N91-28198

SPACE TRANSPORTATION PROPULSION
TECHNOLOGY SYMPOSIUM

OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY
(OEPPS)

The Pennsylvania State University
University Park, PA
25 - 29 June 1990

OPERATIONALLY EFFICIENT PROPULSION
SYSTEM STUDY (OEPSS)

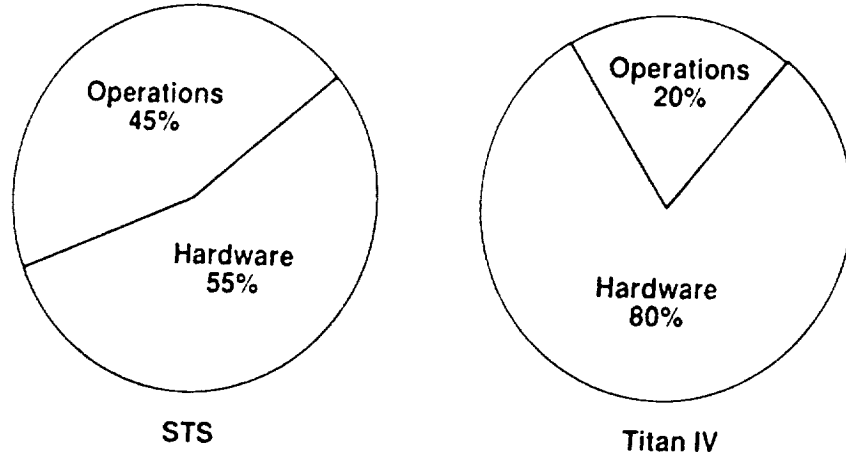NAS 10-11568

April 1989 - April 1990
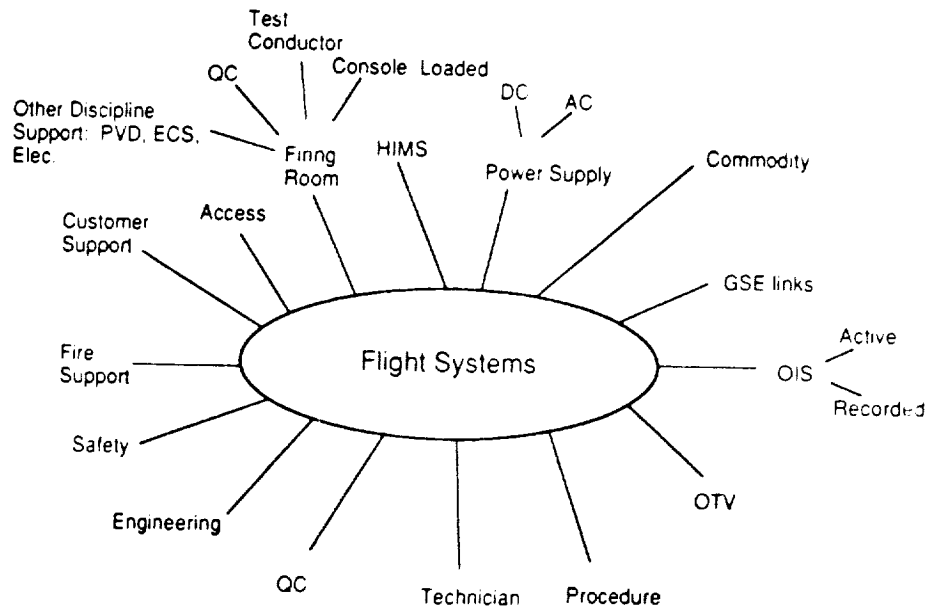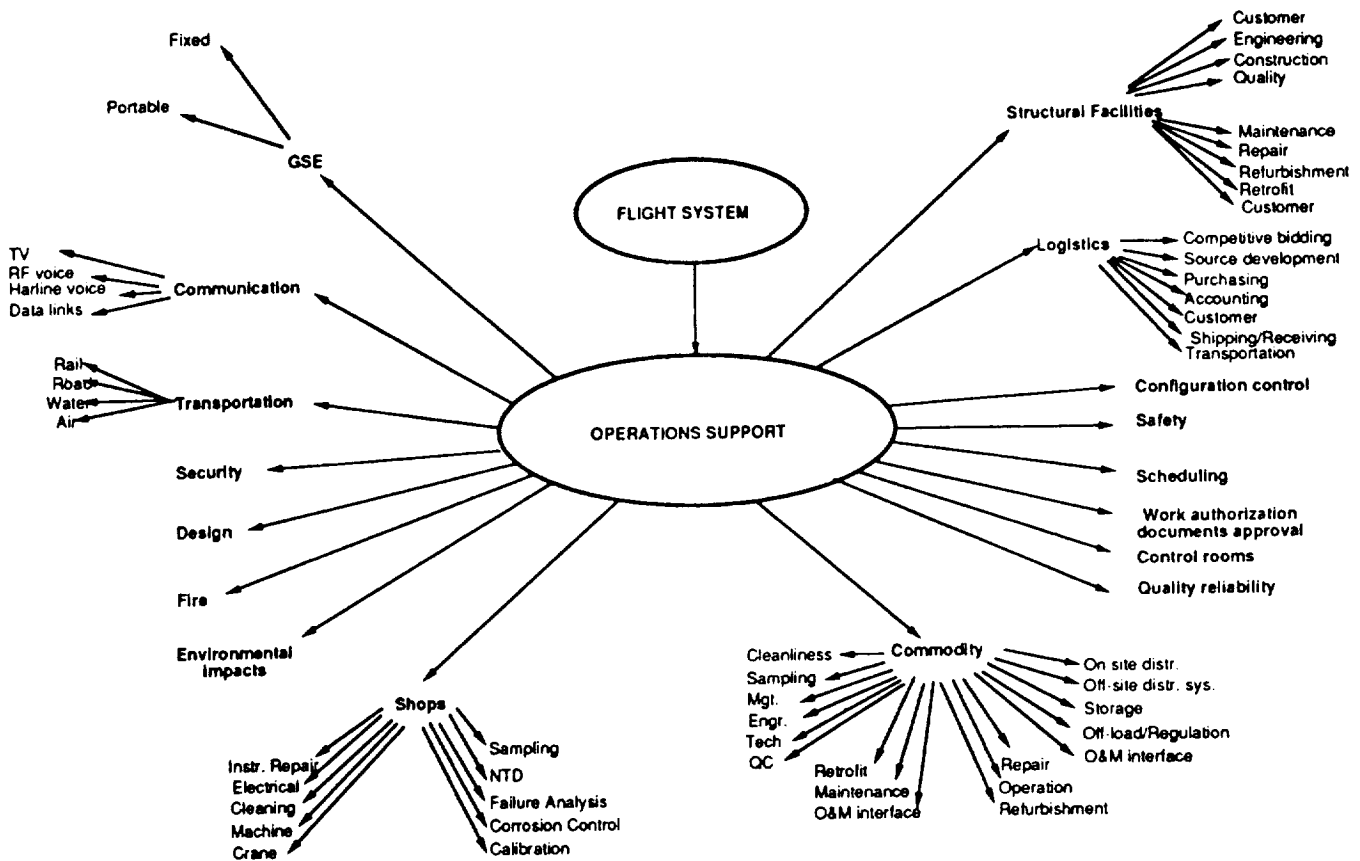
G.S. Wong, G.S. Waldrop, R.J. Byrd, J.M. Ziese

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LAUNCH OPERATIONS COST PER FLIGHT
% of Total Recurring Cost

Operations 45%

Hardware 55%

STS

Operations 20%

Hardware 80%

Titan IV

OPERATIONS SUPPORT SYSTEM IS COMPLEX

Test Conductor

QC

Console Loaded

DC   AC

Other Discipline Support: PVD, ECS, Elec.

Firing Room

HIMS

Power Supply

Commodity

Customer Support

Access

GSE links

Fire Support

Flight Systems

OIS

Active

Recorded

Safety

OTV

Engineering

QC   Technician   Procedure

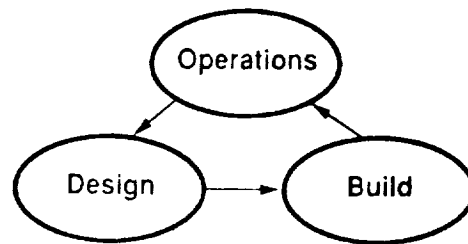# OPERATIONS SUPPORT STRUCTURE IS COMPLEX

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

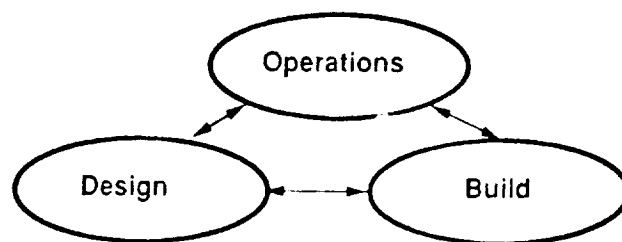# OPERATIONS AND DESIGN MUST BE INTERACTIVE

Design → Build → Operations

Traditional

Operations → Design → Build → Operations
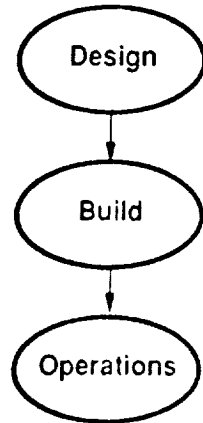
OEPSS

TOTAL QUALITY MANAGEMENT (TQM) FOR OPERATIONS

Total Propulsion System

Operations, Design, Build

OEPSS

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		

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

BASELINE ALS VEHICLE
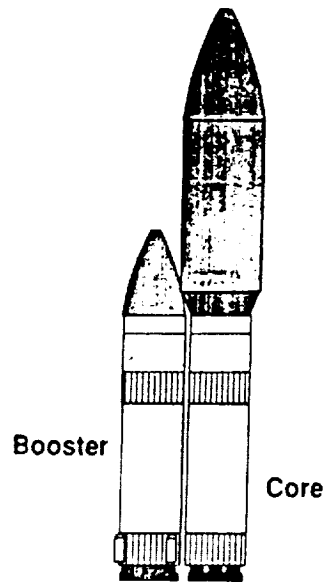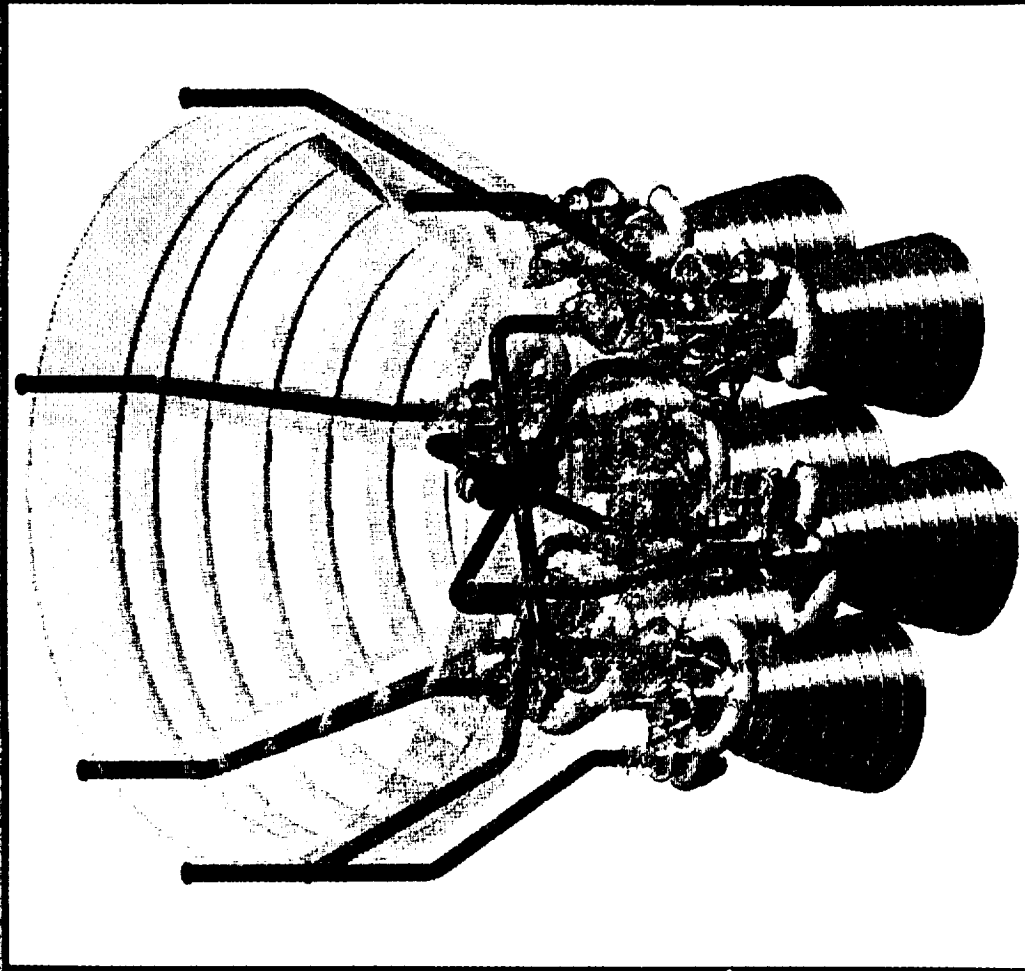
Booster

Core

- 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)

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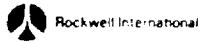
CONVENTIONAL CORE PROPULSION SYSTEM
3 – ENGINE

114
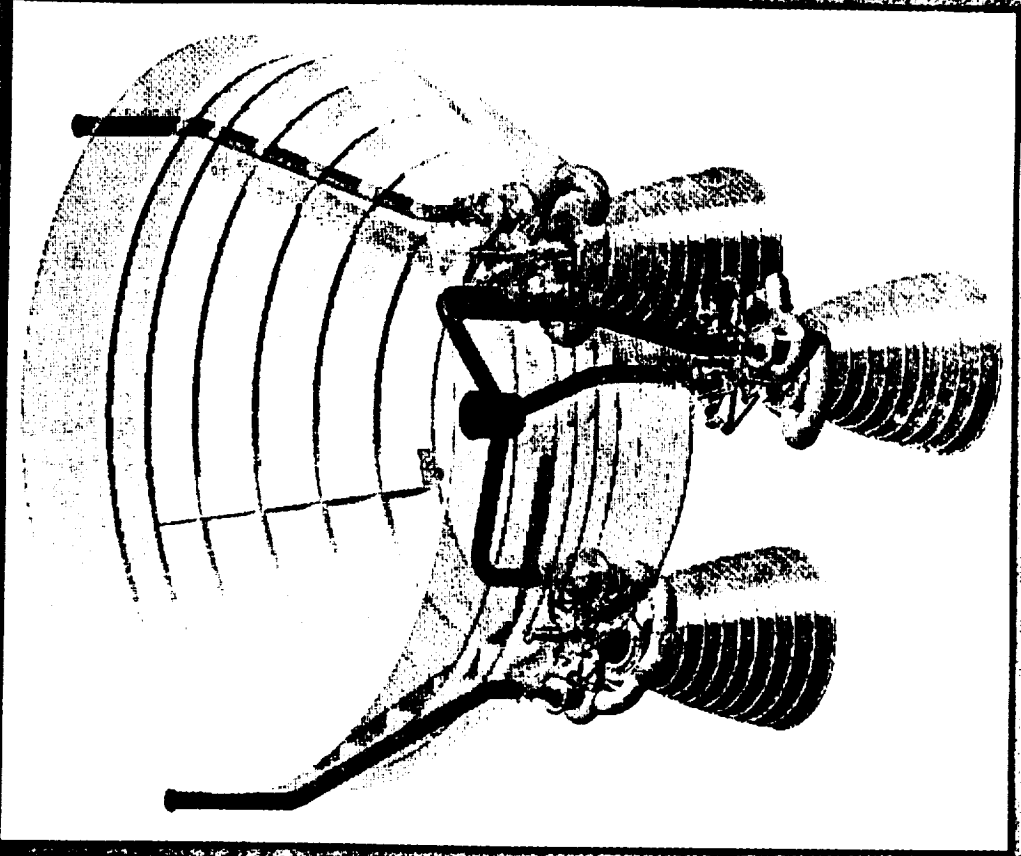
ALS INTEGRATED BOOSTER PROPULSION MODULE

- **Moved center engine to perimeter**

    - Eliminate potential pogo problem

    - Achieves accessibility and commonality

- **Eliminated components and interfaces**

- **Integrated He supply system**

- **Integrated pressurization system**

- **Integrated control/avionics**

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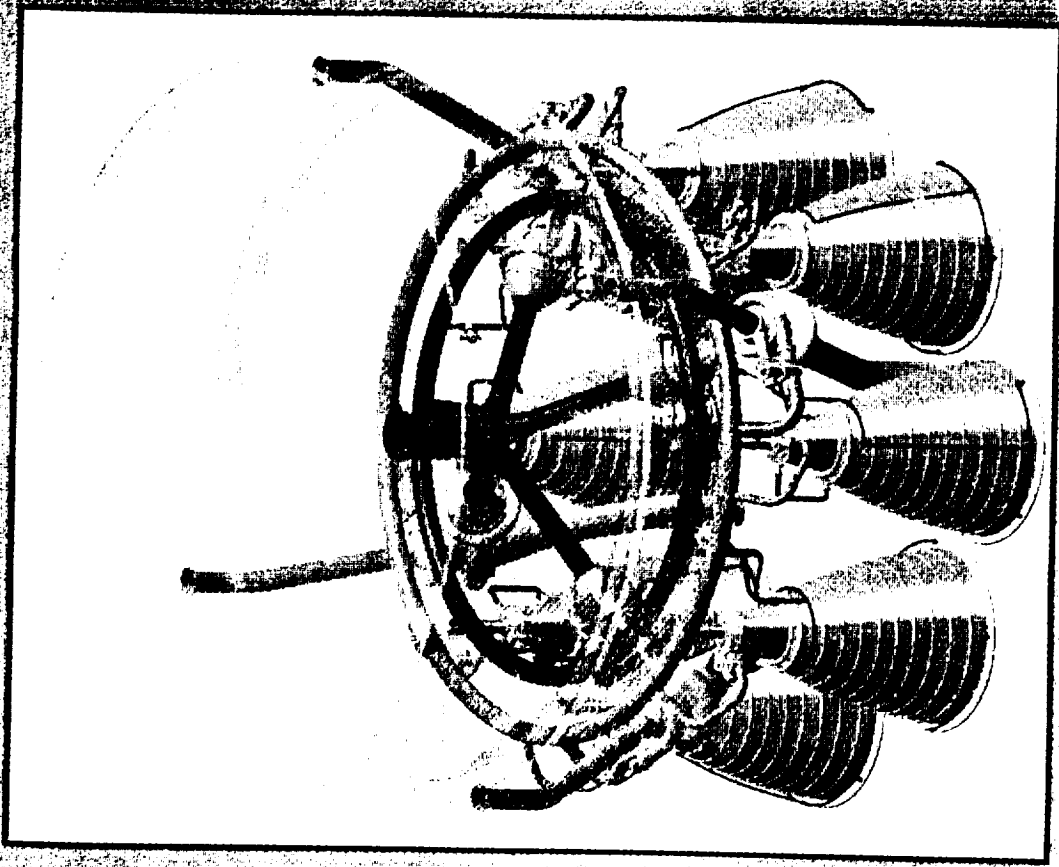
INTEGRATED CORE PROPULSION MODULE – ENGINE
4 – THRUST CHAMBERS

INTEGRATED PROPULSION MODULE – ENGINE ELEMENT
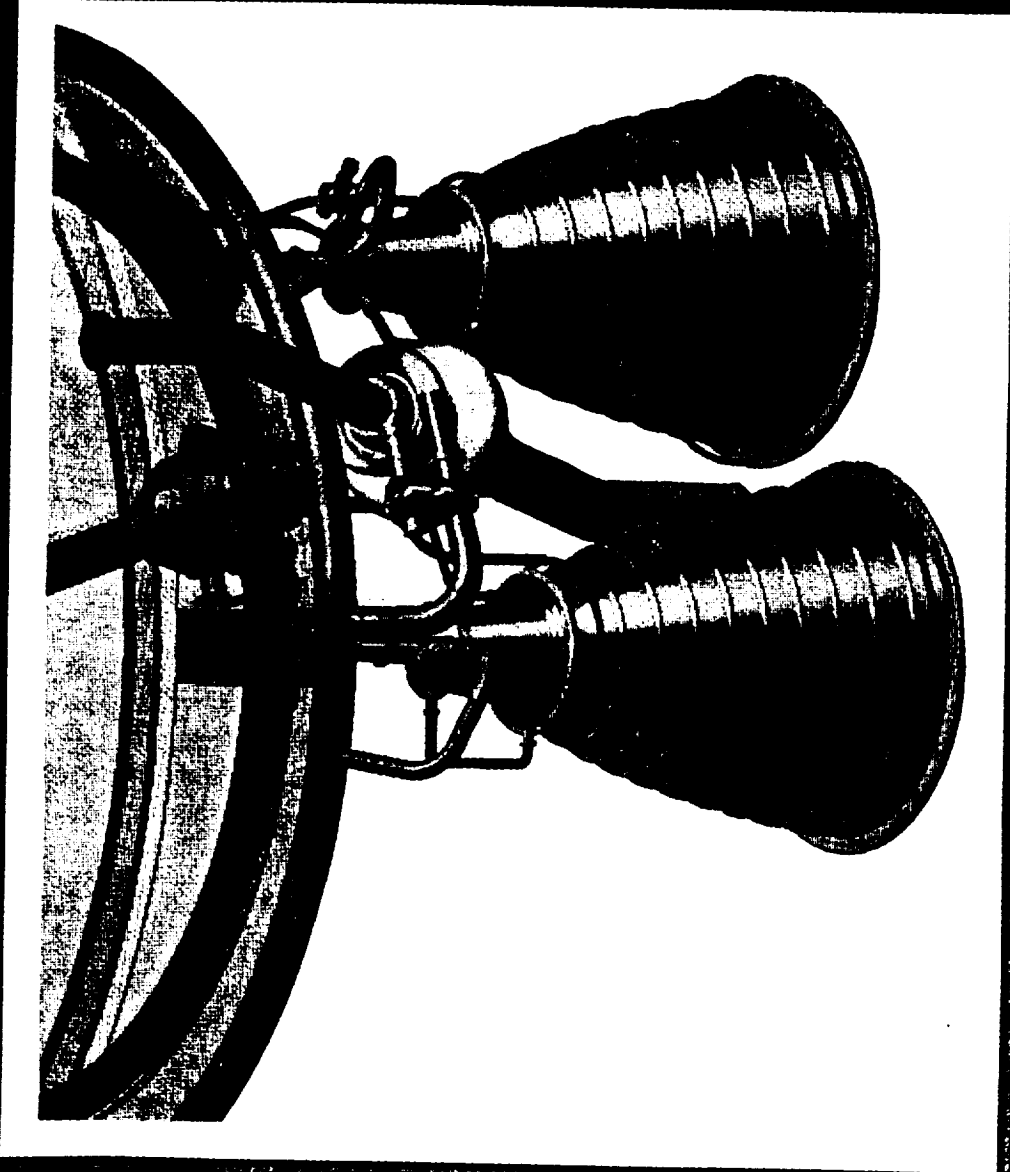
SC89c-30-154A

INTEGRATED PROPULSION MODULE DESIGN INCREASES OPERATIONS EFFICIENCY

- Single He-pressurization system

- Single LOX pressurization system (heat exchanger)

- Single control system

- No flexible propellant lines

- No gimbal actuators

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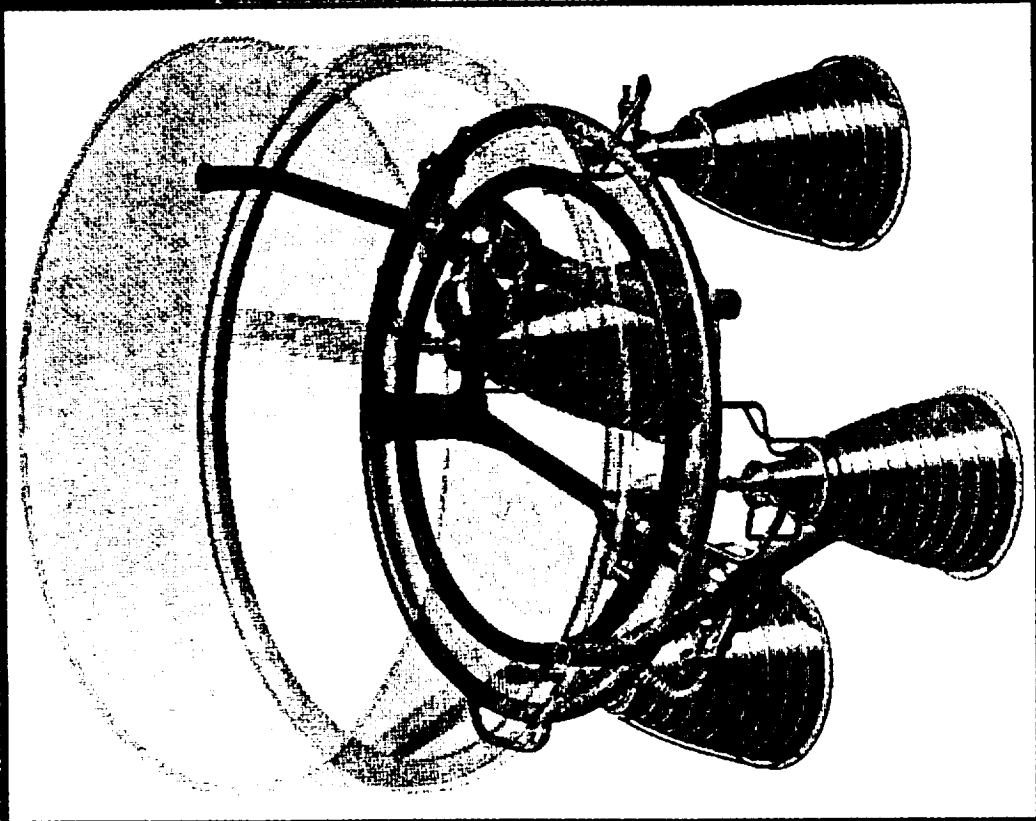 - Gas generators

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

INTEGRATED PROPULSION MODULE MAXIMIZES ROBUSTNESS AND COMMONALITY

- Booster utilizes non-gimbaling thrust chambers: 8 T/C's

- Core provides TVC with gimbaled thrust chambers: 4 T/C's

- 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

Booster

Core
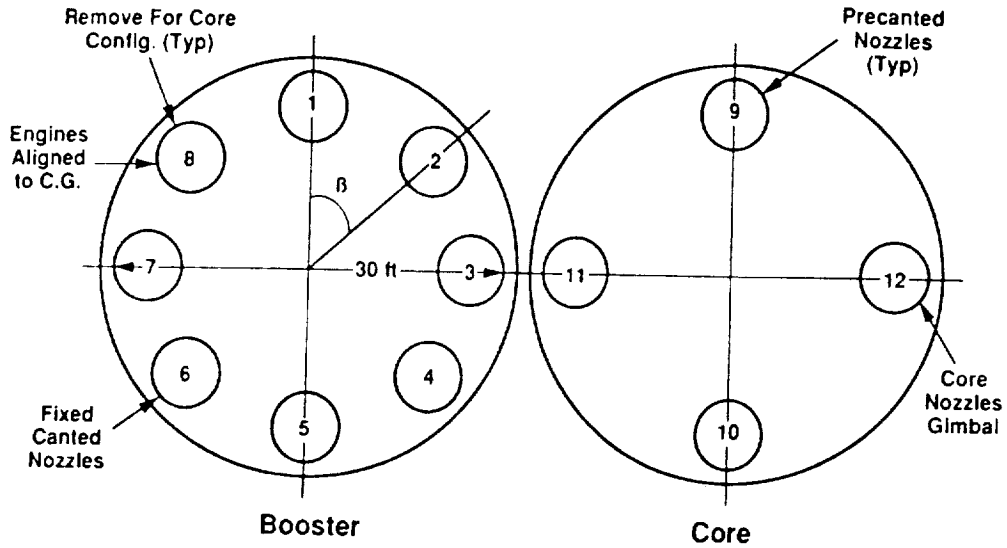
INTEGRATED CONCEPT INCREASES RELIABILITY AND ENGINE-OUT CAPABILITY
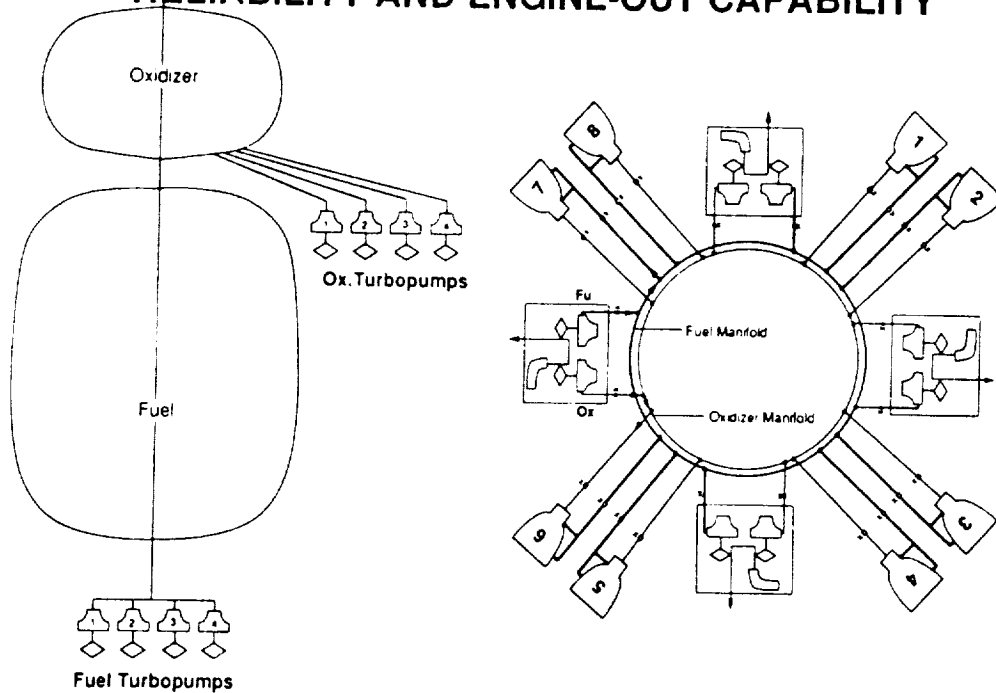
INTEGRATED PROPULSION MODULE
"COMPONENT OUT" CAPABILITY

- **Thrust chamber-out capability**

  - Thrust chamber   85% ⟶ 100% Nom. Oper.

  - Turbopumps   90% ⟶ 97% Nom. Oper.

- **Turbopump out-capability**

  - Turbopumps   90% ⟶ 93% Nom. Oper.

  - Thrust chamber   85%

INTEGRATED PROPULSION MODULE
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	18,600	16,700
LO2-Turbopump	10,000	7,100	6,400

TURBOPUMP OPERATING MAP
Integrated Propulsion System

Head

Stability

Max Speed

One T/C out

7 T/C

Design Point

7/4   7/3

8 T/C

No T/C out

Oper. Point

8/4   8/3

Cavitation

No T/P out   One T/P out

Flowrate

4 T/P Operational   3 T/P Operational
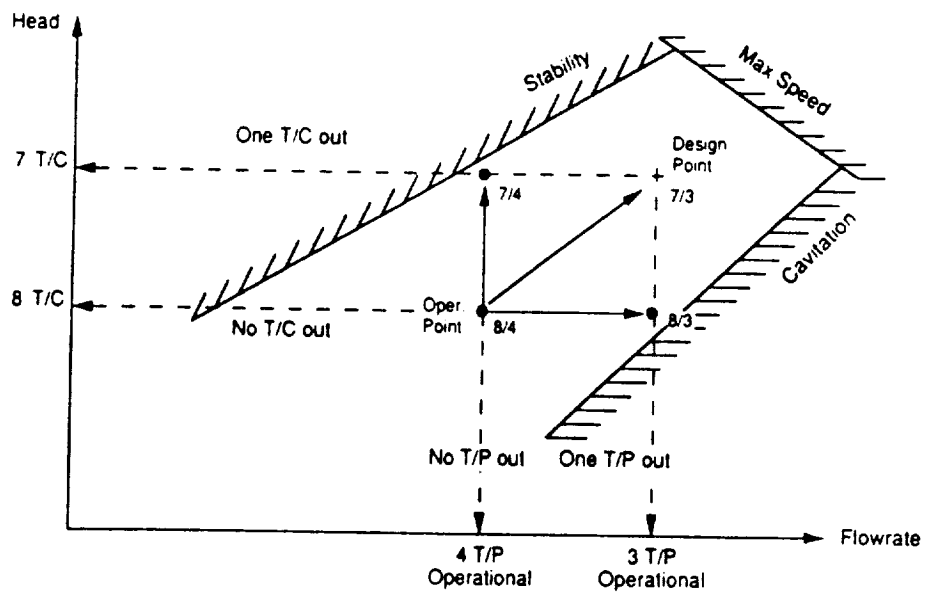
SEPARATE ENGINES VS. INTEGRATED SYSTEM

	Separate Engines	Integrated System
● Control Systems	▯▯▯▯▯▯ 7	1
● He supply system	▯▯▯▯▯▯ 7	▯ 2
● Heat exchanger	▯▯▯▯▯▯ 7	▯ 2
● LOX turbopump	▯▯▯▯▯▯ 7	▯▯▯ 4
● LH₂·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

Table 1

BOOSTER PROPULSION MODULE RELIABILITY
Separate Engines vs. Integrated System

Engine Elements*	Component Reliability	Separate Engines		Integrated system	
		No. of Components	Subsystem 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

Table 2

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

Table 3

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.

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 (LO₂ 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)

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INTEGRATED PROPULSION MODULE IS FLEXIBLE

- "Integrated" propulsion module is a single engine

  - Meets wide range of thrust (1,00,000 - 4,000,000 Klbs)
    by adding or eliminating components

- "Integrated" propulsion module is operationally efficient

  - Simpler
  - More reliable
  - Greater engine-out capability
  - More robust
  - More operable (operationally efficient)
  - Lower cost
  - Lower weight

OEPSS CONCLUSION

- Operations starts at design concept (TQM)

- Integrated design operationally efficient

  - Substantially higher reliability and lower cost

  - New technology not required (enabling)

  - High flight rates and routine access to space

- Other innovative propulsion concepts possible

PROPULSION SYSTEMS OPTIONS-

CURRENT SYSTEMS

EXPENDABLE LAUNCH VEHICLE PROPULSION