RI/RD90-149-5

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

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FOREWORD

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

ABSTRACT

This study was initiated to identify operations problems and cost drivers for current propulsion systems and to identify technology and design approaches to increase the operational efficiency and reduce operations cost for future propulsion systems. To provide readily 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

Simplistic Space Vehicle Design
- Integrate functions
- Efficient component packaging
- Sized to meet performance requirements
- Common concept for different mission needs

Increased Operational Flexibility
- Combined cycle booster propulsion providing power recovery
- Decrease criticality of equipment function
- Provide greater performance margins to accommodate low cost robust approach

High Reliability
- Reduce number of systems and components by maximizing integration and TQM practices

"The Technology Challenge"
Low Cost, Reliable, Timely Access to Space

Maintainability
- High accessibility
- Automatic retest

Operability
- Simple servicing
- Minimum number of major elements

Maximize use of Resources
- Use environmental assets, i.e. Earth atmosphere, Moon surfaces, Mars, etc.
- Productive use of manpower
- Maximize team approach i.e. government, industry, academia

Environmentally clean & affordable
- All LOX/LH_2 as consummables and functional fluids
  - MPS, power, cooling, life support
  - Major reduction in operations staff
  - Adopt low cost manufacturing concepts

Reduced Operations Personnel Skills
- Simplified, integrated robust, highly automated vehicle concept

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14 August 1990

- Introduction -- R. Rhodes
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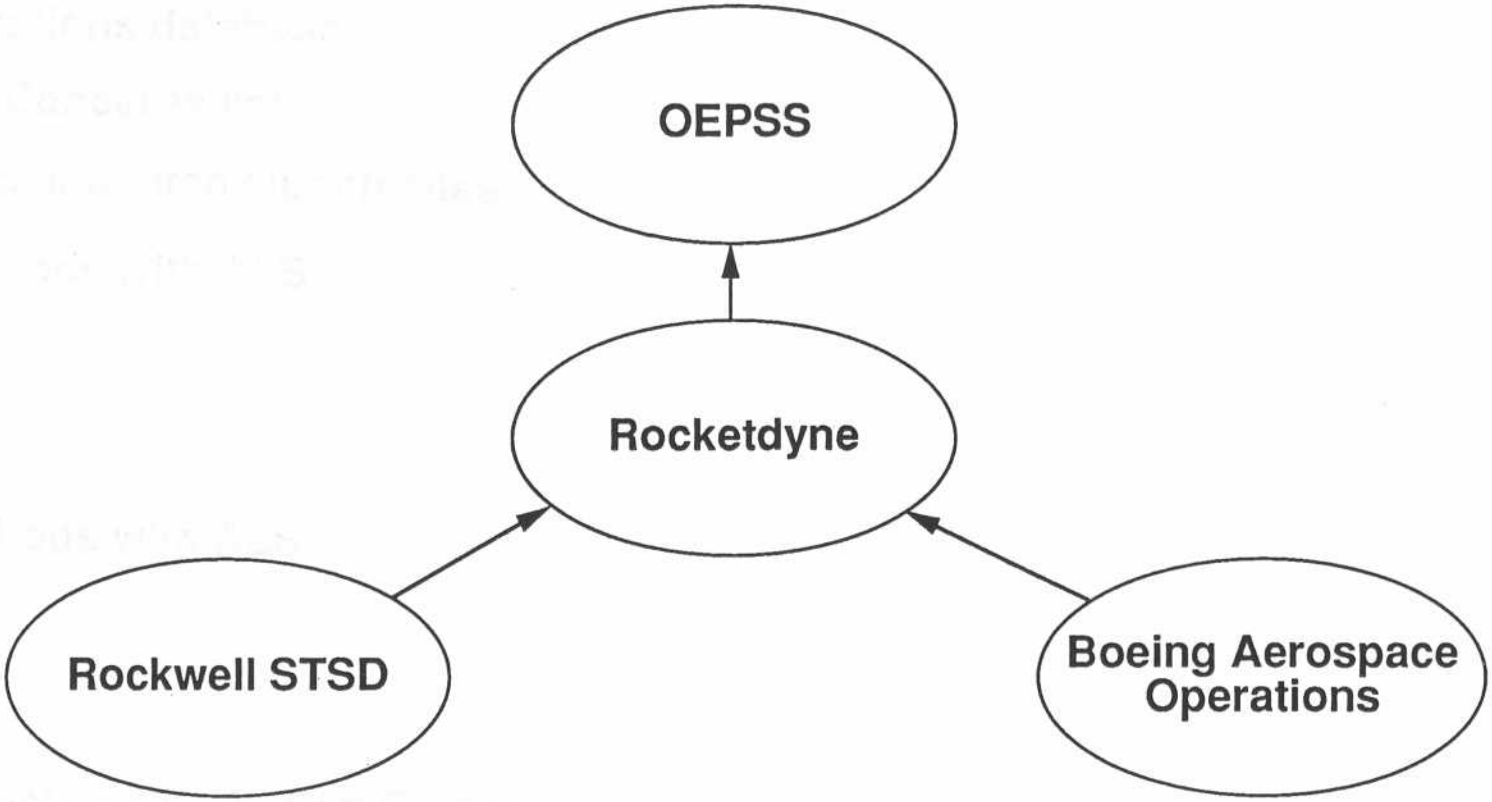
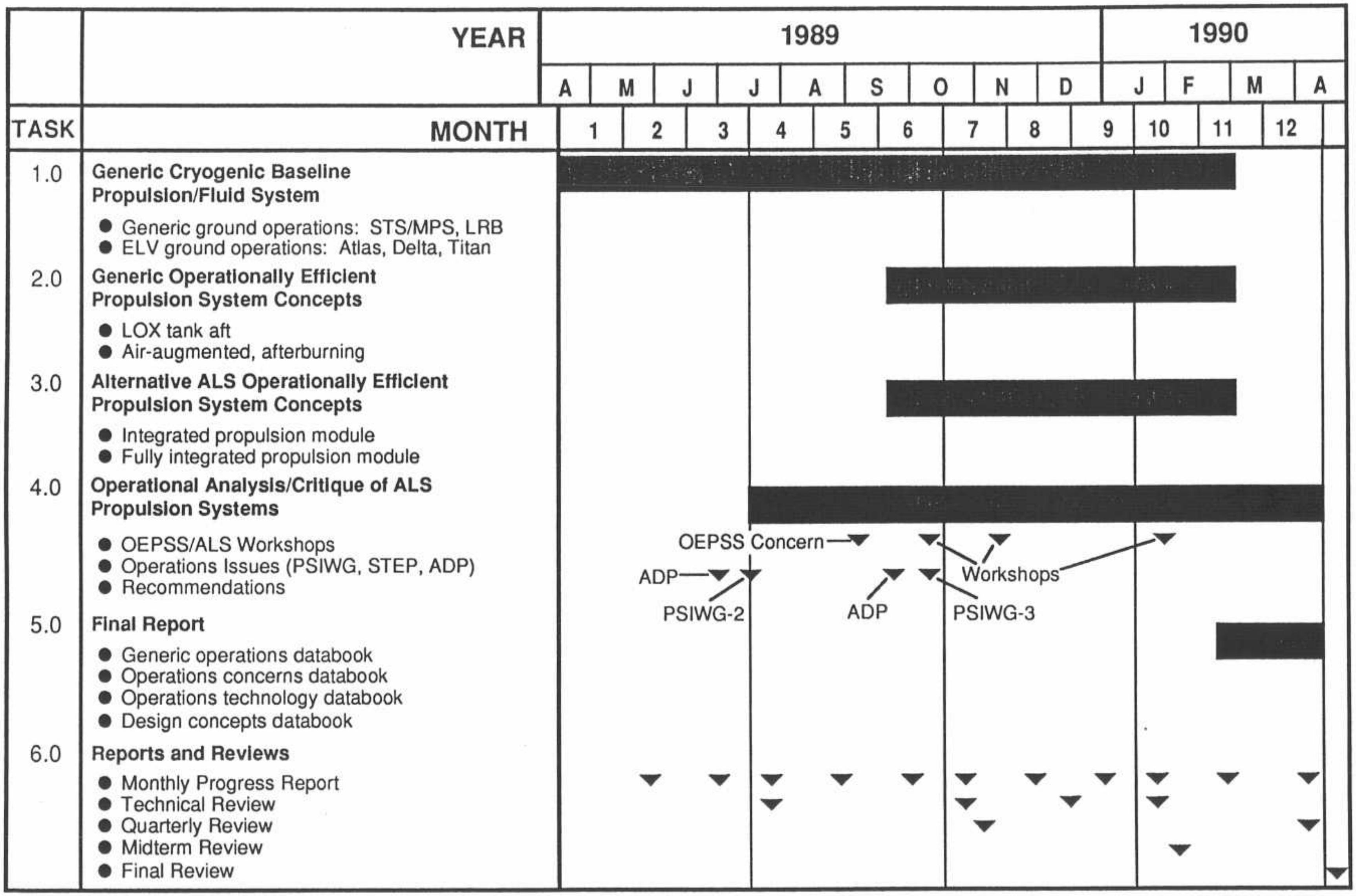
- Operations Problems ---------------------------- G. Waldrop
- Operations Technology ------------------------- G. Wong
- Operations Database

THE OEPSS TEAM

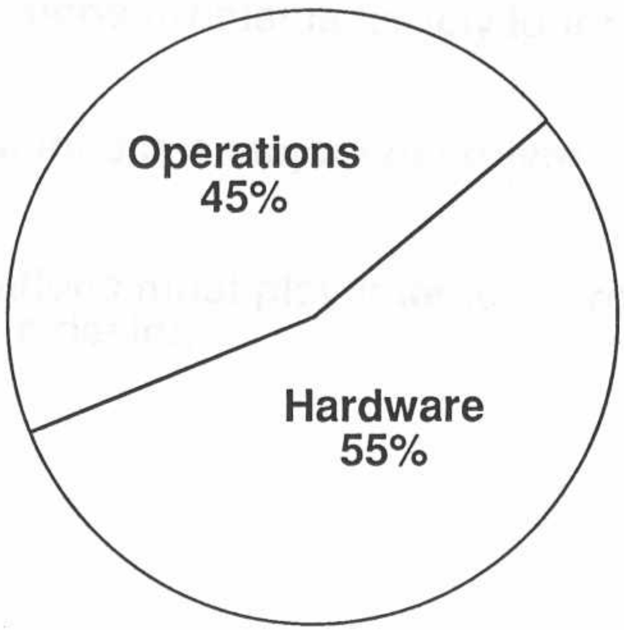


OEPSS STUDY SCHEDULE



LAUNCH OPERATIONS COST PER FLIGHT

% of Total Recurring Cost



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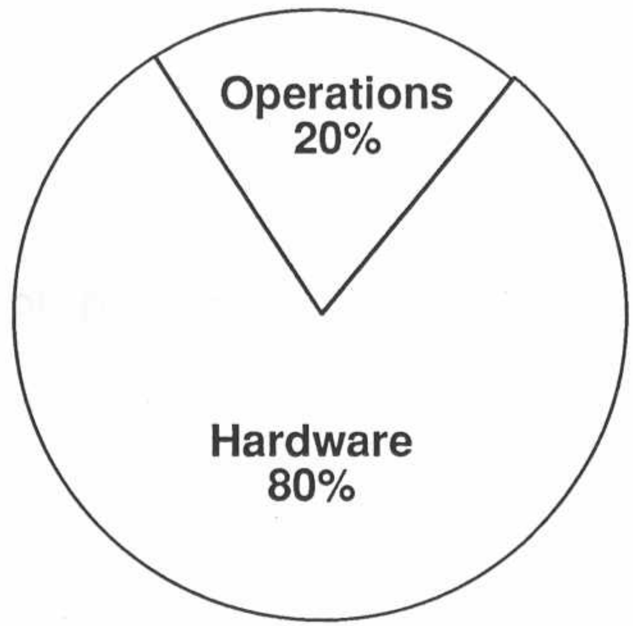
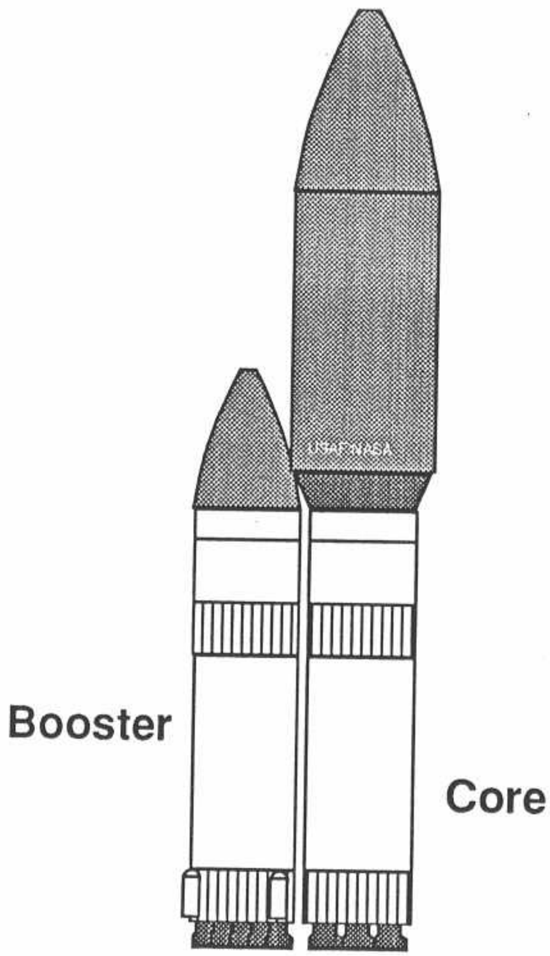


Titan IV

PROPULSION SYSTEM FOR ALS

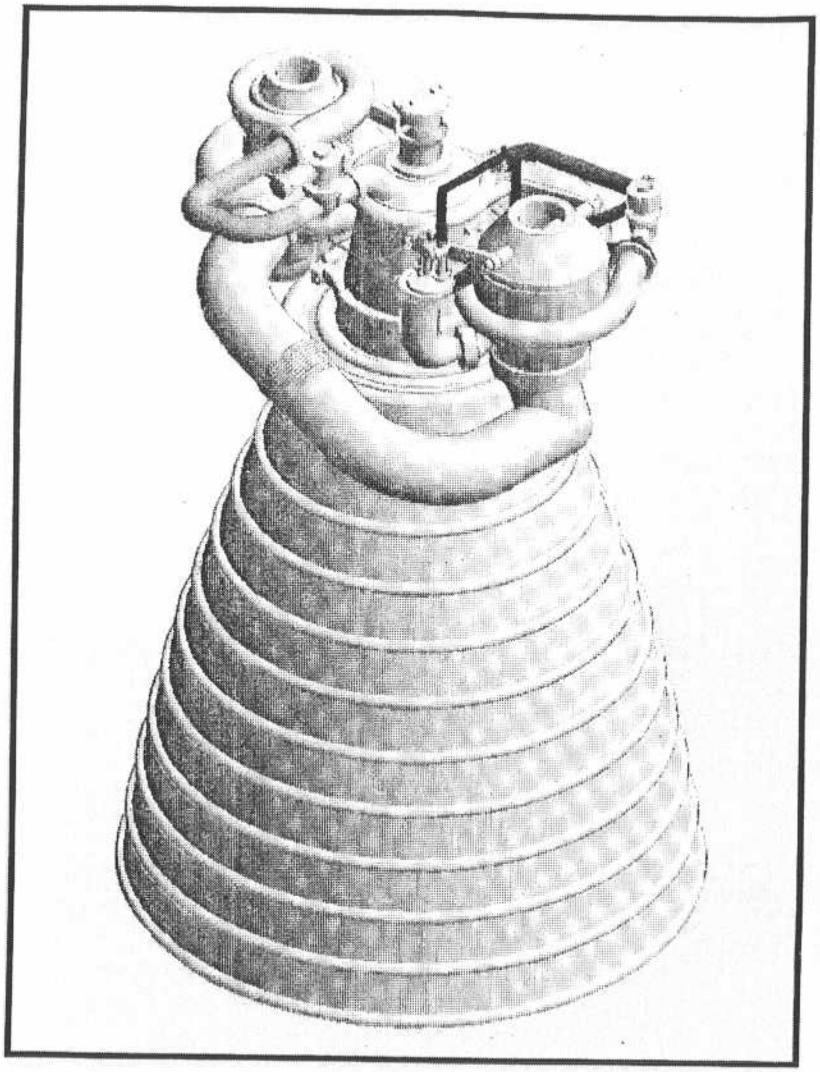
- **Defined as a totally "integrated" system of components and subsystems to provide vehicle thrust and control**
    - Tankage
    - Fluid Systems
    - Structure
    - Thrust Chamber(s)
    - Turbopump(s)
    - Controls
- **Use a "minimum" of components and subsystems to meet the functions of the propulsion 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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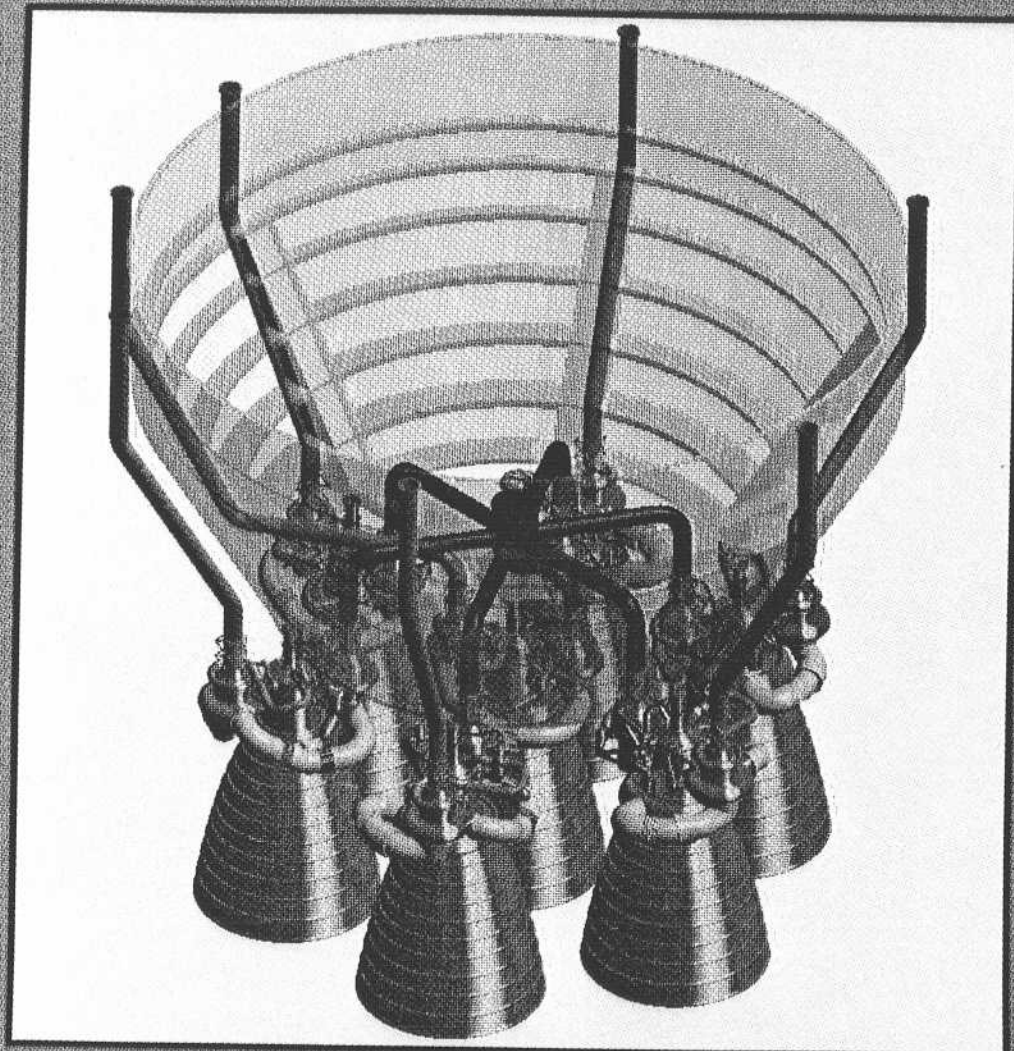
CONVENTIONAL BOOSTER PROPULSION SYSTEM
7 – ENGINE



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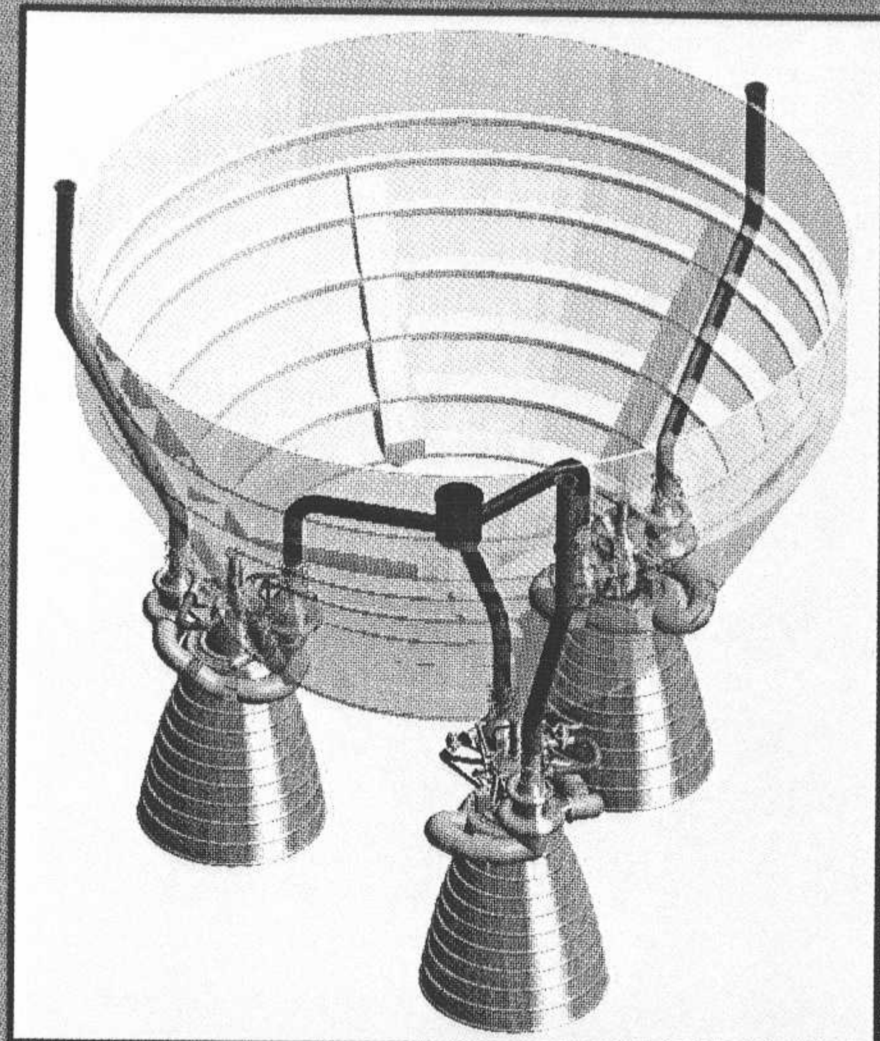
M803

CONVENTIONAL CORE PROPULSION SYSTEM
3 – ENGINE



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FULLY INTEGRATED PROPULSION MODULE

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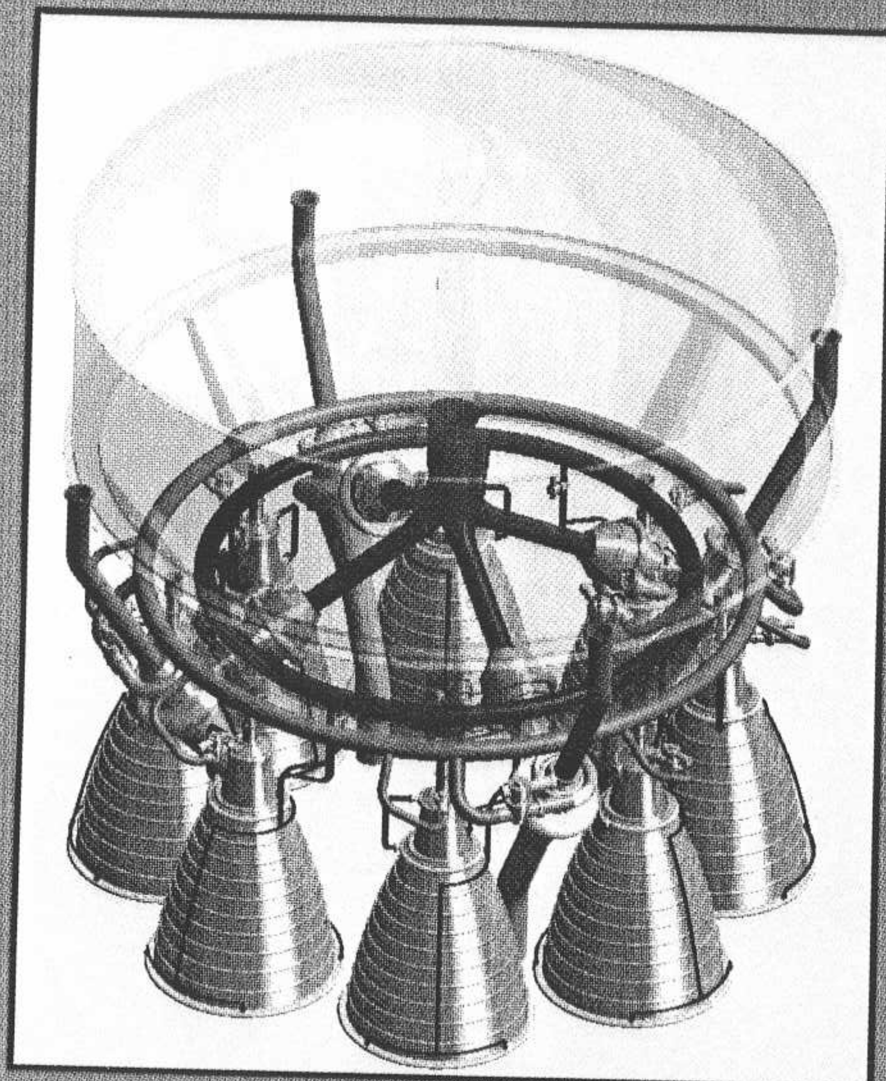
"INTEGRATED" DESIGN INCREASES OPERABILITY

- 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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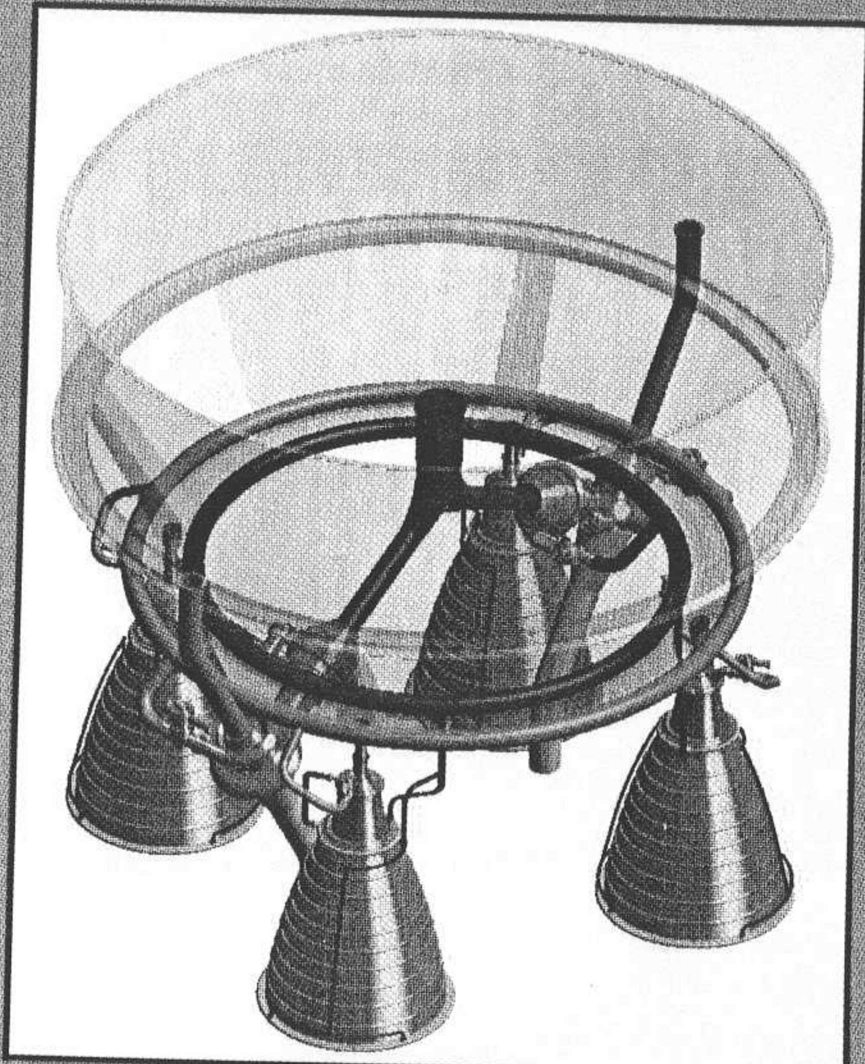
INTEGRATED CORE PROPULSION MODULE – ENGINE
4 – THRUST CHAMBERS



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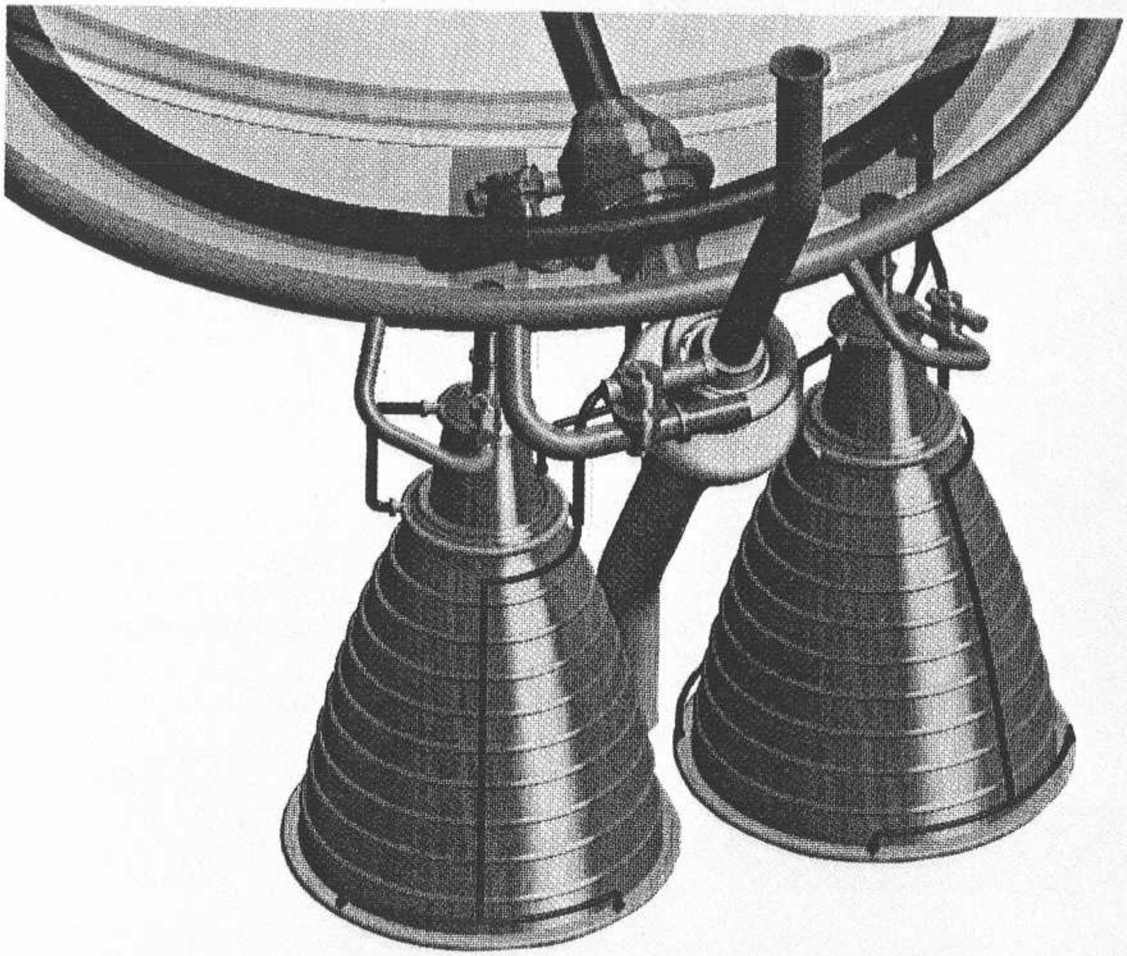
INTEGRATED PROPULSION MODULE – ENGINE ELEMENT



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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

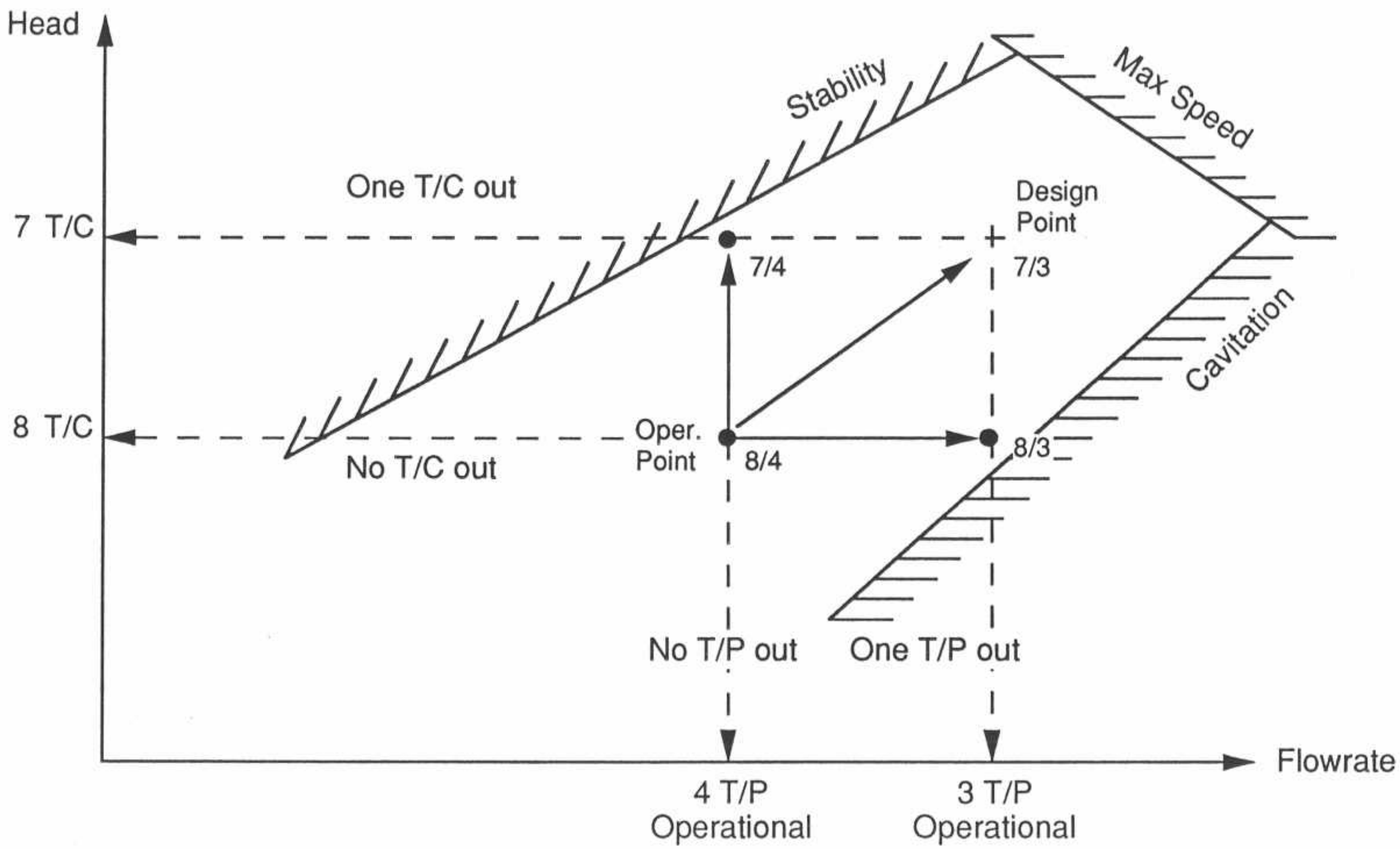
- **Normal engine operation at 85% nominal thrust**
- **Engine operates at 100% thrust with "engine-out" (1-T/C, 1-T/P)**
- **Outer thrust chamber arrangement maximizes maintainability**
- **Booster-core configuration achieves maximum commonality**
  - Identical module thrust structure
  - Identical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

ROBUST TURBOPUMP DESIGN

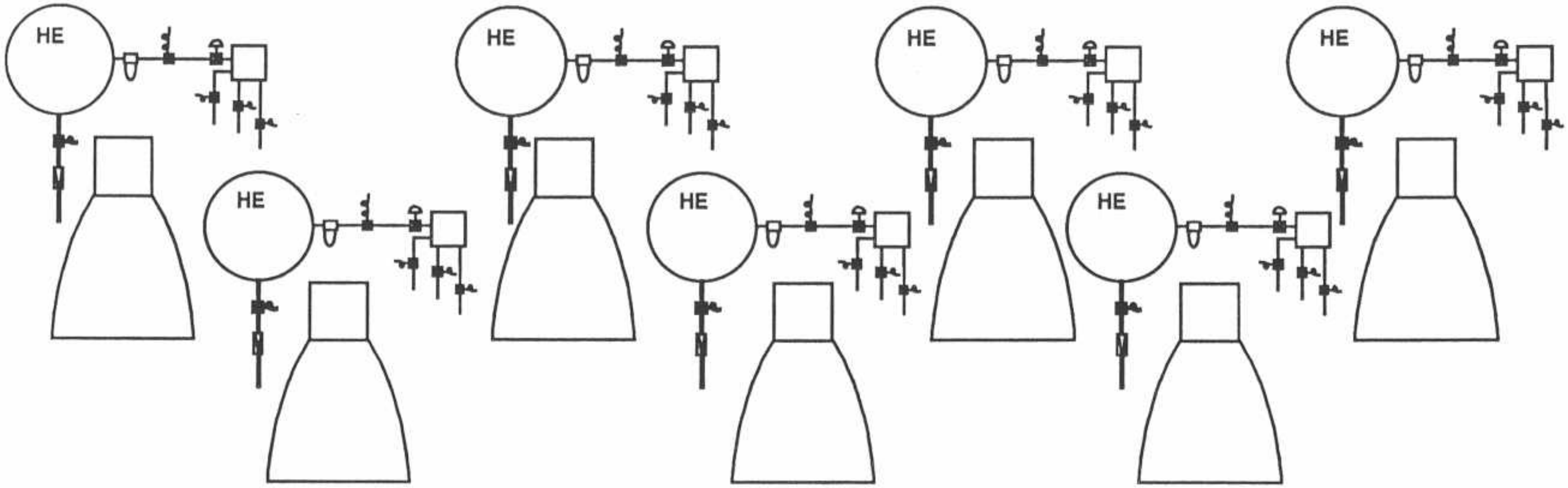
- Lower design speed
- Operating margin

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

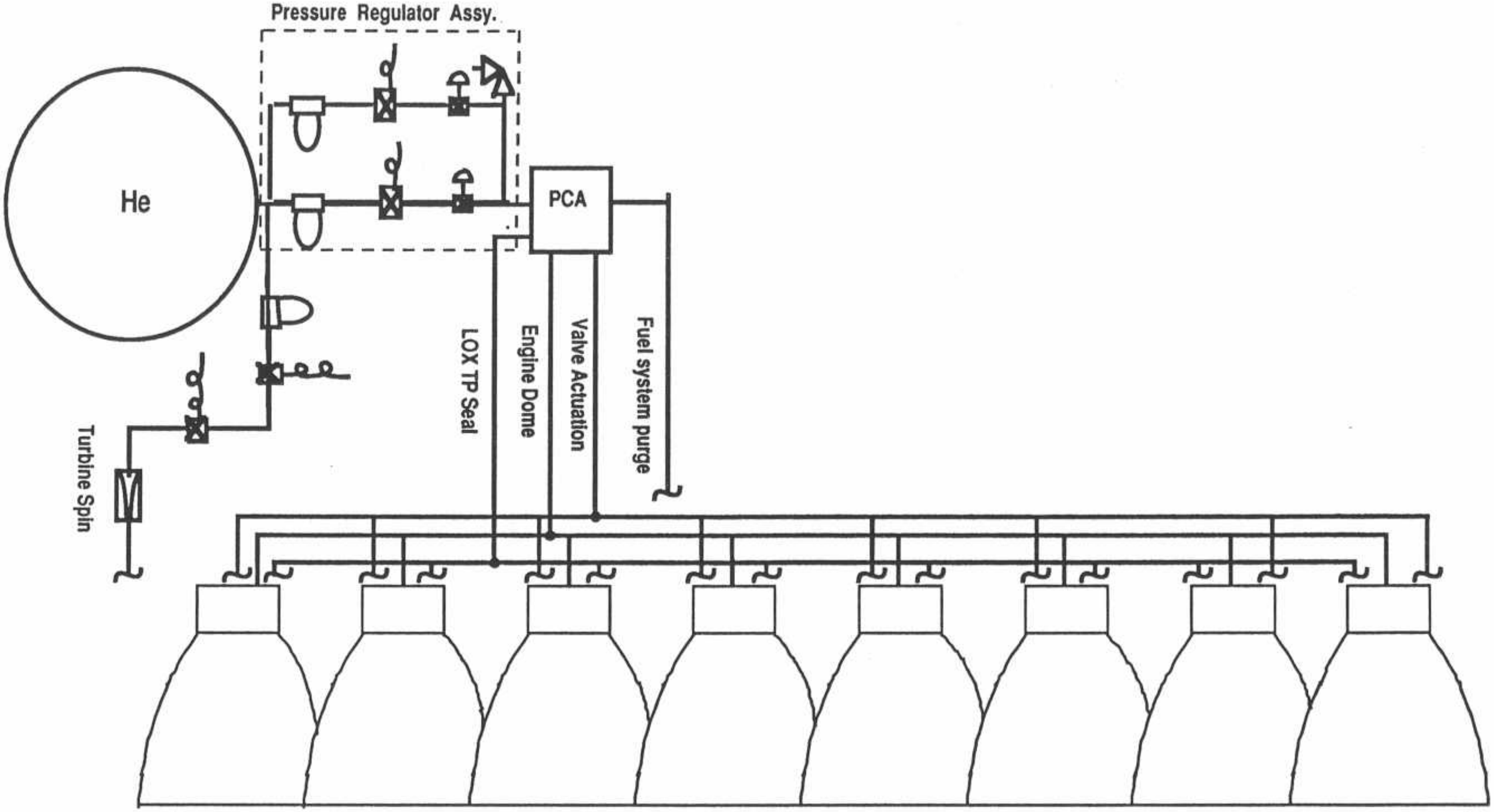


7- Helium tanks

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

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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

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SEPARATE ENGINES VS. INTEGRATED SYSTEM

	Separate Engines	Integrated System
• Control Systems	7	1
• He supply system	7	2
• Heat exchanger	7	2
• LOX turbopump	7	4
• LH_2-turbopump	7	4
• Gas generator	7	4
• Thrust chamber	7	8

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

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

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INTEGRATED DESIGN ADDRESSES OPERATIONS PROBLEMS DIRECTLY

No.	
(1)	Closed aft compartments
(2)	Hydraulic system (valve actuators and TVC)
(3)	Ocean recovery/refurbishment
4	Multiple propellants
5	Hypergolic propellants (safety)
(6)	Accessibility
(7)	Sophisticated heat shielding
(8)	Excessive components/subsystems
(9)	Lack hardware integration
10	Separate OMS/RCS
(11)	Pneumatic system (valve actuators)
(12)	Gimbal system
(13)	High maintenance turbopumps

No.	
14	Ordnance Operations
15	Retractable T-O umbilical carrier plates
16	Pressurization system
17	Inert gas purge
(18)	Excessive interfaces
19	Helium spin start
20	Conditioning/geysering (LO_2 tank forward)
(21)	Preconditioning system
(22)	Expensive helium usage - helium
(23)	Lack hardware commonality
(24)	Propellant contamination
25	Side-mounted booster vehicles (multiple stage propulsion systems)

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

Integrated Engine:	T/C	T/P	Payload Capability, lbs 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

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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

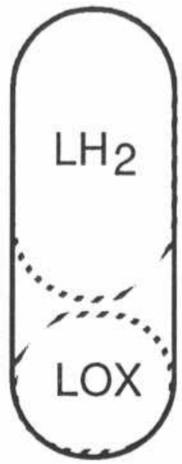
ANTIGEYSER LOX TANK AFT PROPULSION CONCEPT

OEPSS CONCERN - LOX TANK POSITION

- <u>Concern:</u> **ALS vehicle concepts position LOX tank forward of LH_2 tank**
- **<u>Operational impacts</u>**
  - 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
- **<u>Other impacts</u>**
  - LH_2 tank and intertank structure required to support heavy LOX tank

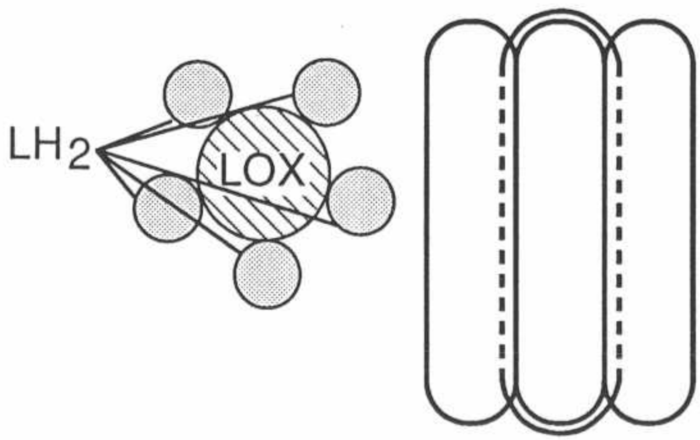
ANTIGEYSER LOX TANK AFT PROPULSION SYSTEM

- **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

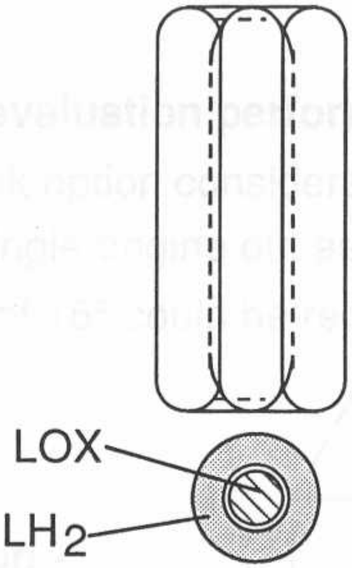
- **<u>Multiple tanks</u> (similar to Saturn 1)**



- 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

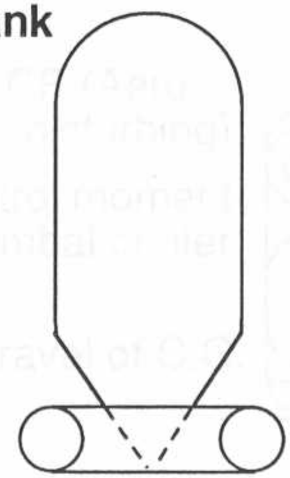
ANTIGEYSER LOX TANK AFT PROPULSION SYSTEM

- **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

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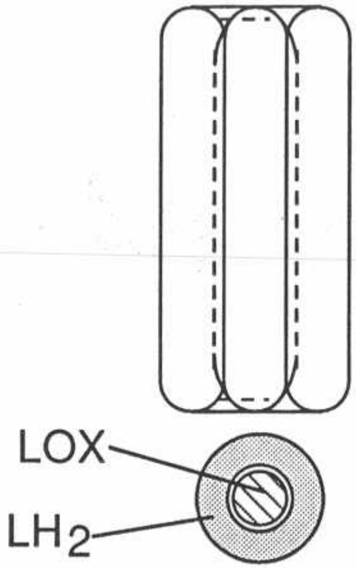
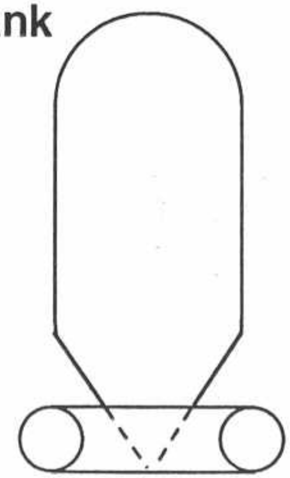
ANTIGEYSER LOX TANK AFT PROPULSION SYSTEM

- **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**

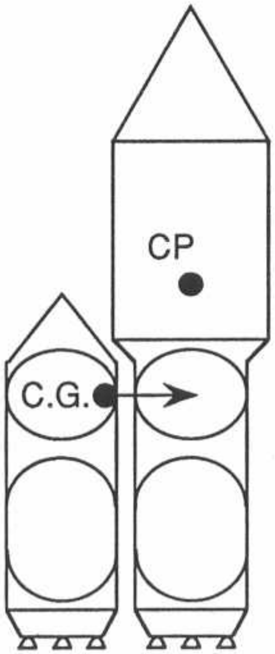


- Both LOX and LH_2 feed lines short
- Greatly reduced pogo & geyser problems
- Tank weight increased (≈ 10%)
- Reduced control authority from aft C.G. location
- Fabrication problems can increase costs
- Efficient thrust load path LOX tank not involved

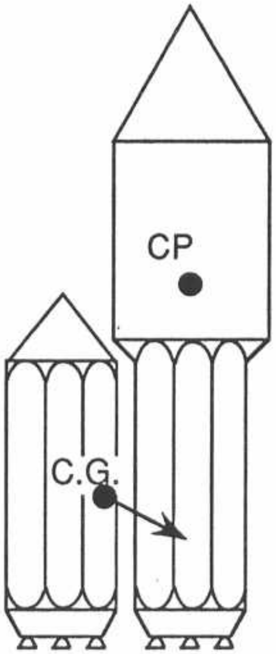
VEHICLE CONTROL IMPACT

- **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

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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

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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

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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

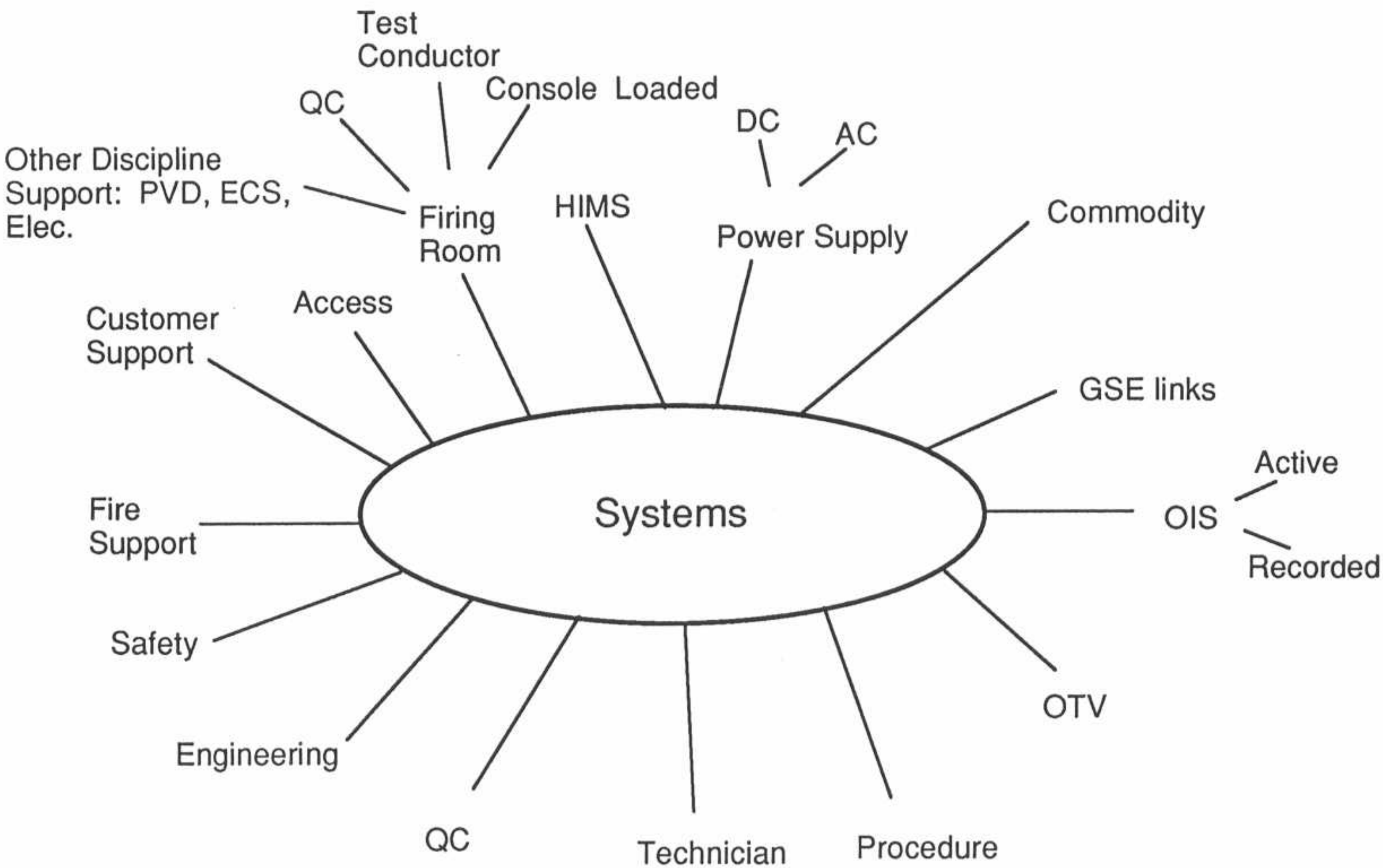
Causes and Effects

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		

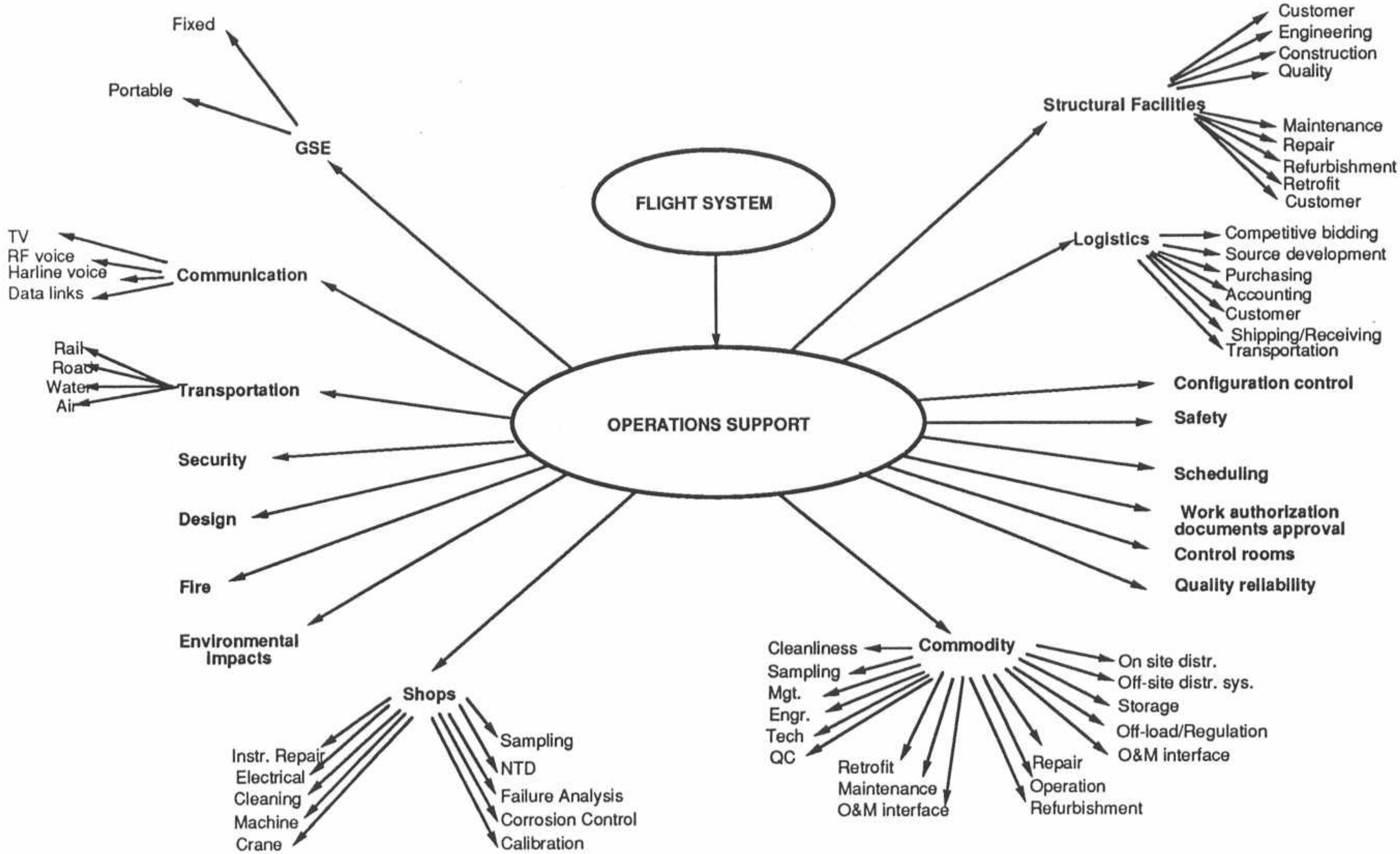
OEPSS CONCERNS LIST

"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

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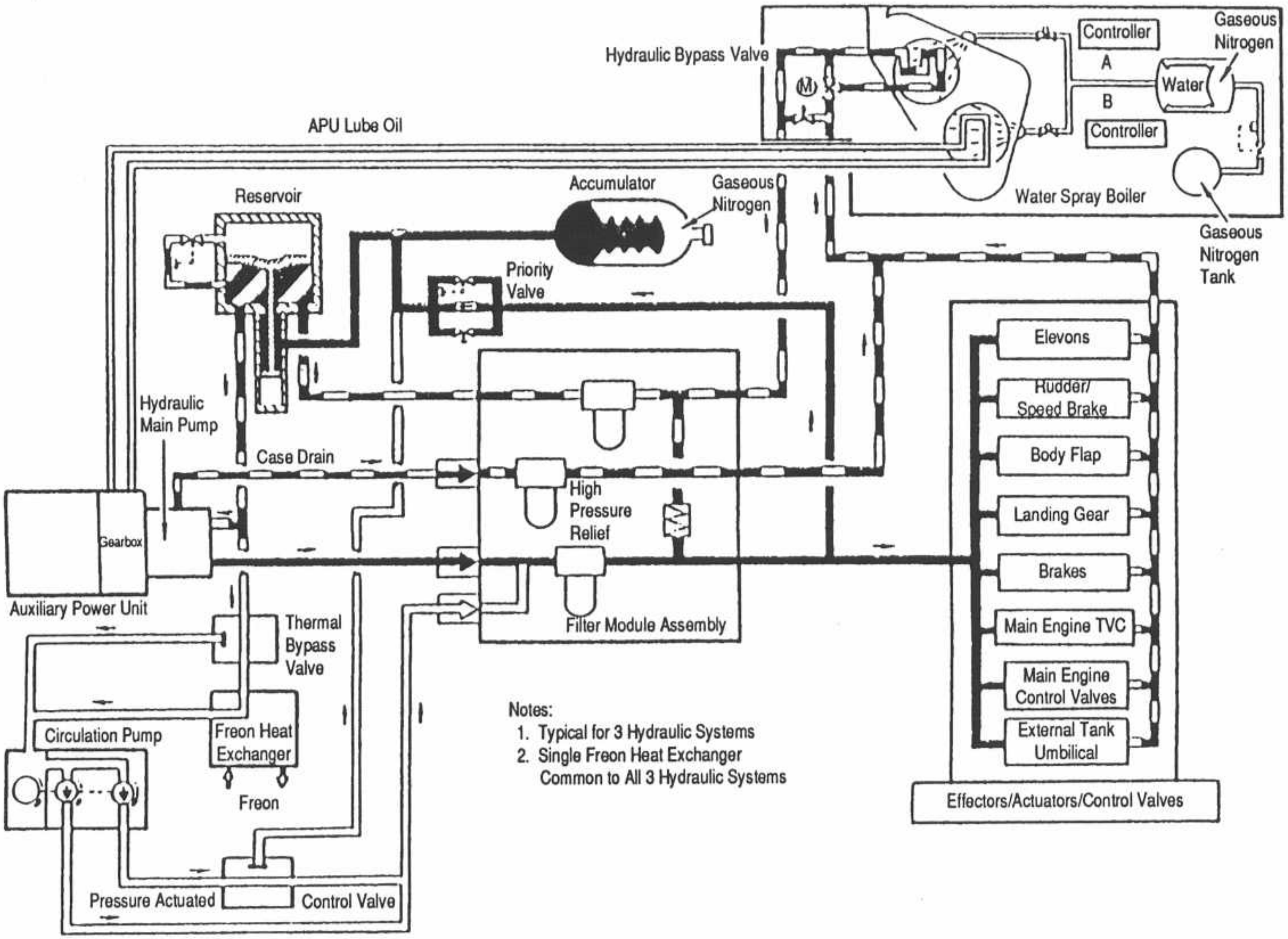
HYDRAULIC POWER SYSTEM



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

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"

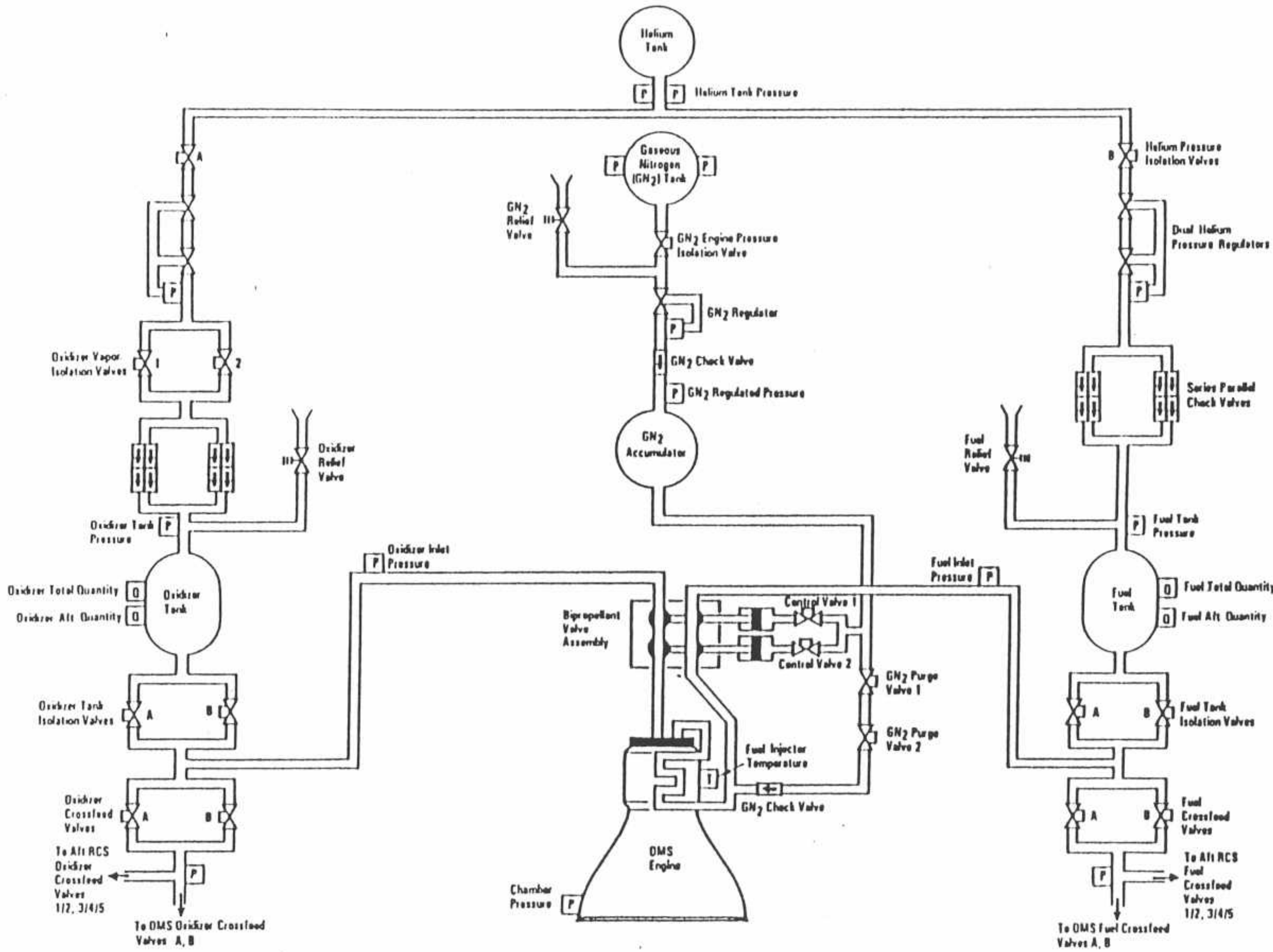
- **Concern: OEPSS - 4**
  - Multiple propellants
- **Operational impacts:**
  - Multiple commodities require:
    - Multiple facilities for storage and transfer
    - Multiple headcount and administrative support
    - Extra support for procurement/logistics
    - Vehicle complexity necessary for multiple 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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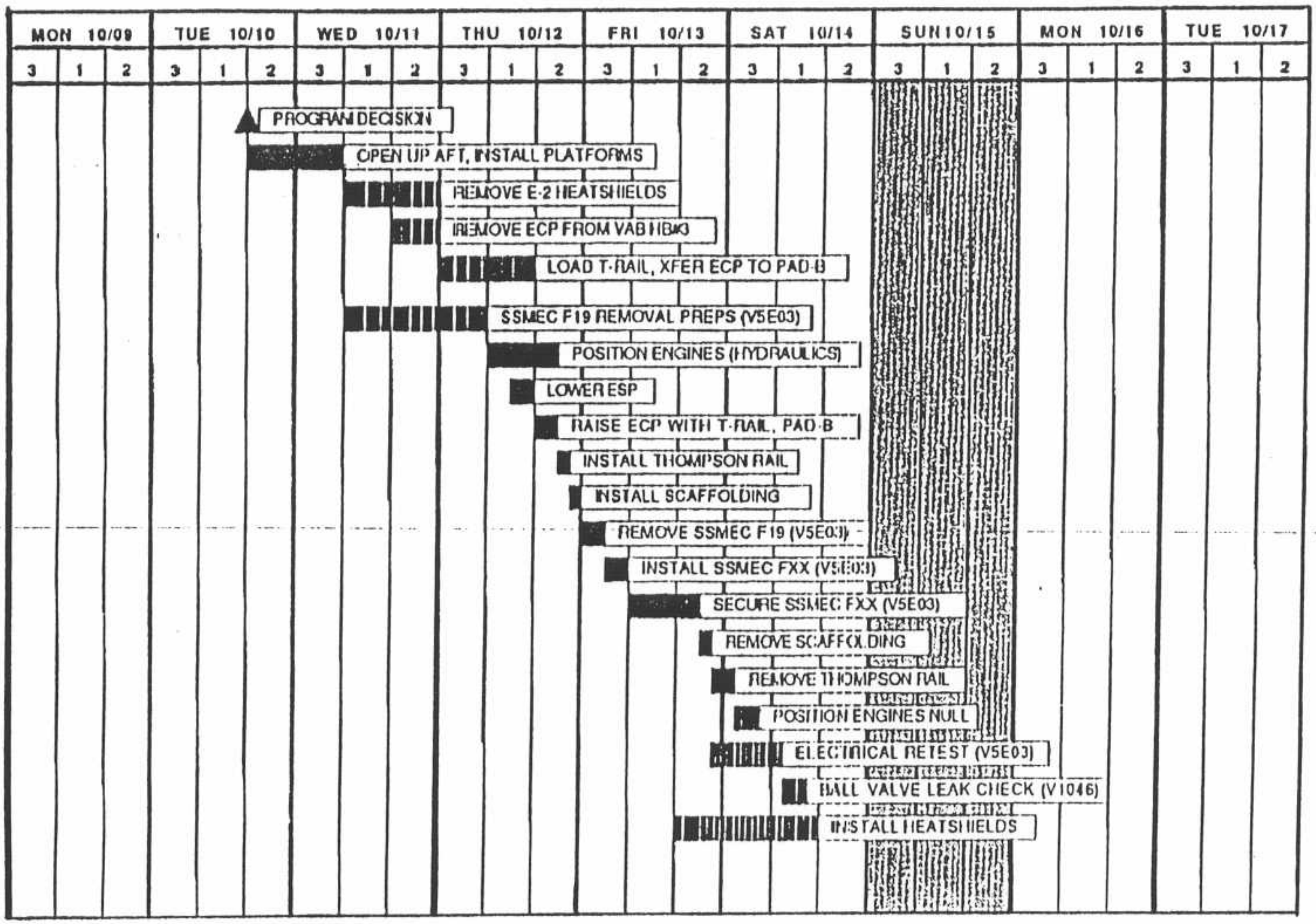
OEPSS CONCERNS LIST

"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"

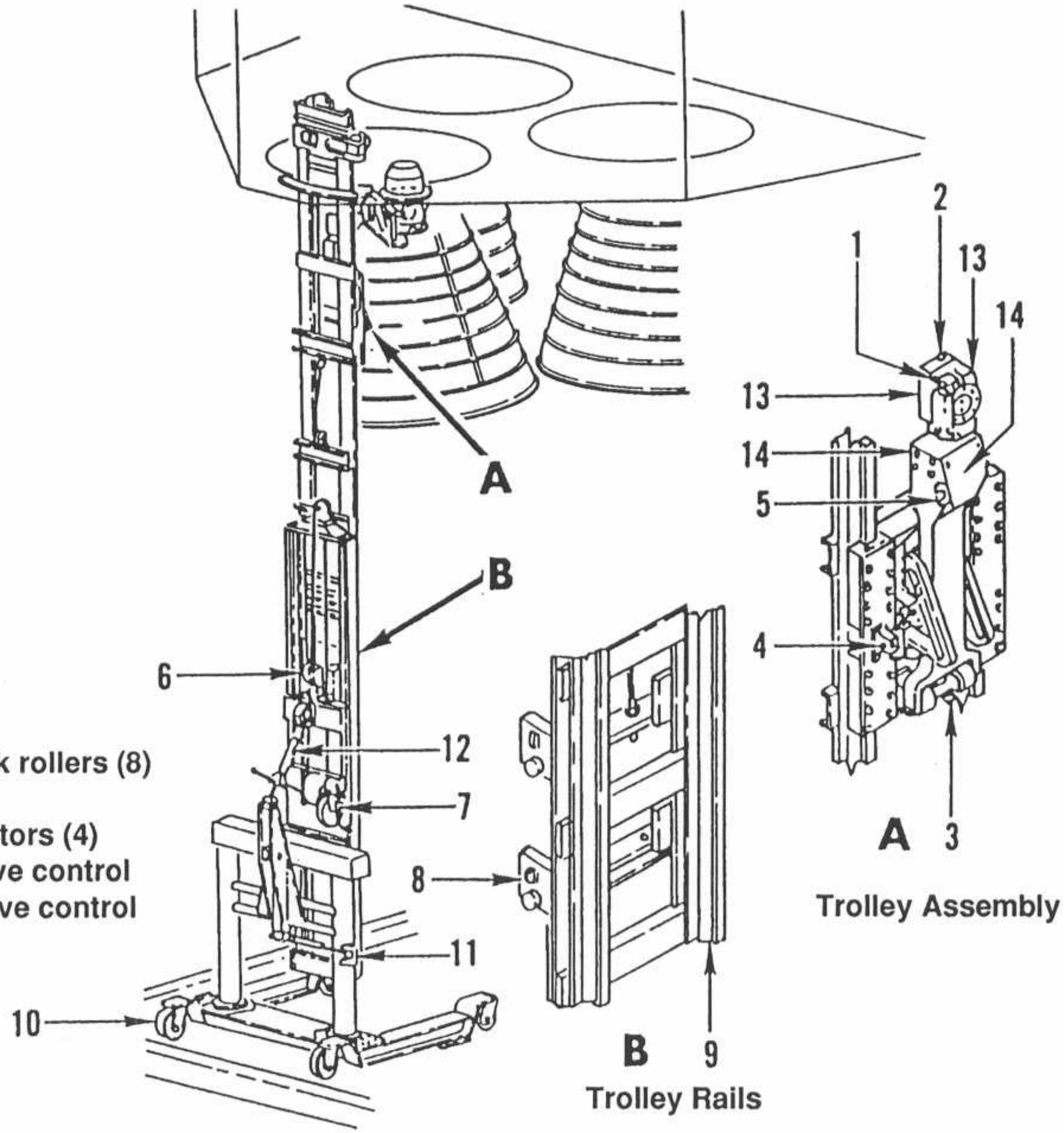
- **Concern: OEPSS - 12**
  - Gimbal system requirements
- **Operational impacts:**
  - System complexity - Actuator system, gimbal bearings, control system
    - Maintenance
    - Servicing
    - Prelaunch checkout
  - Hydraulics - addressed in OEPSS - 2
- **Potential options for consideration:**
  - 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

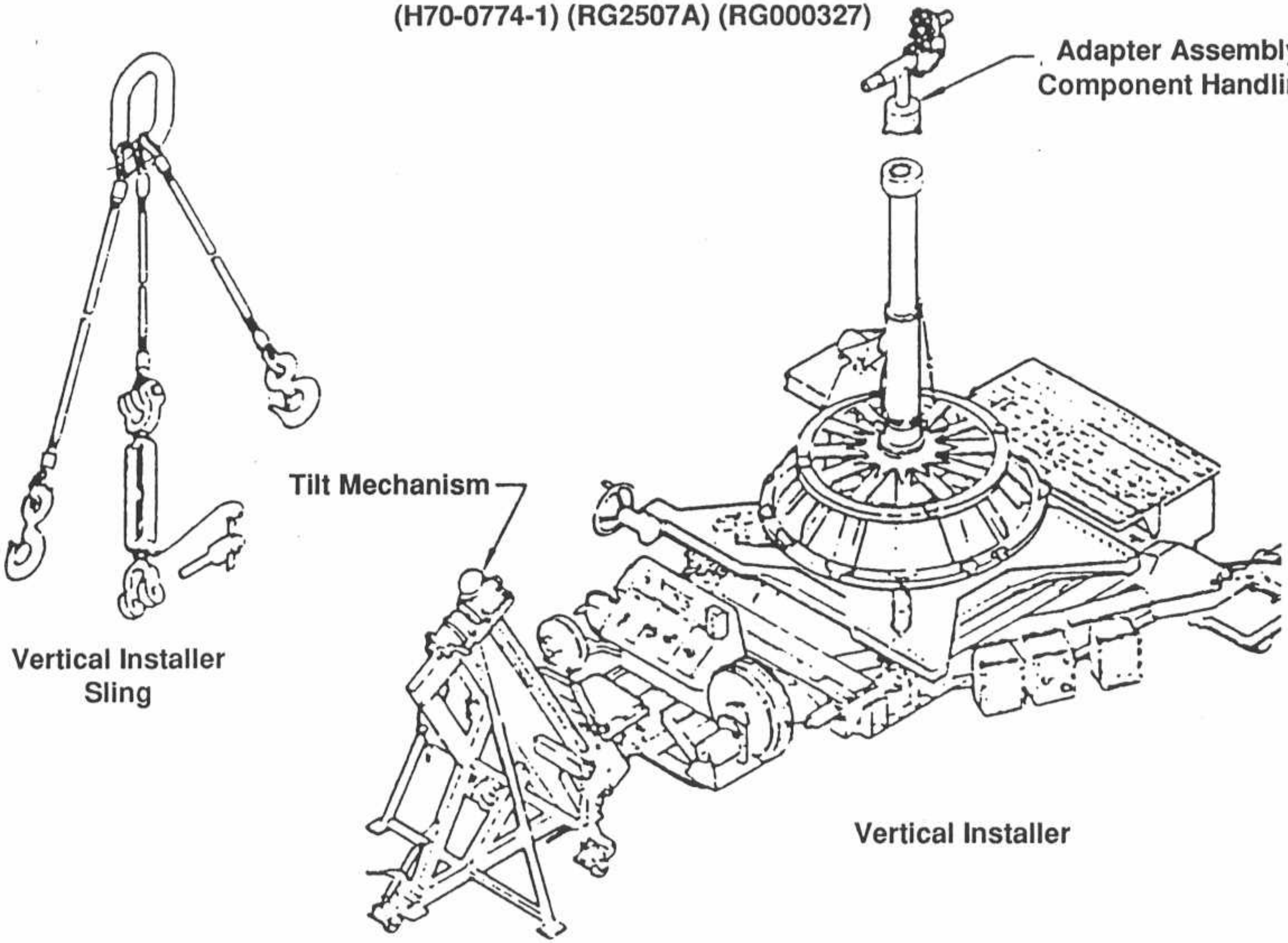


Legend

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

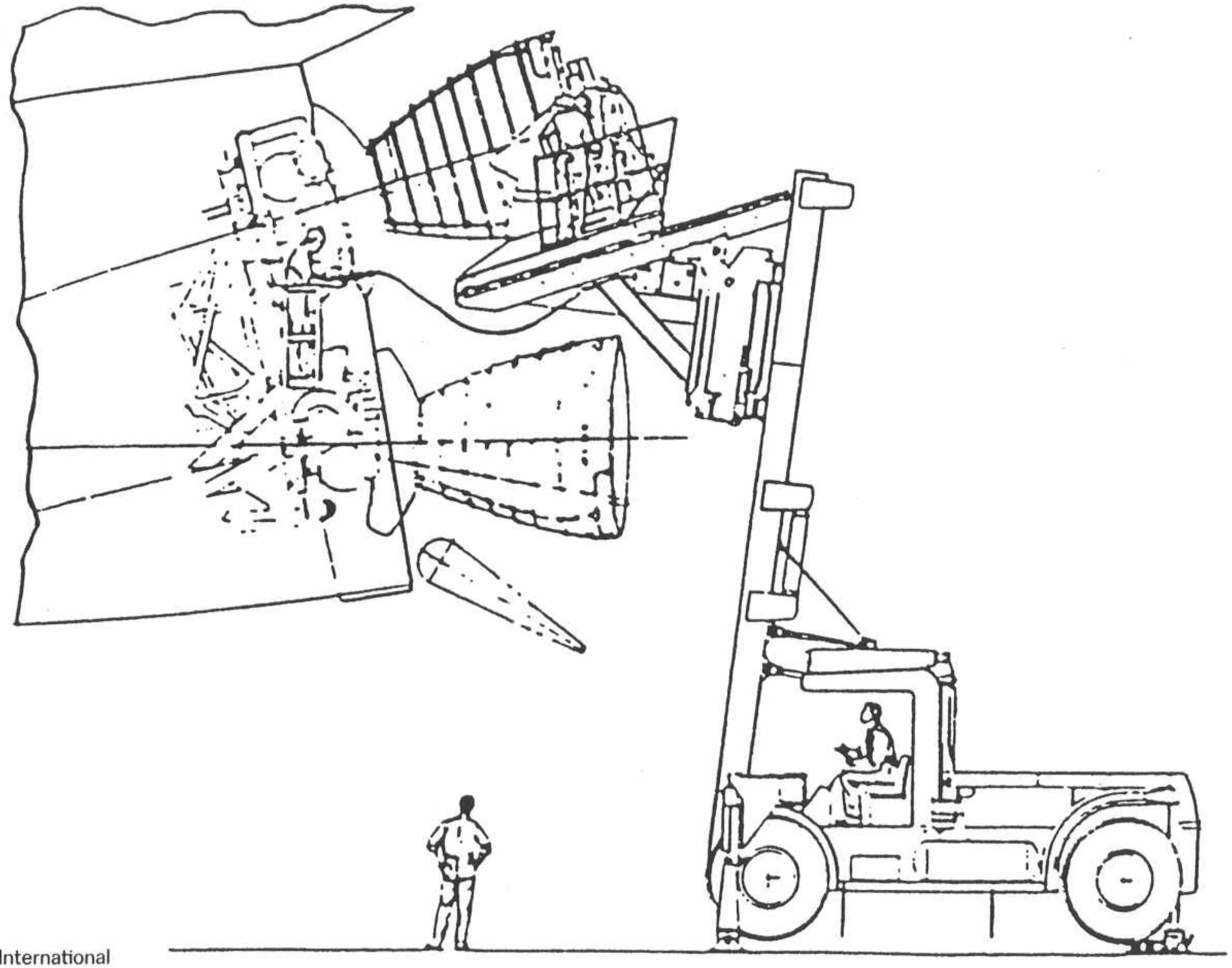
VERTICAL INSTALLER

(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"

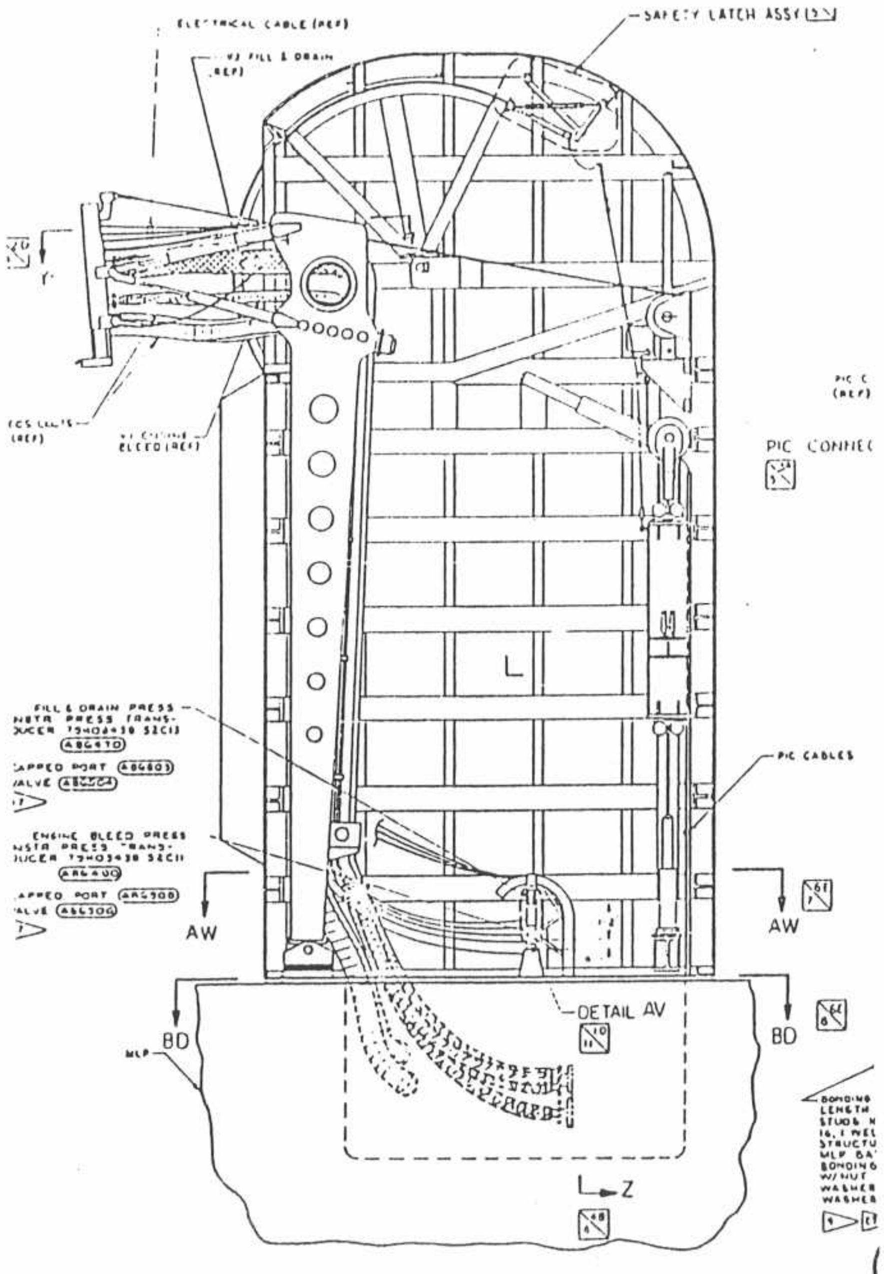
- **Concern: OEPSS - 14**
  - Ordnance operations
- **Operational impacts:**
  - Loss of parallel processing caused by "area clear" evacuations
  - Disposal of unused ordnance from recovered vehicle elements is hazardous and costly
  - Separate, hazardous storage facilities required
- **Potential options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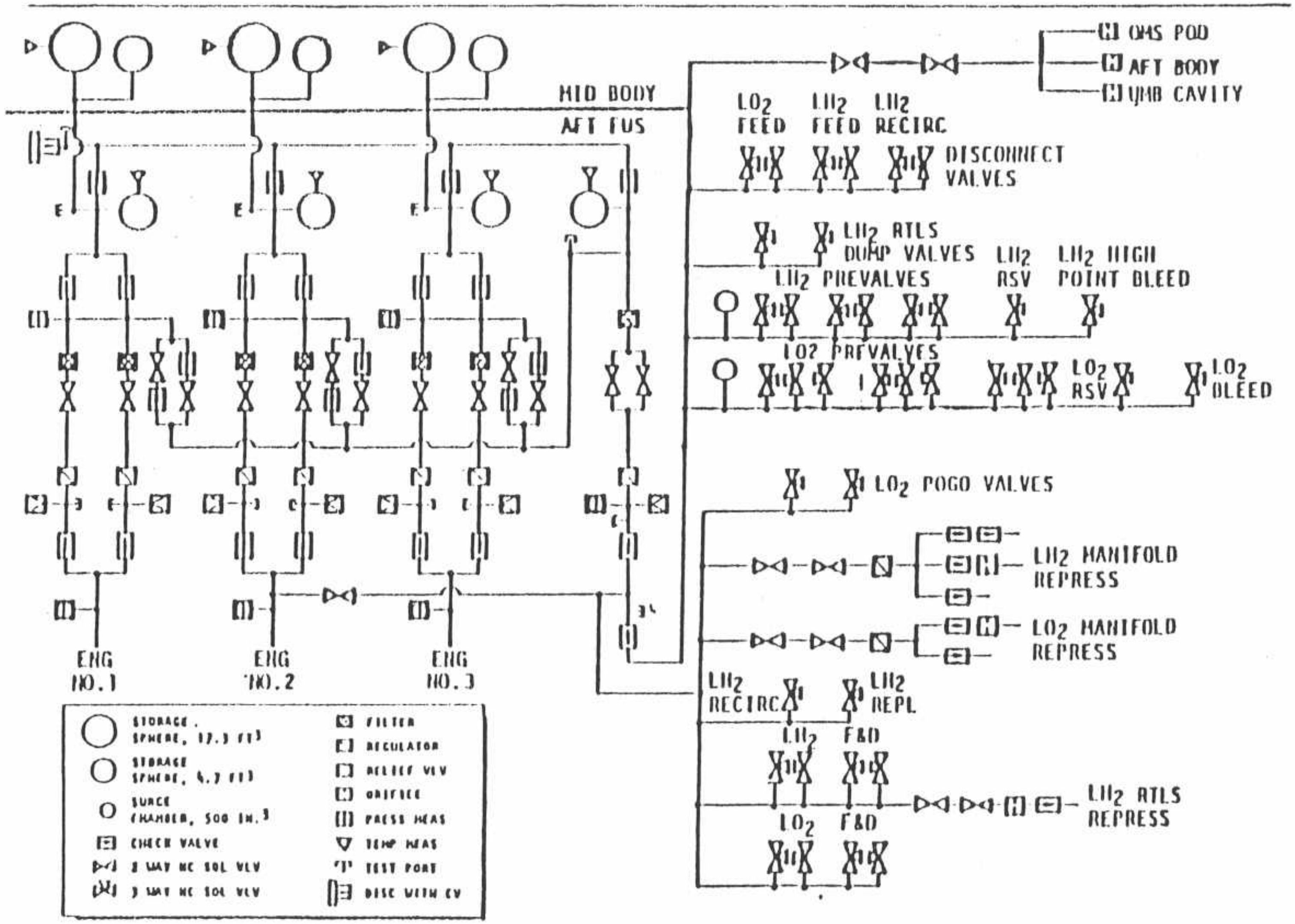
OEPSS CONCERNS LIST
"Launch Site Experience Base"

- **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



OEPSS CONCERNS LIST
"Launch Site Experience Base"

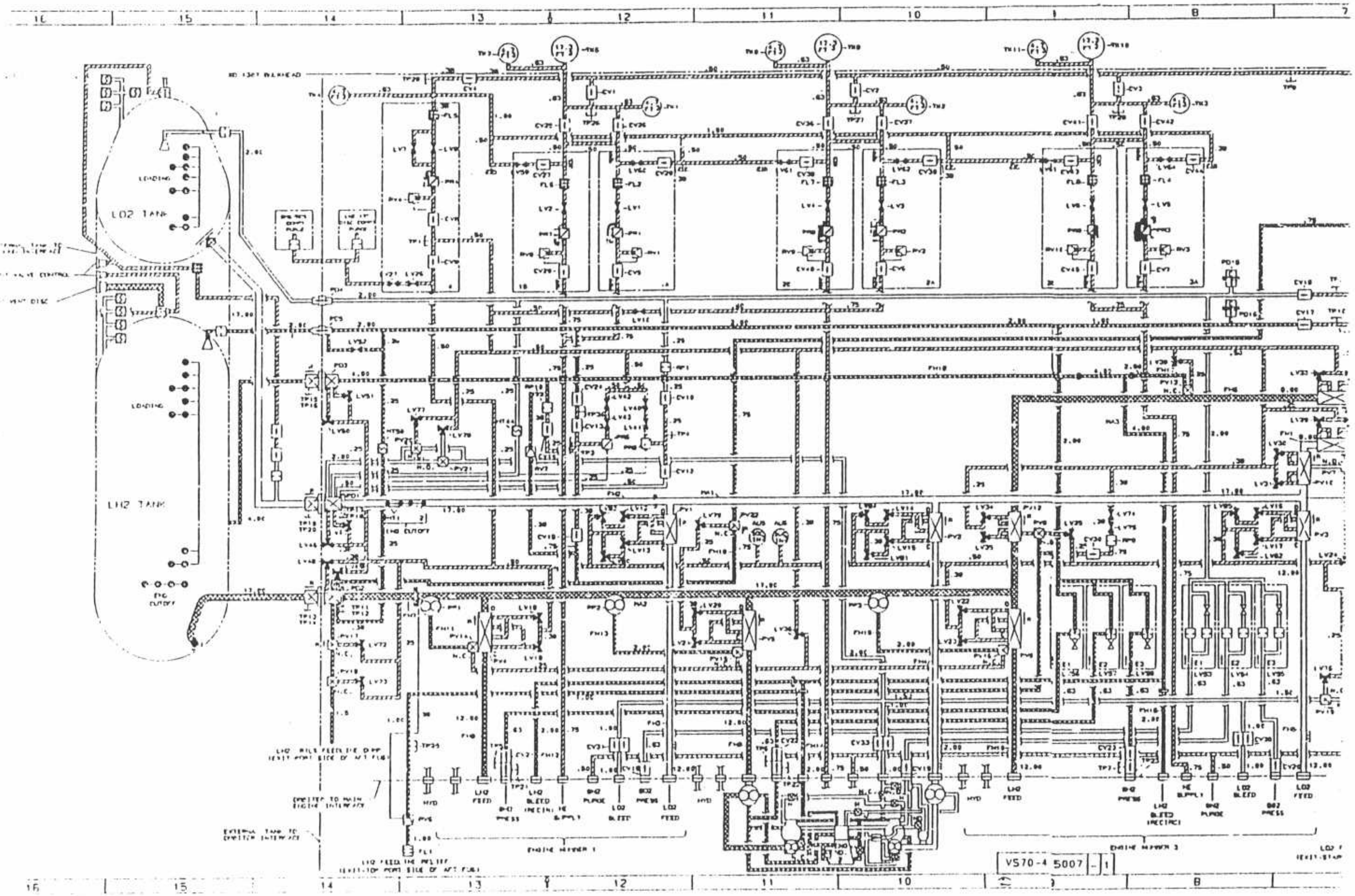
- **Concern:** **OEPSS - 17**
  - Inert gas purging requirements
- **Operational impacts:**
  - Requires sophisticated ground distribution/control system
    - High pressure reduction/control system with redundancy
    - Requires both local and remote operation capability
    - Requires "army" to maintain,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



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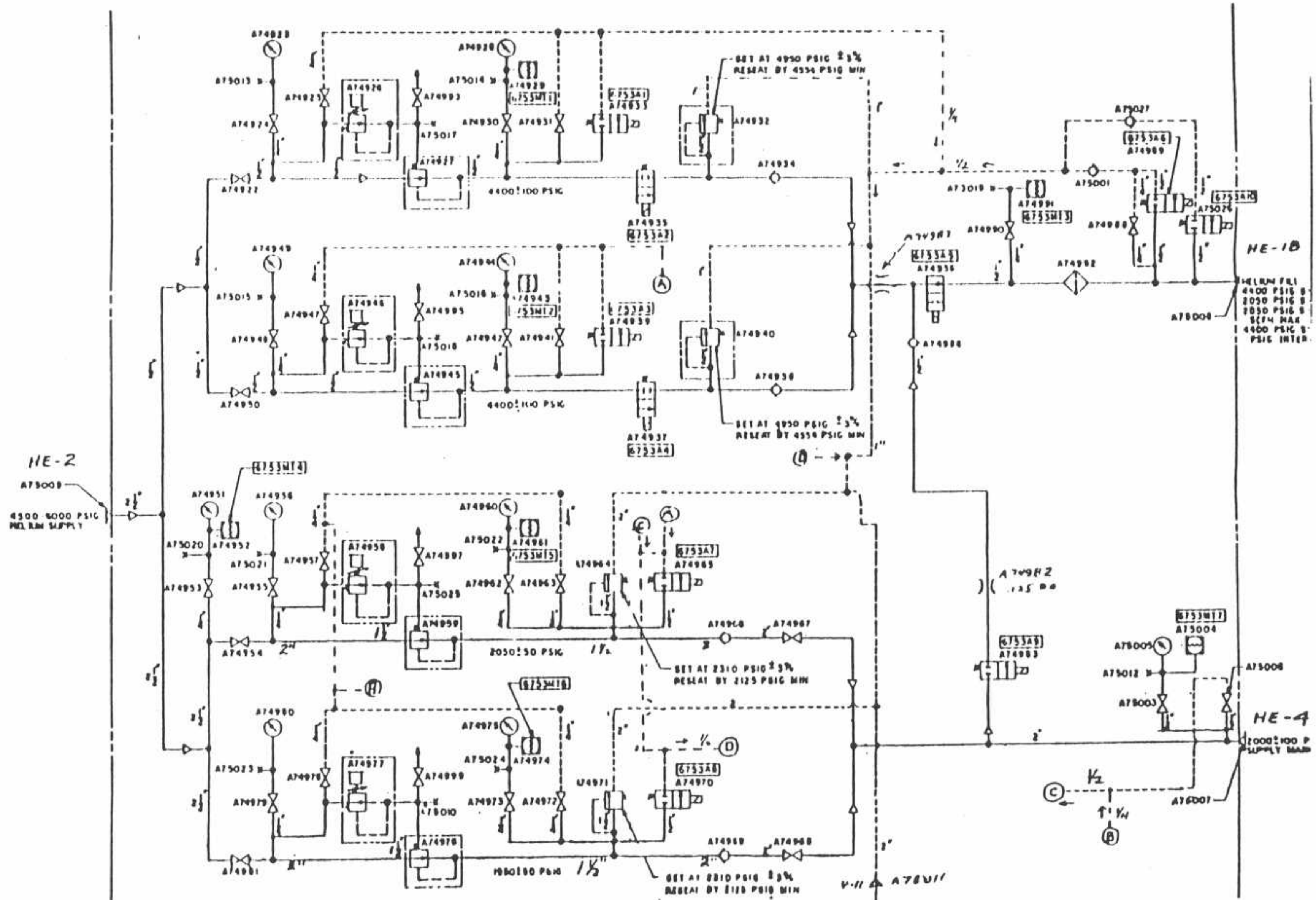
HELIUM SUPPLY PANEL (MLP)



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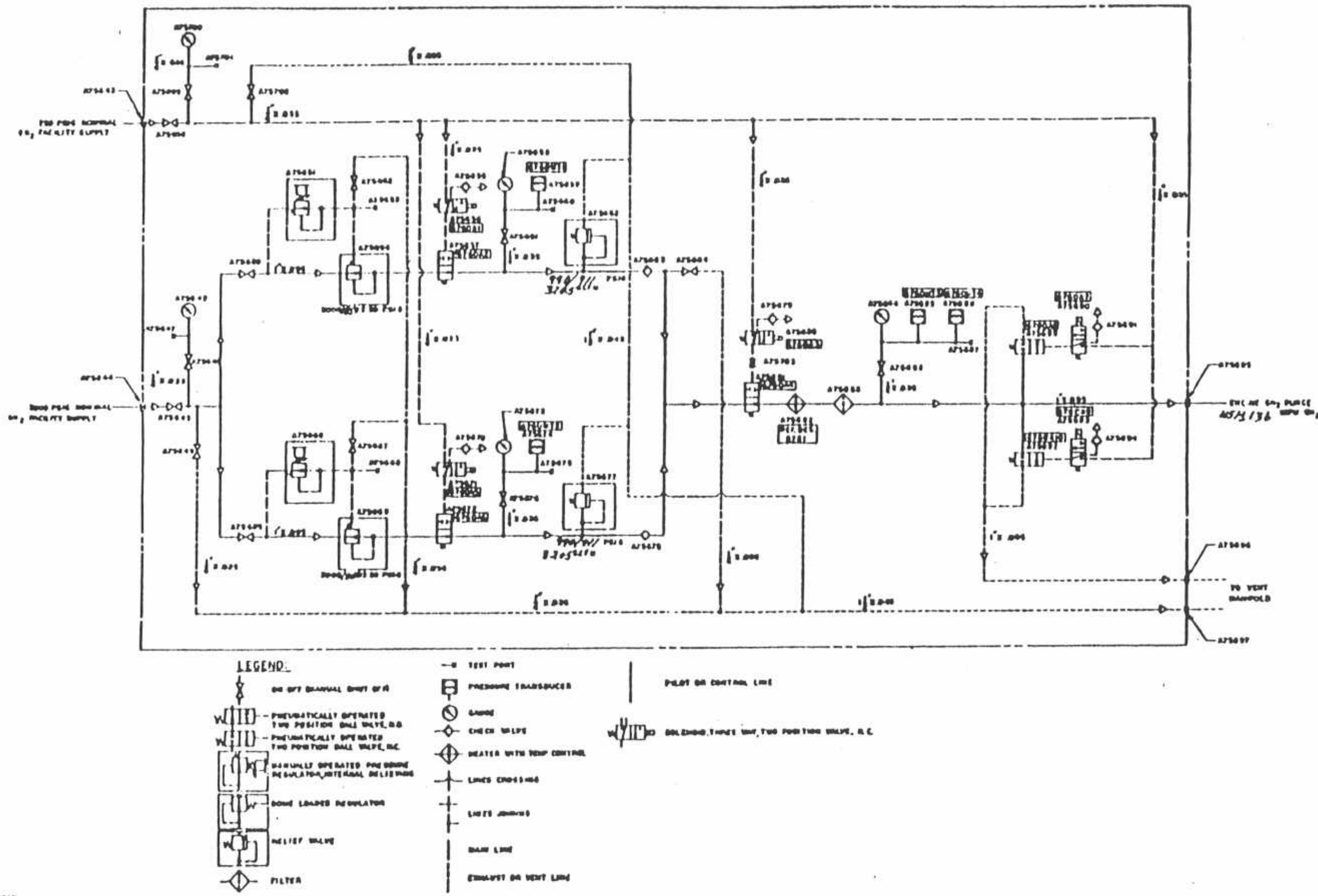
GN_2 PURGE PANEL MLP



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OEPSS CONCERNS LIST

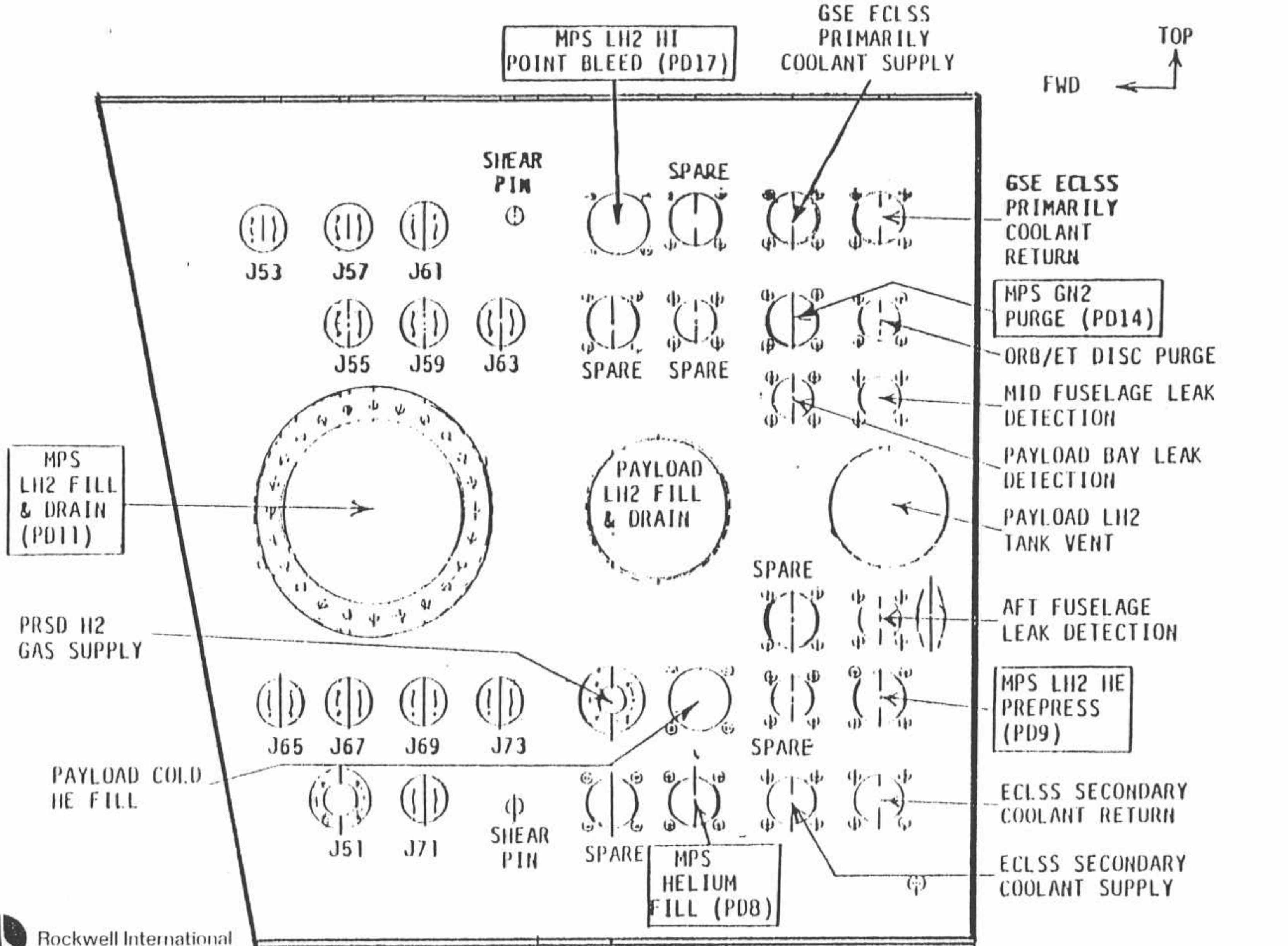
"Launch Site Experience Base"

- **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

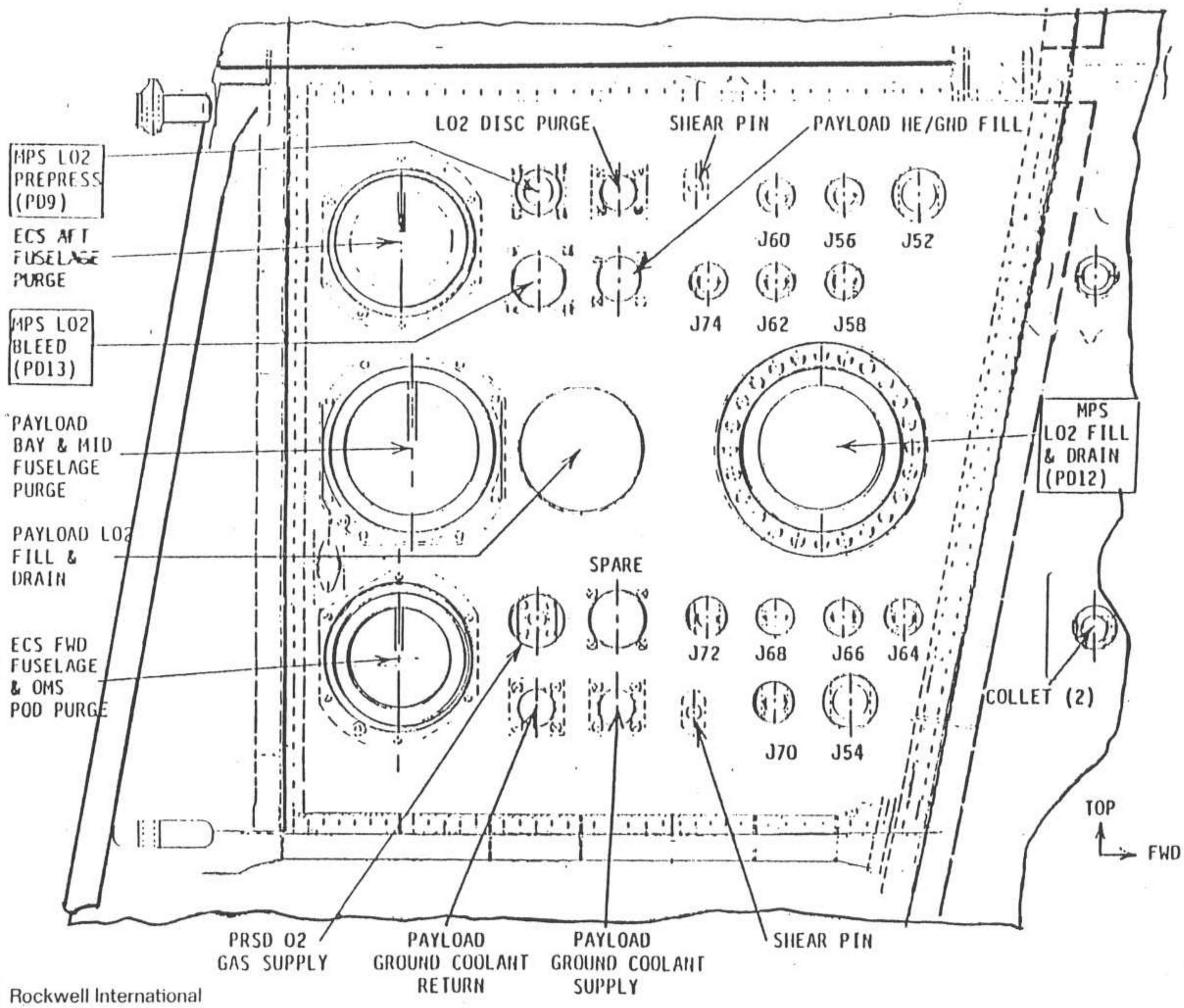
MLP MAIN PROPULSION GSE

- **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



LO2 T-O UMBILICAL PANEL ORBITER RIGHT SIDE



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

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OEPSS CONCERNS LIST

"Launch Site Experience Base"

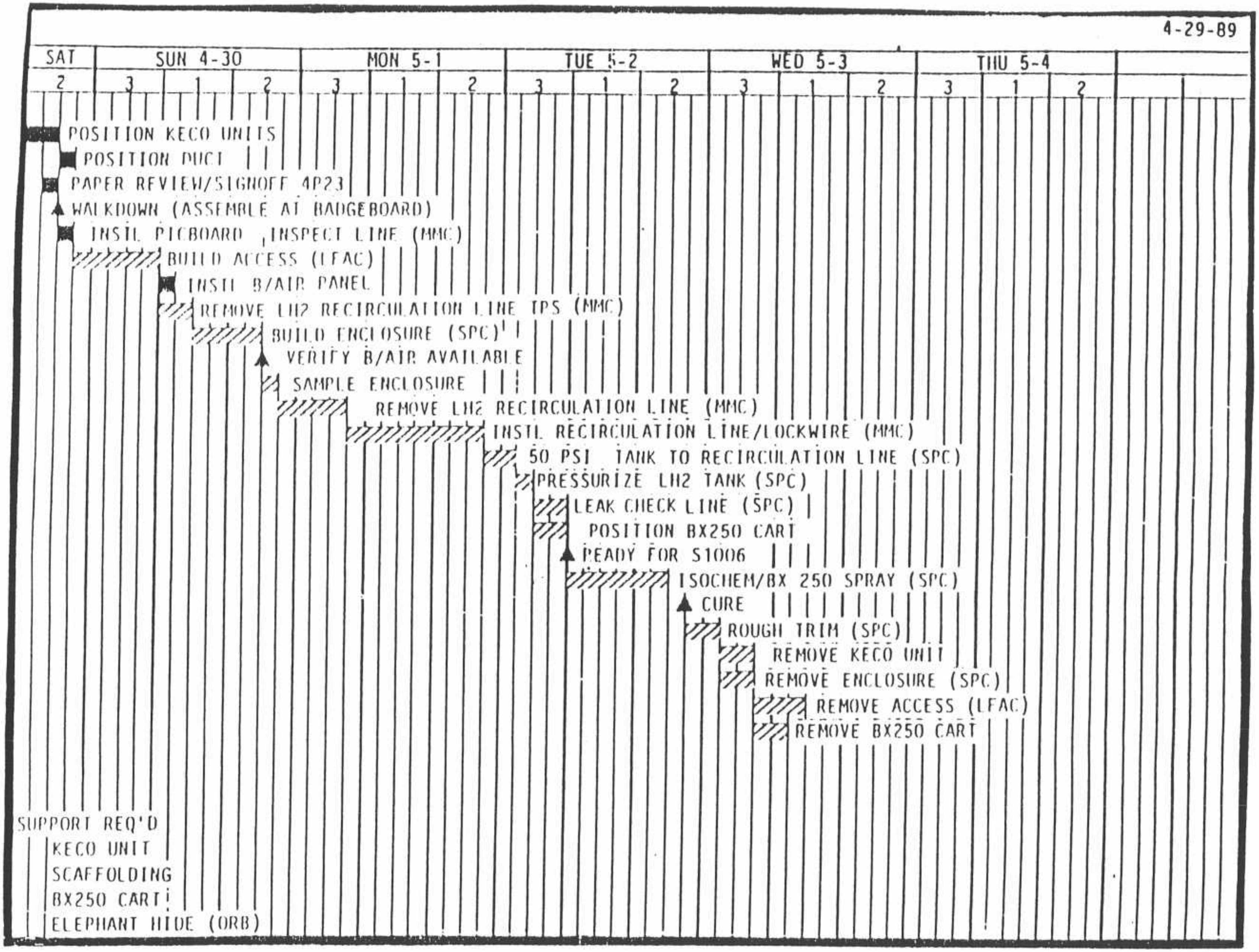
- **Concern: OEPSS - 20**
  - Liquid oxygen tank forward design
- **Operational impacts:**
  - Potential for Geysering - criticality I failure
  - Time-critical operations required for on-pad abort
  - Skilled/experienced engineer required for console
  - Additional hardware and operations required
    - 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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Keeping on schedule is a primary concern, but safety always has top priority.

KSC Integrated Control Schedule

PAD-B
OV-104/STS-30R/FR-1

H/H Crane Usage Restricted/Must Be Approved at Pad Scheduling Meeting 48 Hrs in Advance

72 HR STATUS/CONCURRENCE
(FOR PLANNING PURPOSE ONLY,FR TEST TEAM WILL CNTRL REALTIME IMPLEMENTATION & DEVIATION)
NOTE: ALL WORK COORDINATED W/PAD LEADER, BOX CAR 671
PHONE 7-5074/7-5586 CALL START/COMPLETION OF EACH TASK

FOR SCHEDULE APPROVAL SEE A-6

SUNDAY 2-30-89 | MONDAY 3-1-89 | TUESDAY 3-2-89 | WEDNESDAY 3-3-89 | THR 4 | FRI 5 | SAT 6 | SUN 7 | MON 8 | TUE 9 | WED 10

1800 S9001 K-2 SSV PWR UP
1801
1802 S0007 V1 10 SEQ 34/35
1803
1804
1805
1806
1807
1808
1809
1810
1811 PR ET-29-FP-0356 LH2 RECIRC LINE R&R
1812
1813
1814 AFT ACCESS INSTL
1815 PROT COVER INSTL
1816 DEFORM LH2 RECIRC PUMP PKG
1817 RECIRC LINE REM
1818 RECIRC PUMP R/R (RI)
1819 RECIRC LINE INSTL
1820 PR MPS-0487 RECIRC SYS LK CKS (MASS SPEC)
1821 RECIRC PUMP ELEC CK (DRY SPIN)
1822 READY FOR S1006
1823 RECIRC PKG FOAMING
1824 AFT CLOSEOUT
1825 50-1/50-2 DOOR INSTL
1826
1827 IPR-30RV-0262 MAGELLAN T/S(MILA SUPT)
1828 PR FCS 0194 R/R MS1 SEAT
1829 S6444A ET TPS FEEDLINE INSP
1830 H/H CRANE/RIGGERS
G6152 GVA SEAL CHGOUT/DRYOUT(LCT CLR)
1831 IPR-FR1-8875 LDB #2 T/S(LDB #2 DWN)
1832
1833 G2108 LOX TANK REPLENISH(CLR 150' RAD-LOX FARM)
1834
1835 V1122 K-1 SEQ 37/38 ORBITER ECS/LPAC SYS SUPT
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850 V2357 REV D-1 TSK 162 SAMPLE OXID SCRUBBERS (CLR 200' RAD FARM/NH 75' LVL/295' ABOVE VENT)(0800-0900)
1851 V1258 REV E-2 TSK 162 SAMPLE FUEL SCRUBBERS (CLR 200' RAD FARM/NH 75' LVL/295' ABOVE VENT)(0900-1000)

NO SRB PWR/MECs DOWN - VFCBI REV 0 TO REMAIN IN EFFECT

Preliminary

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KSC INTEGRATED CONTROL SCHEDULE

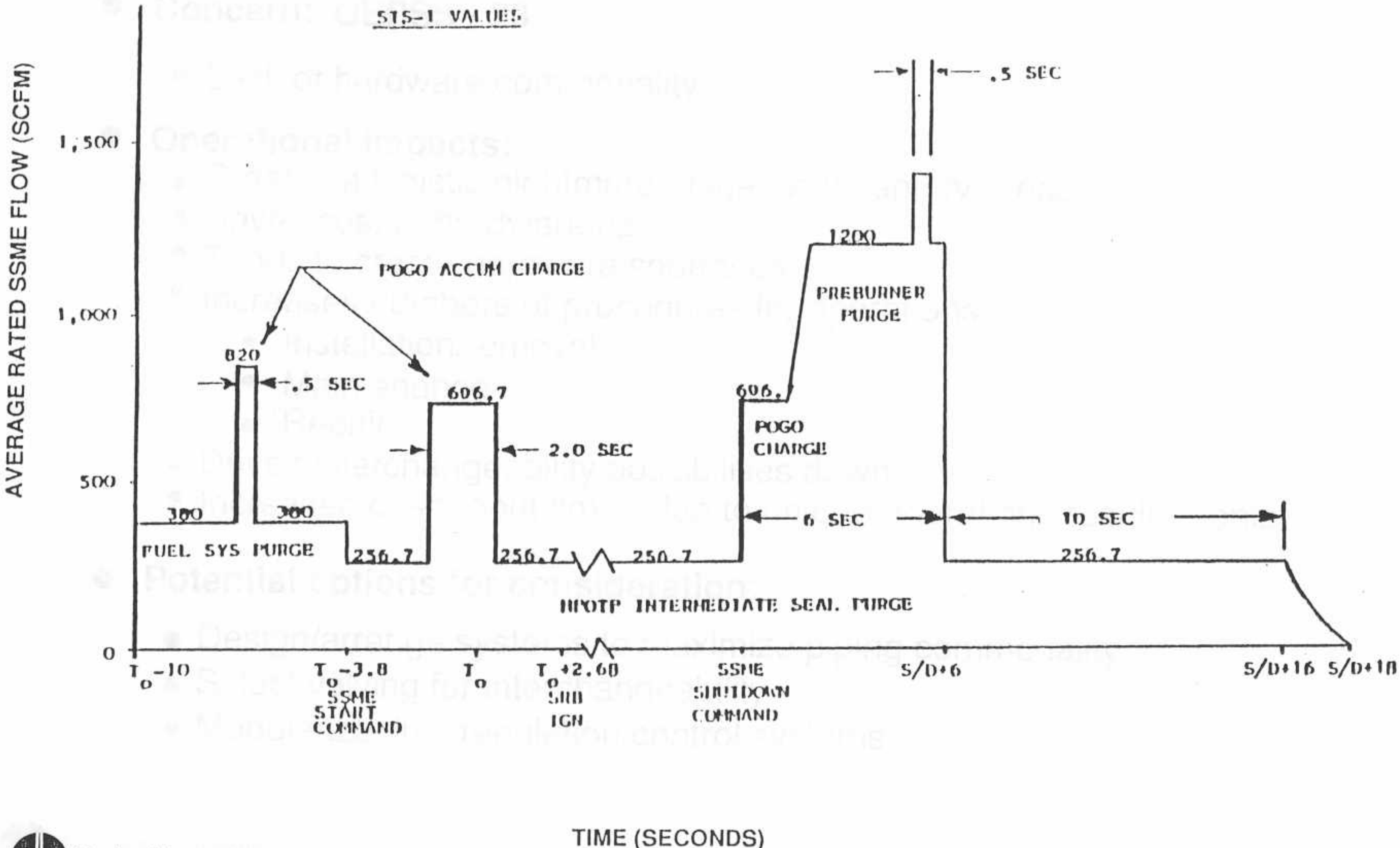
90ALS-109-80

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



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90ALS-109- 82

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

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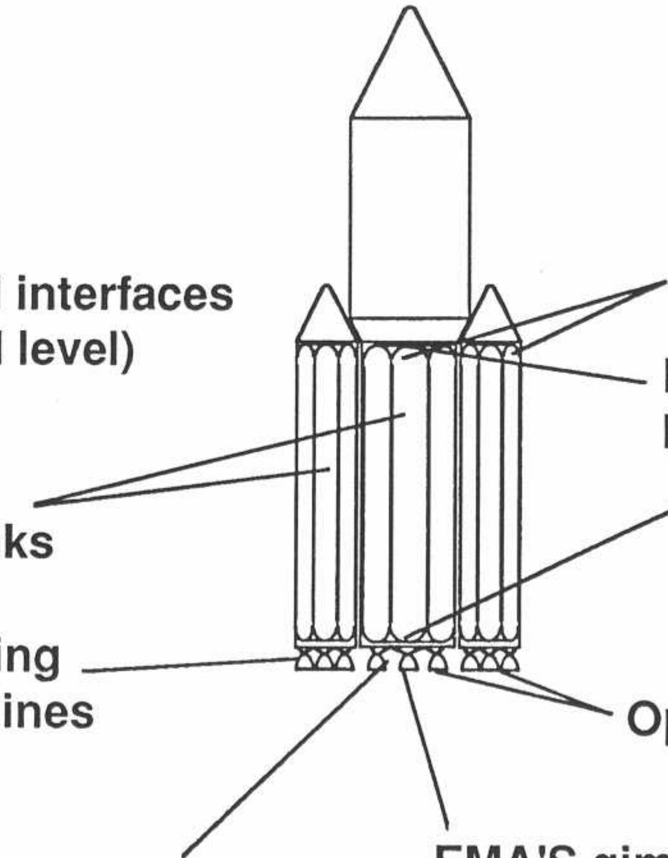
PROPULSION SYSTEM OPERATIONS TECHNOLOGY

- 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 Define environment for drain Perform testing for all cases					
Task II: Seal component testing Procure candidate seals Test seals to characterize					
Task III: Seal package testing Assemble pump seal package 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	Year 2	Year 3	Year 4	Year 5
Task I: Evaluate start with no purges Transient modeling Identify component issues					
Task II: Develop no purge shutdown Identify critical issues Transient modeling to address issues Evaluate proposed shutdown sequence					
Task III: Hardware conceptual design Low volume injector configurations Close coupled valve configurations 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	Year 2	Year 3	Year 4	Year 5
Task I: Engine cycle analysis					
Define candidate cycles					
Identify technology issues					
Task II: Oxygen compatibility testing					
Define turbine component materials					
Identify required testing					
Perform testing					
Task III: LOX rich injector technology					
Design and analysis					
Model flow test					
Hot-fire demonstration component					
Task IV: Transient analysis					
Model system					
Start/shutdown sequence development					
System evaluation					

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 Identify requirements Define candidate methods					
Task II: Test seal concepts Characterize leakage Evaluate operability					
Task III: Define operational impacts Trade seal qualities vs. operability Select sealing method					

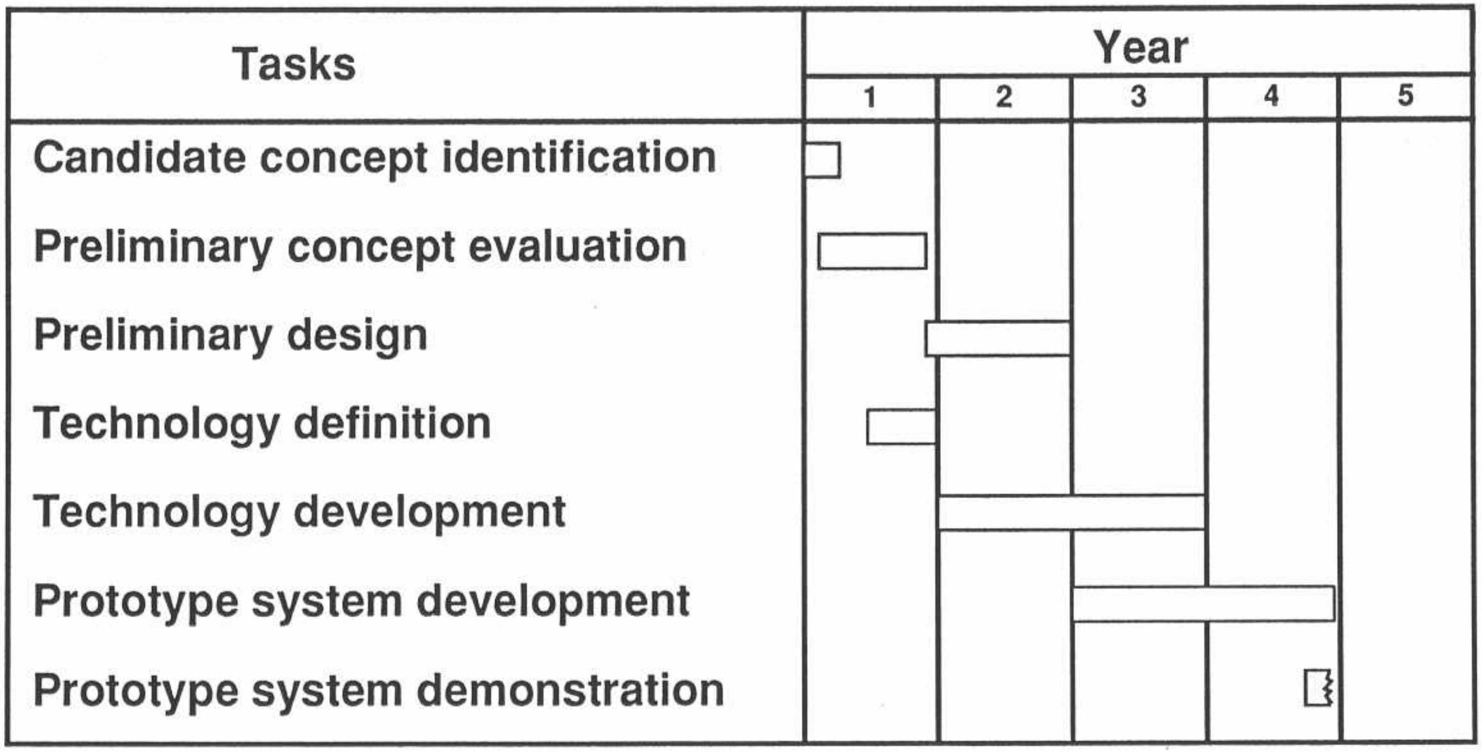
COMBINED O_2/H_2 MPS, OMS, RCS, FUEL CELLS THERMAL MANAGEMENT

- **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

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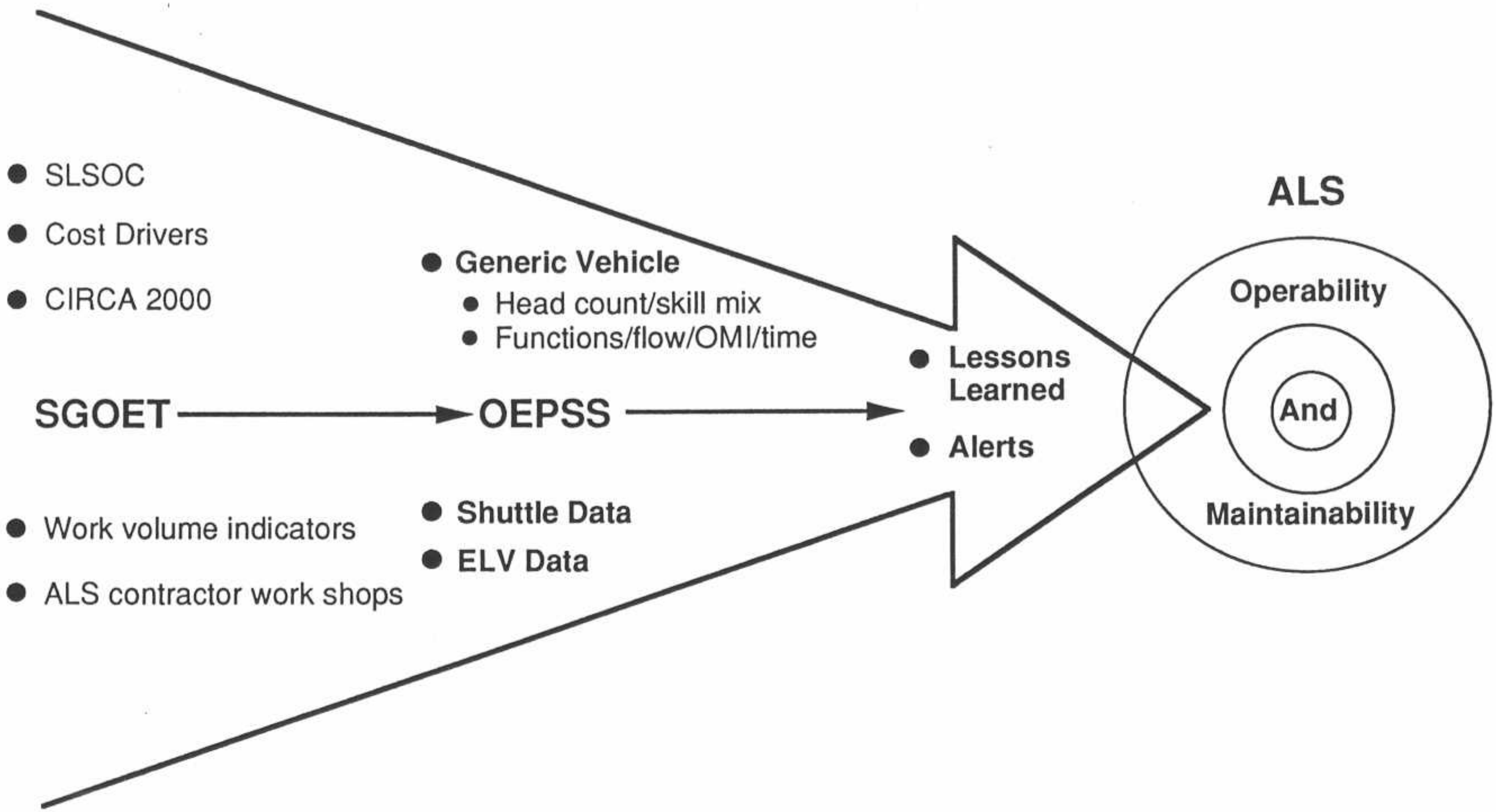
OEPSS FOCUSES ON ALS OPERABILITY



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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

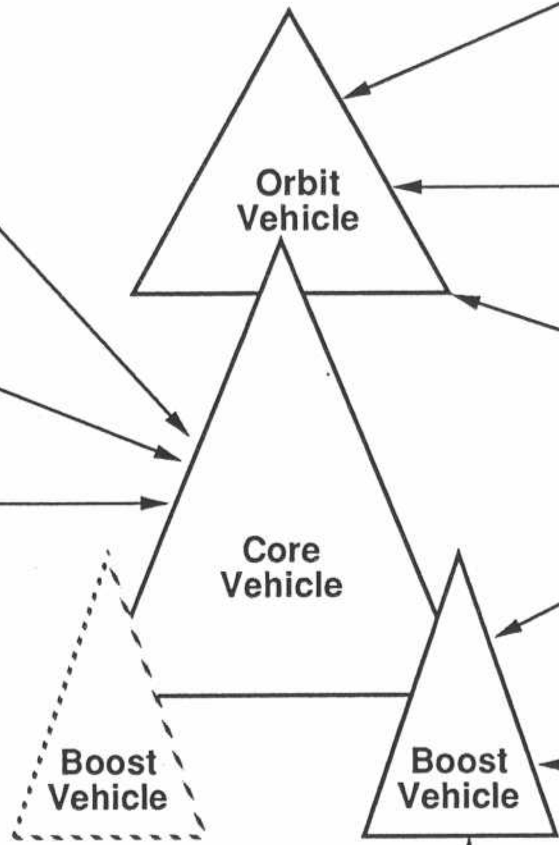
- **Maintenance reduced**
  - No scheduled maintenance
  - Robust designs reduce unscheduled maintenance
- **Components easily replaced**
  - Ready access
  - Retention hardware easily removed
- **Simple ground interface**
  - Rise-off Q/D's at AFT end

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

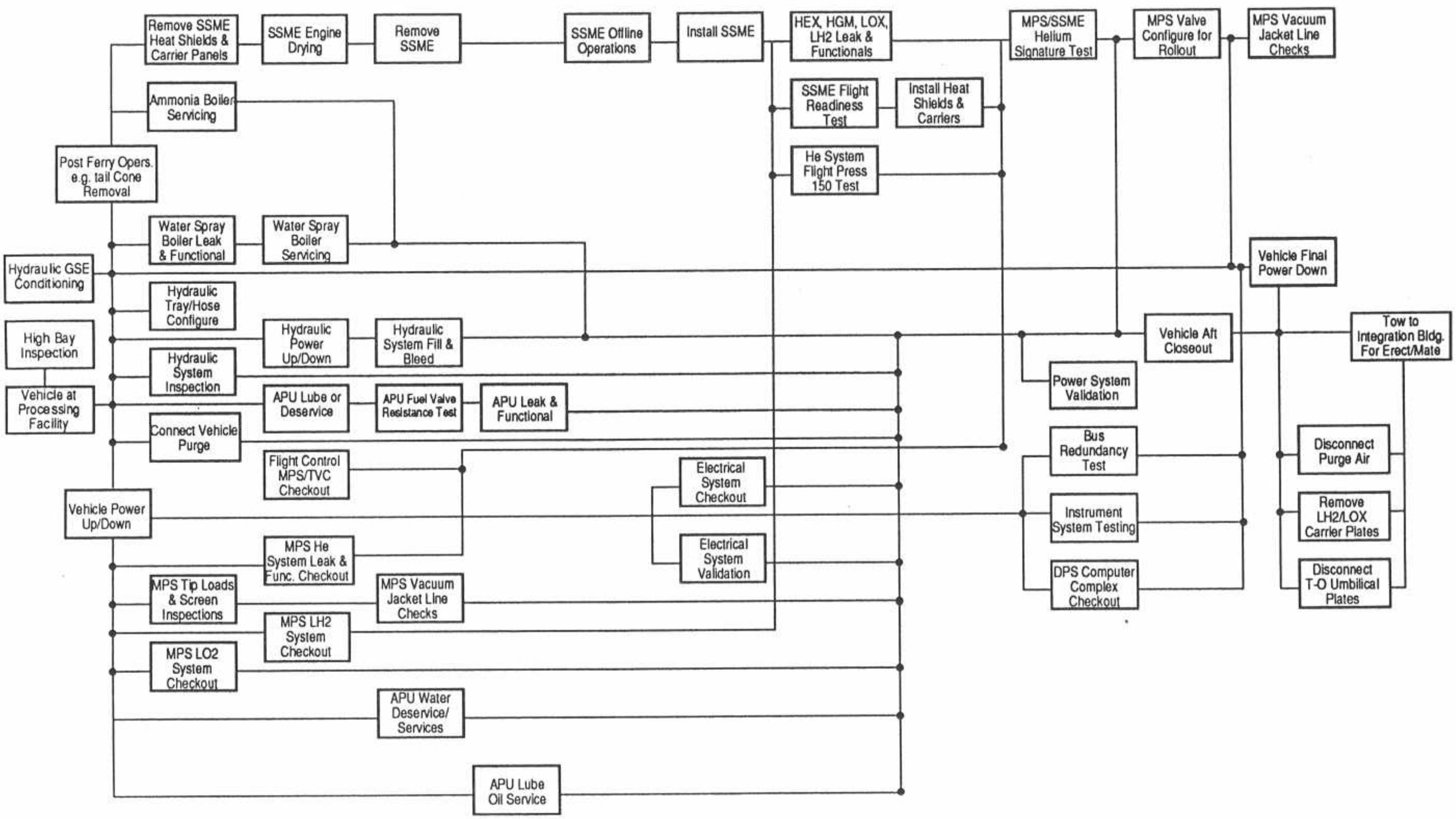
- All vehicles use multiple engines
- Retractable umbilicals for ground-to-vehicle servicing
- Ground propellant, pneumatic, and electrical systems are common to existing launch facilities
- Method of operation is common to existing launch operations
- Processing facilities are common to the existing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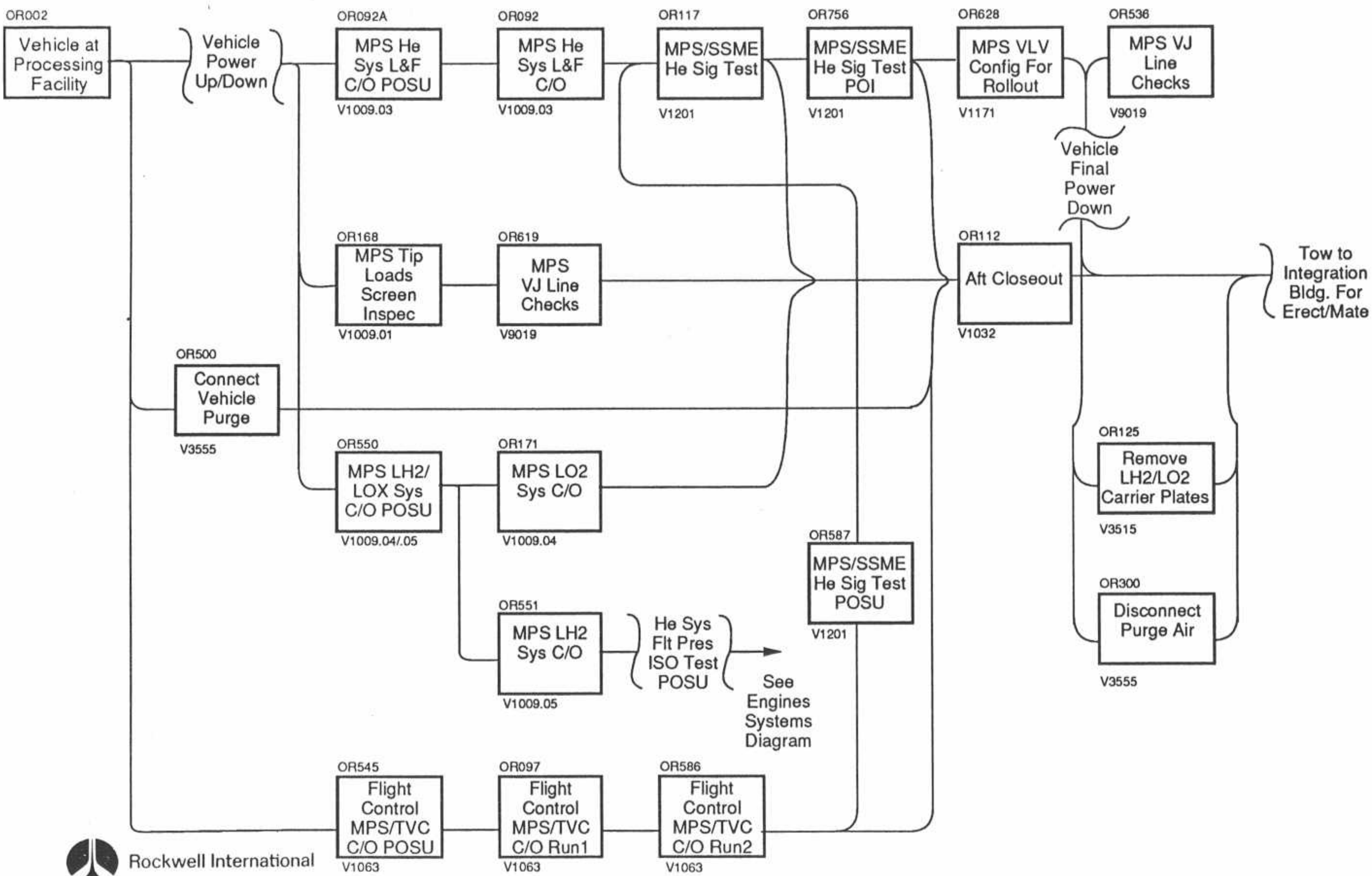
OEPSS GENERIC CORE VEHICLE

MPS Logic Diagram



Rockwell International

Rocketdyne Division

91ALS-060-121

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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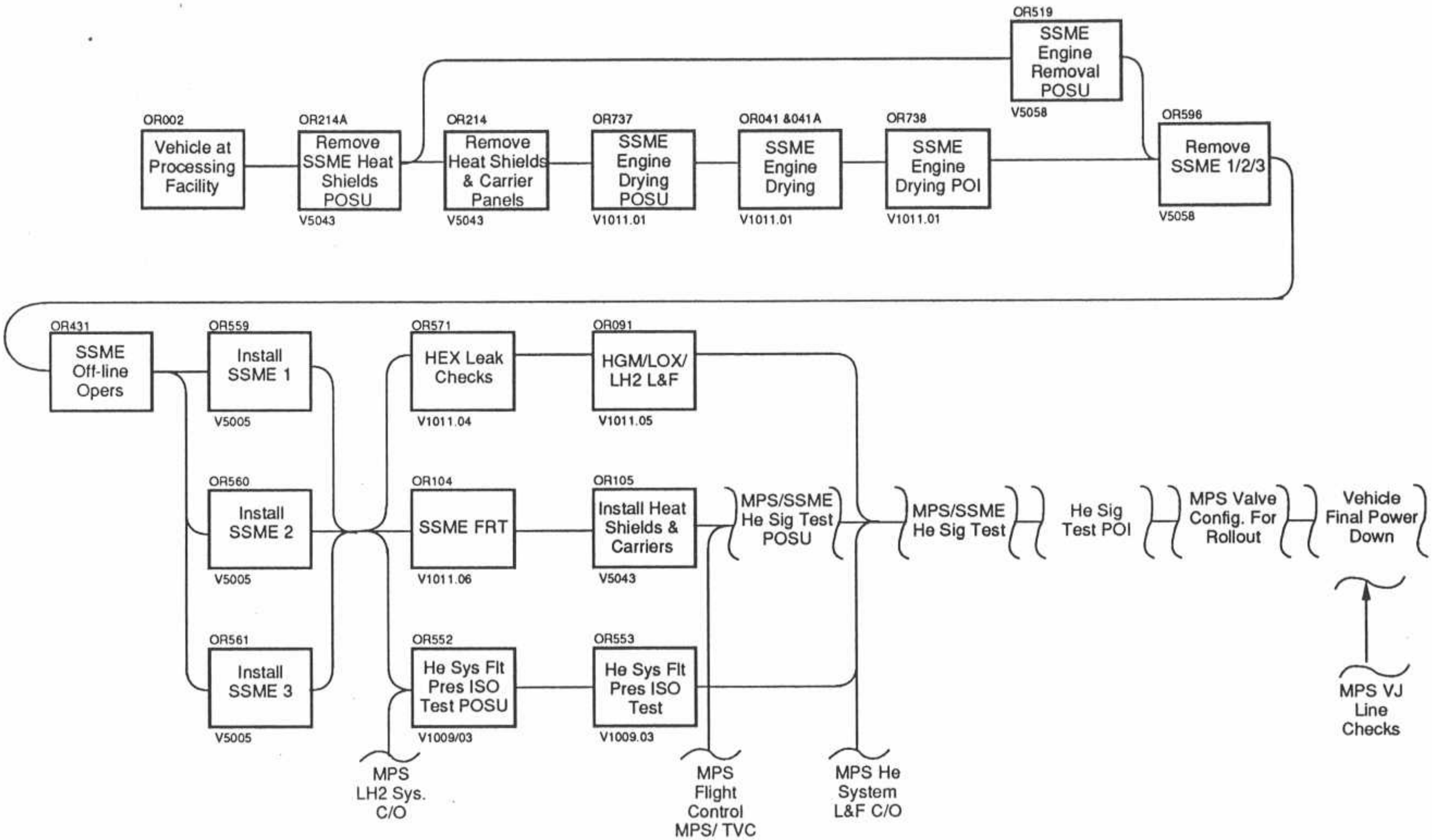
91ALS-060-122

OEPSS GENERIC CORE VEHICLE

Engine System Logic Diagram



- See MPS Logic Diagram -

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91ALS-060-123

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

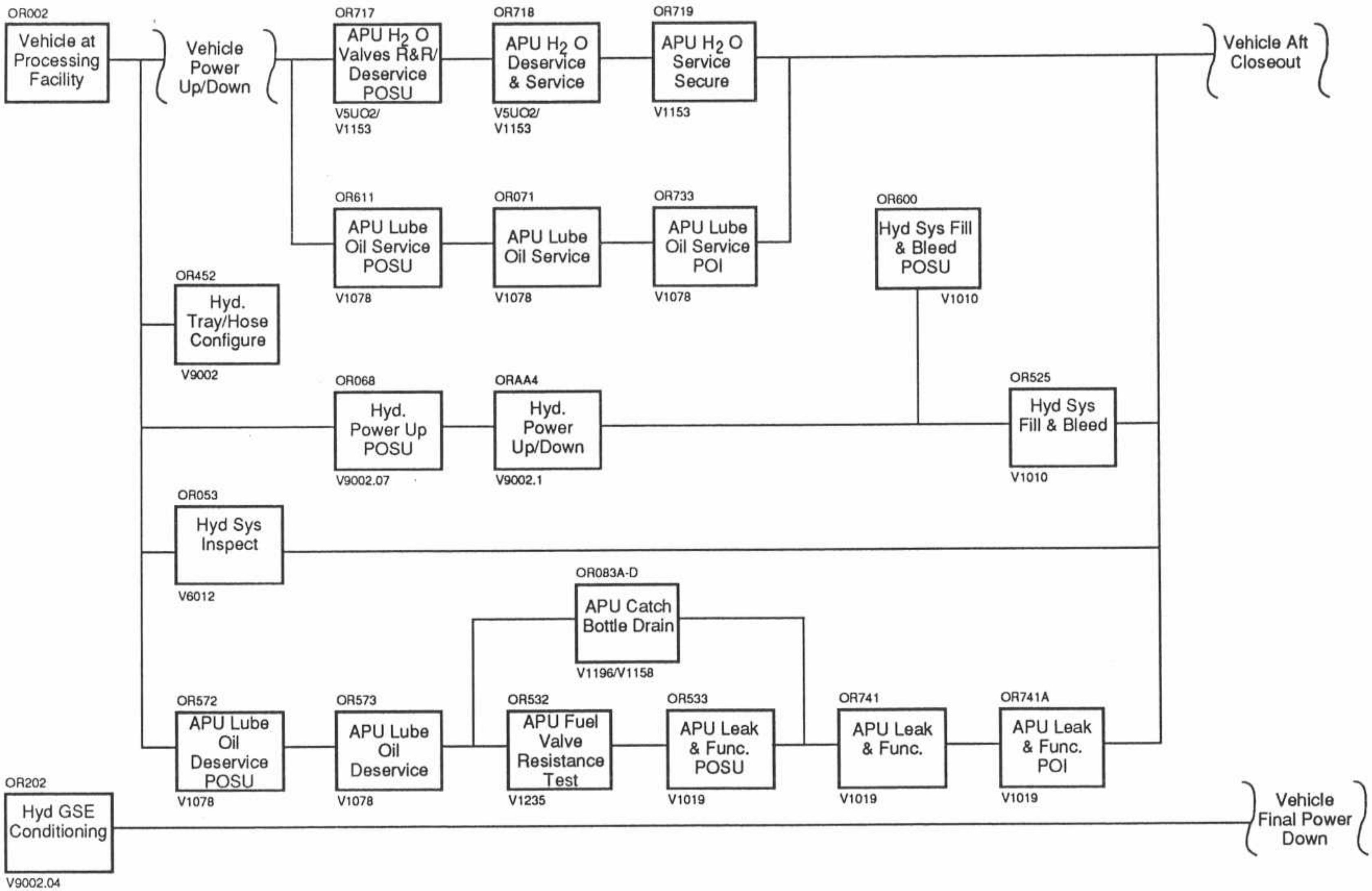
Rockwell International 672 Hrs. is 28 days of 3-shift operations for an average headcount of 18.7 at all times.

Rocketdyne Division

91ALS-060-124

OEPSS GENERIC CORE VEHICLE

Hydraulic and APU Logic Diagram



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91ALS-060-125

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.

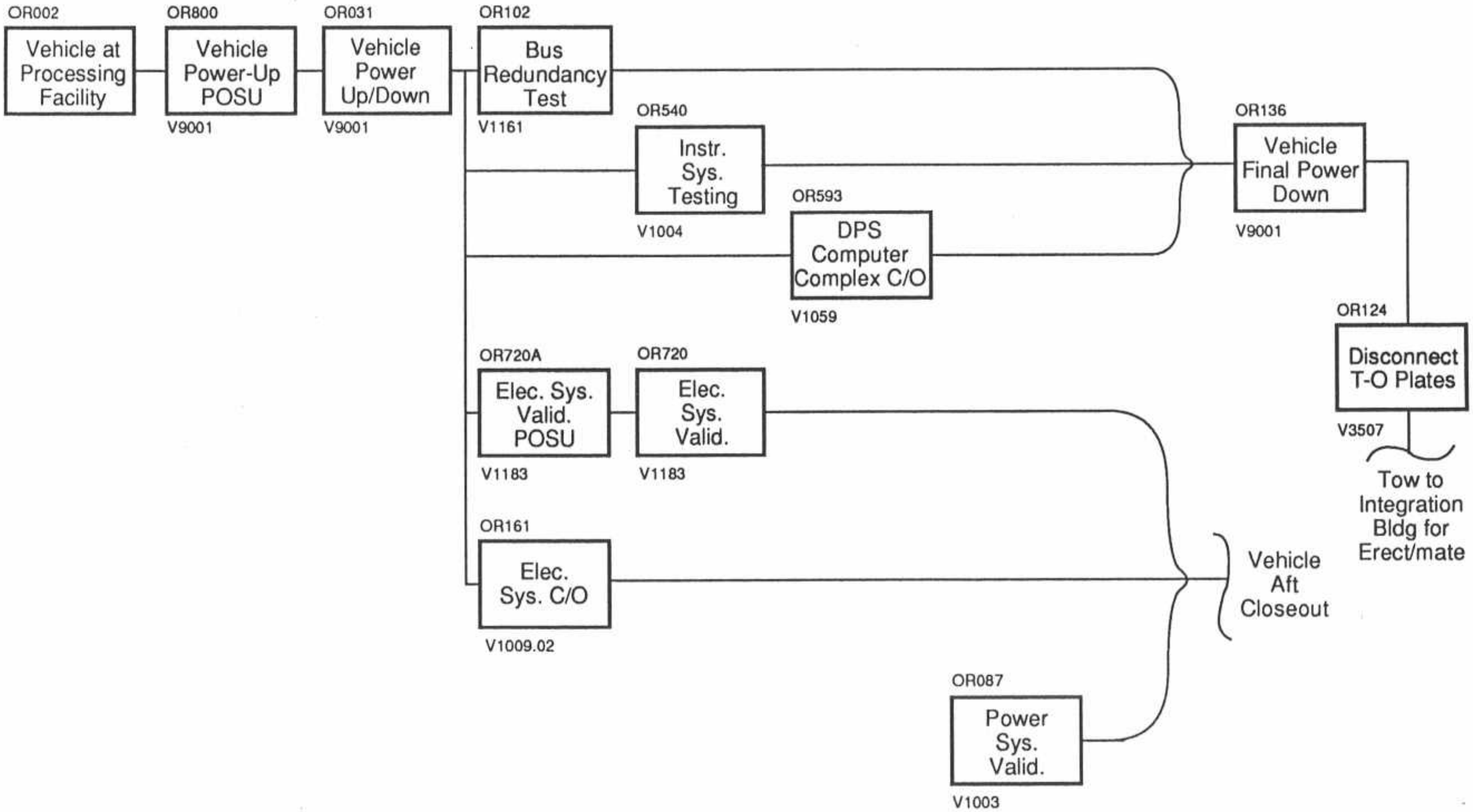
Rockwell International

Rocketdyne Division

91ALS-060-126

OEPSS GENERIC CORE VEHICLE

Electrical Systems Logic Diagram



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91ALS-060-127

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

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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.