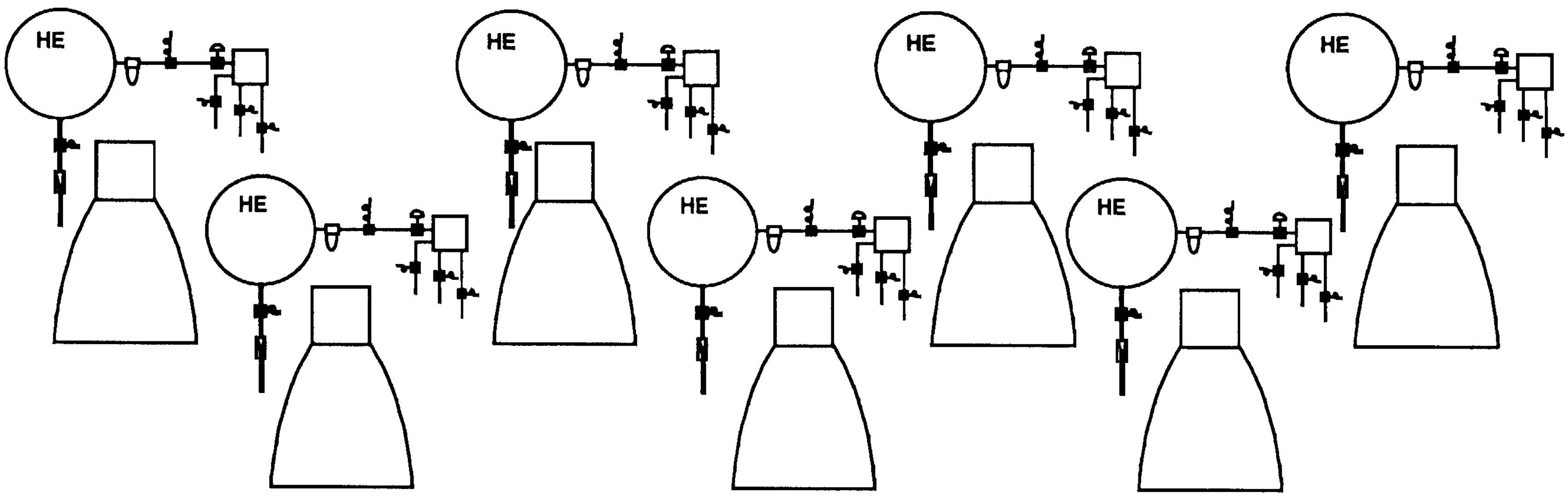
- **Lower design speed**
- **Operating margin**

| Booster | 7-engine (7-T/P) | 8-thrust chamber (4-T/P) | |
|---|---|---|---|
| | Des. RPM (100%) | Des. RPM (100%) | Oper. RPM (90%) |
| LH2-Turbopump | 26,000 | 16,300 | 14,700 |
| LO2-Turbopump | 10,000 | 6,210 | 5,521 |

# TURBOPUMP OPERATING MARGIN



# SEPARATE ENGINE HELIUM SUPPLY SYSTEMS

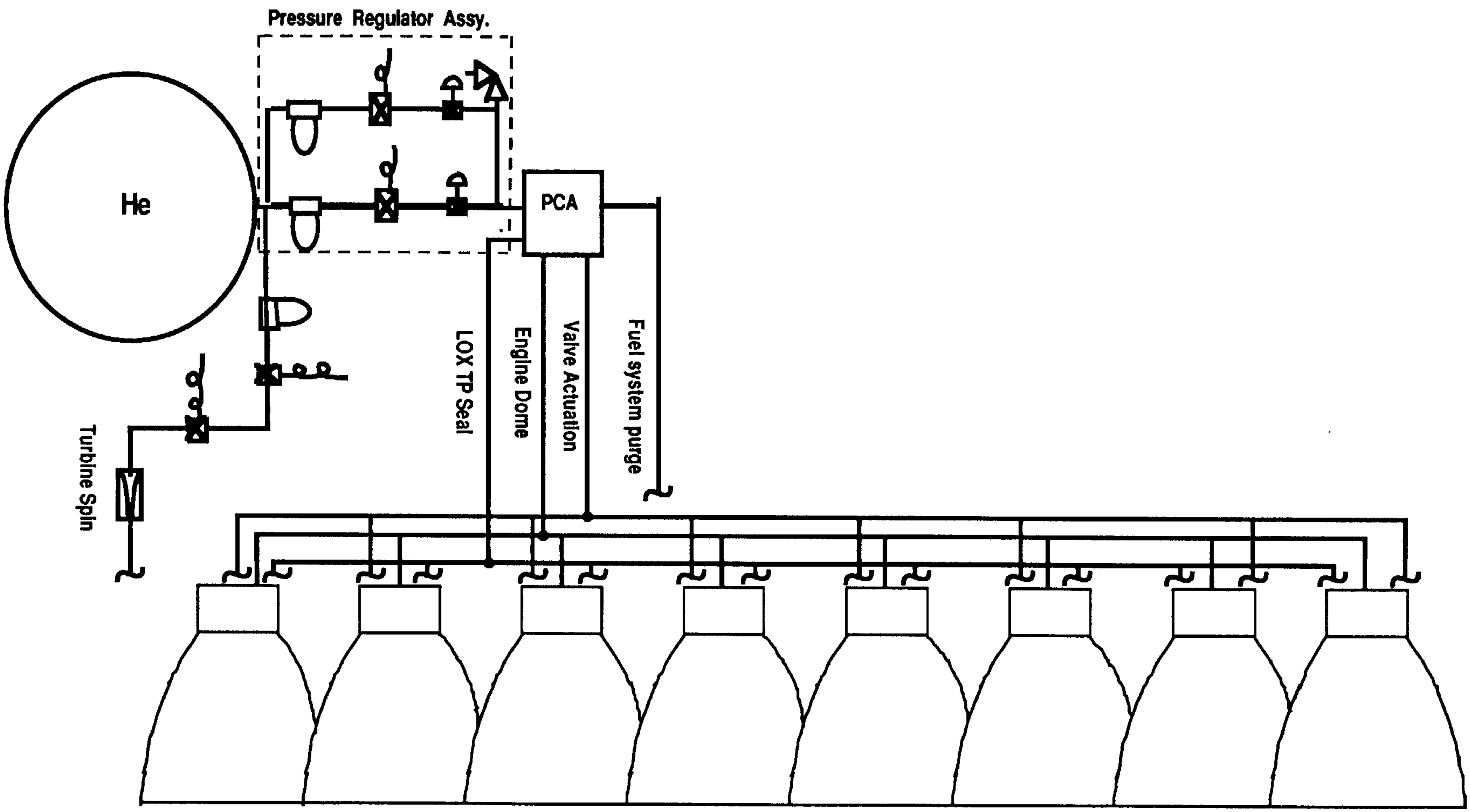



7- Helium tanks

63 - Valves, regulators, filters and PCA's

Many leakage and maintenance requirements

# INTEGRATED ENGINE HELIUM SUPPLY SYSTEM




- 1 - Helium tank
- 9 - Valves, regulators, filters and sonic nozzle
- 1 - Pneumatic Control Assembly (PCA)
- Reduced leakage and maintenance requirements

# THRUST VECTOR CONTROL OPTIONS

| Approach Options | Issues | Recommendations |
|---|---|---|
| 1. Gimbal Booster Engines<br>Gimbal Core Engines | • Complexity<br>• Cost<br>• Reliability | • Acceptable<br>• Evaluate cost and reliability issues |
| 2. Fix Booster Engines<br>Gimbal Core Engines | • Engine out<br>• Large gimbal angles on core engines | • Acceptable for 4-engine core<br>• Requires further evaluation for 3 engine core<br>• Requires fixed engine cant |
| 3. Differential Throttle Booster Engines<br>Gimbal Core Engines | • Response time<br>• Engine reliability<br>• Engine cost | • Evaluate only if Option 2 not feasible |
| 4. Gimbal GG Exhaust<br>Gimbal Core Engines | • Complexity<br>• Requires large thrust | • Evaluate only if Option 2 not feasible |

# THRUST VECTOR CONTROL FOR FIXED BOOSTER AND GIMBALED CORE*

| Precant Angle, Deg. | | Core Gimbal Angle, Deg. (Max Q, Alpha) | |
|---|---|---|---|
| Booster | Core | All engines operating | Engine Out |
| 0 | 0 | 18 | 22 |
| 10 | 0 | 10 | 16 |
| 10 | 5 | 7 | 9 |
| 10 | 5 | 10** | 12** |

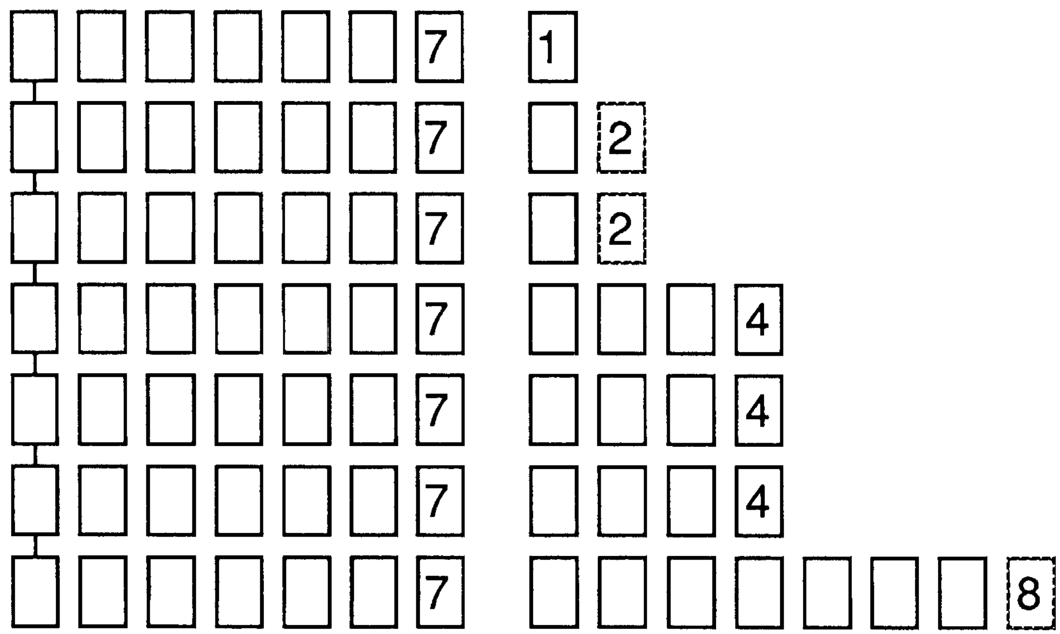
* Based on typical ALS trajectory to LEO

** Booster shutdown and separation condition

# SEPARATE ENGINES VS. INTEGRATED SYSTEM

**Separate Engines** **Integrated System**

- Control Systems
- He supply system
- Heat exchanger
- LOX turbopump
- $LH_2$-turbopump
- Gas generator
- Thrust chamber



# BOOSTER PROPULSION MODULE HARDWARE COMPARISON

## Separate Engines vs. Integrated System

| Engine Elements | Separate Engines | Integrated System (Static) |
|---|---|---|
| | No. of Components | No. of Components |
| Thrust chamber: | | |
| MCC | 7 | 8 |
| Injector | 7 | 8 |
| Nozzle | 7 | 8 |
| Igniter | 7 | 8 |
| Oxidizer turbopump | 7 | 4 |
| Fuel turbopump | 7 | 4 |
| Gas generator | 7 | 4 |
| Heat Exchanger | 7 | 2 |
| Start System | 7 | 1 |
| PCA | 7 | 1 |
| Controller (avionics) | 7 | 1 |
| Gimbal bearing | 7 | 0 |
| Gimbal actuator | 14 | 0 |
| Propellant lines | 14 | 4 |
| Flexible inlet lines | 14 | 0 |
| Fixed inlet lines | 0 | 8 |
| Main valve/actuator | 14 | 24 |
| Prevalves | 14 | 0 |
| Crossover duct/lines | 7 | 0 |
| HP T/P discharge lines | 0 | 8 |
| Ring manifold | 0 | 2 |
| HP T/C inlet lines | 0 | 8 |
| Miscellaneous | 7 | 8 |
| Center engine mount | 1 | 0 |
| Total | 169 | 111 |

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# BOOSTER PROPULSION MODULE RELIABILITY
## Separate Engines vs. Integrated System

| Engine Elements* | Component Reliability | Separate Engines | | Integrated system | |
|---|---|---|---|---|---|
| | | No. of Components | Subystem Reliability | No. of Components | Subsystem Reliability |
| Thrust chamber assy | 0.99978 | 7 | 0.99846 | 8 | 0.99824 |
| T/C ISO valve, ox | 0.99996 | 0 | - | 8 | 0.99968 |
| T/C ISO valve, fuel | 0.99996 | 0 | - | 8 | 0.99968 |
| Oxidizer turbopump | 0.99986 | 7 | 0.99902 | 4 | 0.99944 |
| Fuel turbopump | 0.99972 | 7 | 0.99804 | 4 | 0.99888 |
| MOV | 0.99996 | 7 | 0.99972 | 4 | 0.99984 |
| MFV | 0.99996 | 7 | 0.99972 | 4 | 0.99984 |
| Gas generator | 0.99983 | 7 | 0.99881 | 4 | 0.99932 |
| PCA | 0.99999 | 7 | 0.99993 | 1 | 0.99999 |
| Controller | 0.99996 | 7 | 0.99972 | 1 | 0.99996 |
| Gimbal system | 0.99999 | 7 | 0.99993 | 0 | - |
| Heat exchanger | 0.99989 | 7 | 0.99923 | 2 | 0.99978 |
| Propellant lines | 0.99999 | 14 | 0.99986 | 4 | 0.99996 |
| Inlet line, flex | 0.99980 | 7 | 0.99860 | 0 | - |
| Inlet line, fixed | 0.99980 | 7 | 0.99860 | 4 | 0.99920 |
| Prevalve, oxid | 0.99996 | 7 | 0.99972 | 0 | - |
| Prevalve, fuel | 0.99996 | 7 | 0.99972 | 0 | - |
| Crossover duct | 0.99980 | 7 | 0.99860 | 0 | - |
| HP T/P discharge lines | 0.99999 | 0 | -- | 8 | 0.99992 |
| Ring manifold | 0.99991 | 0 | - | 2 | 0.99982 |
| HP T/C inlet lines | 0.99999 | 0 | - | 8 | 0.99992 |
| Overall reliability | | 0.98775 | | 0.99351 | |

*STME Components

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# BOOSTER PROPULSION MODULE SYSTEM COST**
## Separate Engines vs. Integrated System

| Engine Elements | Unit Cost $K | Separate Engines | | Integrated System | |
|---|---|---|---|---|---|
| | | No. of Components | Cost $K | No. of Components | Cost $K |
| Thrust chamber: | | | | | |
| MCC | 370 | 7 | 2590 | 8 | 2960 |
| Injector | 192 | 7 | 1344 | 8 | 1536 |
| Nozzle | 306 | 7 | 2142 | 8 | 2938 |
| Igniter | 31 | 7 | 217 | 8 | 248 |
| Oxidizer turbopump | 263 | 7 | 1841 | 4 | 1580* |
| Fuel turbopump | 400 | 7 | 2800 | 4 | 2400* |
| Gas generator | 29 | 7 | 203 | 4 | 116 |
| Heat Exchanger | 79 | 7 | 553 | 2 | 316 |
| PCA | 220 | 7 | 1540 | 1 | 220 |
| Controller (avionics) | 96 | 7 | 672 | 1 | 304 |
| Gimbal bearing | 71 | 7 | 497 | 0 | 0 |
| Gimbal actuator | 30 | 14 | 420 | 0 | 0 |
| Propellant lines | 21 | 14 | 294 | 4 | 84 |
| Flexible inlet lines | 18 | 14 | 252 | 0 | 0 |
| Fixed inlet lines | 12 | 0 | 0 | 8 | 96 |
| Main valve/actuator | 35 | 14 | 490 | 24 | 840 |
| Prevalves | 21 | 14 | 294 | 0 | 0 |
| Crossover duct/lines | 166 | 7 | 1162 | 0 | 0 |
| HP T/P discharge lines | 6 | 0 | 0 | 8 | 48 |
| Ring manifold | 100 | 0 | 0 | 2 | 200 |
| HP T/C inlet lines | 6 | 0 | 0 | 8 | 48 |
| Miscellaneous*** | -- | -- | 1767 | -- | 712 |
| **Total Cost , $** | | | **18,861,000** | | **14,646,500** |
| **Cost per Engine, $M** | | | **2.69** **** | | **1.83** |

*Cost factor for regen T/C T/P and HX: 1.2, 1.5 and 2.0
** 500th unit cost
*** 10% separate; 5% integrated
**** Basic STME $2.67M

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# BOOSTER PROPULSION MODULE SYSTEM WEIGHT
## Separate Engines vs. Integrated System

| Engine Elements | Unit Weight Lbs | Separate Engines | | Integrated System | |
|---|---|---|---|---|---|
| | | No. of Components | Weight Lbs | No. of Components | Weight Lbs |
| Thrust chamber: | | | | | |
| MCC | 613 | 7 | 4291 | 8 | 4904 |
| Injector | 364 | 7 | 2548 | 8 | 2912 |
| Nozzle | 2088 | 7 | 14616 | 8 | 16704 |
| Igniter | 31 | 7 | 217 | 8 | 248 |
| Oxidizer turbopump | 1726 | 7 | 12082 | 4 | 9664 (1) |
| Fuel turbopump | 1421 | 7 | 9947 | 4 | 7960 (1) |
| Gas generator | 121 | 7 | 847 | 4 | 484 (2) |
| Heat Exchanger | 101 | 7 | 707 | 2 | 404 (3) |
| Start System | 35 | 7 | 245 | 1 | 70 (3) |
| PCA | 82 | 7 | 574 | 1 | 82 |
| Controller (avionics) | 20 | 7 | 140 | 1 | 20 |
| Gimbal bearing | 158 | 7 | 1106 | 0 | 0 |
| Gimbal actuator | 190 | 14 | 2660 | 0 | 0 |
| Propellant lines | -- | 14 (1186) | 16600 | 4 (1587) | 6348 |
| Flexible inlet lines | 734 | 14 | 10276 | 0 | 0 |
| Fixed inlet lines | 668 | 0 | 0 | 8 | 5344 |
| Main valve/actuator | 144 | 14 | 2016 | 24 | 3456 |
| Prevalve | 75 | 14 | 1050 | 0 | 0 |
| Crossover duct/lines | 214 | 7 | 1498 | 0 | 0 |
| HP T/P discharge lines | 360 | 0 | 0 | 8 | 2880 |
| Ring manifold | 3750 | 0 | 0 | 2 | 7500 |
| HP T/C inlet lines | 300 | 0 | 0 | 8 | 2400 |
| Miscellaneous | 585 | 7 | 4095 | 8 | 4680 |
| Center engine mount | 1826 | 1 | 1826 | 0 | 0 |
| **Total Weight** | | | **87,340** | | **76,058** |

(1) Factor of 1.4; (2) Factor of 1.5; (3) Factor of 2.0

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# INTEGRATED PROPULSION MODULE IS RELIABLE AND LOW COST

| Factor | Separate | Integrated |
|---|---|---|
| • Higher reliability | 0.988* | 0.993* |
| T/C and T/P out | 0** | 0.999** |
| • Lower engine (T/C) cost, $M | 2.67 | 1.83 |
| • Less number of parts | 169 | 111 |
| • Lower potential weight, lbs. | 87,340 | 76,058 |
| • Lower operations cost | 1 | 1/3 |

* No engine-out capability

** With T/C and T/P - out capability

# INTEGRATED DESIGN ADDRESSES OPERATIONS PROBLEMS DIRECTLY

| No. | | No. | |
|---|---|---|---|
| 1 | Closed aft compartments | 14 | Ordnance Operations |
| 2 | Hydraulic system (valve actuators and TVC) | 15 | Retractable T-O umbilical carrier plates |
| 3 | Ocean recovery/refurbishment | 16 | Pressurization system |
| 4 | Multiple propellants | 17 | Inert gas purge |
| 5 | Hypergolic propellants (safety) | 18 | Excessive interfaces |
| 6 | Accessibility | 19 | Helium spin start |
| 7 | Sophisticated heat shielding | 20 | Conditioning/geysering ($LO_2$ tank forward) |
| 8 | Excessive components/subsystems | 21 | Preconditioning system |
| 9 | Lack hardware integration | 22 | Expensive helium usage - helium |
| 10 | Separate OMS/RCS | 23 | Lack hardware commonality |
| 11 | Pneumatic system (valve actuators) | 24 | Propellant contamination |
| 12 | Gimbal system | 25 | Side-mounted booster vehicles (multiple stage propulsion systems) |
| 13 | High maintenance turbopumps | | |

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# INTEGRATED PROPULSION MODULE IS FLEXIBLE

- **"Integrated" propulsion module is a single engine**
  - Meets wide range of thrust (1,000,000 - 4,000,000 lbs) by adding or eliminating components
- **"Integrated" propulsion module is operationally efficient**
  - Simpler
  - More reliable
  - More robust
  - More operable (operationally efficient)
  - Greater engine-out capability
  - Lower cost
  - Lower weight

# INTEGRATED PROPULSION MODULE HAS WIDE PAYLOAD RANGE

**P/L = 20,000 to 200,000 lbs**

| | | | Payload Capability, lbs | | | | | |
|---|---|---|---|---|---|---|---|---|
| Integrated Engine: | T/C | T/P | 20K | 40K | 80K | 120K | 160K | 200K |
| 1. Single Element | 2 | 1 | X | | | | | |
| 2. Core: 2 x Elements | 4 | 2 | | X | | | | |
| 3. Booster: 4 x Elements | 8 | 4 | | | X | | | |
| 4. Booster + Core: ALS | 12 | 6 | | | | X | | |
| 5. 2 x Boosters | 16 | 8 | | | | | X | |
| 6. 2 x Boosters + Core | 20 | 10 | | | | | | X |

# CONCLUSIONS

- Operational efficiency starts at design concept (TQM)
- Integration results in simpler design
- Simple design requires less operations support
- Integration yields higher reliability and lower cost
- New technology not required

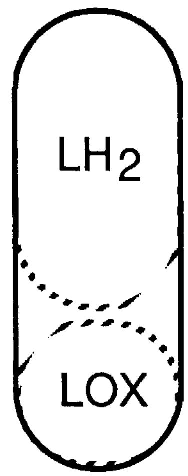
# ANTIGEYSER LOX TANK AFT PROPULSION CONCEPT

# OEPSS CONCERN - LOX TANK POSITION

- **Concern:** **ALS vehicle concepts position LOX tank forward of $LH_2$ tank**
- **Operational impacts**
  - Potential for geysering in LOX feed lines
    - Heating of long feed lines form bubbles and ejection of liquid into tank
    - Rapid refill of lines creates possible catastrophic waterhammer
    - Control can require critical active systems and continuous monitoring
  - Propellant preconditioning difficulty
    - Heat into long feed line can raise propellant temperature above acceptable limits for engine operation
    - Can require bleed or recirculation system
  - Checkout of long feed lines
    - Access difficult for inspection and leak check
  - High propellant transfer pressures required
    - Elevation of LOX tank requires ground pumps for propellant loading
- **Other impacts**
  - $LH_2$ tank and intertank structure required to support heavy LOX tank

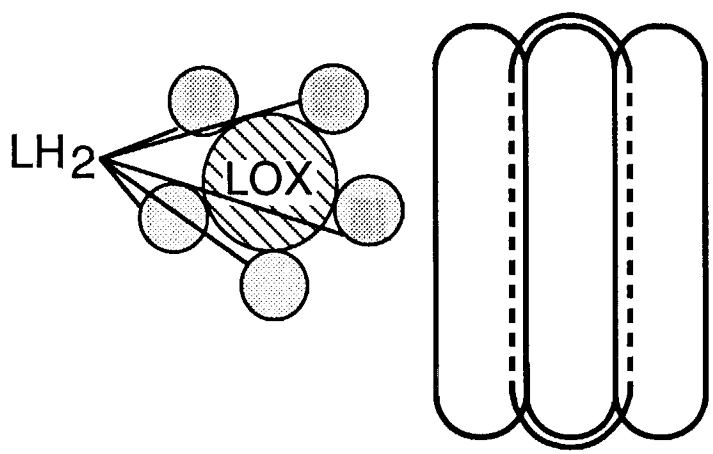
# ANTIGEYSER LOX TANK AFT PROPULSION SYSTEM

- **Reverse tank positions (LOX aft, $LH_2$ fwd)**




- Short LOX feed lines greatly reduce geysering and pogo problems
- Smaller LOX tank results in shorter feed lines from forward tank
- Weight reduction of feed lines and intertank structure
- Reduced control authority from aft C.G. location
- Cost similar to ALS vehicles

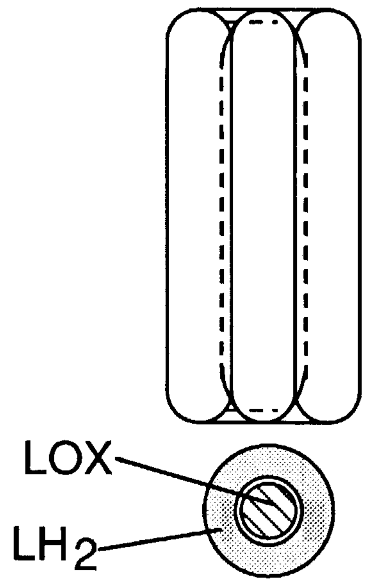
- **<u>Multiple tanks</u> (similar to Saturn 1)**




- Both LOX and $LH_2$ feed lines short
- Greatly reduced pogo and geyser problems
- Tank weight increased (= 10%)
- Large change in C.G. locations during burn increases engine gimbal requirements
- Higher total tank set cost may be offset by easier fabrication and transportation of individual tanks

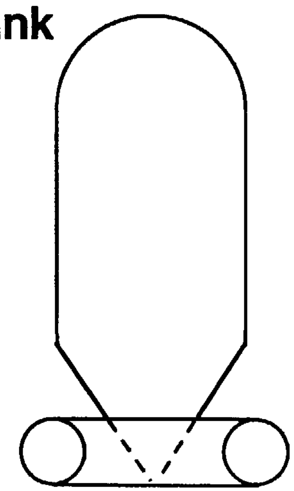
# ANTIGEYSER LOX TANK AFT PROPULSION SYSTEM

- **Concentric tanks**




- Both LOX and $LH_2$ feed lines short
- Greatly reduced pogo & geyser problems
- Tank weight increased (= 10%)
- Large change in C.G. locations during burn increases engine gimbal requirements
- Fabrication problems can increase costs
- Thrust loads carried by outer tank

- **Toroidal LOX tank**

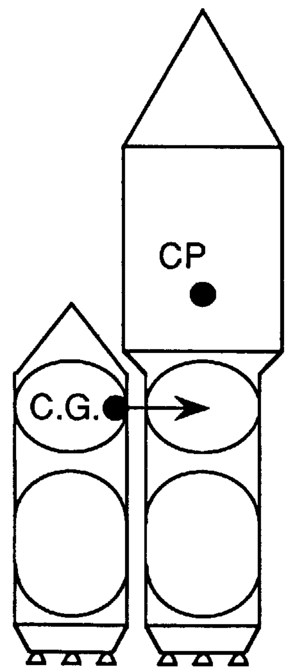


- Both LOX and $LH_2$ feed lines short
- Greatly reduced pogo & geyser problems
- Tank weight increased (≈ 10%)
- Reduced control authority from aft C.G. location
- Fabrication problems can increase costs
- Efficient thrust load path LOX tank not involved

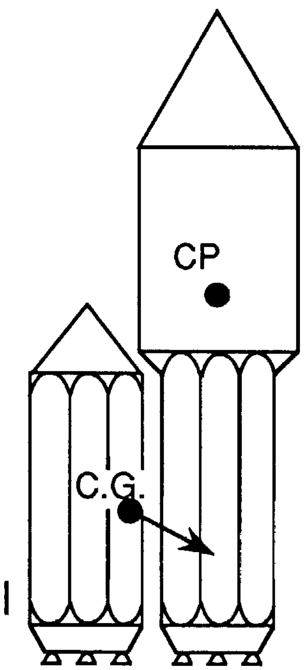
# VEHICLE CONTROL IMPACT

- **Vehicle control evaluation performed for LOX aft vehicle**
  - Concentric tank option considered representative
  - Worse case single engine out assumed
  - Gimbal angle of 16° could be required

- **ALS configuration - C.G. fwd**
  - C.G. near CP (Aero forces less disturbing)
  - Large control moment (Engine gimbal center to C.G.)
  - Small aft travel of C.G.




- **LOX tank aft configuration evaluated**
  - C.G. further from CP
  - Shorter control moment
  - Large C.G. travel



# SUMMARY & RECOMMENDATION

- **Summary**
  - Locating the LOX tank at the aft of the vehicle will significantly reduce operations costs
  - Locating the aft end of both tanks aft (concentric or multiple tank options) can further lower operations costs
  - Increased tankage costs may partially offset the operations cost reductions
  - More engine gimbaling is required with LOX tank aft
    - Gimbal angles can be accommodated with feed line design
    - Symmetric vehicle rather than side mounted booster greatly reduces gimbaling requirements
- **Recommendation:**
  - Develop vehicle/propulsion design using LOX tank aft to reduce operations costs

# ROCKET ENGINE AIR-AUGMENTED AFTERBURNING PROPULSION CONCEPT

# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS)

## Agenda
## 14 August 1990

- Introduction ---------------------------------------- R. Rhodes
- Operationally Efficient Integrated P/M ------------ G. Wong
- √ Operations Problems ----------------------------- G. Waldrop
- Operations Technology --------------------------- G. Wong
- Operations Database

# OPERATIONALLY EFFICIENT SYSTEM

- **Any vehicle or system that simplifies, reduces or eliminates operations requirements**
  - Less manpower
  - Lower cost
  - Shorter timelines
  - Less equipment, facilities
  - High operability
    - Technician level operation

# OEPSS CONCERNS LIST

- **Follows on the heels of SGOE/T findings**
- **Focused on propulsion system only**
- **Represents "launch site experience base"**
    - Expendable launch vehicles (Atlas, Delta, Titan)
    - Apollo/Saturn
    - NSTS
- **Major launch site operations cost drivers**

# OEPSS IDENTIFIES OPERATIONS PROBLEMS

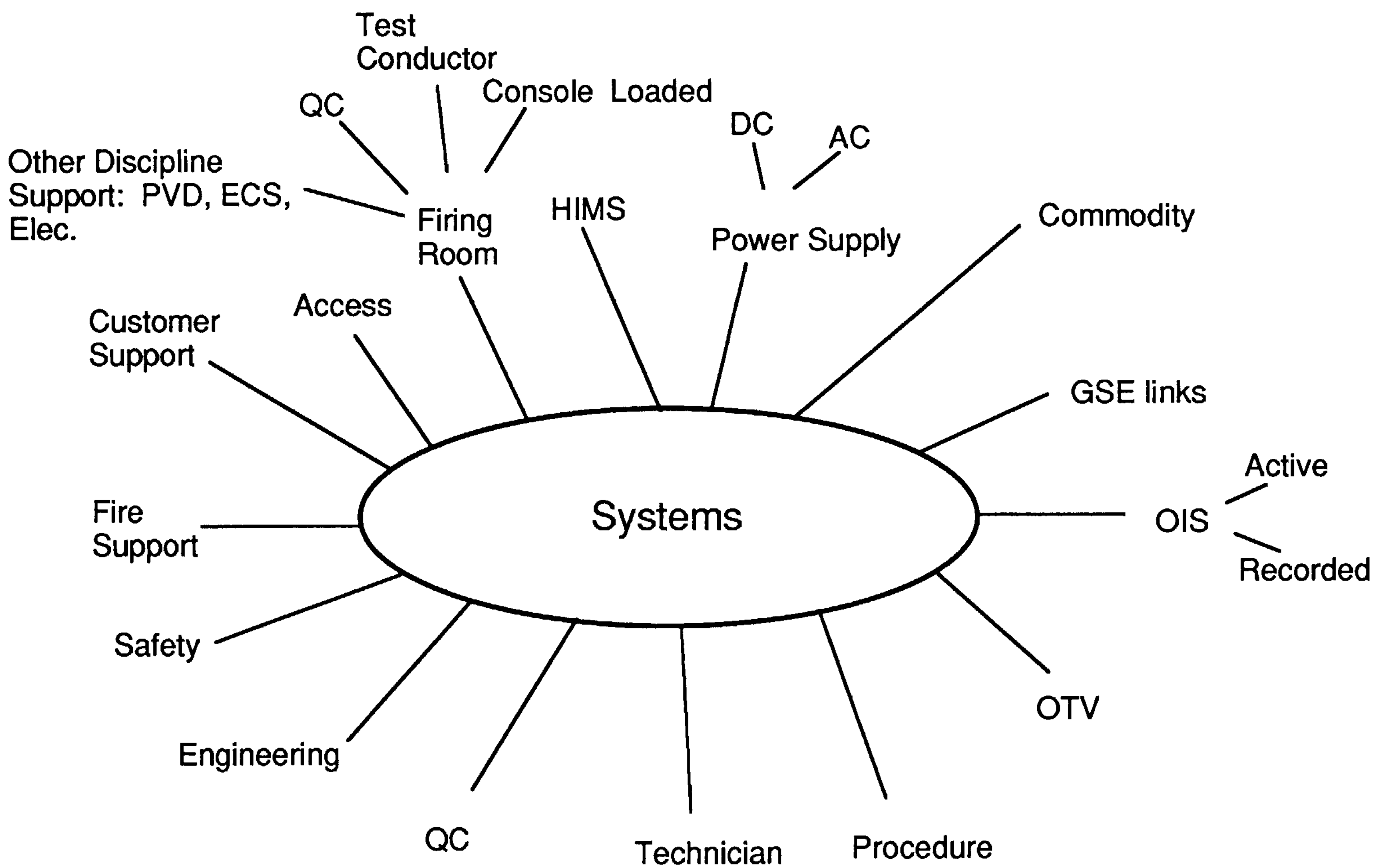
## Causes and Effects

| No. | | No. | |
|---|---|---|---|
| 1 | Closed aft compartments | 14 | Ordnance Operations |
| 2 | Hydraulic system (valve actuators and TVC) | 15 | Retractable T-O umbilical carrier plates |
| 3 | Ocean recovery/refurbishment | 16 | Pressurization system |
| 4 | Multiple propellants | 17 | Inert gas purge |
| 5 | Hypergolic propellants (safety) | 18 | Excessive interfaces |
| 6 | Accessibility | 19 | Helium spin start |
| 7 | Sophisticated heat shielding | 20 | Conditioning/geysering ($LO_2$ tank forward) |
| 8 | Excessive components/subsystems | 21 | Preconditioning system |
| 9 | Lack hardware integration | 22 | Expensive helium usage - helium |
| 10 | Separate OMS/RCS | 23 | Lack hardware commonality |
| 11 | Pneumatic system (valve actuators) | 24 | Propellant contamination |
| 12 | Gimbal system | 25 | Side-mounted booster vehicles (multiple stage propulsion systems) |
| 13 | High maintenance turbopumps | | |

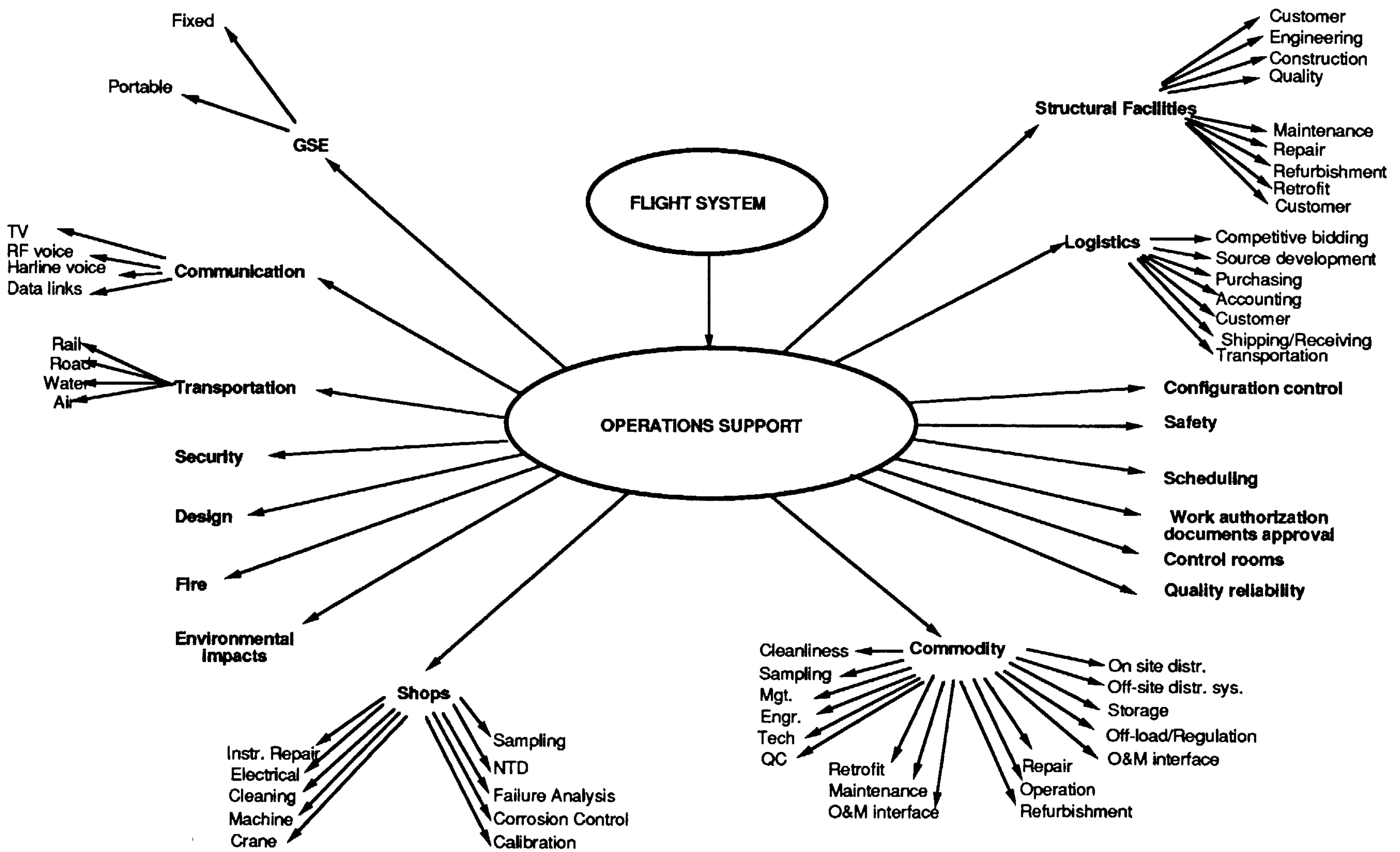
# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Launch site systems create a "Nightmare" in process scheduling**



# OPERATIONS SUPPORT STRUCTURE IS COMPLEX



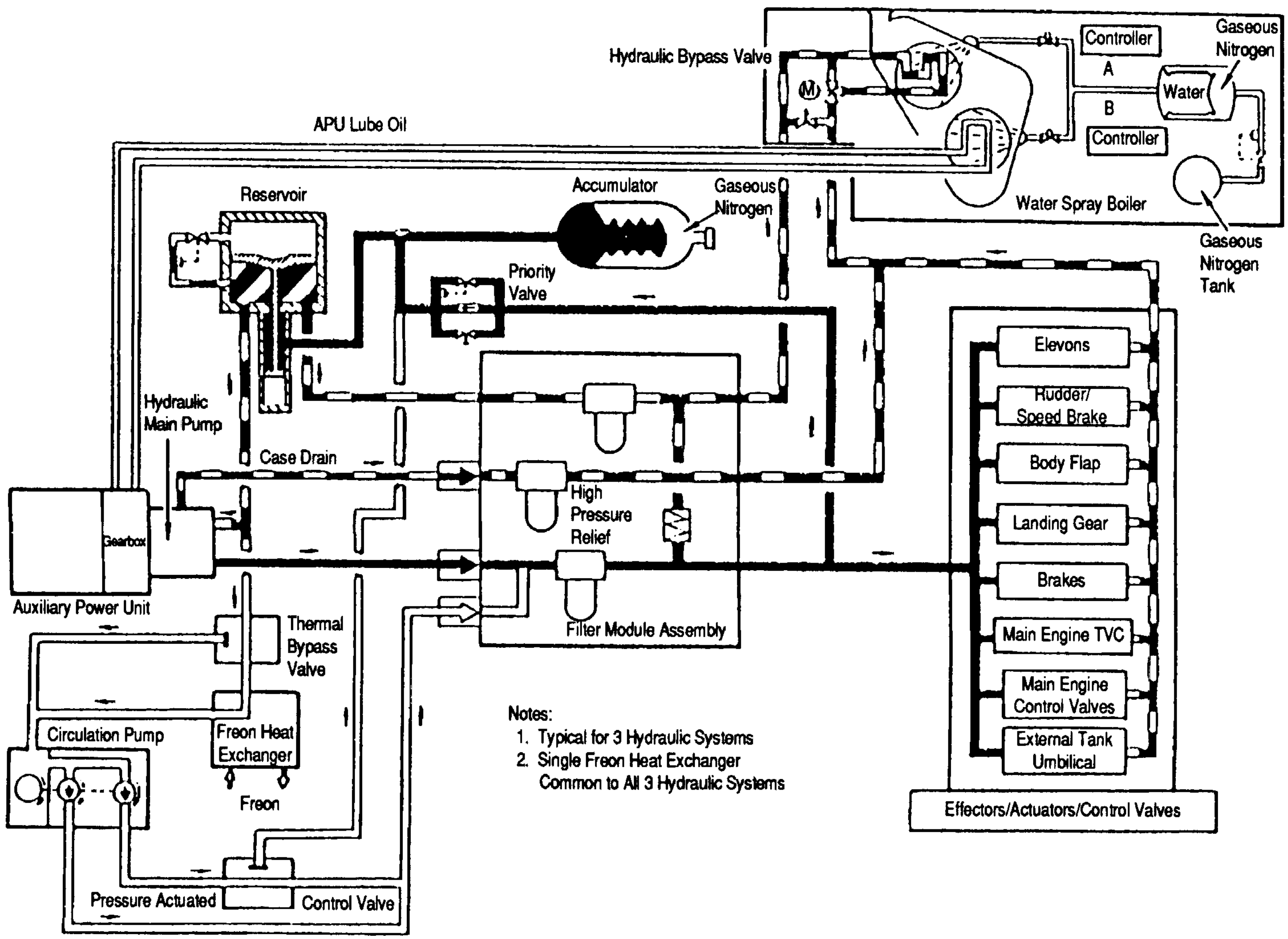
# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 1**
  - Closed aft compartments
- **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
  - Unnatural personnel passageways elevates potential for H/W 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 config.

# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 2**
  - Hydraulic system for valve actuators and thrust vector control
- **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:**
  - Electromechanical actuators

# HYDRAULIC POWER SYSTEM




Notes:
1. Typical for 3 Hydraulic Systems
2. Single Freon Heat Exchanger Common to All 3 Hydraulic Systems

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# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 3**
  - Ocean recovery and refurbishment
- **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, 3-shift operations to recycle for launch
    - SRBs require hazardous, tedious recovery from ocean impact, removal of 5000 part-numbered components, cross-country shipment and further intensive refurbishment prior to reload. Dynamic water impact and galvanic corrosion are creating 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"

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

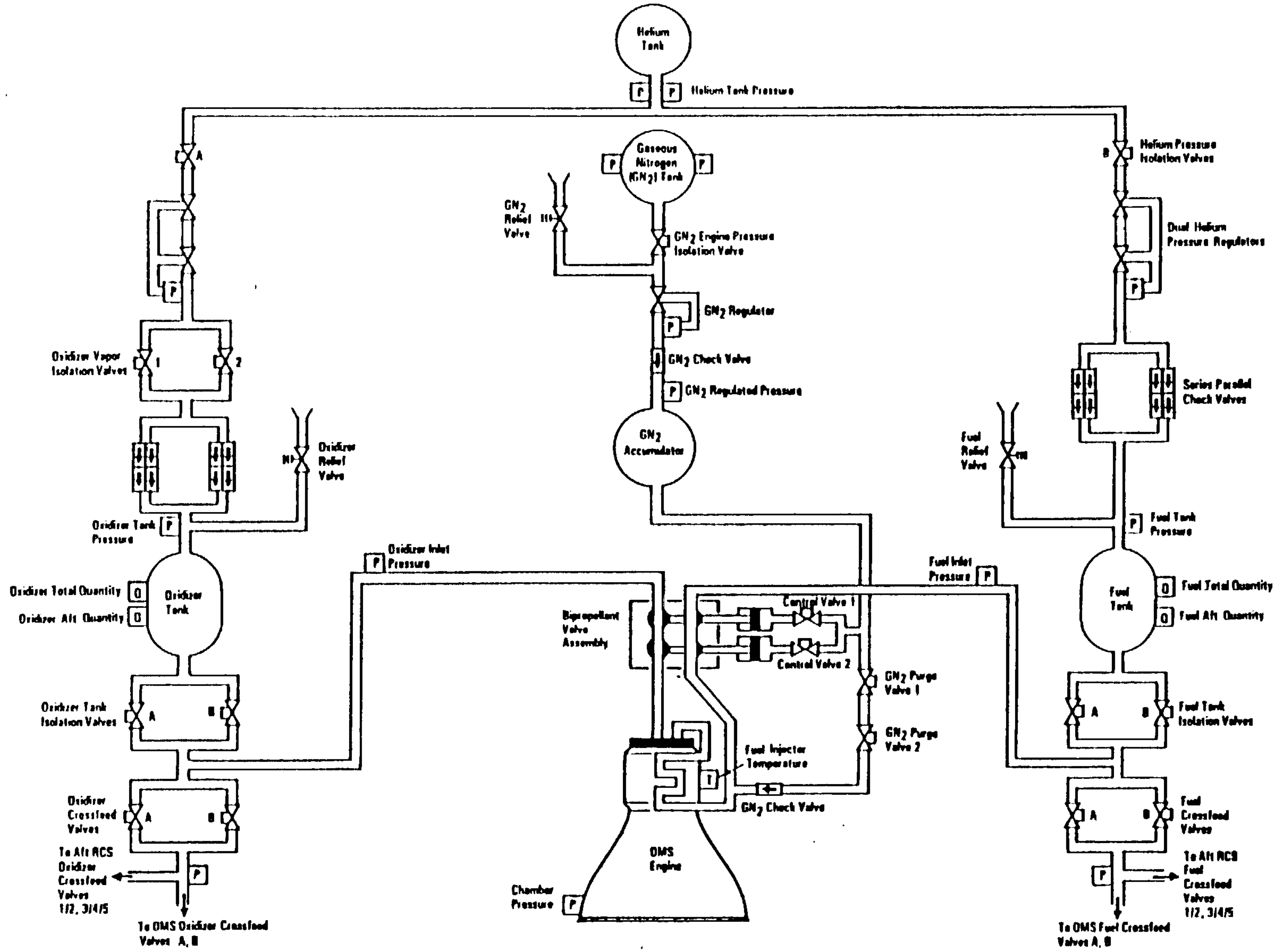
- **Concern: OEPSS - 4**
  - Multiple propellants
- **Operational impacts:**
  - Multiple commodities require:
    - Multiple facilities for storage and transfer
    - Multiple headcount and administrative support
    - Extra support for procurement/logistics
    - Vehicle complexity necessary for multiple systems requiring multiple propellants/commodities
- **Potential options for consideration:**
  - Use LOX/LH2 for all consideration:
    - Main propulsion
    - OMS
    - RCS
    - PRSD/propellant-grade fuel cell
    - APU

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 5**
  - Hypergolic propellant
- **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/GH2, etc.
  - Devise totally encapsulated system that is processed offline 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)

# OMS PRESSURIZATION AND PROPELLANT FEED SYSTEM

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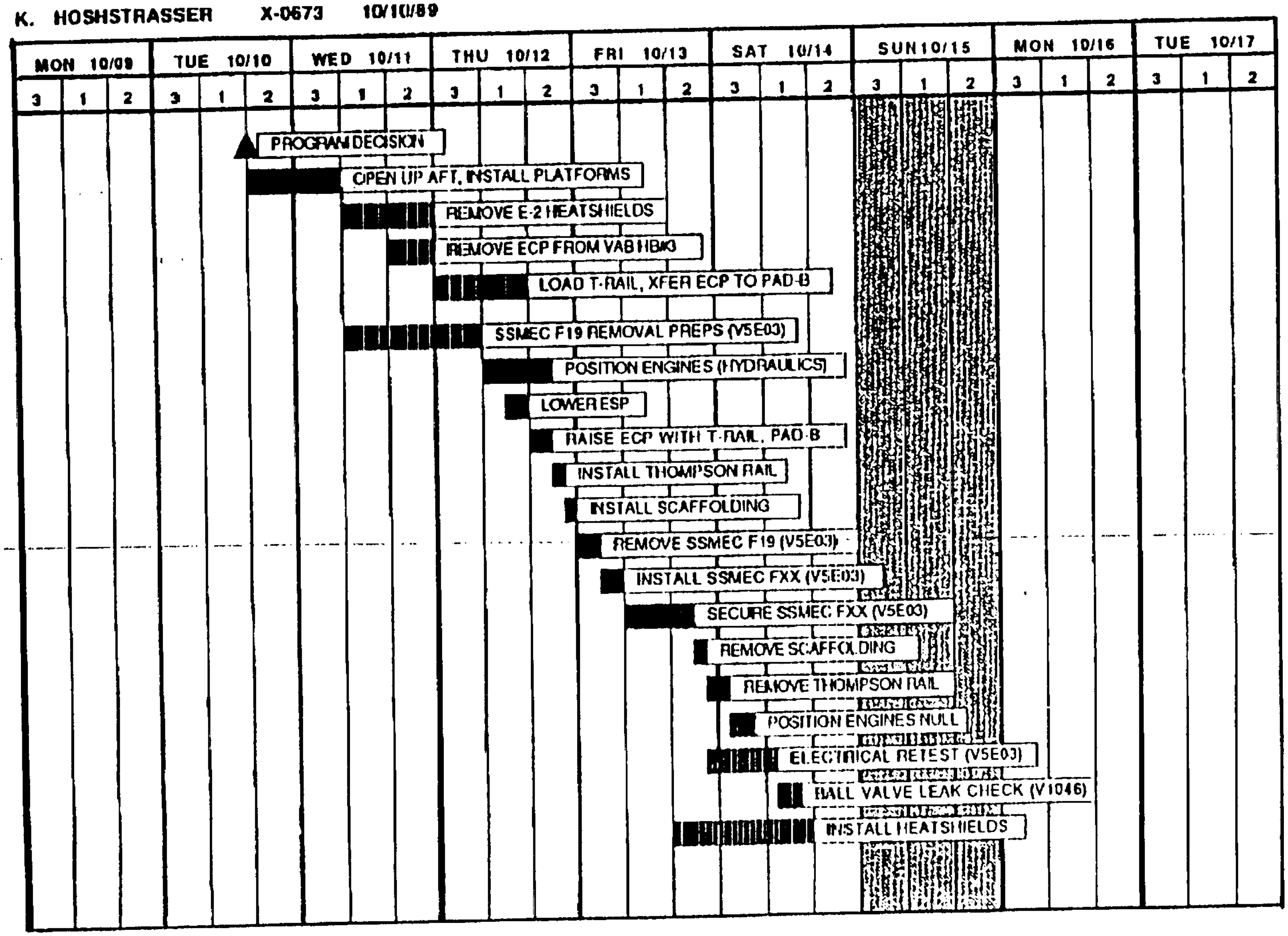
# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 6**
  - Accessibility
- **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

# ME 2030 CONTROLLER R & R (VERTICAL)

K. HOSHSTRASSER X-0673 10/10/89



# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern:** **OEPSS - 7**
  - Sophisticated heat shielding
- **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 overpessure 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
  - Move sensitive components

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 8**
  - Excessive component/subsystem interfaces
- **Operational impacts:**
  - Every interface must be verified
    - Leak checks
    - Electrical checks
    - Mechanical integrity checks
  - Interfaces can separate subsystems with differing requirements
    - Unnecessary checkout complication
- **Potential options for consideration:**
  - Integrate subsystems into larger subsystems/systems
  - Develop modules to replace components

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 9**
  - Lack of Hardware Integration
- **Operational impacts:**
  - Leads to numerous interfaces
    - Mechanical - adds weight - potential for leakage
    - Electrical - adds weight - potential for connector/pin damage
  - Increases number of components
    - Stand-alone 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
  - Drives 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)

# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 10**
  - Separate OMS and RCS
- **Operational impacts:**
  - Maintenance and prelaunch checkout of multiple tankage and associated systems
    - Added functional component checks
    - Added leak checks
  - Fill 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, RCS

# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 11**
  - Pneumatic system for valve actuators
- **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

# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

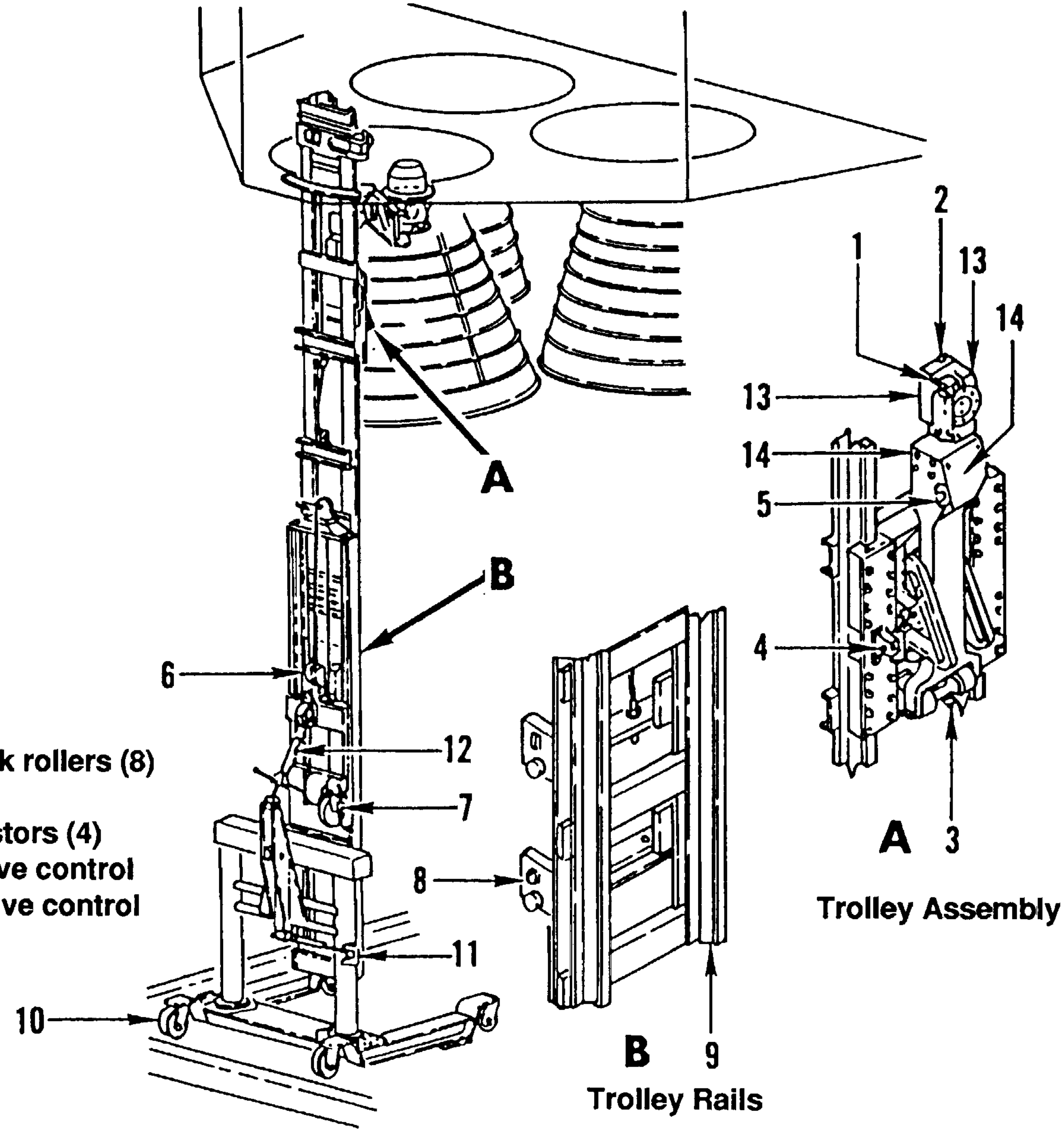
- **Concern: OEPSS - 12**
  - Gimbal system requirements
- **Operational impacts:**
  - System complexity - Actuator system, gimbal bearings, control system
    - Maintenance
    - Servicing
    - Prelaunch checkout
  - Hydraulics - addressed in OEPSS - 2
- **Potential options for consideration:**
  - Simplify system
    - EMA's replace hydraulic cylinders
    - Consider reducing number of engines gimbaled
    - Hinge instead of gimbal
  - Consider alternate methods of TVC
    - Differential throttling
    - GG exhaust vectoring
    - Vanes

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern:** **OEPSS - 13**
  - High maintenance turbopumps - recoverable propulsion system
- **Operational impacts:**
  - Requirements for repeated torque and shaft travel measurements
    - Final engine checkout/pump replacement
    - Post engine installation in vehicle
  - 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

# VERTICAL RAIL OPERATION




A Trolley Assembly

B Trolley Rails

**Legend**

1. Yaw control
2. Pitch control
3. Elevation control
4. Azimuth control
5. Roll control
6. Trolley drive winch
7. Elevator track winch
8. Trolley to elevator track rollers (8)
9. Trolley rails (2)
10. Elevator stanchion castors (4)
11. Elevator track slew drive control
12. Elevator track pitch drive control

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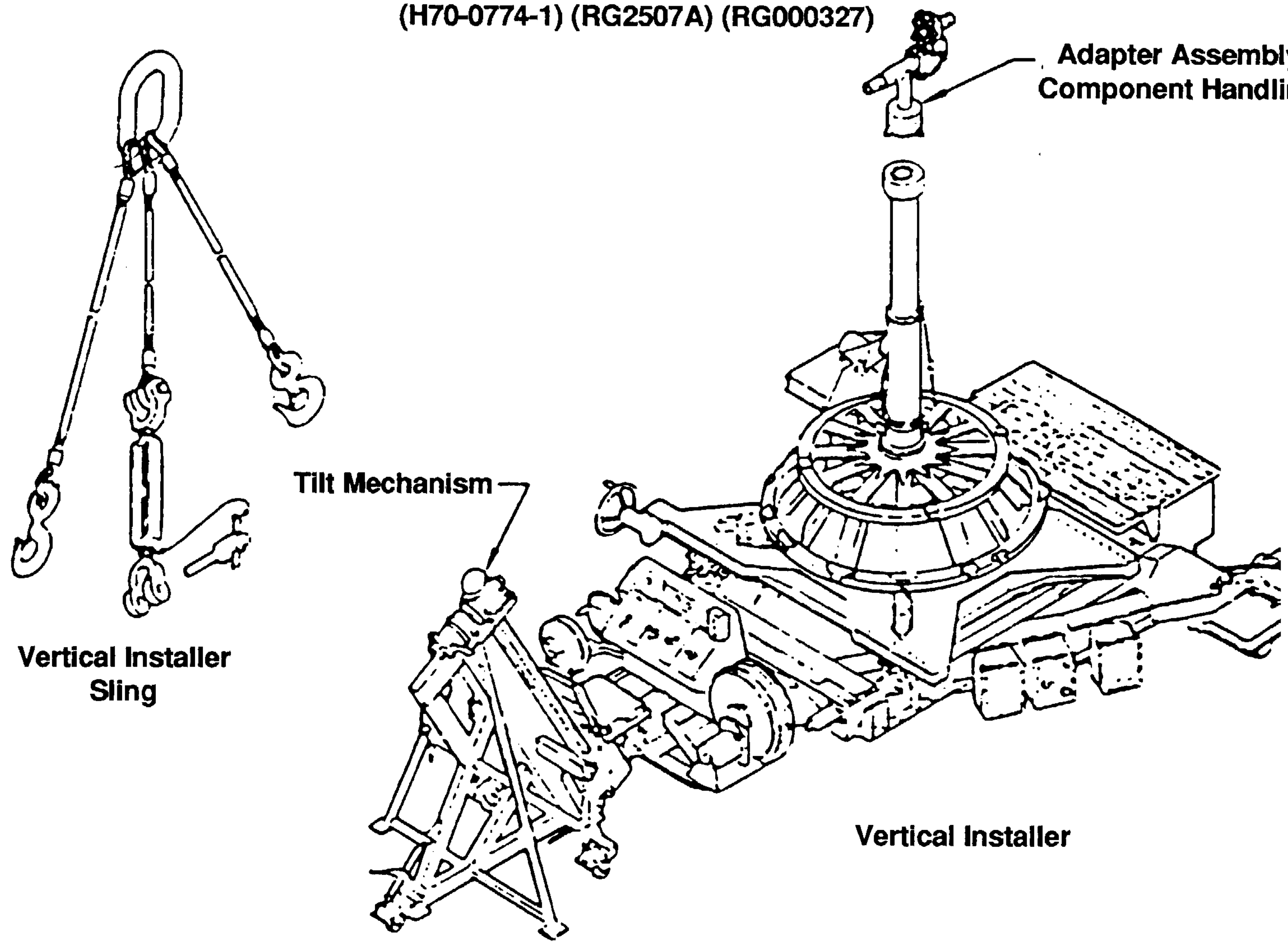
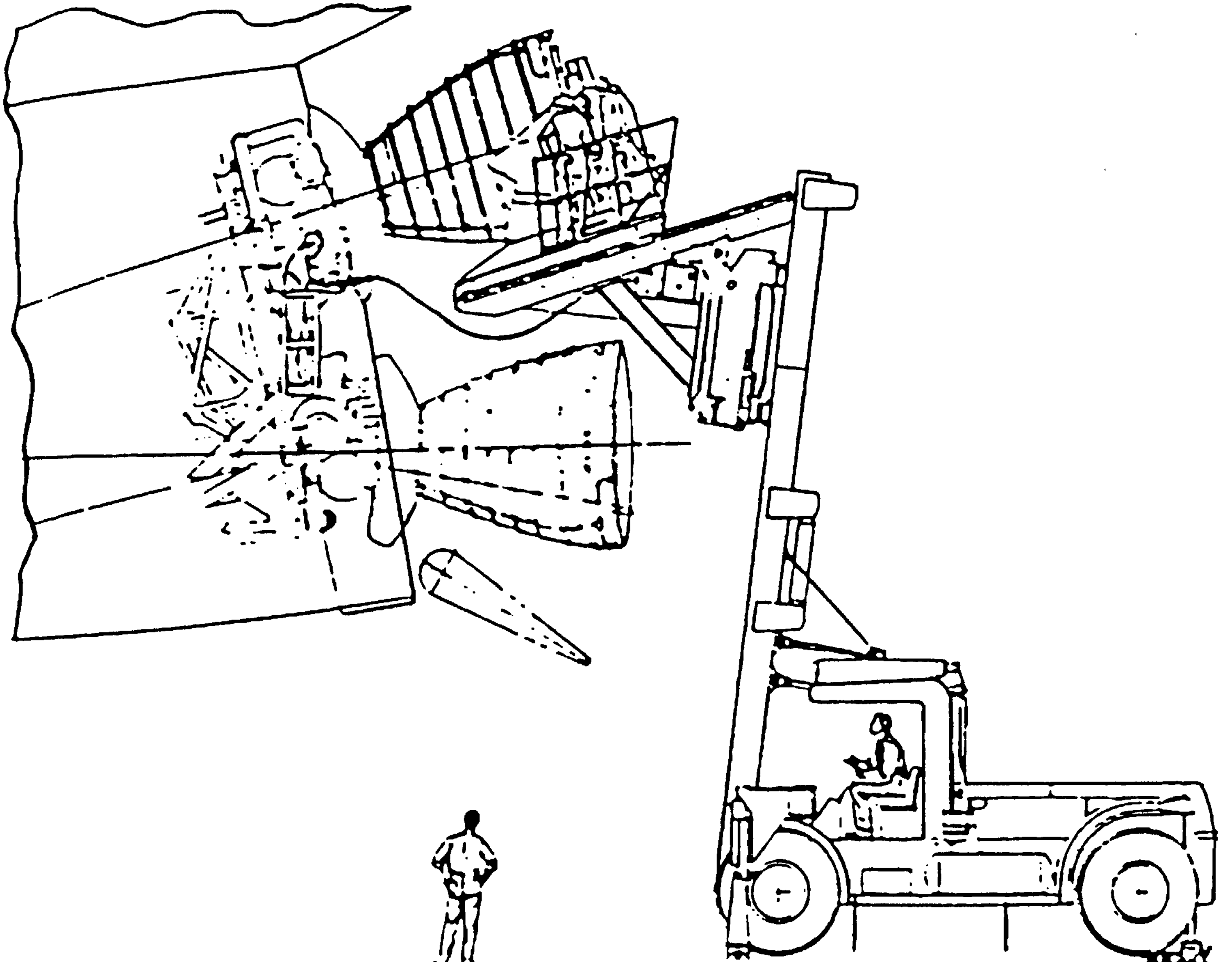
# VERTICAL INSTALLER

(H70-0774-1) (RG2507A) (RG000327)




**Purpose: Install SSME Vertically Into Orbiter or Test Stand**

# HORIZONTAL ENGINE REMOVAL



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# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

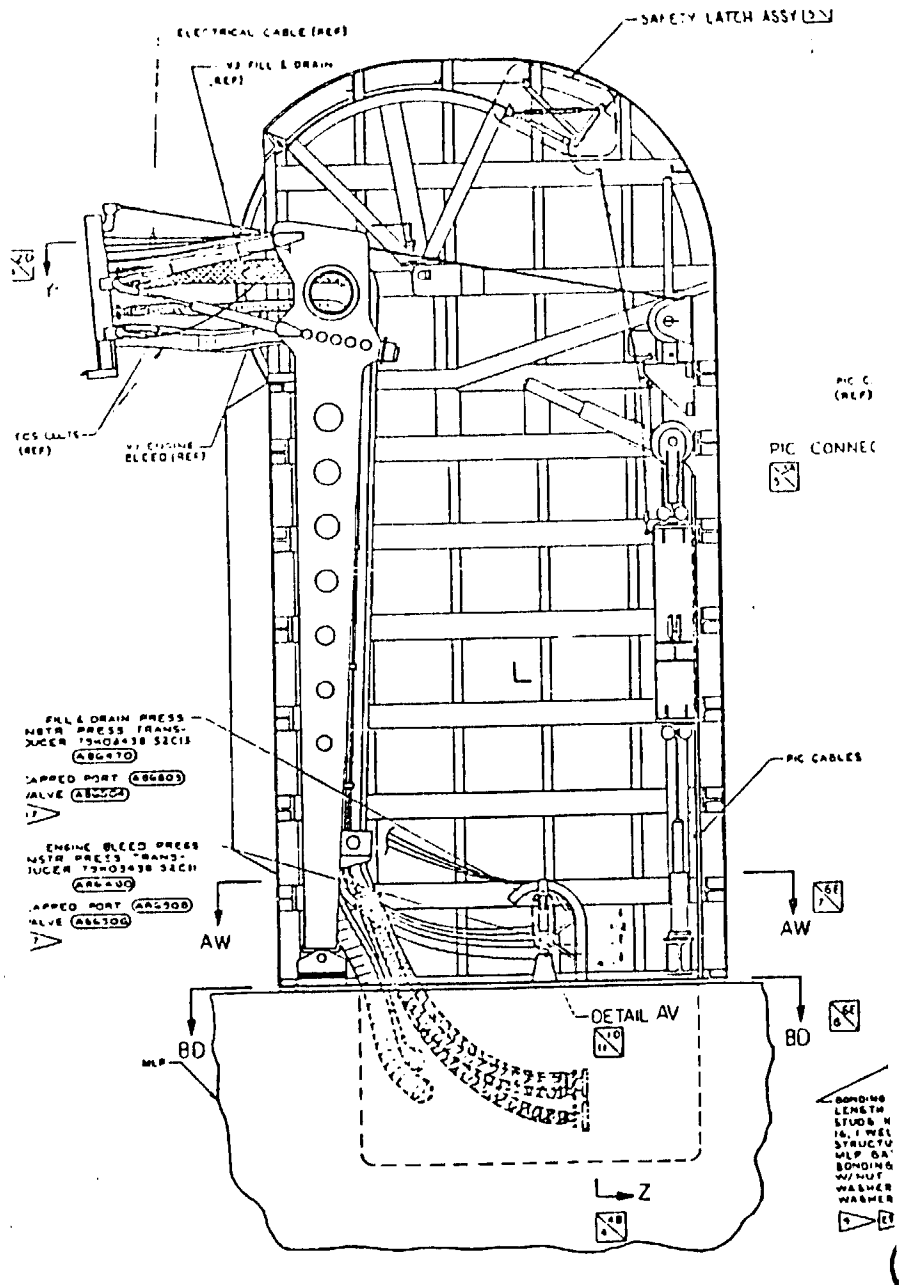
- **Concern: OEPSS - 14**
  - Ordnance operations
- **Operational impacts:**
  - Loss of parallel processing caused by "area clear" evacuations
  - Disposal of unused ordnance from recovered vehicle elements is hazardous and costly
  - Separate, hazardous storage facilities required
- **Potential options 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

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 15**
  - Retractable umbilical carrier plates
- **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:**
  - Lift-off umbilicals - no retraction of plates - separation occurs as vehicle moves away.
  - Consider simple design and low cost quick disconnect to justify discarding after launch versus expensive maintenance procedures

# RETRACTABLE UMBILICALS

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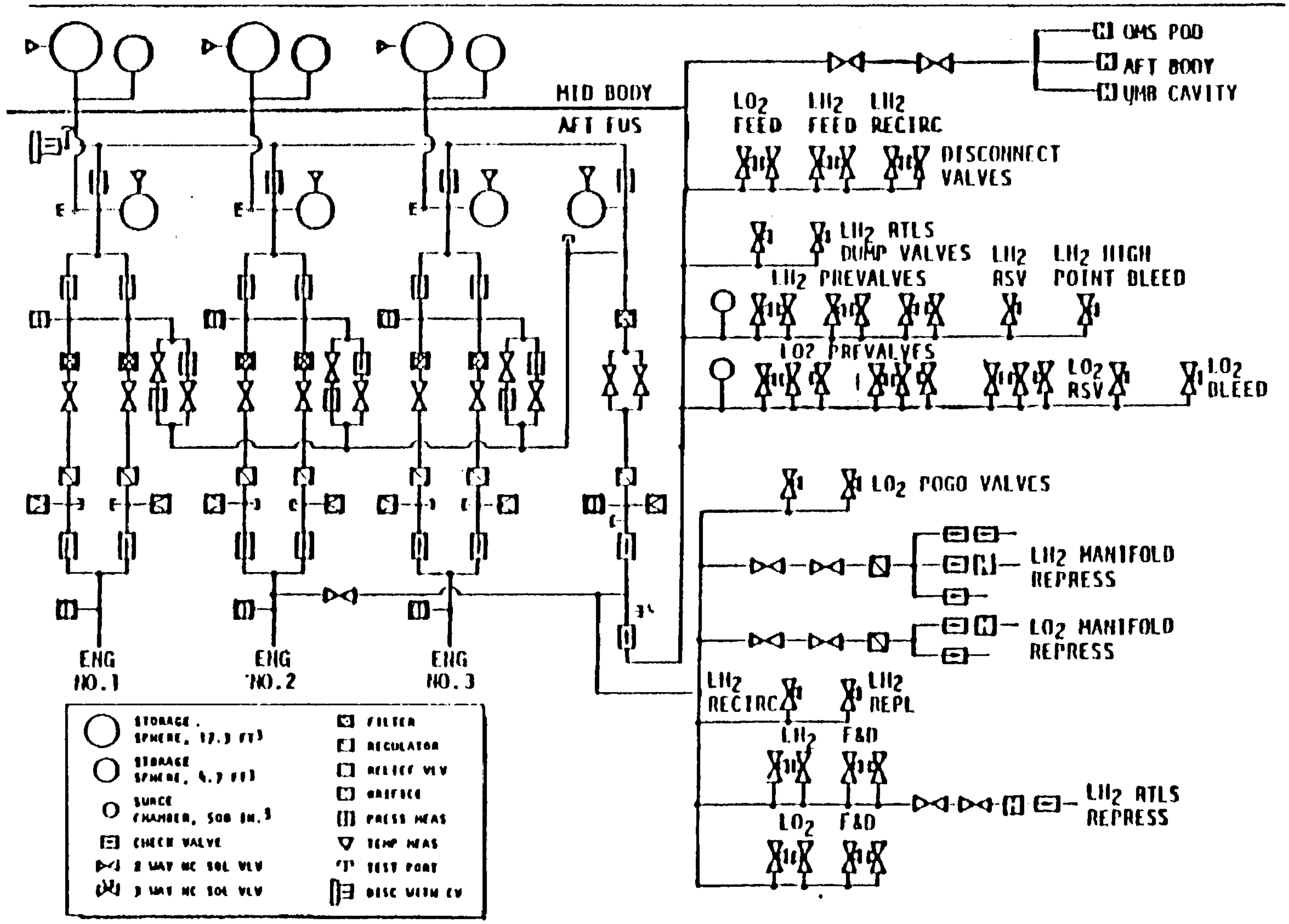
# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 16**
  - Pressurization systems
- **Operational Impacts:**
  - Conventional system requires extensive maintenance and checkout
    - Long plumbing runs from engines and ground interfaces to top of propellant tanks
      - 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

# MAIN PROPULSION SYSTEM
## HELIUM SUBSYSTEM SCHEMATIC

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# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

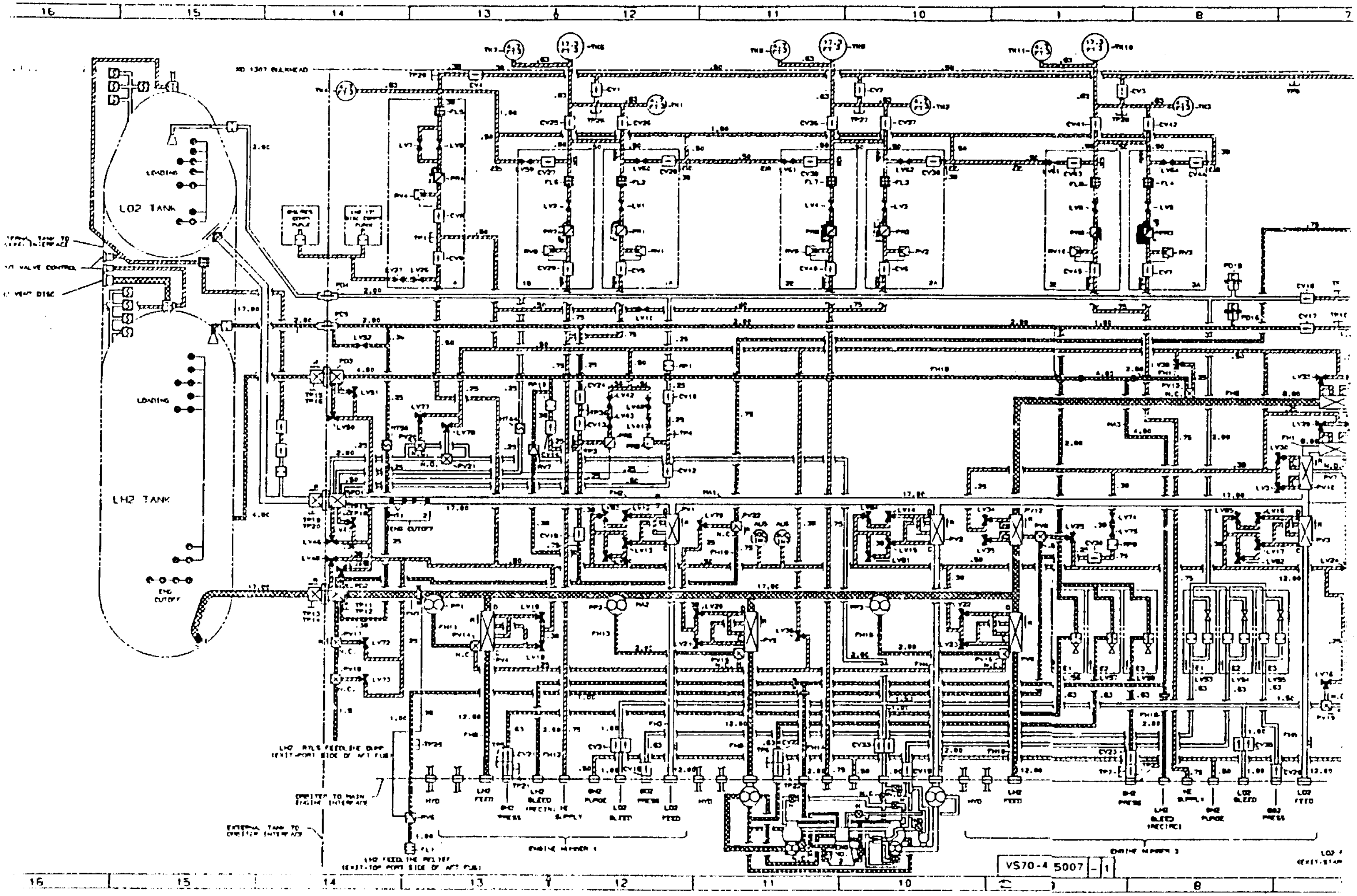
- **Concern:** **OEPSS - 17**
  - Inert gas purging requirements
- **Operational impacts:**
  - Requires sophisticated ground distribution/control system
    - High pressure reduction/control system with redundancy
    - Requires both local and remote operation capability
    - Requires "army" to maintain, 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

# LOX BLEED SYSTEM OPERATIONS IMPACTS*

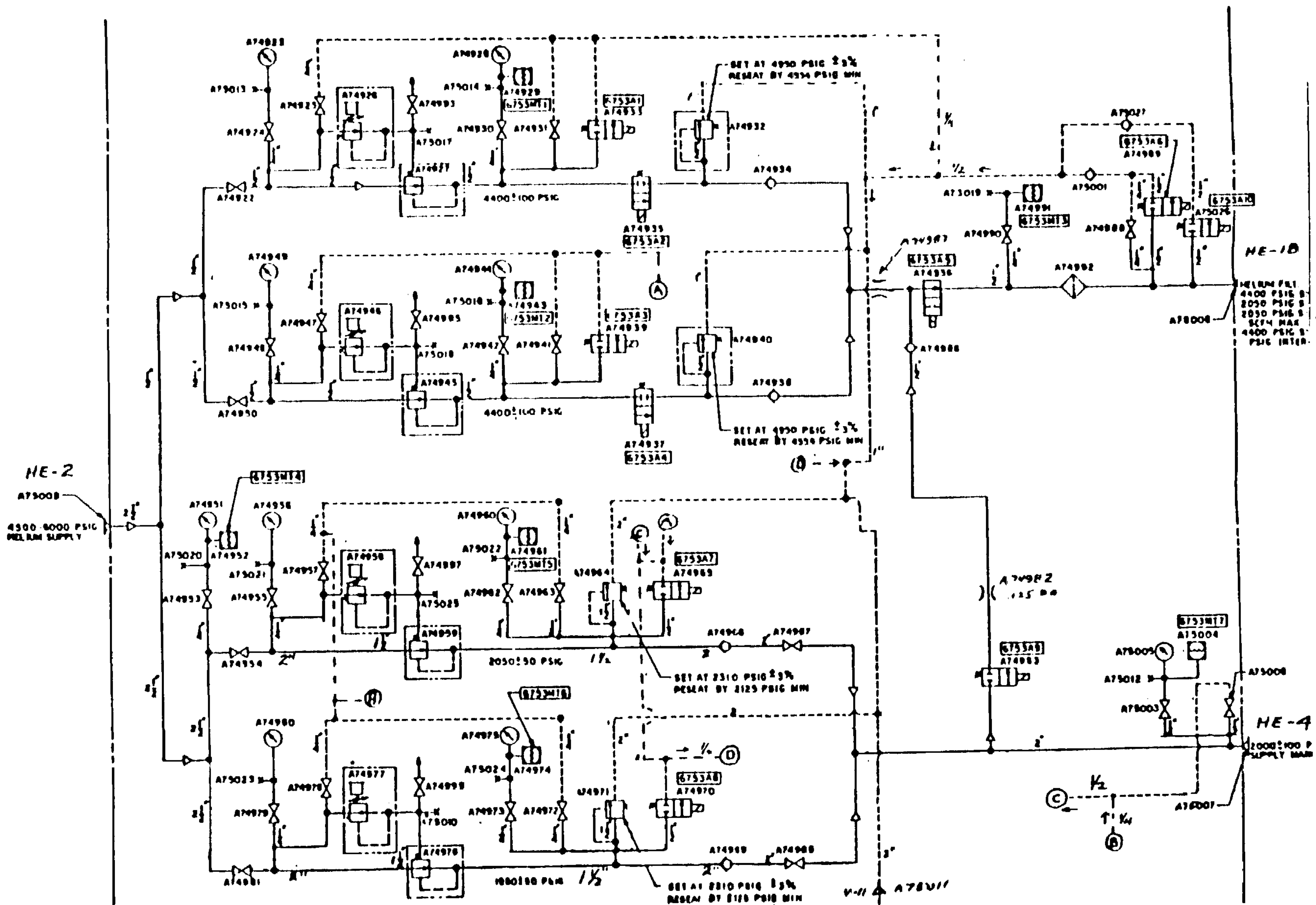
- **Vehicle-to-ground interface**
  - Connect: Techs (3), QC (1), Engr. (1) — 3 hr
  - Leak checks: Techs (5), QC (3), Engr. (5) — 3 hr
- **Vehicle LOX bleed system**
  - Maintenance: Tech (1), QC (1), Engr. (1) — 8 hr
- **Ground LOX bleed system**
  - Maintenance: Tech (1), QC (1), Engr. (1) — 8 hr
- **Engine LOX bleed valve**
  - Leak checks: Techs (1), QC (1), Engr. (1) — 6 hr
  - Removal/replacement: Techs (2), QC (1), Engr. (1) — 28 hr

* Direct support, only, success oriented

# STS MPS SYSTEM



# HELIUM SUPPLY PANEL (MLP)

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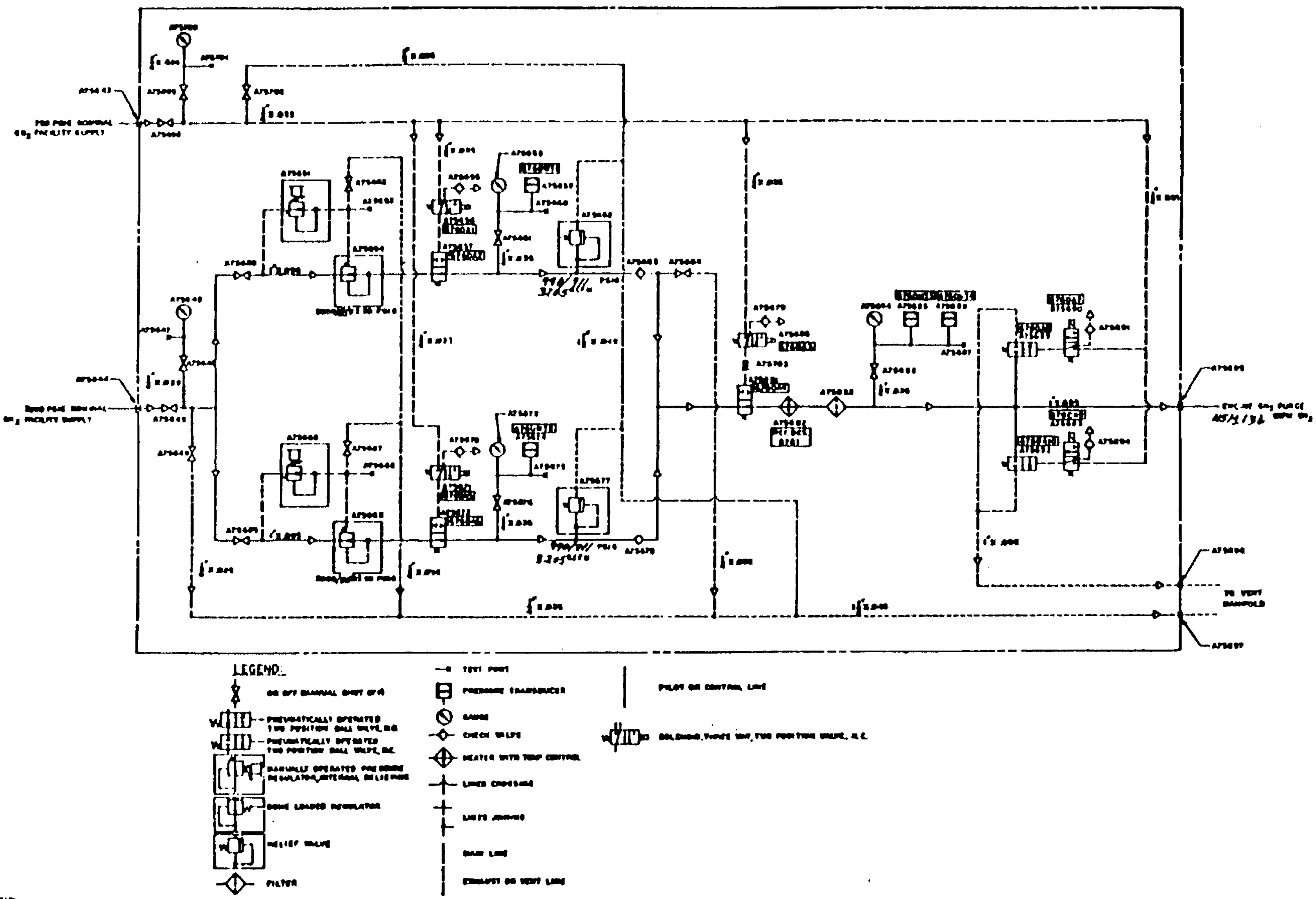
# $GN_2$ PURGE PANEL MLP

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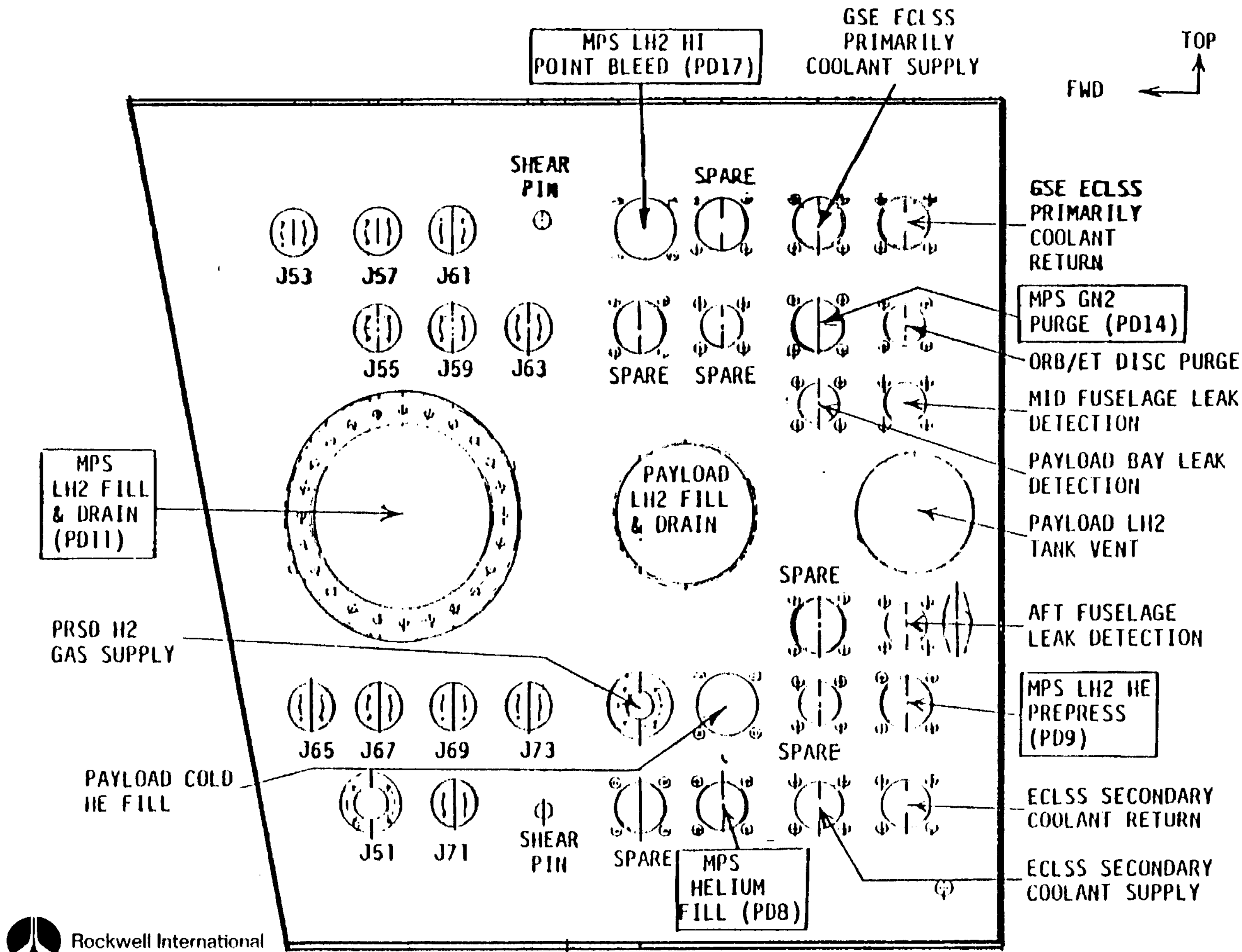
# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern:** **OEPSS - 18**
  - Numerous interfaces
- **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 non-integrated 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

# MLP MAIN PROPULSION GSE

- **Interfaces orbiter with ground propellant systems**
  - LO2 TSM
    - LO2 propellant fill and drain
    - LO2 ET HE prepress
    - LO2 bleed
  - LH2 TSM
    - LO2 propellant fill and drain
    - LO2 ET HE prepress
    - LO2 high point bleed
    - HE bottle fill
    - SSME GN2 purge

# LH2 T-O UMBILICAL PANEL ORBITER LEFT SIDE

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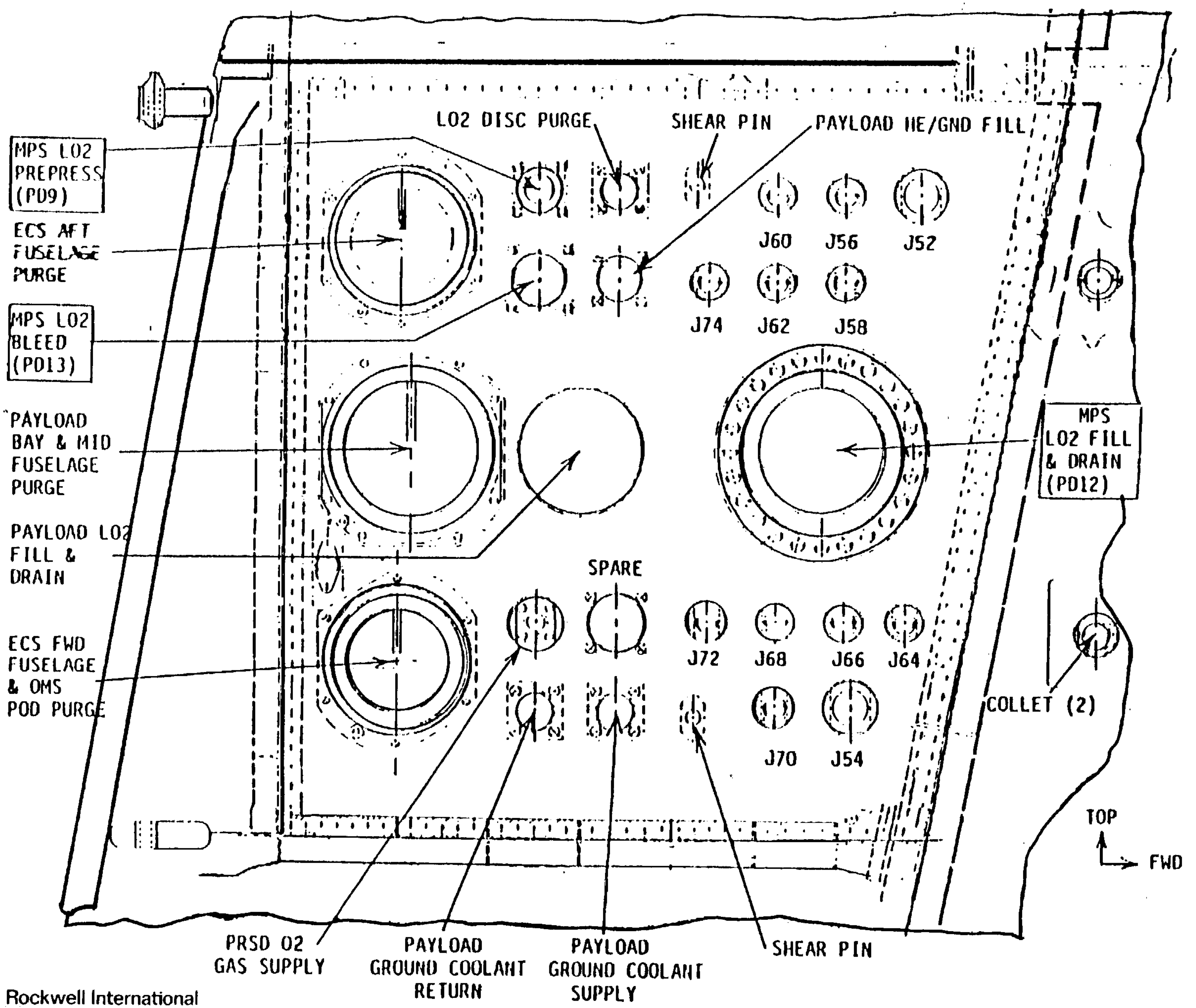
# LO2 T-O UMBILICAL PANEL ORBITER RIGHT SIDE

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# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 19**
  - Helium spin start
- **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

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

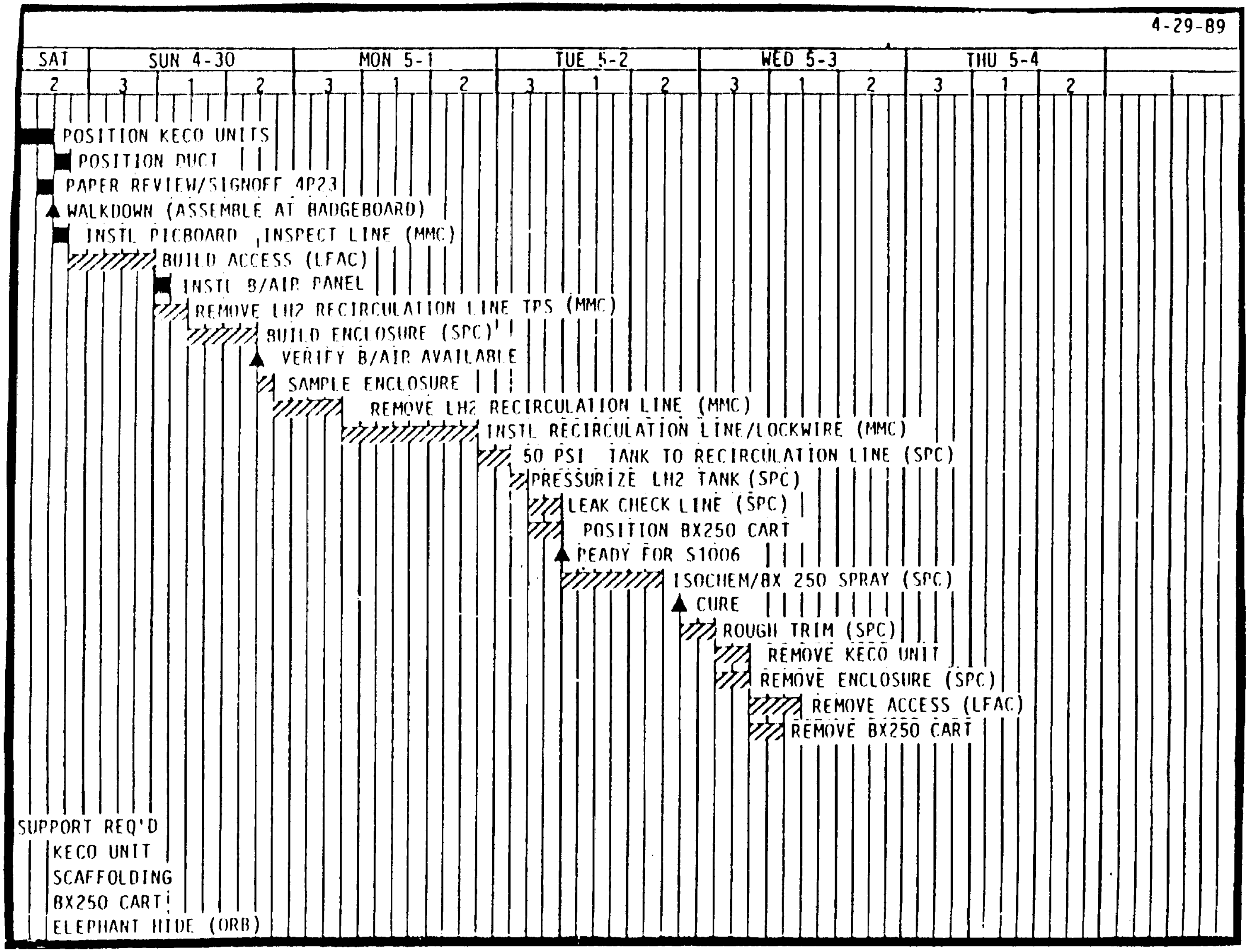
- **Concern: OEPSS - 20**
  - Liquid oxygen tank forward design
- **Operational impacts:**
  - Potential for Geysering - criticality I failure
  - Time-critical operations required for on-pad abort
  - Skilled/experienced engineer required for console
  - Additional hardware and operations required
    - 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

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 21**
  - Preconditioning system
- **Operational impacts:**
  - Added flight hardware
    - Hydrogen recirc 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

# STS-3OR R&R LH2 RECIRCULATION LINE REV B

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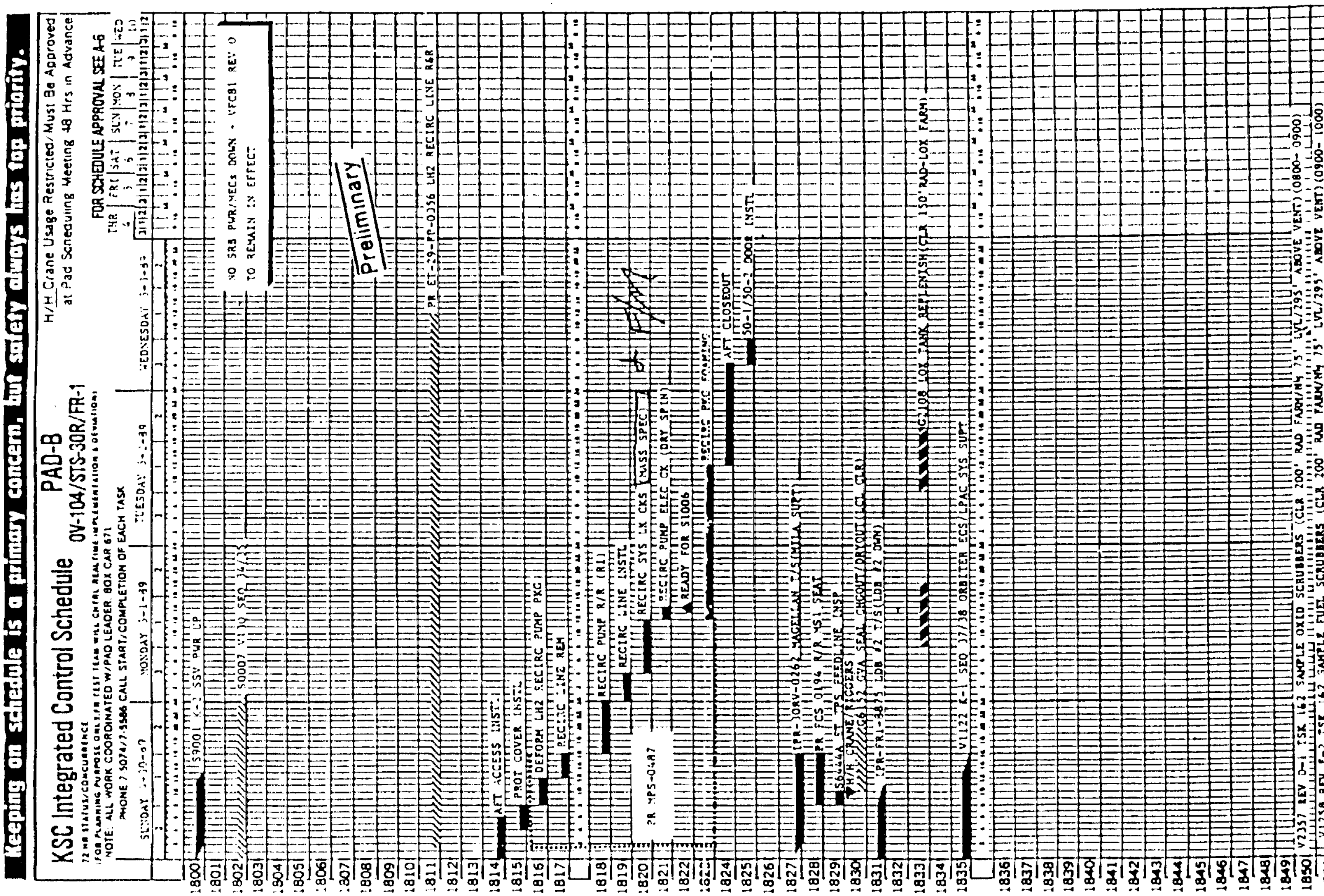
# KSC INTEGRATED CONTROL SCHEDULE

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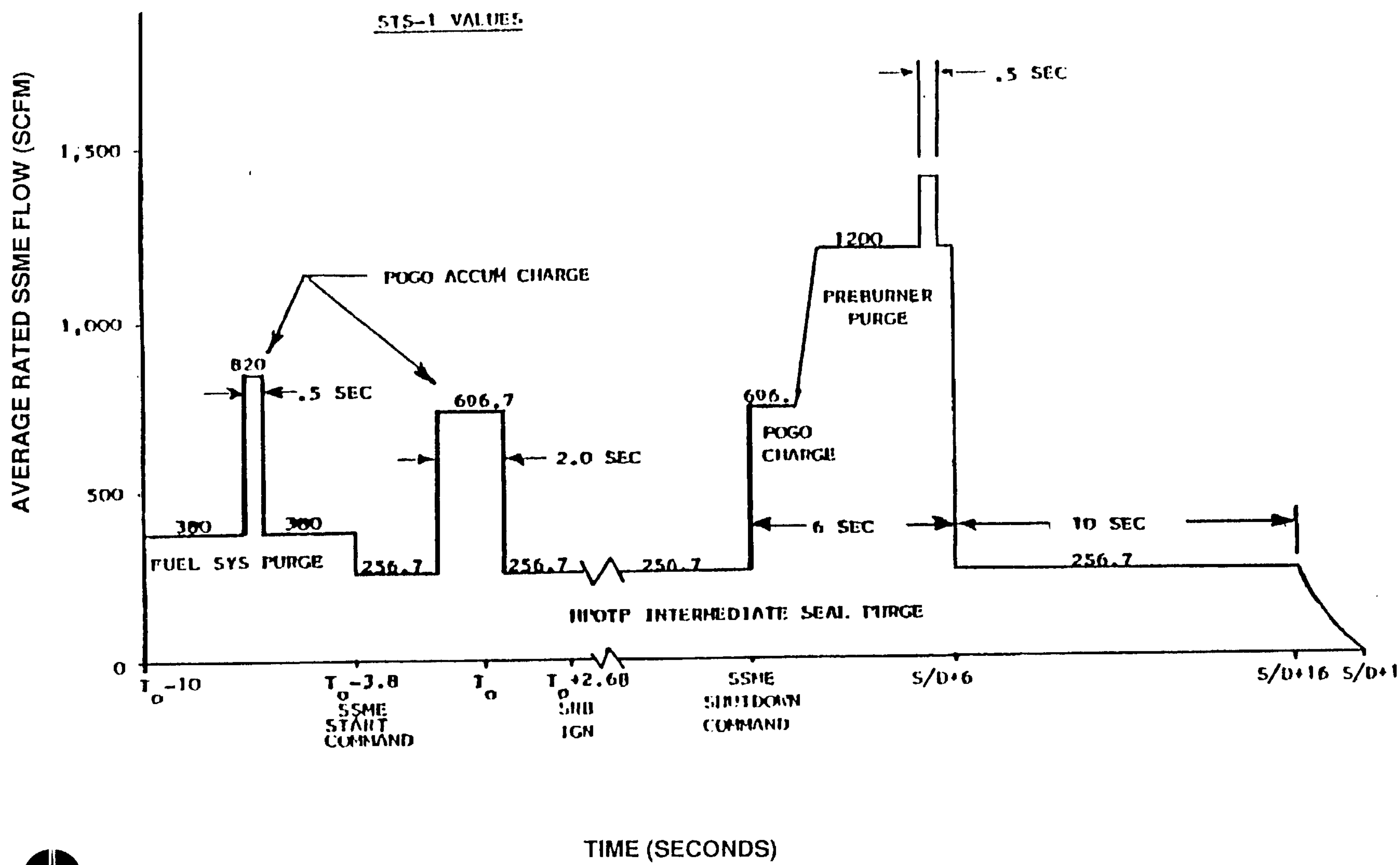
# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern: OEPSS - 22**
  - Expensive commodity usage - Helium
- **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 the 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.

# MPS HELIUM SYSTEM
## SSME HELIUM SUPPLY RATED FLOW VS. TIME



# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 23**
  - Lack of hardware commonality
- **Operational impacts:**
  - Creates a logistic nightmare - gigantic inventory areas
  - Drives cost of hardware up
  - Tends to create hardware shortages
  - Increases numbers 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

# OEPSS CONCERNS LIST

## "Launch Site Experience Base"

- **Concern: OEPSS - 24**
  - Contamination
- **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

# OEPSS CONCERNS LIST
## "Launch Site Experience Base"

- **Concern:** **OEPSS - 25**
  - Side mount booster launch vehicles
- **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
    - Increases 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
  - Lift-off drift drags flame across platform and systems adding to refurbishment operations and costs
  - Increases propulsion flight hardware checkout, ie separate tanks, pressurization system, feed systems, control valves, instrumentation, etc.
  - Doubles ground control consoles and software
  - Add 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

# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS)

## Agenda
## 14 August 1990

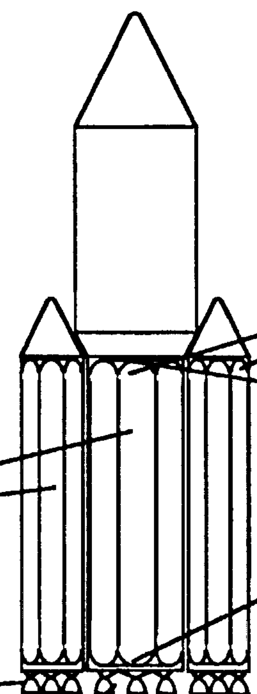
- Introduction ---------------------------------------- R. Rhodes
- Operationally Efficient Integrated P/M ------------ G. Wong
- Operations Problems ---------------------------- G. Waldrop
- √ Operations Technology ------------------------ G. Wong
- Operations Database

# PROPULSION SYSTEM OPERATIONS TECHNOLOGY

- No purge pump seals
- No purge combustion chamber (start-shutdown)
- Oxidizer-rich turbine, LOX turbopump
- Hermetically sealed inert engine and tanks (prelaunch)
- Combined $O_2/H_2$, MPS, OMS, RCS, fuel cell, thermal control systems
- Flash boiling tank pressurization
- Zero - NPSH pumps
- Large flow range pumps
- Differential throttling
- Electric Motor Actuator (EMA)
- No leakage mechanical joints
- Automated self-diagnostic condition monitoring system
- Integrated modularized propulsion module concept
- Anti-geyser, LOX tank aft propulsion concept
- Rocket engine air-augmented afterburning concept

# OPERATIONALLY EFFICIENT LAUNCH VEHICLE

- No pneumatics
- No hydraulics
- No APU
- No OMS
- Minimum ground interfaces (none above pad level)



# OPERATIONS TECHNOLOGY APPLICATION

| Technology | Vehicle Systems | | | | | | |
|---|---|---|---|---|---|---|---|
| | STS | Sh-C | LRB | ELV | ALS | Sh-II | Space |
| • No purge pump seals | | | X | | X | X | X |
| • No purge combustion chamber (start-shutdown) | | | X | X | X | | X |
| • Oxidizer-rich turbine, LOX turbopump | | | X | | X | X | X |
| • Hermetically sealed inert engine and tanks (prelaunch) | | | X | | X | | |
| • Combined $O_2/H_2$ MPS, OMS, RCS, fuel cell, thermal control systems | | X | | | X | X | X |
| • Flash boiling tank pressurization | | | X | | X | X | X |
| • Zero - NPSH pumps | | | X | X | X | X | X |
| • Large flow range pumps | | | X | | X | X | X |
| • Differential throttling | | | | | X | | |
| • Electric Motor Actuator (EMA) | X | X | X | X | X | X | X |
| • No leakage mechanical joints | | | X | X | X | | X |
| • Automated self-diagnostic condition monitoring system | X | X | X | X | X | X | X |
| • Integrated modularized propulsion module concept | | X | X | | X | X | X |
| • Anti-geyser, LOX tank aft propulsion concept | | | X | | X | X | |
| • Rocket engine, air augmented afterburning concept | | | X | | X | X | |

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# OPERATIONS CONCERNS RESOLVED BY TECHNOLOGY

**OEPSS Concerns:** ~~1~~ ~~2~~ ~~3~~ ~~4~~ ~~5~~ ~~6~~ ~~7~~ ~~8~~ ~~9~~ ~~10~~ ~~11~~ ~~12~~ ~~13~~ 14 ~~15~~ ~~16~~ ~~17~~ ~~18~~ ~~19~~ ~~20~~ ~~21~~ ~~22~~ ~~23~~ ~~24~~ 25

| Technology | OEPSS Concerns Addressed |
|---|---|
| • No purge pump seals | 8 17 18 22 |
| • No purge combustion chamber (start-shutdown) | 8 17 18 21 22 |
| • Oxidizer-rich turbine, LOX turbopump | 8 13 17 22 |
| • Hermetically sealed inert engine and tanks (prelaunch) | 8 17 18 21 22 24 |
| • Combined $O_2/H_2$, MPS, OMS, RCS, fuel cell, thermal control systems | 4 5 8 9 10 24 |
| • Flash boiling tank pressurization | 8 9 16 18 24 |
| • Low NPSH pumps | 13 16 19 21 |
| • Large flow range pumps | 8 13 19 21 |
| • Differential throttling | 2 7 8 12 |
| • Electric Motor Actuator (EMA) | 2 6 9 11 12 15 18 24 |
| • No leakage mechanical joints | 1 2 3 5 8 11 16 17 18 21 |
| • Automated, self-diagnostic, condition monitoring system | 1 6 11 12 13 15 21 24 |
| • Integrated modularized propulsion module concept | 1 2 3 6 7 8 9 11 12 13 18 19 21 22 23 24 |
| • Anti-geyser, LOX tank aft propulsion concept | 9 19 20 21 |
| • Rocket engine, air-augmented afterburning concept | 3 9 16 17 |

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# OPERATIONS TECHNOLOGY PROGRAM

## No Purge Pump Seals

- **Objective**
  - Eliminate need for LOX turbopump helium buffer purge
  - Allow engine design that requires no helium
- **Approach**
  - Determine LOX/turbine gas flammability limits for applicable pressures
  - Perform seal test series to evaluate candidate configurations
  - Perform seal test series with pump simulation seal package
- **Schedule**
  - 4 years

# NO PURGE PUMP SEAL PROGRAM

| Tasks | Year 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Task I: Flammability limits testing**<br>Define environment for drain<br>Perform testing for all cases | | | | | |
| **Task II: Seal component testing**<br>Procure candidate seals<br>Test seals to characterize | | | | | |
| **Task III: Seal package testing**<br>Assemble pump seal package<br>Test package to verify acceptability | | | | | |

# OPERATIONS TECHNOLOGY PROGRAM

## No Purge Combustion Chamber

- **Objective**
  - Eliminate start and shutdown purges
  - Allow engine design that requires no helium
- **Approach**
  - Evaluate start with no purges
  - Develop shutdown sequence which minimizes/eliminates injector damage
  - Design close coupled propellant valves and low volume injector manifolds
- **Schedule**
  - 2 years

# NO PURGE COMBUSTION CHAMBER PROGRAM

| Tasks | Year 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Task I: Evaluate start with no purges**<br>Transient modeling<br>Identify component issues | | | | | |
| **Task II: Develop no purge shutdown**<br>Identify critical issues<br>Transient modeling to address issues<br>Evaluate proposed shutdown sequence | | | | | |
| **Task III: Hardware conceptual design**<br>Low volume injector configurations<br>Close coupled valve configurations<br>Tank ullage gas purge | | | | | |

# OPERATIONS TECHNOLOGY PROGRAM

## Oxidizer-rich Turbine For LOX Turbopump

- **Objective**
  - Eliminate need for LOX turbopump helium buffer purge
  - Allow engine design that requires no helium
- **Approach**
  - Analyze candidate engine cycles
  - Perform oxygen compatibility testing on turbine components
  - Develop LOX rich injector technology
  - Perform engine start/shutdown analysis
- **Schedule**
  - 4 years

# OXIDIZER RICH TURBINE TECHNOLOGY PROGRAM

| Tasks | Year 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Task I: Engine cycle analysis**<br>Define candidate cycles<br>Identify technology issues | | | | | |
| **Task II: Oxygen compatibility testing**<br>Define turbine component materials<br>Identify required testing<br>Perform testing | | | | | |
| **Task III: LOX rich injector technology**<br>Design and analysis<br>Model flow test<br>Hot-fire demonstration component | | | | | |
| **Task IV: Transient analysis**<br>Model system<br>Start/shutdown sequence development<br>System evaluation | | | | | |

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# OPERATIONS TECHNOLOGY PROGRAM

## Hermetically Sealed Inert Engine And Tanks (Prelaunch)

- **Objective**
  - Eliminate purge requirements prior to start
  - Allow engine design that requires no helium at launch pad
- **Approach**
  - Define engine sealing concepts
  - Characterize seal concepts through test
  - Define operational impacts
- **Schedule**
  - 1 year

# HERMETICALLY SEALED INERT ENGINE PROGRAM

| Tasks | Year | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| **Task I: Sealing concepts**<br>Identify requirements<br>Define candidate methods | | | | | |
| **Task II: Test seal concepts**<br>Characterize leakage<br>Evaluate operability | | | | | |
| **Task III: Define operational impacts**<br>Trade seal qualities vs. operability<br>Select sealing method | | | | | |

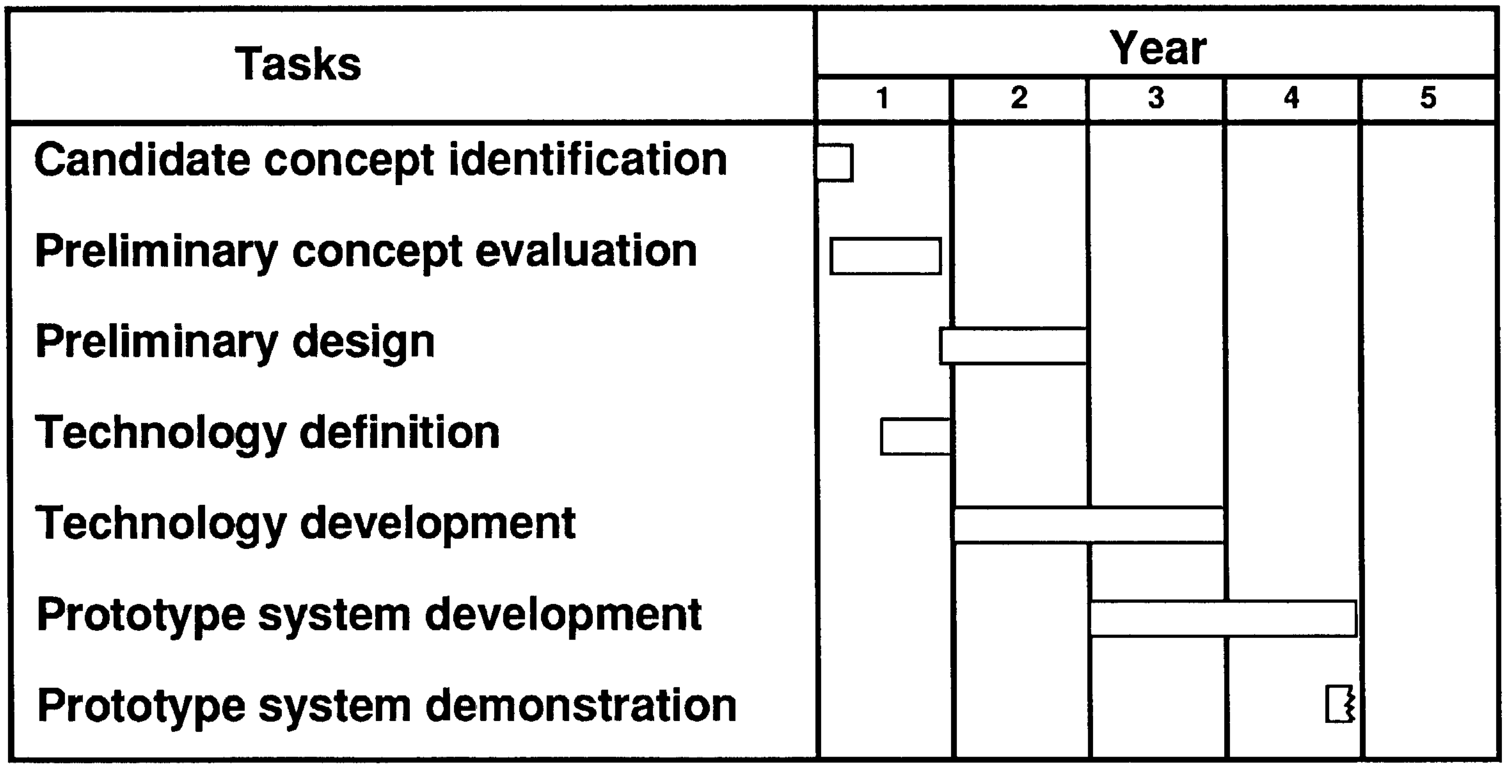
# COMBINED $O_2/H_2$ MPS, OMS, RCS, FUEL CELLS THERMAL MANAGEMENT

- **Objective**
  - Develop a design for an integrated hydrogen/oxygen system
    - Replaces conventional separate MPS, OMS, RCS, and fuel cell systems
    - Goal is a single propellant tank set providing $O_2$ and $H_2$ for all functions
    - As a minimum, the design should incorporate single ground fill interface for each propellant
  - Incorporate into the design other features to provide operational efficiency

# COMBINED $O_2/H_2$ MPS, OMS, RCS, FUEL CELLS THERMAL MANAGEMENT

- **Approach**
  - Create candidate system configurations which integrate one or more of the MPS, OMS, RCS, and fuel cell systems
  - Perform preliminary evaluation of the candidate systems based on appropriate criteria
    - Feasibility
    - Cost
    - Operability
    - Technology
    - Potential applications
  - Select options which best meet criteria for more detailed study
    - Develop preliminary designs for specific applications
    - Identify subsystem or component technology development requirements
  - Develop preliminary design of most promising concept
  - Continue concept development through prototype demonstration
- **Schedule 4 years**

# COMBINED $O_2/H_2$ MPS, OMS, RCS, FUEL CELLS THERMAL MANAGEMENT



# COMBINED $O_2/H_2$ MPS, OMS, RCS, FUEL CELLS

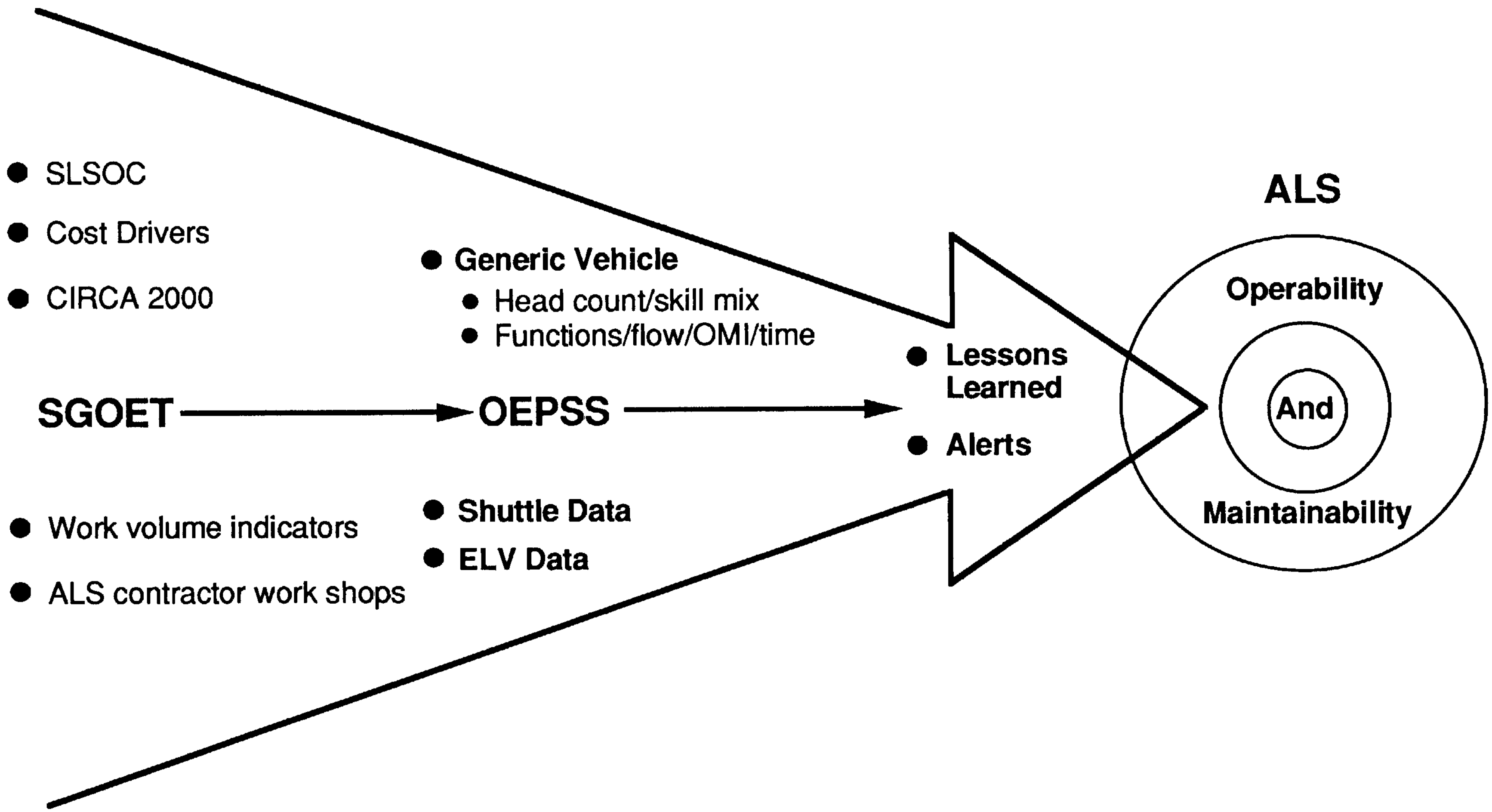
- **Operational requirements eliminated**
  - Toxic propellant handling
    - Personnel hazards
    - Serial processing time
  - Multiple propellant sets
    - Multiple tank sets to maintain, checkout, and service
      - Multiple associated fill, vent, insulation, etc., systems
    - Separate vehicle interfaces and ground support systems for each vehicle system
  - Multiplicity of components/functions/requirements
    - Each system has different types of components with unique maintenance, checkout, and servicing requirements
    - Separate systems need separate crews of ground support personnel
    - Complex logistics requirements

# OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS)

## Agenda
## 14 August 1990

- Introduction -------------------------------------- R. Rhodes
- Operationally Efficient Integrated P/M ------------ G. Wong
- Operations Problems ------------------------------ G. Waldrop
- Operations Technology ---------------------------- G. Wong
- √ Operations Database

# OEPSS FOCUSES ON ALS OPERABILITY



# SHUTTLE GROUND OPERATIONS EFFICIENCIES/ TECHNOLOGIES STUDY (SGOE/T)

- **Shuttle prime data base**
  - Functions/responsibilities
  - Manpower
  - Timelines
  - Work volume indicators
- **Operational cost drivers**
- **STAS assessment**
- **Circa 2000 vehicle concept**

# SGOE/T LESSONS LEARNED - THE PROBLEMS

- **Vehicle processing/launch preps**
  - Systems not readily serviceable
  - Too many people
  - Too much time
  - High cost
- **Principal problem categories**
  - Vehicle preparations
  - Personnel evacuations
    - Hypergols
    - Ordnance
  - Complex vehicle trail
    - Multiple handling
    - Hazardous rotation and high lifts
  - Multiple, complex support facilities and GSE
    - Large operational and maintenance headcount and material investment

# GROUND OPERATIONS COST DRIVERS

## Vehicle

- Propulsion
  - Main
  - OMS/RCS
- Access/ Maintainability
- Avionics/electronics
- Structure
  - Tankage
- Energy storage
- Ordnance
- Payloads

## Test and Checkout

- Ground operations
  - Computers
  - Test requirements
  - Payloads
  - Autonomous vehicle
    - Onboard T&C
    - Ground power
- Processing attitude
  - Horizontal
  - Vertical
- Transfer to pad
- Vehicle rotation to vertical

## Launch Pad

- Vehicle support structure
  - Stage/mate
  - Water/ECS
  - Flame trench
- Propellant systems
  - Carriers
- Vehicle interfaces
  - Propellants
  - Command/control
- Vehicle access

# VEHICLE CONFIGURATION COST DRIVERS

- **Simplified, robust propulsion system**
  - Integrate MPS, OMS, RCS
  - Less sensitive start requirements
    - Thermal conditioning
    - Valve timing
  - Delete/minimize all purges and pre-pressurization
    - Electro-mechanical valves
  - No gimballed engines
    - TVC by Delta thrust
  - No hydraulics
- **Electronic health and status monitoring**

# VEHICLE CONFIGURATION COST DRIVERS

- **Leak resistant tankage and plumbing**
- **One oxidizer/one fuel**
  - Minimize ground facilities
- **No hypergols**
  - Eliminates costly, life support equipment
- **Robust thermal protection systems**
- **High density electrical power storage**
  - Eliminate/simplify APU

# TEST AND CHECKOUT COST DRIVERS

- **Integrated fault tolerant avionics**
  - Computer interconnectivity
- **Onboard test and checkout**
  - Eliminate/minimize GSE
  - Isolated systems enable parallel activity
- **Returned vehicle components contain self-test elements**
  - Verify flight readiness/problem isolation
- **Eliminate/simplify ground power**
  - Eliminate vehicle power-up as milestone event

# LAUNCH PAD COST DRIVERS

- **Flyaway umbilicals/QDs**
  - Auto-mate geometry
  - Gravity powered exhaust protection doors
  - No retracting umbilical carriers

- **No hardwire interfaces**
  - Optical/RF/IR links
  - Minimal launch control interface
  - No ground power
    - Vehicle and payload autonomous for 24 hr + mission
  - Electrical ground and propellants connect only

# INTEGRATED CMS VITAL TO EFFICIENT OPERATIONS

- **Automated vehicle/propulsion system checkout**
- **Enhanced red line (safety) monitoring**
  - Detect impending flight failures
  - Take action to assure a completed mission
- **Automated maintenance decision capability**
  - Performance and trend analysis
- **Direct, non-intrusive measurement of key failure parameters**
- **Modular system for ease of reconfiguration**

# LESSONS LEARNED YIELD EFFICIENT OPERATIONS

- **System design**
  - Minimize separable joints
  - Simplify fastening systems
  - Maximize accessibility
  - Maximize hardware commonality
  - Minimize fluid requirements
- **Integration**
  - Minimize interfaces
  - Minimize installation/removal
  - Maximize accessibility
- **Testing**
  - Minimize routine maintenance
  - Minimize functional checkouts
  - Maximize automation
- **GSE**
  - Minimize quantity
  - Simplify operation
  - Promote commonality/multiple use

# INTEGRATION OF PROPULSION SYSTEM REQUIREMENTS

- **Start sequence does not require pre-conditioning**
  - Eliminates bleed system
  - Eliminates re-circ pumps and pre-valves
  - No need for critical propellant inlet start box
- **Control functions integrated into vehicle**
  - Significant reduction in hardware
  - Electronics located in more benign environment
- **Regulated helium supply**
  - Nitrogen purge not required
- **Engine supplies electrical power tor TVC**
  - Power take-off from pump shaft, or
  - Separate gas driven turbine

# OPERATIONAL EFFICIENCY ENHANCED BY SIMPLE SYSTEMS

- **No hydraulics system**
  - Electromechanical actuators (EMA) for TVC
- **Simplified helium system**
- **No vacuum jacketed feed lines**
- **Common feed line design**
- **Common valve design**
  - Single type cryo valve
  - Single type solenoid valve

# OPERATIONAL CONSIDERATIONS STRONG DESIGN DRIVER

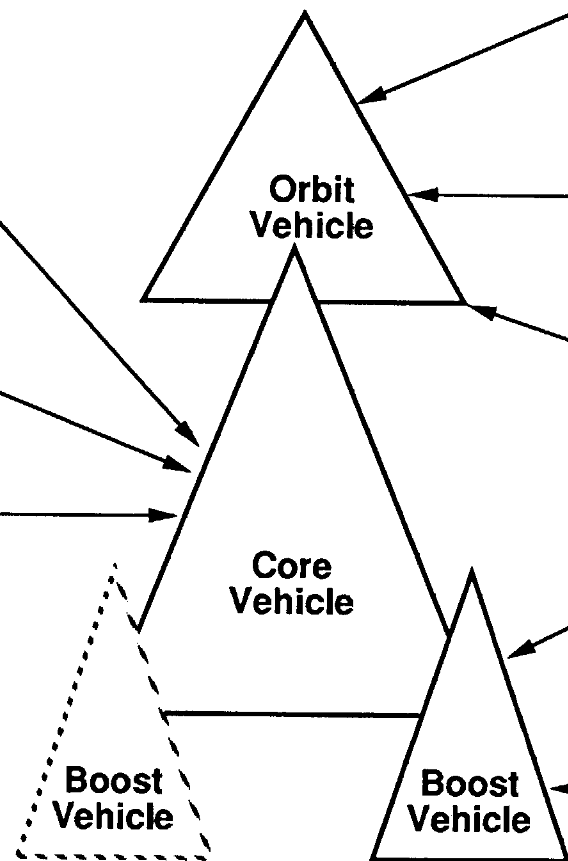
- **Maintenance reduced**
  - No scheduled maintenance
  - Robust designs reduce unscheduled maintenance
- **Components easily replaced**
  - Ready access
  - Retention hardware easily removed
- **Simple ground interface**
  - Rise-off Q/D's at AFT end

# GENERIC VEHICLE DESCRIPTION

**LOX/LH$_2$ (Multiple Engines)**
- Line Replaceable Unit
- Turbopump Fed
- Augmented Spark Ignition
- Gimbal Capability
- Engine Supervisory Avionics
- Hydraulic/Pneumatic Valve Actuators
- Limited Throttle Capability
- Single Start

**Propellant Management System**
- Engine Conditioning
- Tank Pressure
- Fill/Drain
- Tank Conditioning

**Propulsion System Support (Ground/Flight)**
- Electric Power
- Pneumatics
- Hydraulics
- Hazardous Gas Detection/Alert System
- Ground Support for Checkout




**Propulsion Systems Support (Ground/Flight)**
- Command Avionics System
- Pneumatics
- Electric Power
- Ground Support for Checkout

**Attitude Adjustment System**
- Hypergolic Fuel Oxidizer
- Pressure Fed
- Electric Valves

**Orbit Adjustment System**
- Hypergolic Fuel/Oxidizer
- Pressure Fed
- Gimbal Capability (Electric)
- Electric Valves

**Propulsion System Support (Ground/Flight)**
- Electric Power
- Pneumatics
- Hydraulics
- Ground Support for Checkout

**Propellant Management System**
- Engine Conditioning
- Tank Pressure
- Fill/Drain
- Tank Conditioning

**LOX/LH$_2$ (Multiple Engines)**
- Line Replaceable Unit
- Turbopump Fed
- Augmented Spark Ignition
- Gimbal Capability
- Engine Supervisory Avionics
- Hydraulic/Pneumatic Valve Actuators
- Limited Throttle Capability
- Single Start

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# GENERIC VEHICLE DATABASE

- Booster - Expendable $LOX/LH_2$ - Modeled after KSC/LSOC Liquid Rocket Booster (LRB) Integration Study
- Core - Recoverable $LOX/LH_2$ Propulsion Module - Modeled after KSC/STS Orbiter refurbishment ground processing
- Core - Expendable $LOX/LH_2$ Tankage - Modeled after KSC/STS external tank ground processing
- Orbiter - Recoverable, unmanned, Hypergolic Propulsion System modeled after KSC/STS Orbiter refurbishing processing
- Solid Rocket Booster (SRB) data are included for reference only - Generic vehicle baseline does not include solid propellants

# GENERIC VEHICLE ASSUMPTIONS

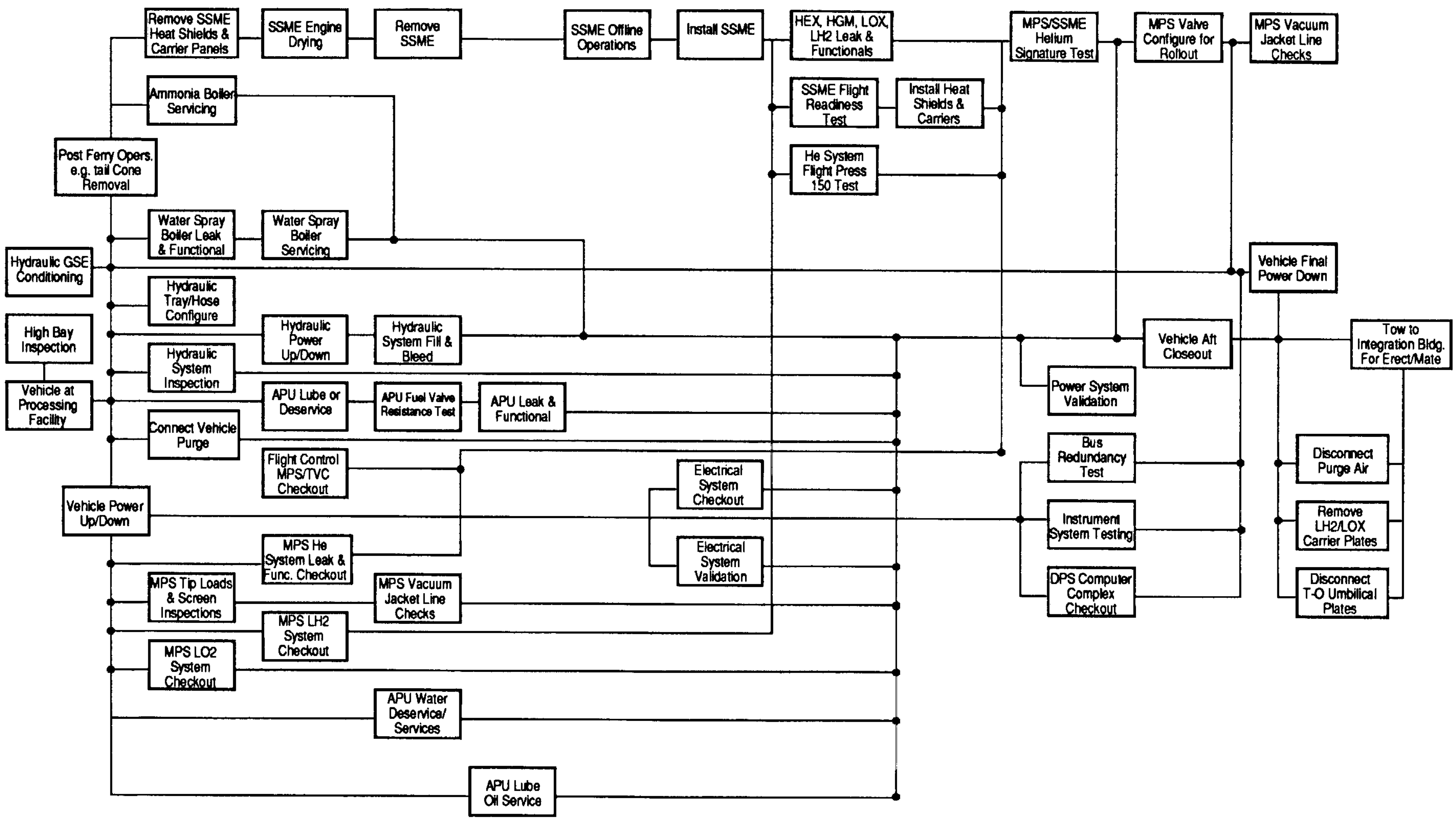
- All vehicles use multiple engines
- Retractable umbilicals for ground-to-vehicle servicing
- Ground propellant, pneumatic, and electrical systems are common to existing launch facilities
- Method of operation is common to existing launch operations
- Processing facilities are common to the existing launch facilities

# GENERIC CORE VEHICLE PROPULSION SYSTEM DATA GENERATED

- **Top logic diagram generated for LOX/$LH_2$ propulsion system**
- **Logic diagram and processing duration and manpower generated for major systems:**
  - Engine system
  - Main propulsion system
  - Hydraulics/APU systems
  - Electrical systems
  - Thermal control systems

# OEPSS GENERIC CORE VEHICLE TOP LOGIC DIAGRAM

## Recoverable LOX/LH2 Propulsion System

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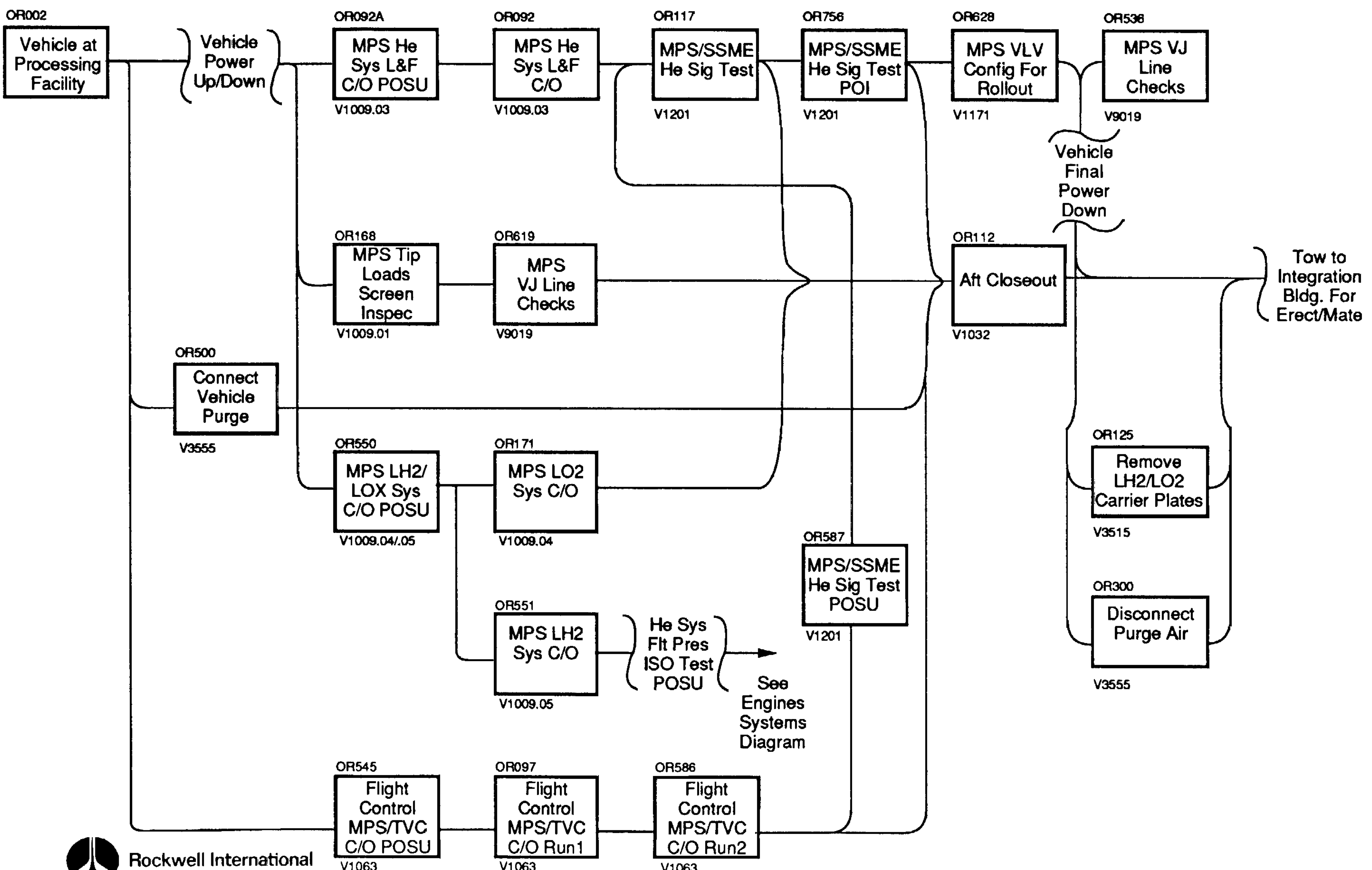
# OEPSS GENERIC CORE VEHICLE

## MPS Logic Diagram

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# OEPSS GENERIC CORE VEHICLE

## Main Propulsion System Processing Duration and Manpower

| Oper. | OMI | Activity | Dur. Hrs. | Head Count | Manhours |
|---|---|---|---|---|---|
| 0R002 | - | Vehicle at Processing Facility | - | - | |
| 0R092A | V1009.03 | MPS He sys. L&F C/O POSU | 16 | 9 | 144 |
| 0R092 | V1009.03 | MPS He sys. L&F C/O | 48 | 9 | 432 |
| 0R117 | V1201 | MPS/SSME He sig test | 40 | 11 | 440 |
| 0R756 | V1201 | MPS/SSME He sig test POI | 16 | 5 | 80 |
| 0R628 | V1171 | MPS VLV config. for rollout | 4 | 2 | 8 |
| 0R536 | V9019 | MPS vacuum jacket line checks | 8 | 5 | 40 |
| 0R168 | V1009.01 | MPS tip loads & screen inspect | 56 | 9 | 504 |
| 0R619 | V9019 | MPS VJ line checks | 8 | 5 | 40 |
| 0R112 | V1032 | Aft closeout * | 312 | 15 | 4680 |
| 0R500 | V3555 | Connect vehicle purge | 4 | 7 | 28 |
| 0R125 | V3515 | Remove LH2/LO2 carrier plates | 4 | 3 | 12 |
| 0R550 | V1009.04/.05 | MPS LH2/LO2 Sys. C/O POSU | 16 | 8 | 128 |
| 0R171 | V1009.04 | MPS LO2 sys. C/O | 48 | 8 | 384 |
| 0R587 | V1201 | MPS/SSME He Sig test POSU | 72 | 7 | 504 |
| 0R300 | V3555 | Disconnect purge air | 4 | 7 | 28 |
| 0R551 | V1009.05 | MPS LH2 sys C/O | 48 | 8 | 384 |
| 0R545 | V1063 | Flight control MPS/TVC C/O POSU | 8 | 4 | 32 |
| 0R097 | V1063 | Flight control MPS/TVC C/O Run 1 | 10 | 4 | 40 |
| 0R586 | V1063 | Flight control MPS/TVC C/O Run 2 | 10 | 4 | 40 |
| | | TOTAL | 732 | | 7948 |

* Aft closeout includes the full spectrum of vehicle activities (not propulsion only)

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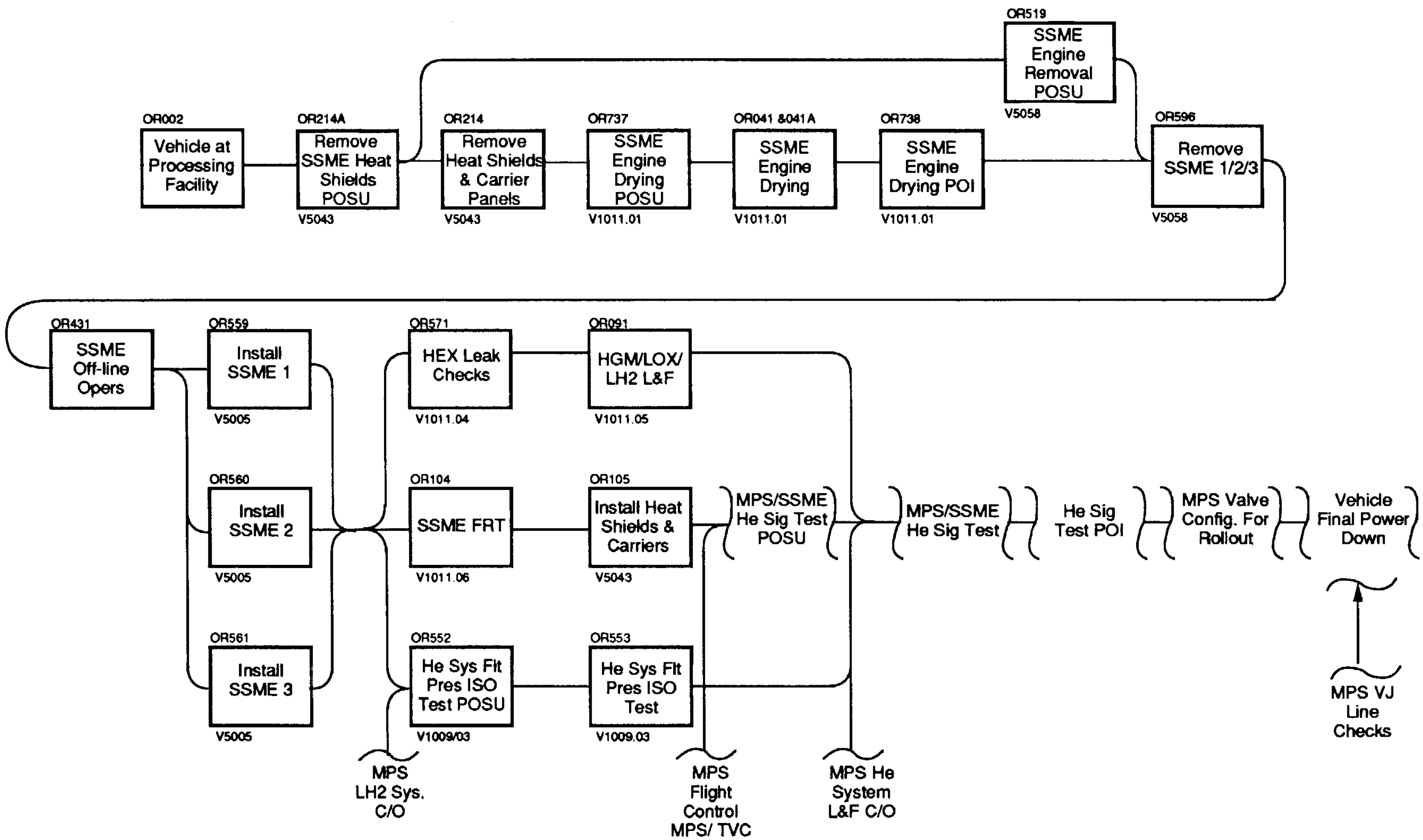
# OEPSS GENERIC CORE VEHICLE

## Engine System Logic Diagram




- See MPS Logic Diagram -

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# OEPSS GENERIC CORE VEHICLE
## Engine Systems Processing Duration and Manpower

| Oper. | OMI | Activity | Dur. Hrs. | Head Count | Manhours |
|---|---|---|---|---|---|
| 0R002 | - | Vehicle at Processing Facility | - | - | |
| 0R214A | V5043 | Remove SSME heat shields & carriers POSU | 9 | 12 | 108 |
| 0R214 | V5043 | Remove SSME heat shields & carriers | 103 | 12 | 1236 |
| 0R737 | V1011.01 | SSME engine drying POSU | 20 | 3 | 60 |
| 0R041/0.41A | V1011.01 | SSME engine drying | 24 | 7 | 168 |
| 0R738 | V1011.01 | SSME engine drying P0I | 5 | 3 | 15 |
| 0R519 | V5058 | SSME engine removal POSU | 64 | 14 | 896 |
| 0R596 | V5058 | Remove SSME 1/2/3 | 32 | 14 | 448 |
| 0R431 | - | SSME offline opers | 672 | *18.7 | 12544 |
| 0R559 | V5005 | Install SSME1 | 12 | 15 | 180 |
| 0R560 | V5005 | Install SSME2 | 12 | 15 | 180 |
| 0R561 | V5005 | Install SSME3 | 12 | 15 | 180 |
| 0R571 | V1011.04 | Hex leak checks | 50 | 3 | 150 |
| 0R091 | V1011.05 | HGM/LOX/LH2 L&F | 54 | 4 | 216 |
| 0R104 | V1011.06 | SSME FRT | 12 | 6 | 72 |
| 0R105 | V5043 | Install heat shields and carriers | 72 | 10 | 720 |
| 0R552 | V1009.03 | He sys flt pres ISO test POSU | 16 | 8 | 128 |
| 0R553 | V1009.03 | He sys flt pres ISO test | 24 | 8 | 192 |
| | | TOTAL | 1193 | | 17,493 |

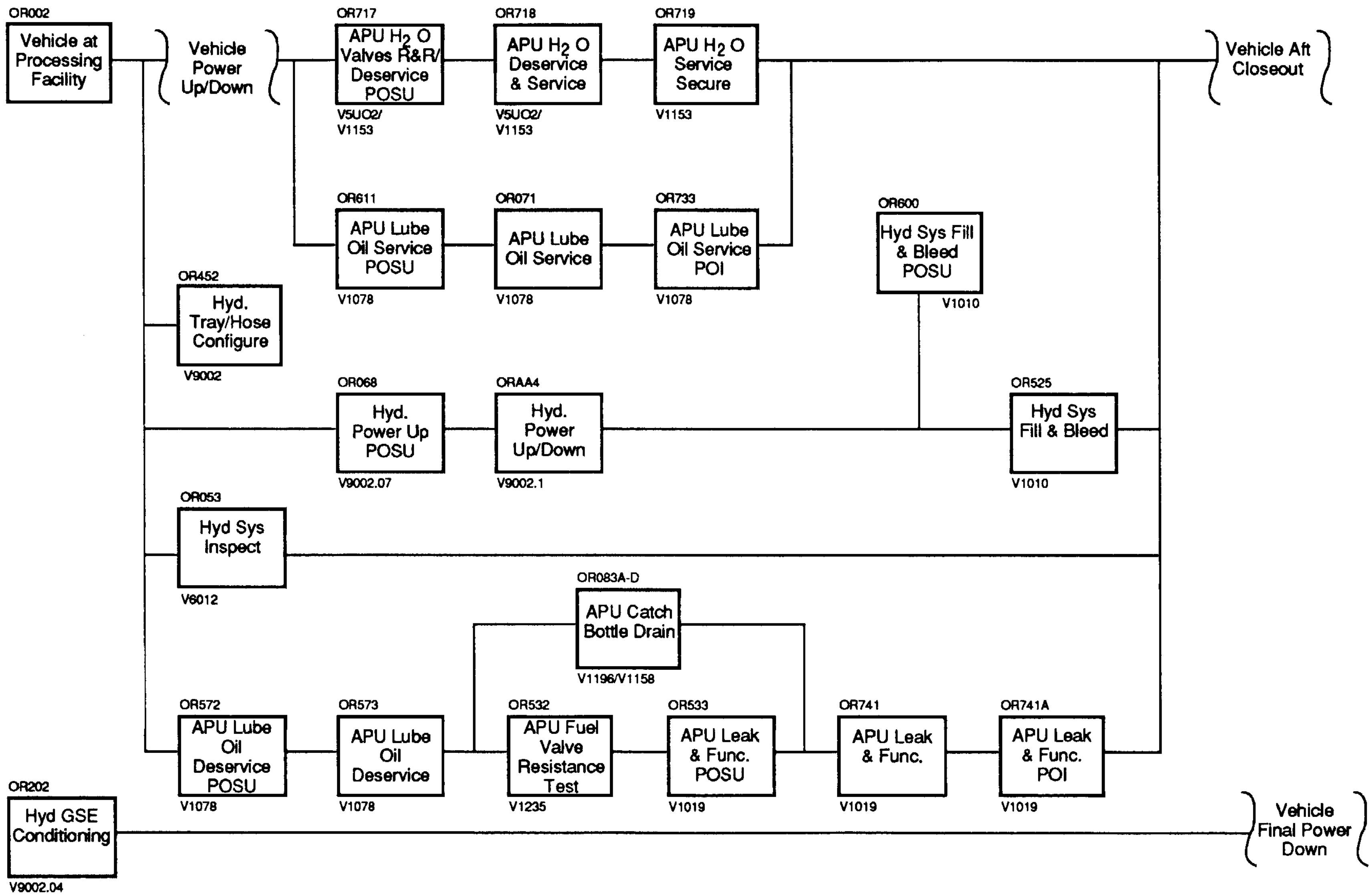
* Rocketdyne manpower for SSME offline O&M

| | Techs | Quality | Engrs. |
|---|---|---|---|
| 1st Shift | 8 | 3 | 12 |
| 2nd Shift | 8 | 3 | 2 |
| 3rd Shift | 6 | 2 | 1 |
| Shop support | 6 | 3 | 2 |
| | 28 | 11 | 17 |

TOTAL - 56 Heads

672 Hrs. is 28 days of 3-shift operations for an average headcount of 18.7 at all times.

# OEPSS GENERIC CORE VEHICLE
## Hydraulic and APU Logic Diagram

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# OEPSS GENERIC CORE VEHICLE
## Hydraulics and APU Processing Duration and Manpower

| Oper. | OMI | Activity | Dur. Hrs. | Head Count | Manhours |
|---|---|---|---|---|---|
| 0R002 | - | Vehicle at Processing Facility | - | - | |
| 0R717 | V5U02/V1153 | APU H20 VLVS R&R/Deservice POSU | 32 | 5 | 160 |
| 0R718 | V5U02/V1153 | APU H20 Deservice/Service | 80 | 8 | 640 |
| 0R719 | V1153 | APU H20 Service secure | 4 | 4 | 16 |
| 0R611 | V1078 | APU lube oil service POSU | 8 | 5 | 40 |
| 0R071 | V1078 | APU lube oil service | 26 | 10 | 260 |
| 0R733 | V1078 | APU lube oil service POI | 8 | 4 | 32 |
| 0R600 | V1010 | Hyd. sys. fill & bleed POSU | 24 | 5 | 120 |
| 0R452 | V9002 | Hyd. tray/hose configure | 10 | 11 | 110 |
| 0R068 | V9002.07 | Hyd Power-up POSU | 17 | 3 | 51 |
| 0RAA4 | V9002.1 | Hyd. Power-up/down | 2 | 11 | 22 |
| 0R525 | V1010 | Hyd.sys. fill & bleed | 32 | 14 | 448 |
| 0R053 | V6012 | Hyd. sys. inspect | 64 | 4 | 256 |
| 0R083 A-D | V1196/1158 | APU catch bottle drain | 96 | 23 | 2208 |
| 0R572&A | V1078 | APU lube/oil deservice POSU (STSX .67)* | 64 | 10 | 640 |
| 0R573 | V1078 | APU lube/oil deservice | 9 | 10 | 90 |
| 0R532 | V1235 | APU fuel vlv. resistance test | 40 | 5 | 200 |
| 0R533 | V1019 | APU leak & functional POSU | 16 | 10 | 160 |
| 0R741 | V1019 | APU leak & functional | 176 | 10 | 1760 |
| 0R741A | V1019 | APU leak & functional POI | 48 | 8 | 384 |
| | | TOTAL | 756 | | 7597 |

* Contains POSU for 3 procedures; one of which is for OMS/RCS hypergols not used by generic core.

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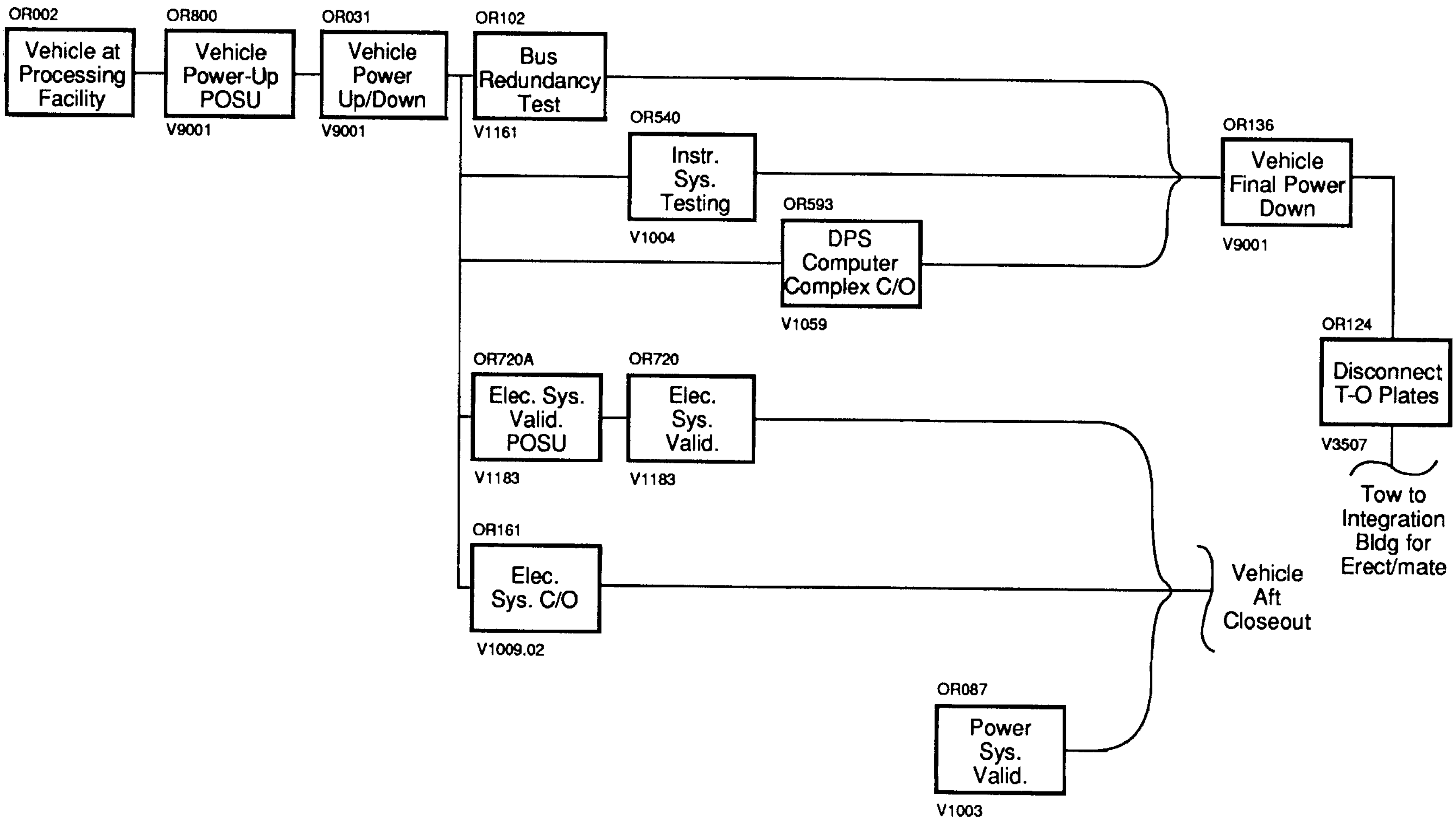
# OEPSS GENERIC CORE VEHICLE

## Electrical Systems Logic Diagram

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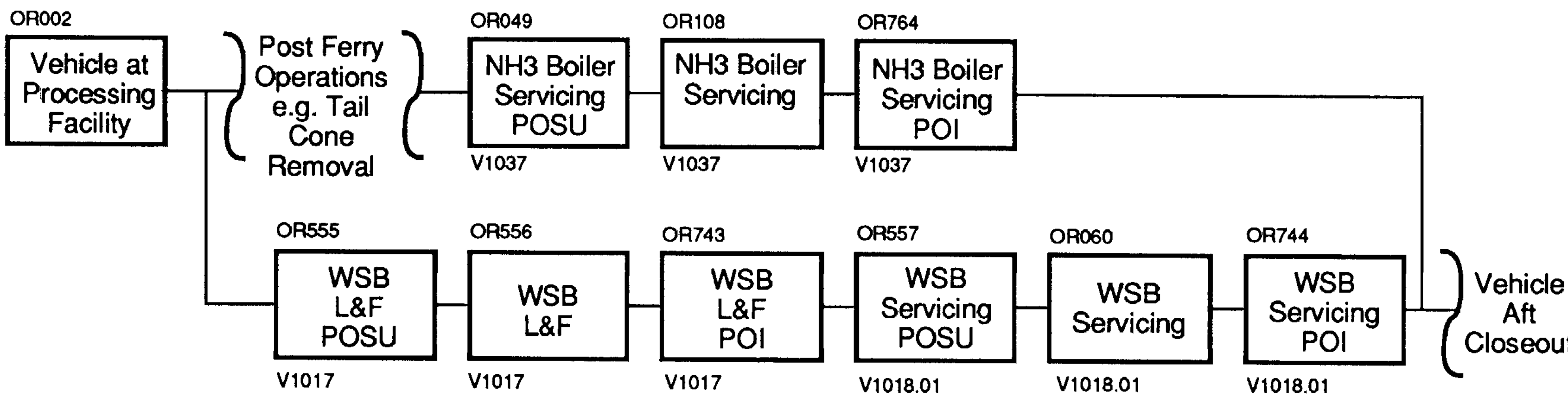
# OEPSS GENERIC CORE VEHICLE

## Electrical Systems Processing Duration and Manpower

| Oper. | OMI | Activity | Dur. Hrs. | Head Count | Manhours |
|---|---|---|---|---|---|
| 0R002 | - | Vehicle at Processing Facility | - | - | |
| 0R800 | V9001 | Vehicle power-up POSU | 26 | 14 | 364 |
| 0R031 | V9001 | Vehicle power-up/down | 2 | 10 | 20 |
| 0R102 | V1161 | Bus redundancy test 128/15 x.5 | 64 | 8 | 512 |
| 0R540 | V1004 | Instrument system testing | 48 | 5 | 240 |
| 0R593 | V1059 | DPS computer complex c/o | 8 | 4 | 32 |
| 0R136 | V9001 | Vehicle final power down | 2 | 8 | 16 |
| 0R124 | V3507 | Disconnect T-O umbilical plates | 4 | 6 | 24 |
| 0R720A | V1183 | Electrical system validation POSU | 8 | 14 | 112 |
| 0R720 | V1183 | Electrical system validation | 20 | 7 | 140 |
| 0R161 | V1009.02 | Electrical system C/O | 44 | 8 | 352 |
| 0R087 | V1003 | Power system validation | 48 | 11 | 528 |
| | | TOTAL | 274 | | 2340 |

# OEPSS GENERIC CORE VEHICLE

## Active Thermal Control System Logic Diagram



# OEPSS GENERIC CORE VEHICLE

## Active Thermal Control System
## Processing Duration and Manpower

| Oper. | OMI | Activity | Dur. Hrs. | Head Count | Manhours |
|---|---|---|---|---|---|
| 0R002 | - | Vehicle at Processing Facility | - | - | |
| 0R049 | V1037 | Ammonia boiler servicing POSU | 64 | 7 | 448 |
| 0R108 | V1037 | Ammonia boiler servicing | 24 | 11 | 264 |
| 0R764 | V1037 | Ammonia boiler servicing POI | 2 | 4 | 8 |
| 0R555 | V1017 | WSB leak and functional POSU | 32 | 5 | 160 |
| 0R556 | V1017 | WSB leak and functional | 144 | 8 | 1152 |
| 0R743 | V1017 | WSB leak and functional POI | 4 | 4 | 16 |
| 0R567 | V1018.01 | WSB servicing POSU | 8 | 7 | 56 |
| 0R060 | V1018.01 | WSB servicing | 12 | 7 | 84 |
| 0R744 | V1018.01 | WSB servicing POI | 2 | 4 | 8 |
| | | TOTAL | 292 | | 2196 |

# OEPSS GENERIC CORE VEHICLE

## Processing Critical Path Tasks and Duration

| Activity | | Duration, hrs. |
|---|---|---|
| 0R002 | Vehicle at Processing Facility door | - |
| 0R214 | Remove SSME heat shields and carriers | 103 |
| 0R737 | SSME engine drying POSU | 20 |
| 0R041 | SSME engine drying | 24 |
| 0R738 | SSME engine drying POI | 5 |
| 0R596 | Remove SSME (20 hr/engine) x 3 | 90 |
| 0R431 | SSME offline operations 672 hrs | - |
| 0R559 | Install SSME (12 hr/engine) x 3 | 36 |
| 0R571 | SSME HEX leak checks | 50 |
| 0R091 | SSME HGM/LOX/LH2 leak and functional | 54 |
| 0R105 | Install SSME heat shield and carrier | 72 |
| 0R587 | MPS/SSME He signature test (preps) | 72 |
| 0R117 | He signature test | 40 |
| 0R756 | He signature test POI | 16 |
| 0R112 | Vehicle aft closeout | 312 |
| | TOTAL | 894 |

1. 894 hrs equates to 111.7 shifts
2. LSOC planning for STS-33 shows 57 days process time for these tasks; an average 2.1 shifts per day, 7 days per week.

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