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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

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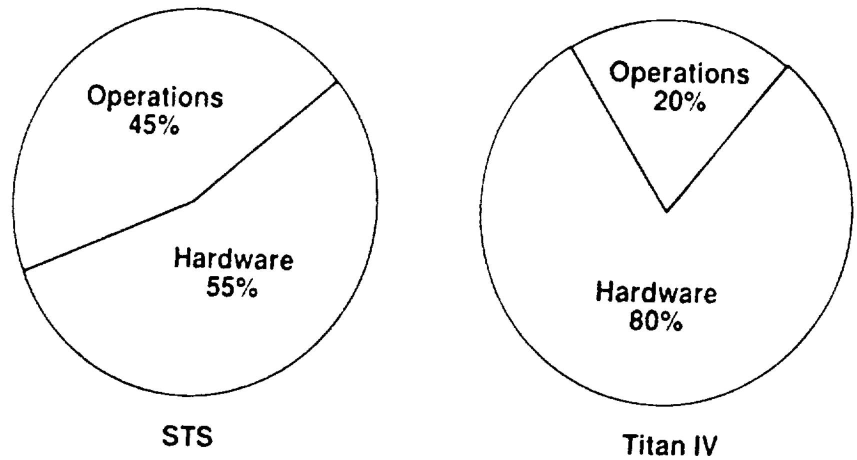
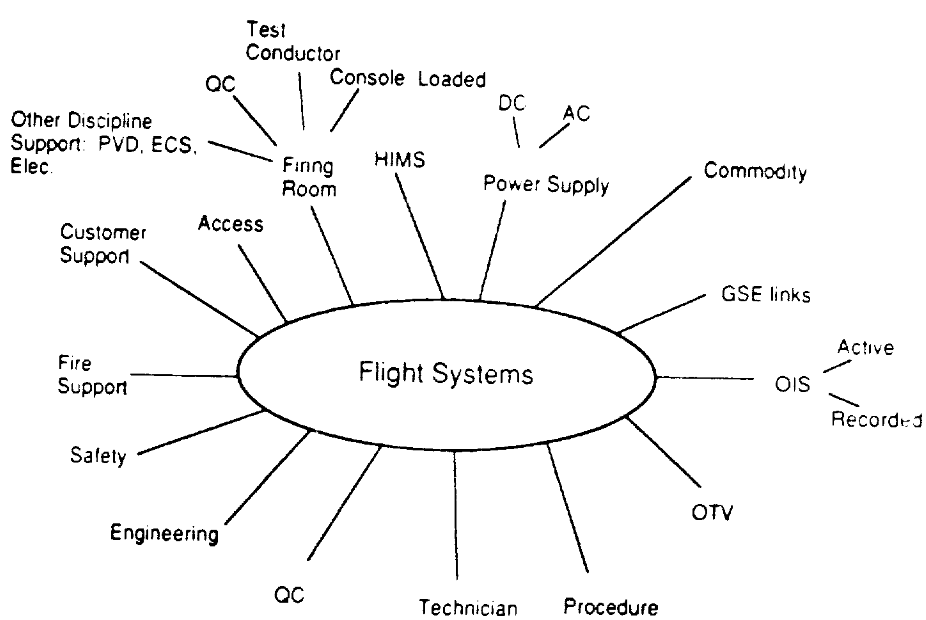
LAUNCH OPERATIONS COST PER FLIGHT

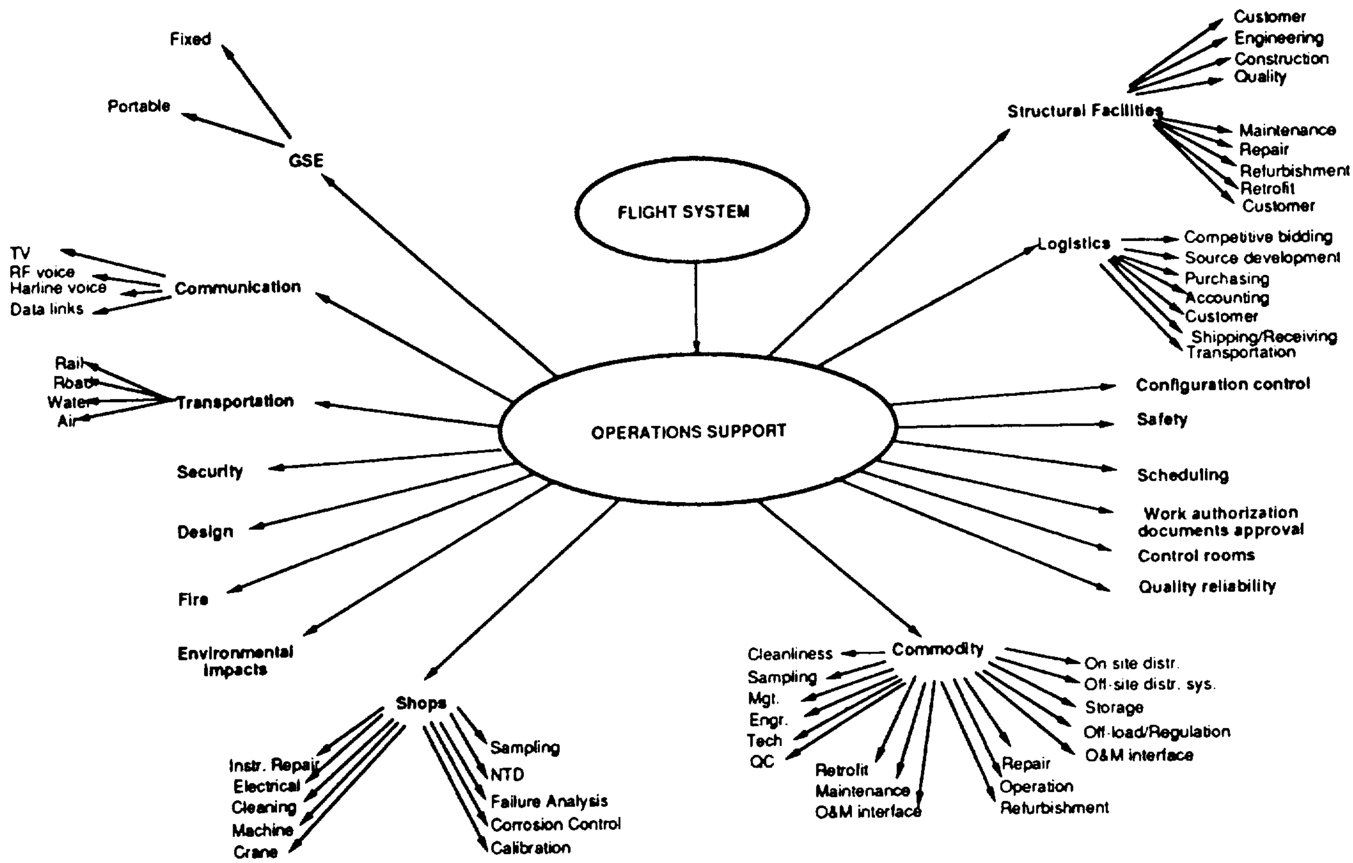
% of Total Recurring Cost



OPERATIONS SUPPORT SYSTEM IS COMPLEX



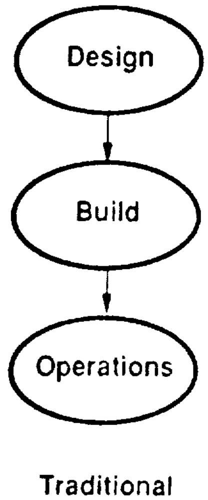
OPERATIONS SUPPORT STRUCTURE IS COMPLEX

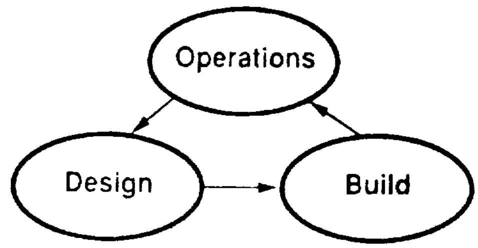


OPERATIONS PROBLEMS RESULTS IN HIGH COST

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

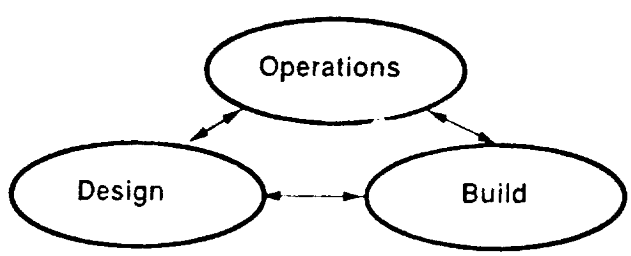
OPERATIONS AND DESIGN MUST BE INTERACTIVE





TOTAL QUALITY MANAGEMENT (TQM) FOR OPERATIONS

Total Propulsion System



OEPSS

OEPSS IDENTIFIES OPERATIONS PROBLEMS

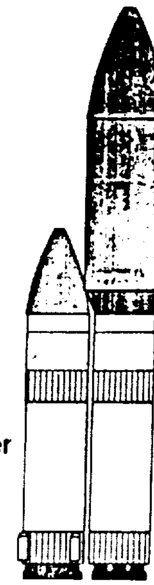
Causes and Effects

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



• 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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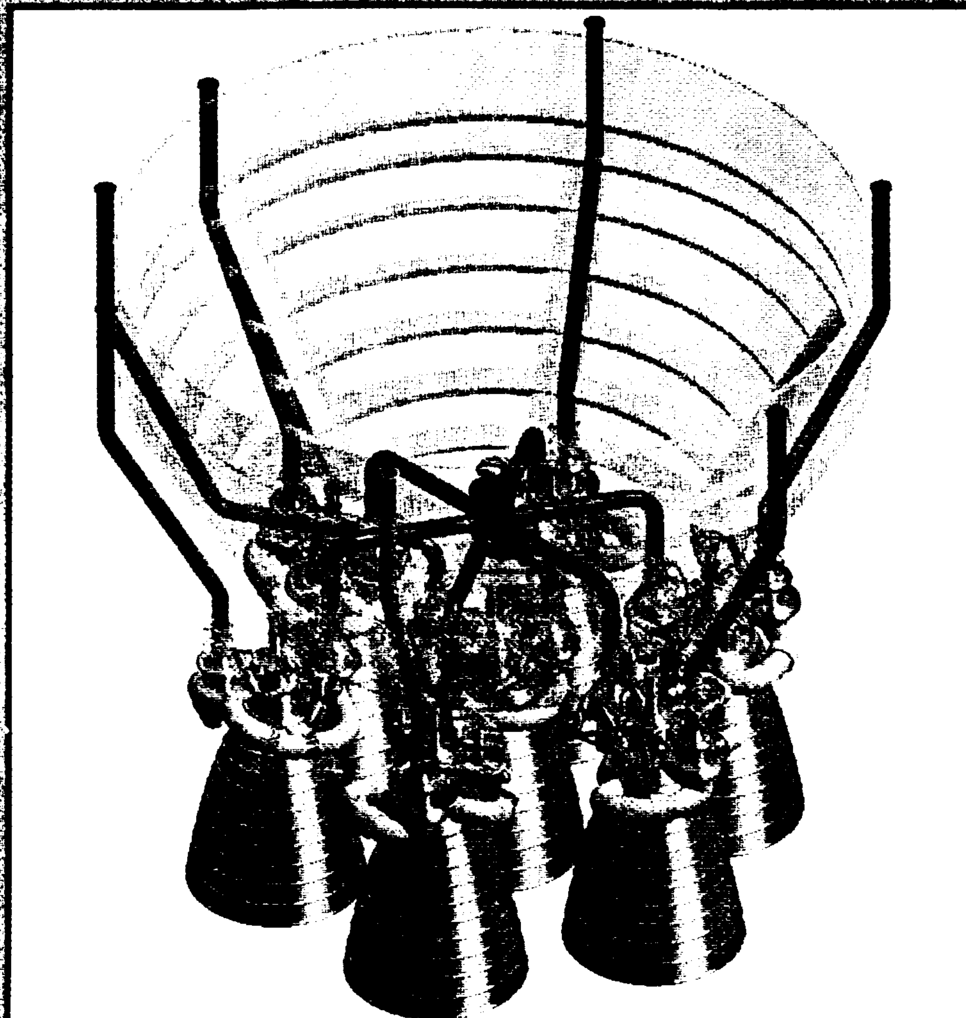
CONVENTIONAL BOOSTER PROPULSION SYSTEM
7 – ENGINE



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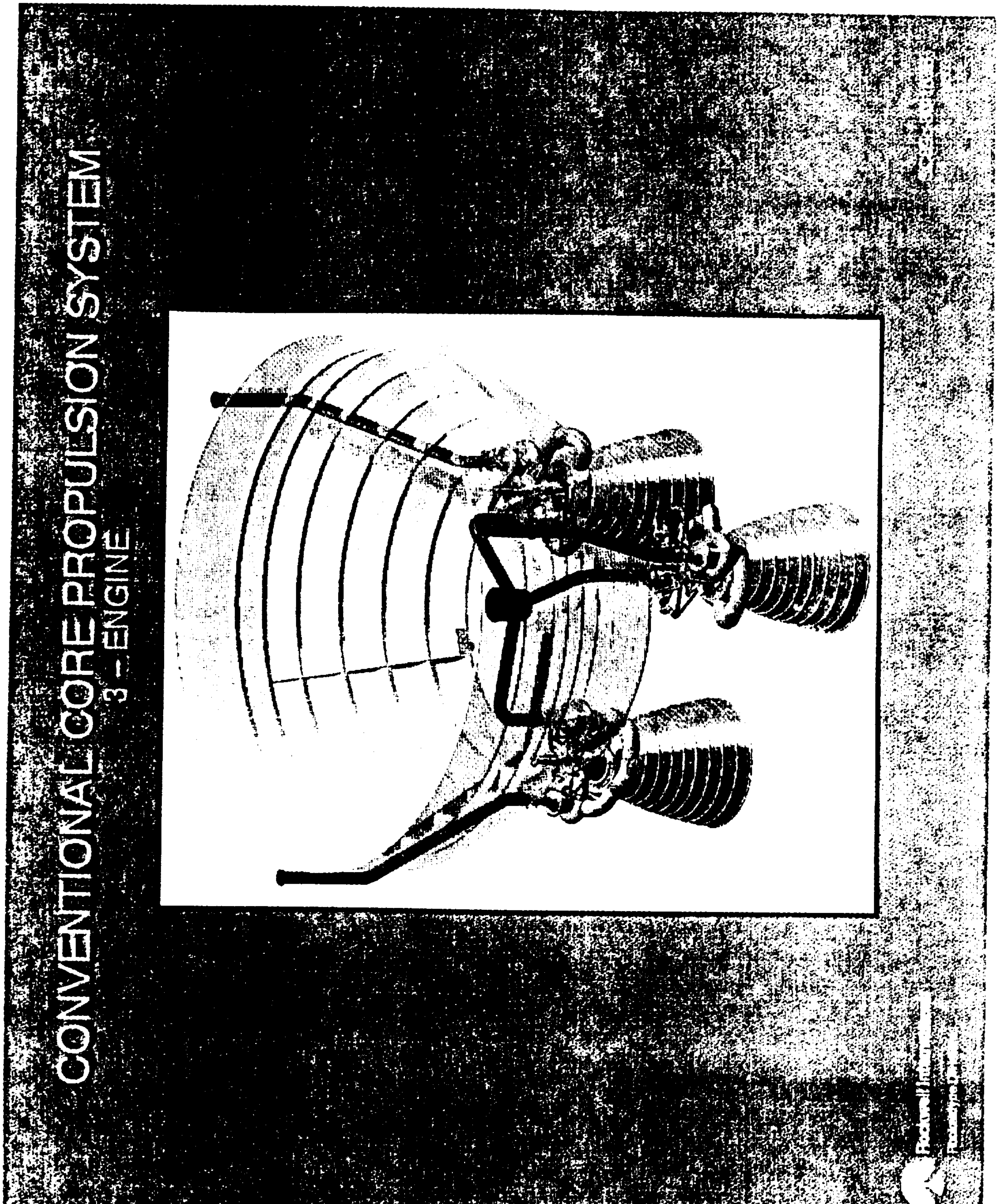

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ALS INTEGRATED BOOSTER PROPULSION MODULE

- **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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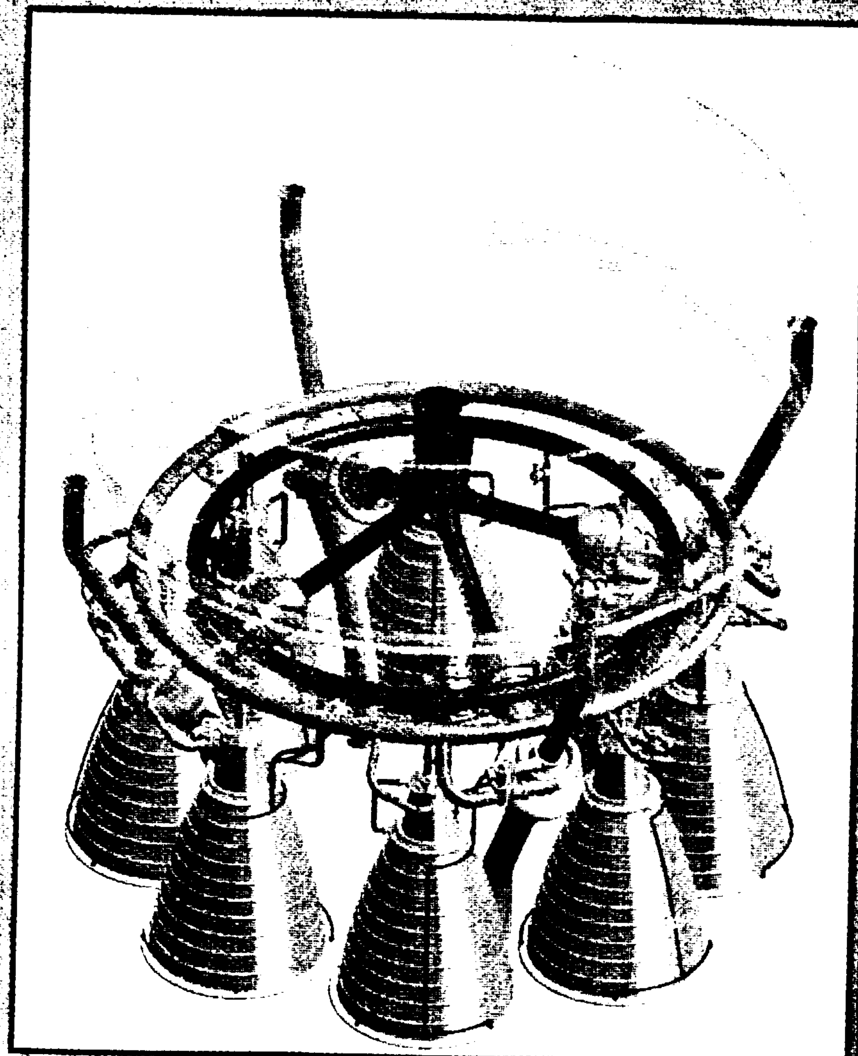
INTEGRATED BOOSTER PROPULSION MODULE – ENGINE

8 – THRUST CHAMBERS



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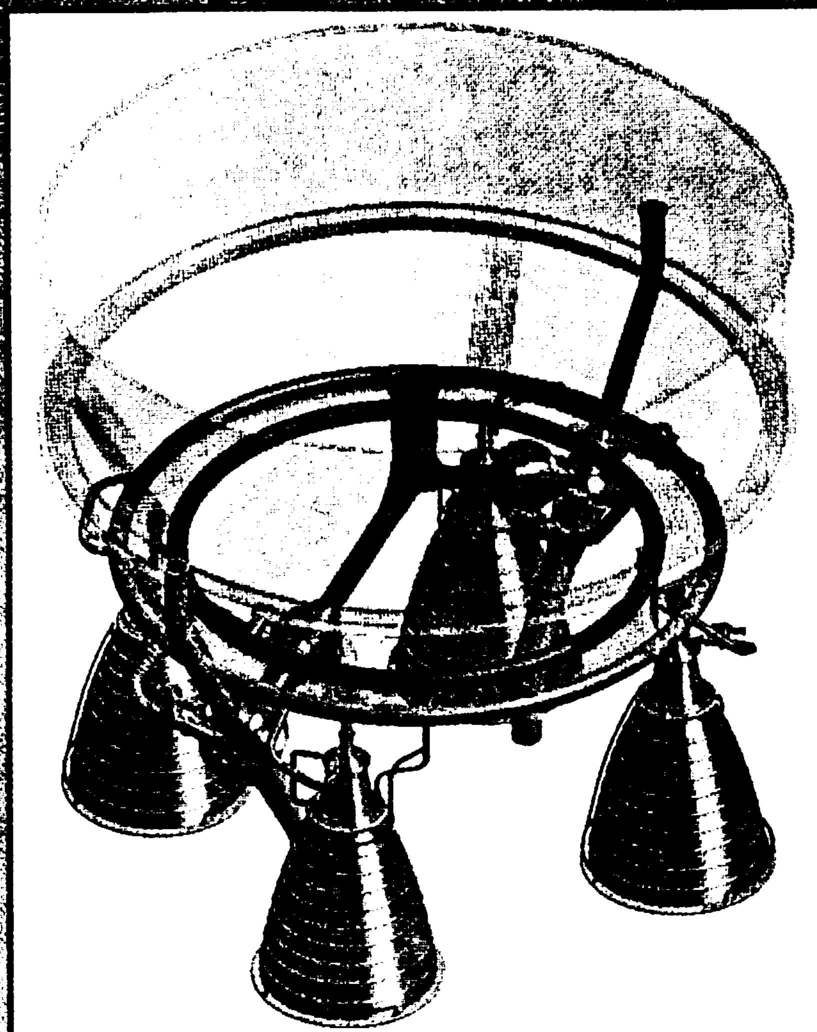
INTEGRATED CORE PROPULSION MODULE – ENGINE
4 – THRUST CHAMBERS



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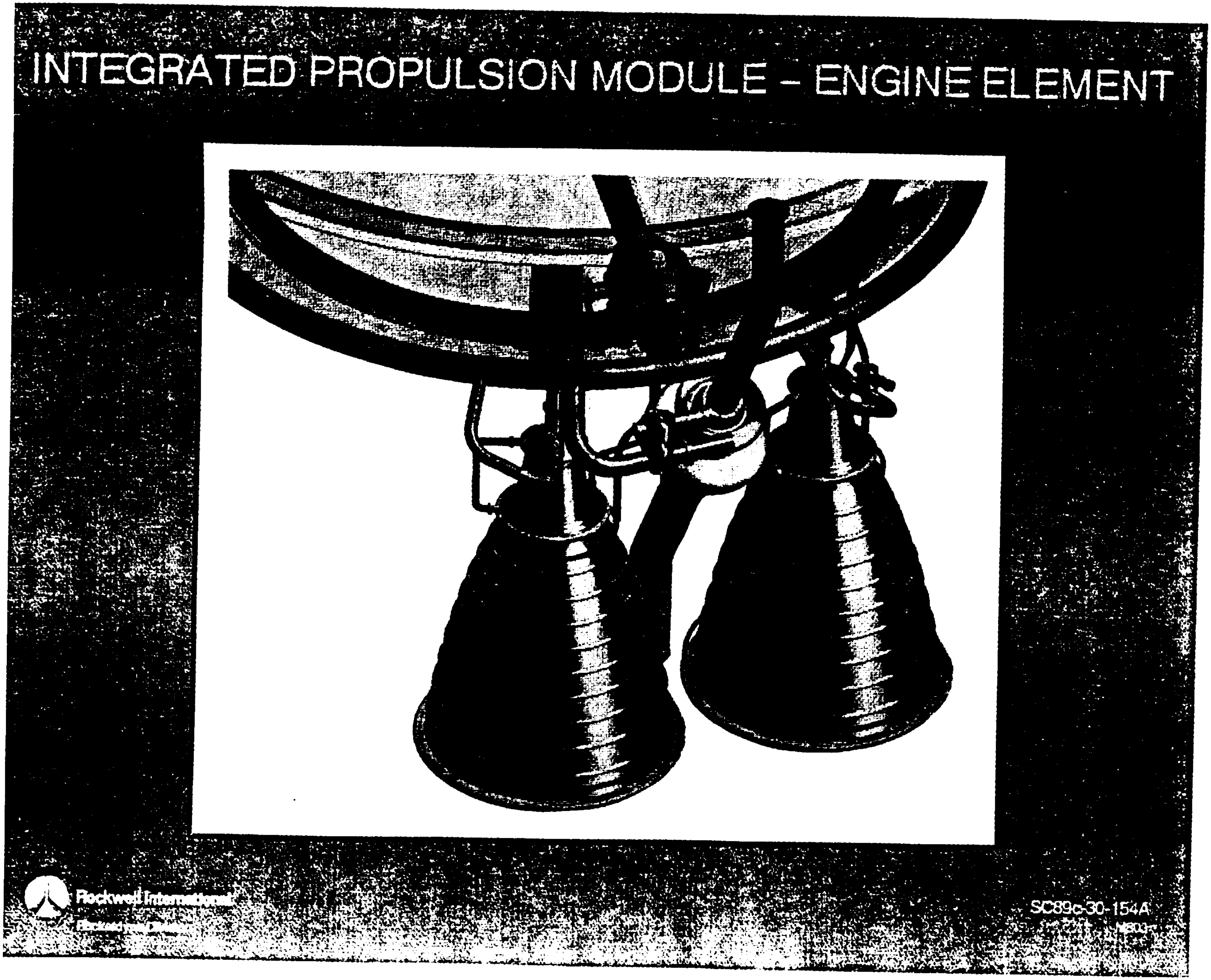

INTEGRATED PROPULSION MODULE - ENGINE ELEMENT
Rockwell International
SC89c-30-154A

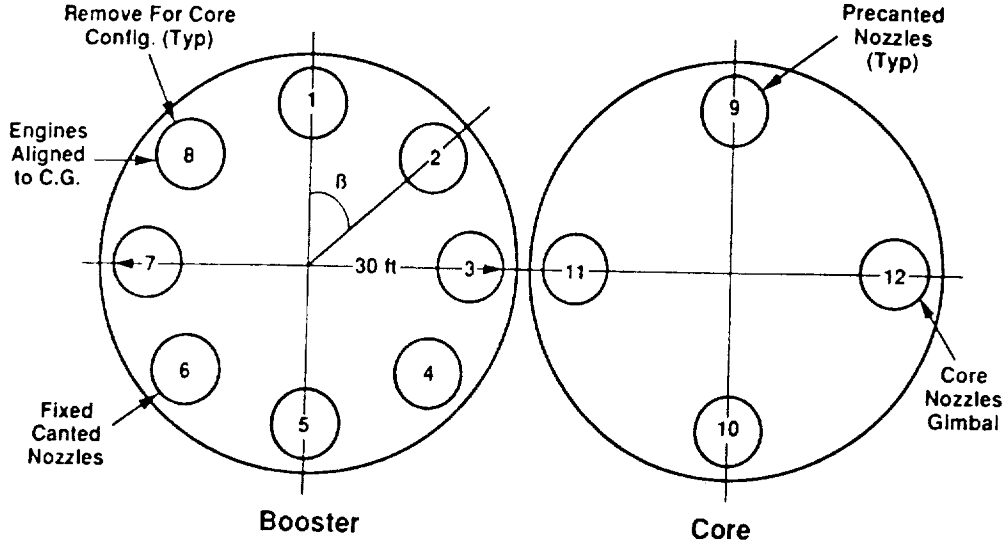
INTEGRATED PROPULSION MODULE DESIGN INCREASES OPERATIONS EFFICIENCY

- 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

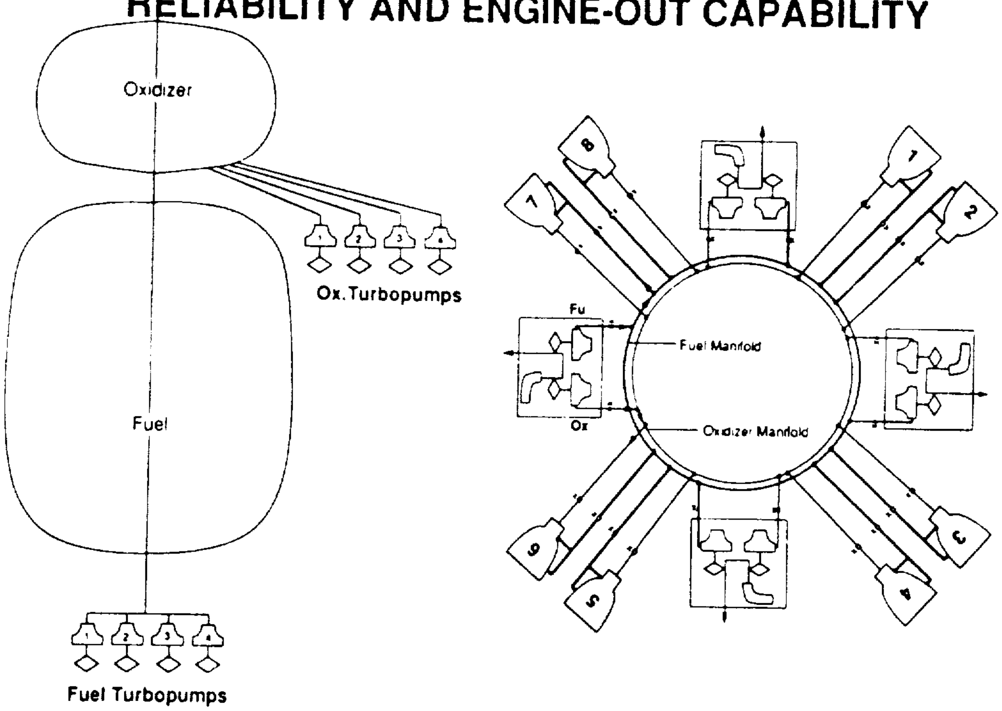
INTEGRATED PROPULSION MODULE MAXIMIZES ROBUSTNESS AND COMMONALITY

- 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



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

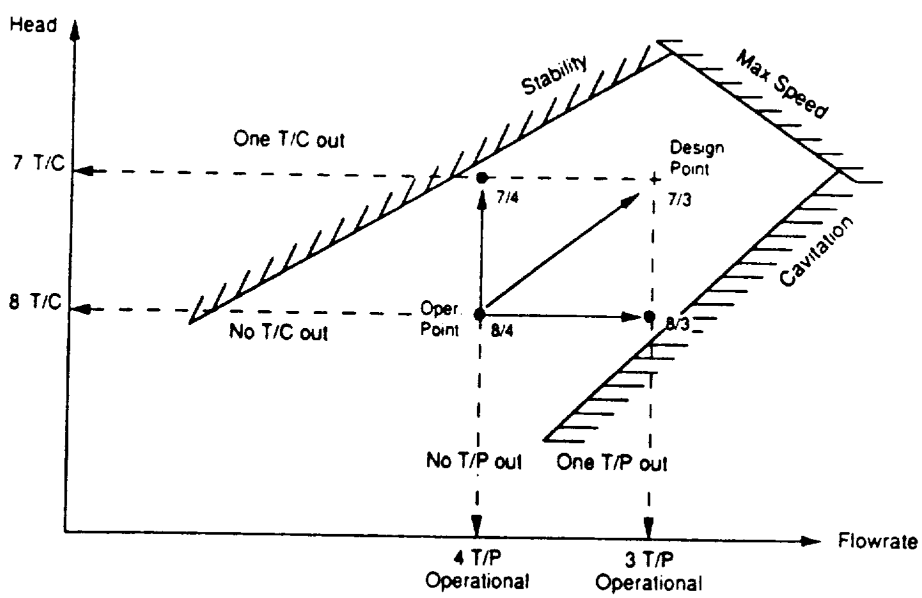
Engine Operation	Thrust Chamber (T/C) % Rated Thrust	Turbopumps (T/P) % Rated Speed
Nominal	85	90
T/C - Out	100	97
T/P - Out	85	93
T/C and T/P-Out	100	100

ROBUST TURBOPUMP DESIGN

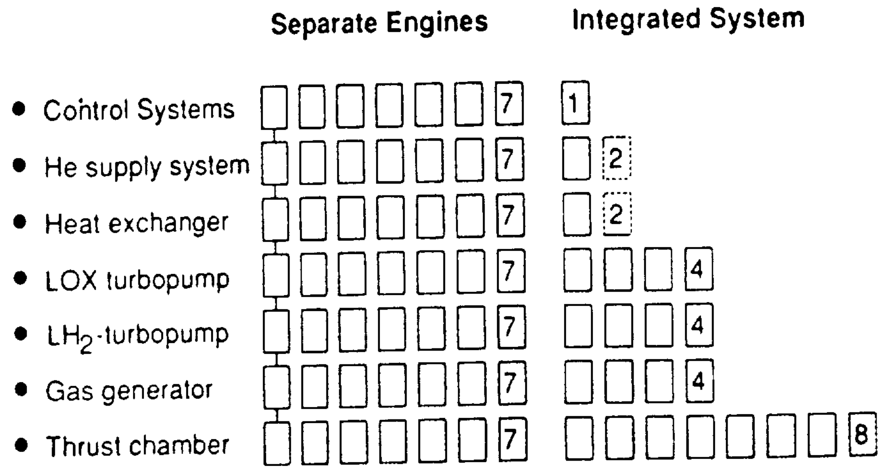
- Lower design speed
- Operating margin

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



SEPARATE ENGINES VS. INTEGRATED SYSTEM



BOOSTER PROPULSION MODULE HARDWARE COMPARISON

Separate Engines vs. Integrated System

Engine Elements	Separate Engines No. of Components	Integrated System (Static) 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
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 (1,00,000 - 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