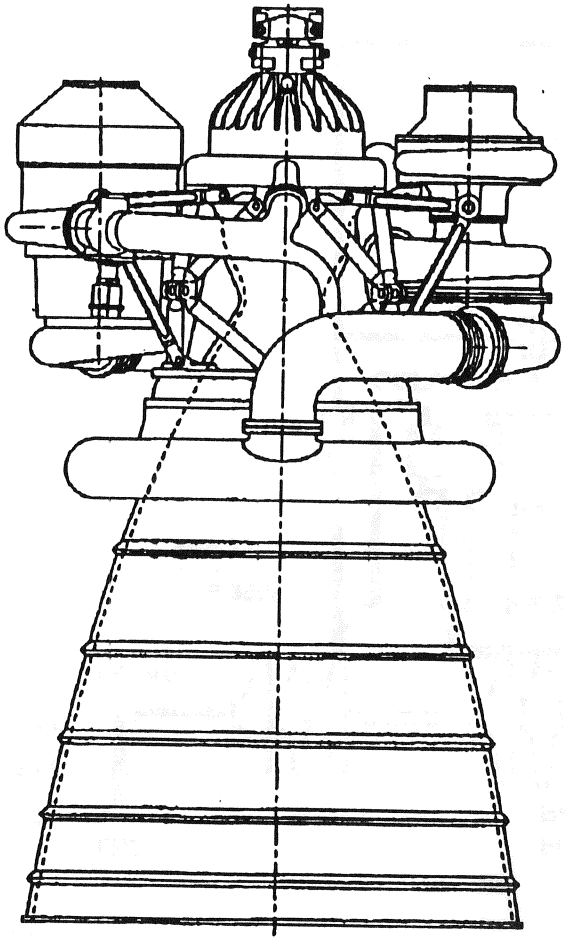
OVERALL DESCRIPTION OF ENGINE

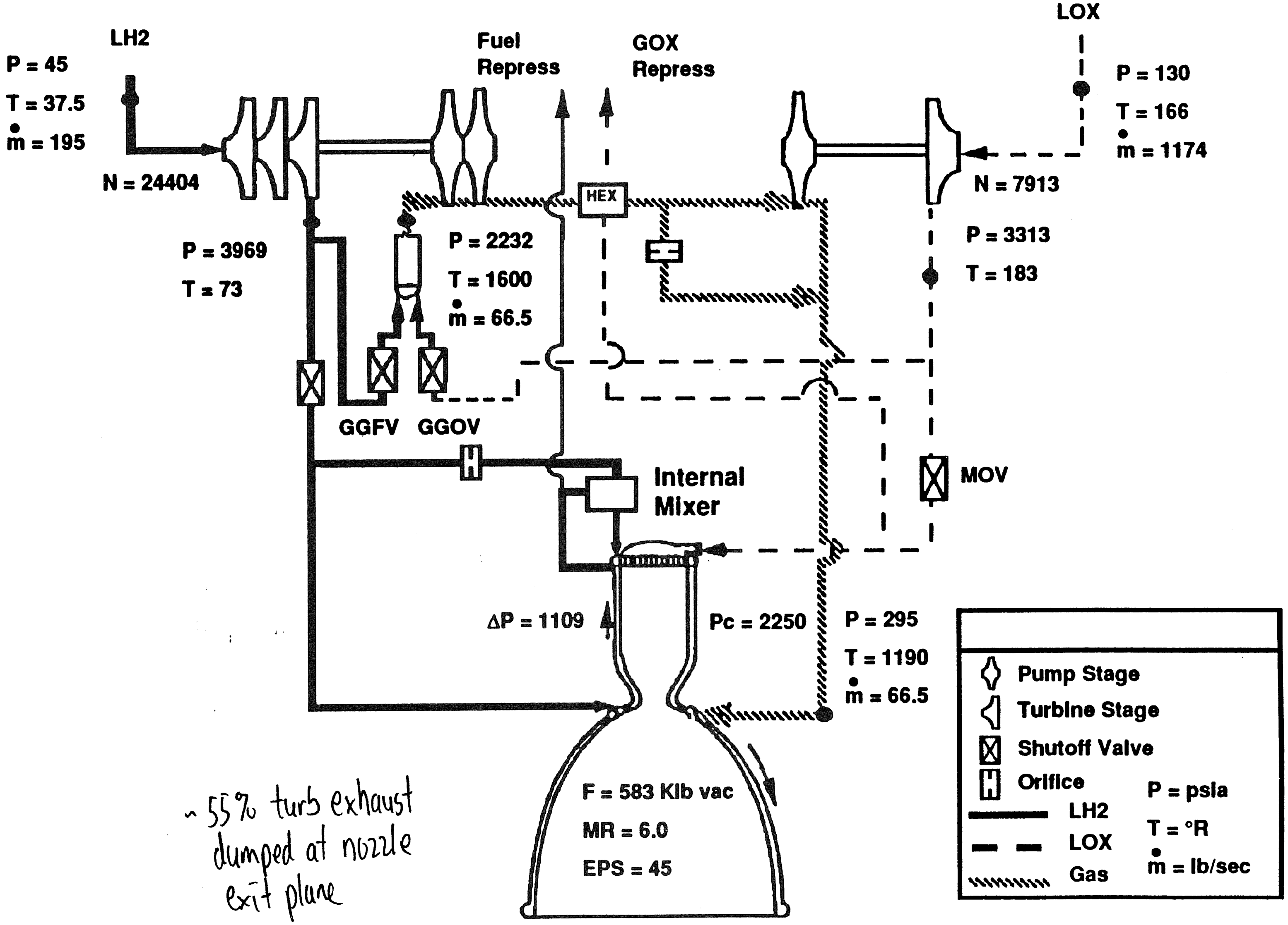
Engine Characteristics



Performance	
Thrust, lbs	583,000 (vacuum)
Chamber Pressure, psia	2250
Mixture Ratio	6.0
Min. Specific Impulse (vac) sec	430.5
Weight, lbs	8000 — no margin- P-W recommending 10% ⇒ 8800 lbs
Area Ratio	45
Cost (MFY91$)	
500th Unit @ 30 / yr.	4500 K
Reliability	
Demonstrated	.99 @ 90%
Design	.999
Other	
Duty Cycle	10 missions
Salt Spray	Yes
Stepped Thrust	70/100%
Open Loop Control	Yes
Tank Head Start	Yes

STME SCHEMATIC

Rated Conditions



~55% turb exhaust dumped at nozzle exit plane

ENGINE THRUST LEVEL

- Current baseline is 583,000 lb (vac.)
- Design and manufacturing efforts are maturing and tooling release starting
- * No obvious driver to increase thrust at this time when considering family of vehicles
- If thrust is going to change -- need to do it now - the longer we wait the more it will cost
- Recommend decision by end of October

* driver will be tank stretch study - if can increase tank volume, can increase thrust

PERFORMANCE RESERVES

Current Engine Requirements:

- **Specific impulse:**
  - Stage Average (minimum) 430.5 sec.
  - Single engine average 432.5 sec.
- **Thrust & mixture ratio accuracy ±3%**

Status:

- **Significant study effort and design changes being considered to increase specific impulse**
- **Thrust and mixture ratio accuracy may be improved substantially with a modified acceptance/calibration procedure (no hardware change)**
- **Flight affects could be minimized with simple open loop control system (oxidizer pump discharge pressure)**

Recommend joint vechicle/engine team to:

- **Establish the required specific impulse margin (to be held by the engine)**
- **Determine the optimum thrust and mixture ratio accuracy and establish the accuracy margin**

STME WEIGHT RESERVE

- Current weight goal 8000 lbs.
- Does not include weight reserve
- Recommend additional 10% reserve to be held by engine

⇒ 8800 lb STME includes 10% margin

RELIABILITY ISSUE

Demonstrated reliability as shown by engine test (throttled or fixed thrust)	**0.99 @ 90%** or **0.997 @ 50%**
Design (point) reliability as determined by design features and history (throttled or fixed thrust)	**0.999** (confidence not applicable)

- **Recommend joint working group to discuss**
  - Use of demo or design reliability
  - If demo reliability, what confidence level
  - Effect of holddown
  - Correlation of failure

EXHAUST GASES
MANAGEMENT/BASE HEATING

- **Baseline design uses turbine exhaust gases to cool the nozzle extension - gases discharged at exit plane**
- **Selection based on:**
  - Production cost savings
  - Development program flexibility and cost saving
  - Versatility for change/adaptation to mission requirements
  - Similarity to previous operational systems
- **Current studies Involve trading area ratio against performance, payload and weight**
- **Change in design approach to regeneratively cooled nozzle with "cat eye" injection of turbine exhaust gases into main stream gases (upstream of exit plane is significant cost impact)**
  - Production cost delta $745K (500th unit @ 30/year)
  - Any area ratio change during development program would severely impact development costs

Recommend joint review of issue and agreed upon evaluation plan

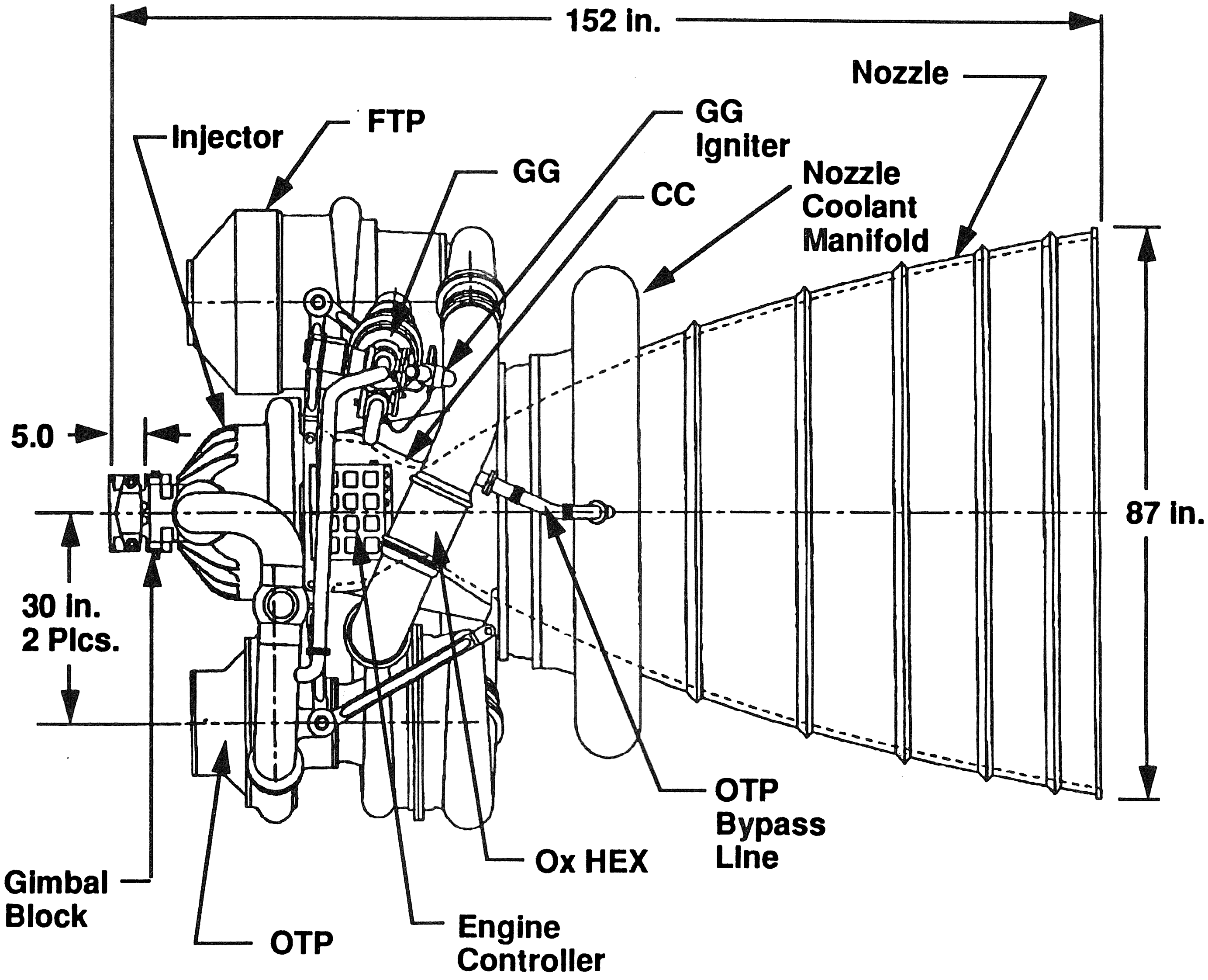
ADDITIONAL NEAR TERM VEHICLE/ENGINE TRADES

- **LOX & LH_2 main stage NPSP requirements**
- **Feed system requirements**
  - Bleed (O_2) recirculation (H_2)
  - Inlet line conditions
  - Pre-press level
  - Inlet line geometry
  - Filters
  - Pressure loss
- **Electrical interface requirements**
  - Power type/level

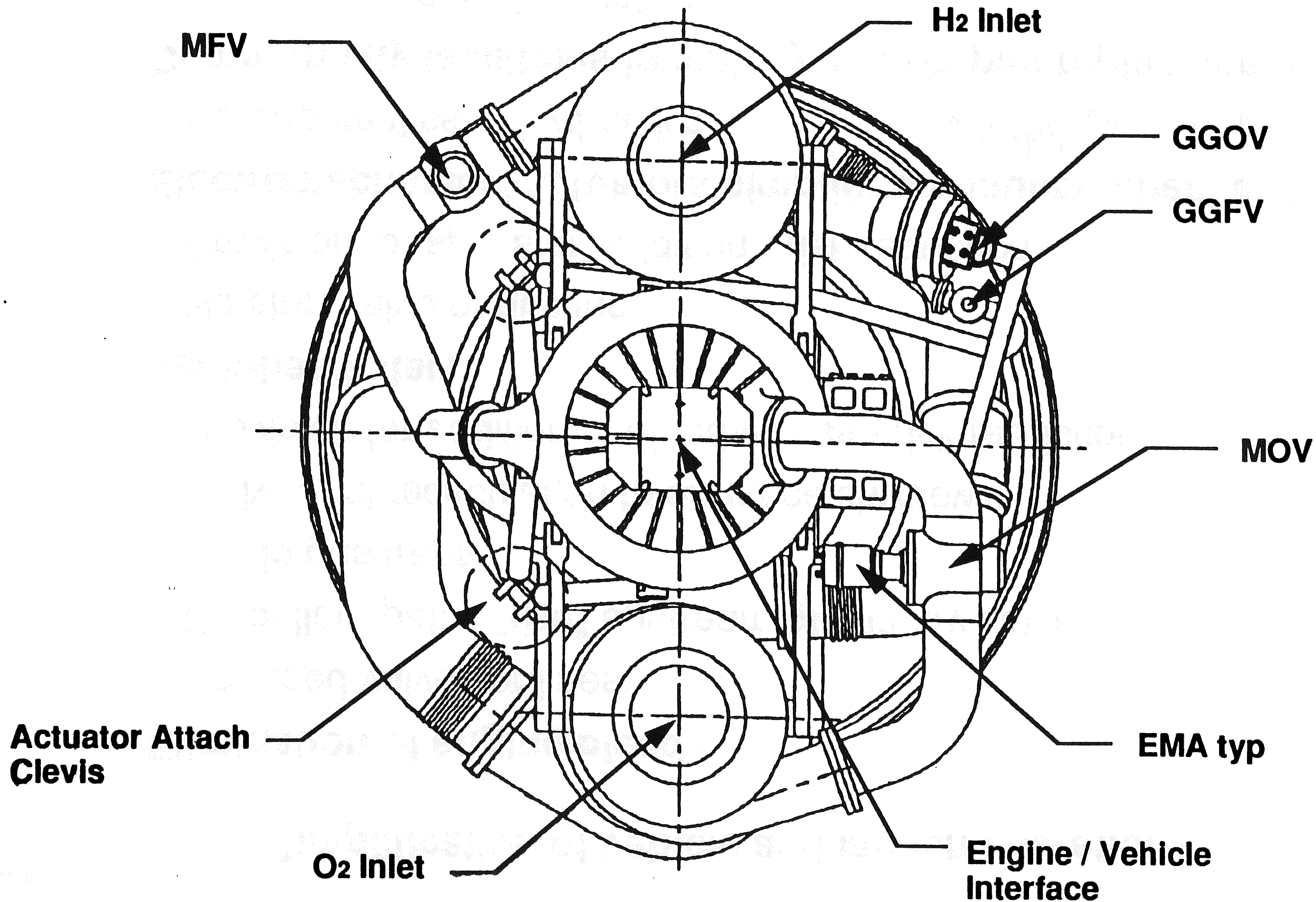
ENGINE ARRANGEMENT

- **Physically integrates components designed by team members:**
  - Combustion Chamber - Rocketdyne
  - Controller - Aerojet
  - Fuel Turbopump - Rocketdyne
  - Injector - Aerojet
  - Nozzle - Pratt & Whitney
  - Oxidizer Turbopump - Pratt & Whitney
- **Component CAD files used in layout**
- **Minor component modifications to facilitate arrangement**
  - Changed oxidizer pump rotation direction to improve line routing
- **Review and iteration with STPT members**
- **CAD file of layout being used for engine / vehicle integration**
- **Arrangement is an outgrowth of J2 engine configuration**

STME SIDE VIEW



STME TOP VIEW



OPERABILITY CONSIDERATIONS

Simplification of vehicle and launch operations

- **Elimination of engine bleeds**
  - No bleed valves or lines
  - Propellant paths "rise" upstream of primary valves
    - No gas traps
    - Natural recirculation to enhance chilldown
  - Provision for addition of bleed valves - risk reduction
- **Tank-head start**
  - No start valve or ducting
  - Provision for spin start addition - risk reduction
- **Electromechanical actuators simplify pre-launch checkout**
  - No pneumatics or hydraulics - 1 failure & will shut-down, not loss of 2 like SSME
- **Commonality facilitates inventory and on-pad replacement**
  - Electromechanical actuators
  - Seals and fasteners

OPERABILITY CONSIDERATIONS (Cont.)

- **Reduction of potential leak paths**
  - Proven joint and seal designs
  - Reduced number of joints
- **Simple component installation**
  - ☆ No stretch bolt joints
- **Automated pre-launch controls checkout**
- **Minimum flight-critical instrumentation**
  - Simple safety monitoring approach
  - Launch commit without 100% operability of instrumentation
- **Balanced complement of instrumentation for post-flight diagnostics (analysis and failure reconstruction)**

ENGINE RELIABILITY ENHANCEMENT

- **Non-intrusive oxidizer heat exchanger (for tank pressurization)**
- **Simple safety monitoring approach. Safe engine shutdown triggered by abnormal values of:**
  - Chamber pressure
  - Interpropellant seal purge pressure
  - Gas generator temperature

  (preliminary)
- **Mechanically linked gas generator valves (to prevent GG mixture ratio excursions)**
- **Prudent use of redundancy in control system**
  - Dual EMA motors and resolvers
  - Duplex / triplex controller electronics
  - Dual power source

MAXIMUM DESIGN CONDITION

- **Defined by an industry and government team**
- **Ensures a robust design by including significant operational margin and development margin**
- **Accounts for all aspect of the operating envelope**
  - Flight effect
    - All potential mission profiles included
    - LOX and LH2 inlet temperature variations
    - LOX and LH2 inlet pressure variations
    - Other variations (i.e. repress) to be incorporated when defined
  - Hardware variations
    - Account for as built component to component differences in hardware characteristics
  - Calibration variations
    - Account for the variability to calibrate an engine to nominal conditions
    - 3 % on thrust and mixture ratio
    - 3.6 % on GG temperature
- **Development margin**
  - 10 % thrust margin
  - Included for robustness and to reduce development risks
  - Minimize redesign of components due to development shortfalls

LOW COST STME DESIGN PHILOSOPHY

Design-To-Cost Integral Part of Design Process

- New Manufacturing Techniques
- Advanced Development Programs Used to Investigate Low Cost Ideas
- Suppliers Integral Part of Design Effort
- Designers Working To Cost Goals
- Costs Continually Estimated and Tracked
- Cost Drivers Identified and Worked
- Trade Studies Used to Select Lowest Cost Concepts
- Zero RID"s
- Zero MR's

idealists!

HIGH RELIABILITY STME DESIGN PHILOSOPHY

Design For Reliability Integral Part of Design Process

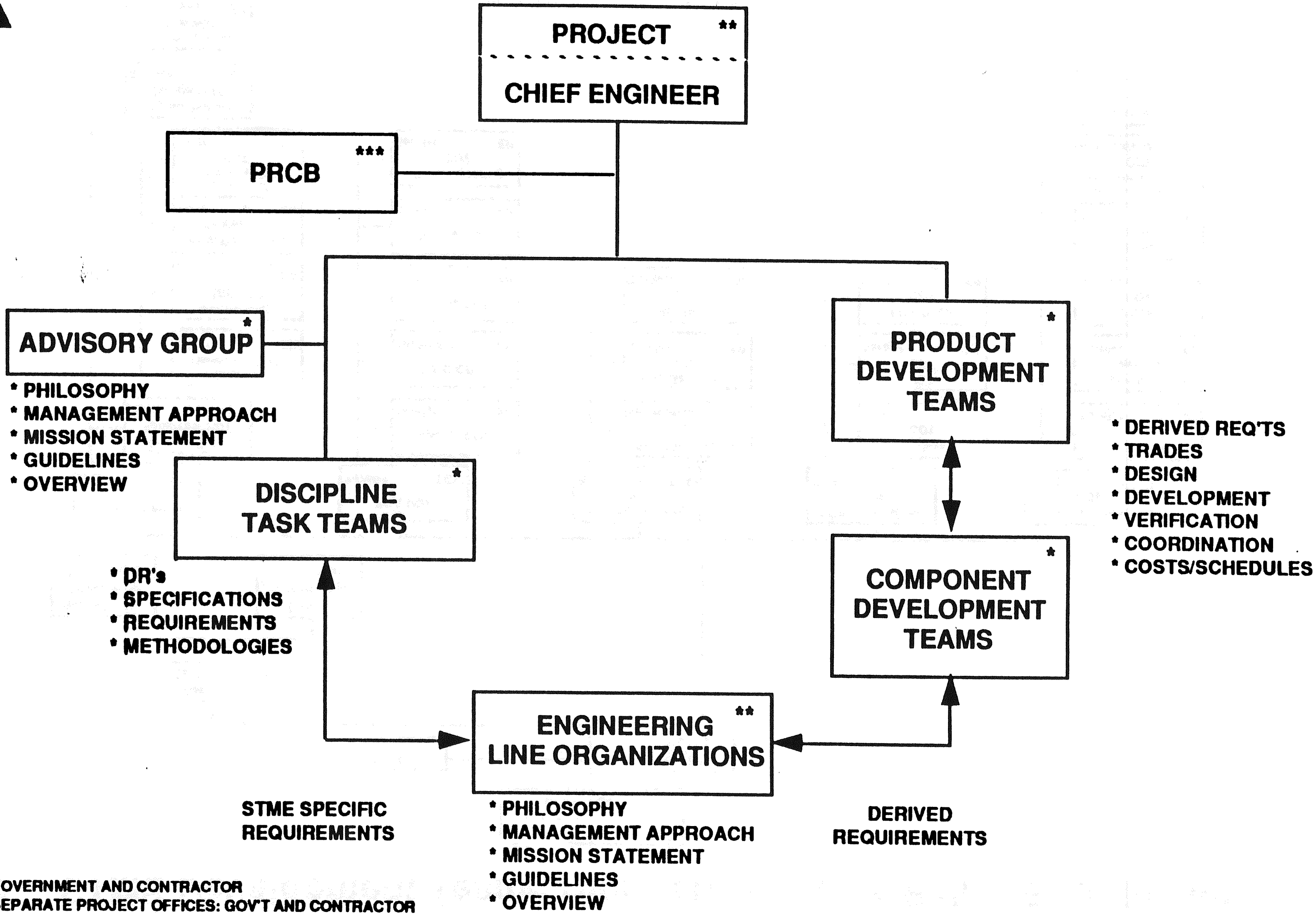
- Concurrent engineering
- Design to reliability goals
- Reliability lessons learned
- Bottoms-up failure modes and effects analysis
- Tops-down fault tree analysis
- Reliability tracking
- New Manufacturing techniques
- Reliability demonstration program
- 10% development margin

castings, fewer welds.

STME ALLOCATIONS

Description	Cost, FY 91$ 500th Unit	Weight, lbs.	Design Reliability
TURBOMACHINERY:			
OXYGEN TURBOPUMP	510	1390	0.999793
FUEL TURBOPUMP	630	1370	0.999821
COMBUSTION DEVICES:			
MAIN INJECTOR	500	1035	0.999962
COMBUSTION CHAMBER	520	1451	0.999980
NOZZLE	530	1567	0.999975
GAS GENERATOR	120	78	0.999942
IGNITERS	70	13	0.999979
CONTROLS			
CONTROLLER	350	35	0.999975
SENSORS	160	35	0.999998
VALVES/ACTUATORS	210	193	0.999812
INTERCONNECTS	210	17	0.999991
PNEUMATIC SYSTEM	150	18	0.999989
PROPELLANT DUCTS	180	315	0.999677
SUPPORT DEVICES:			
GIMBAL BEARING	50	121	0.999983
HEAT EXCHANGER	70	17	0.999973
MISC. HARDWARE	100	345	0.999944
ASSEMBLY AND CHECKOUT	60		
ACCEPTANCE	80		
ENGINE TOTAL	**4500K**	**8000**	**0.999**

HOW PROGRAM WILL OPERATE



PROJECT **

CHIEF ENGINEER

PRCB ***

ADVISORY GROUP *
- PHILOSOPHY
- MANAGEMENT APPROACH
- MISSION STATEMENT
- GUIDELINES
- OVERVIEW

DISCIPLINE TASK TEAMS *
- DR's
- SPECIFICATIONS
- REQUIREMENTS
- METHODOLOGIES

PRODUCT DEVELOPMENT TEAMS *

COMPONENT DEVELOPMENT TEAMS *
- DERIVED REQ'TS
- TRADES
- DESIGN
- DEVELOPMENT
- VERIFICATION
- COORDINATION
- COSTS/SCHEDULES

ENGINEERING LINE ORGANIZATIONS **
- PHILOSOPHY
- MANAGEMENT APPROACH
- MISSION STATEMENT
- GUIDELINES
- OVERVIEW

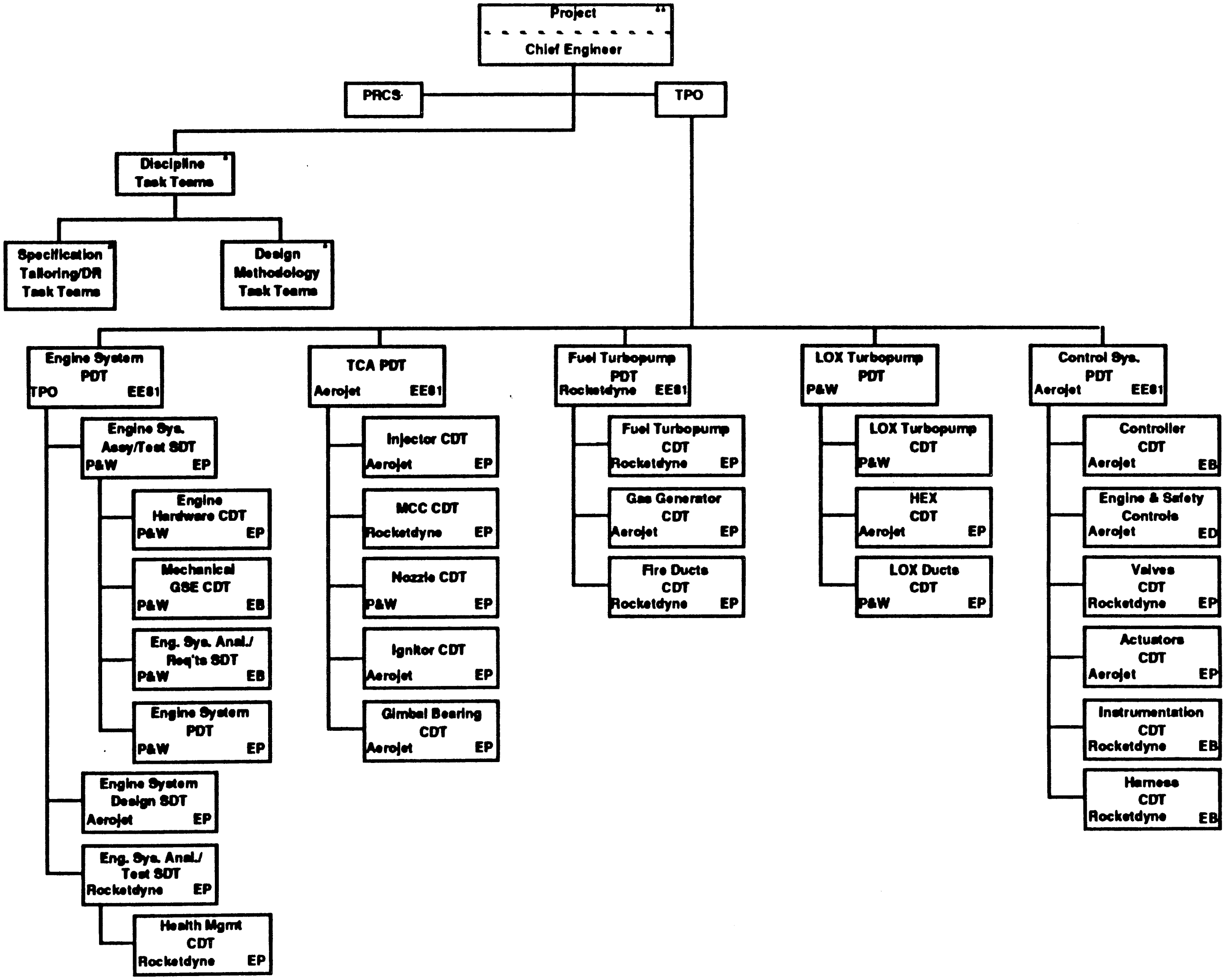
STME SPECIFIC REQUIREMENTS

DERIVED REQUIREMENTS

* GOVERNMENT AND CONTRACTOR
** SEPARATE PROJECT OFFICES: GOV'T AND CONTRACTOR
*** GOVERNMENT ONLY

STME REQUIREMENT SELECTION

STME Development Teams Hierarchy - Teams Being Established



SUMMARY PREVIOUS ENGINE TECHNICAL TRADES

- Engine Propellants - Hydrogen / Oxygen
- Engine Cycle - Gas Generator
- Engine Control Points - Five Valves
- Nozzle Cooling Concept - Film / Dump Cooling
- Start Concept - Tank Head Start
- Engine Purge Gas-He Only
- Variable Thrust - Dual Thrust Setting - 70% (MPL)
  100% (RPL)
- Control Concept - Open Loop Thrust & Mixture Ratio Control

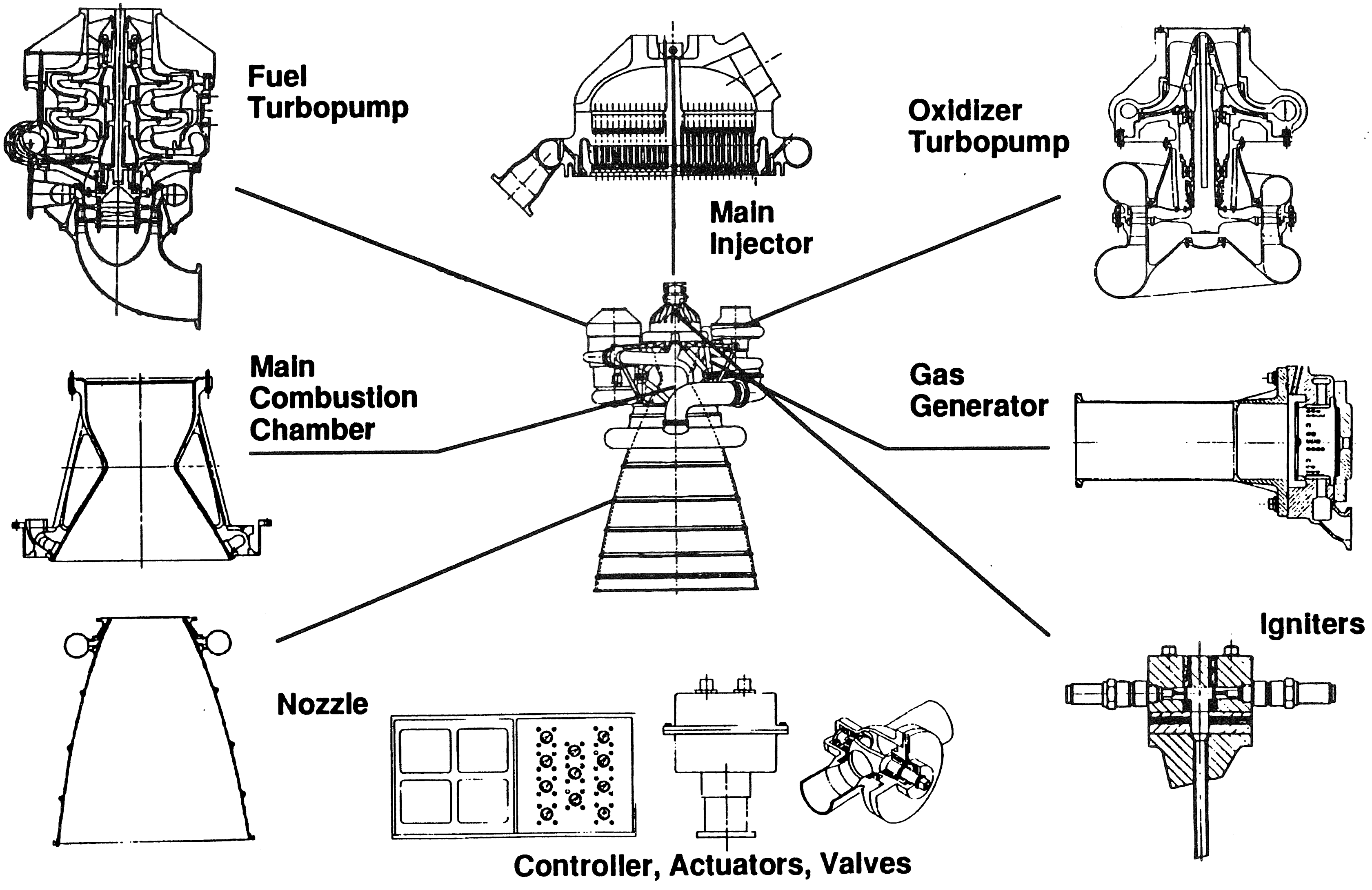
STME HAS STRONG TECHNICAL BACKGROUND

- Trades and Studies Conducted 7500 +
  - Engine system level trades
  - Engine component level trades
  - Manufacturing Studies
  - Assembly Facilities Studies
  - Test Facilities Studies
  - Overhaul Facilities Studies

SUMMARY CURRENT ENGINE TECHNICAL TRADES

- **Nozzle Configuration**
  - Common vs. separate nozzle for booster & core
  - Optimum separate nozzle or truncated nozzle
- **Engine Specific Impulse Improvement**
  - Nozzle area ratio
  - Mixture ratio control
  - Engine mixture ratio
  - Split-Flow turbopump
  - General component performance improvement
- **Fuel and Oxygen Pressurization**
  - Pressurant temperature
  - Pressurant fluid (O_2 or He)
  - Pump NPSH vs vehicle tank pressure trade
- **Engine Maintenance**
  - Maintenance concept
  - Installation concept
  - Engine access / clearance
- **Engine Start**
  - Valve schedules
  - Tank pre-pressurization level
  - Pump / line conditioning
  - Pump heat leaks
  - Pump NPSH requirements

MAJOR ENGINE COMPONENTS

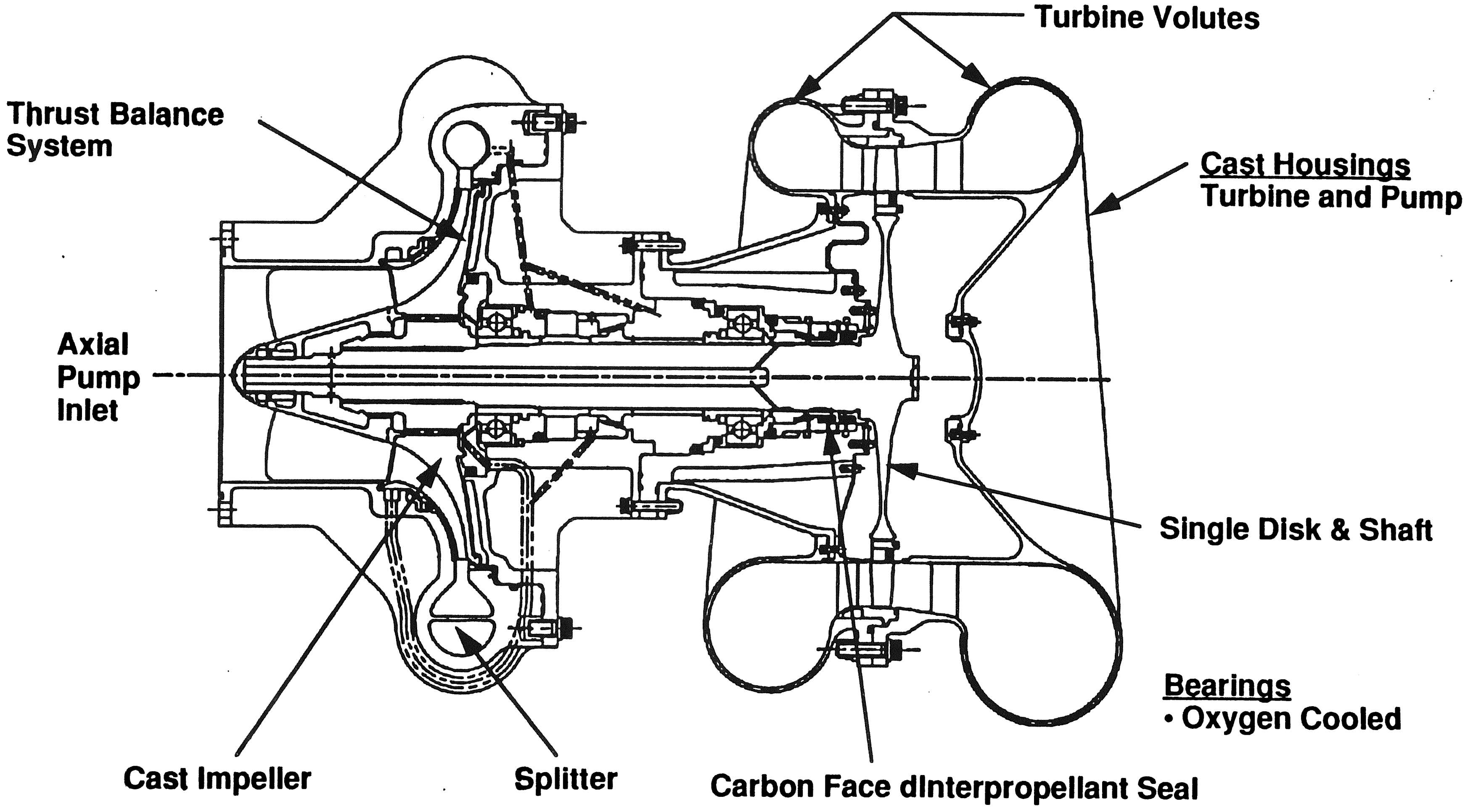


FEATURES OF COMPONENTS

- Component features
- Operating characteristics
- Key trades
- ADP input
- Future plans

OXYGEN TURBOPUMP

Features Reliability & Low Cost



Turbine Volutes

Thrust Balance System

Cast Housings
Turbine and Pump

Axial Pump Inlet

Single Disk & Shaft

Bearings
- Oxygen Cooled

Cast Impeller

Splitter

Carbon Face dInterpropellant Seal

OXYGEN TURBOPUMP CHARACTERISTICS

Pump concept

- Cast axial inlet housing
  - Achieve low cost, minimize flow distortion
- Cast volute discharge housing with splitter
  - Reduce side loads & minimize flow distortion
- Cast inducer / impeller
  - Achieve low fabrication cost
- Thrust balance provided by impeller
  - Eliminate need of separate thrust piston

Turbine concept

- Cast volute inlet and discharge housings
  - Reduce side loads & minimize flow distortion
- Cast airfoils
  - Achieve low fabrication & materials cost
- Single disk / shaft
  - Reduce machining cost, eliminate need for assembly

Other

- Carbon face IPS
  - Reduce helium leakage
- Common ball bearings
  - Eliminate need of separate P/N
- Damper seal
  - Increase reliability

OPERATING PARAMETERS

Oxidizer Turbopump

Parameter	Nominal Values (RPL)
Pump	
Inlet Pressure, psia	130
Inlet Temp, °R	166
NPSH, ft	228
Inlet Flowrate, #M / sec	1174
Discharge Pressure, psia	3313
Rotor Speed, rpm	7913
Turbine	
Inlet Pressure, psia	524
Inlet Temperature, °R	1301
Inlet Flowrate, #M / sec	63
Horsepower	19,272

SIGNIFICANT TRADE STUDIES

Oxidizer Turbopump

Trade	Resolution	Rationale
• Shaft / disk configuration	• One-piece forging	• Reduced machining cost, no assembly
• Interpropellant seal configuration	• Carbon face seal	• Less helium consumption
• Impeller fabrication process	• Fine grain casting	• Lower fabrication cost
• Thrust balance system	• Integral thrust balance using impeller back face and vortex vanes	• Elimination of separate thrust piston
• Number turbine stages	• Single stage turbine	• Fewer parts, lower cost
• Turbine blade configuration	• Hollow, shrouded blades with dovetail attachment	• Less pull on rim; single attachment produces known load split

LOX TURBOPUMP ADP CONTRIBUTIONS

Task #1201, contract NAS-37595

- **Cast turbine housing development & material evaluation**
    - Demonstrated Haynes material using existing SSME-ATD tooling
    - Testing PWA1490 test specimens from production SSME - ATD housing for hydrogen degration evaluation-complete 7/91
    - Characterizing PWA 1490 material - complete 3/92
- **Fine grain cast PWA-1490 impeller development**
    - Full-scale impeller demonstrated in existing tooling
    - Metallurgically evaluate test impellers - 6/91
    - Spin test impellers - 11/91
- **Ball bearing design and demonstration**
    - Detailed drawings complete
    - Order ball bearings - 5/91
    - Ball bearing rig tests - 9/92 - 2/93
- **Hydrostatic bearing design and material evaluation**
    - Procure materials for LOX frictional heating tests - test 7/91
    - Design of bearing - complete 12/91
- **Disk / shaft demonstration and material evaluation**
    - Forged full-scale Waspaloy and A286 disk / shafts & verified material properties

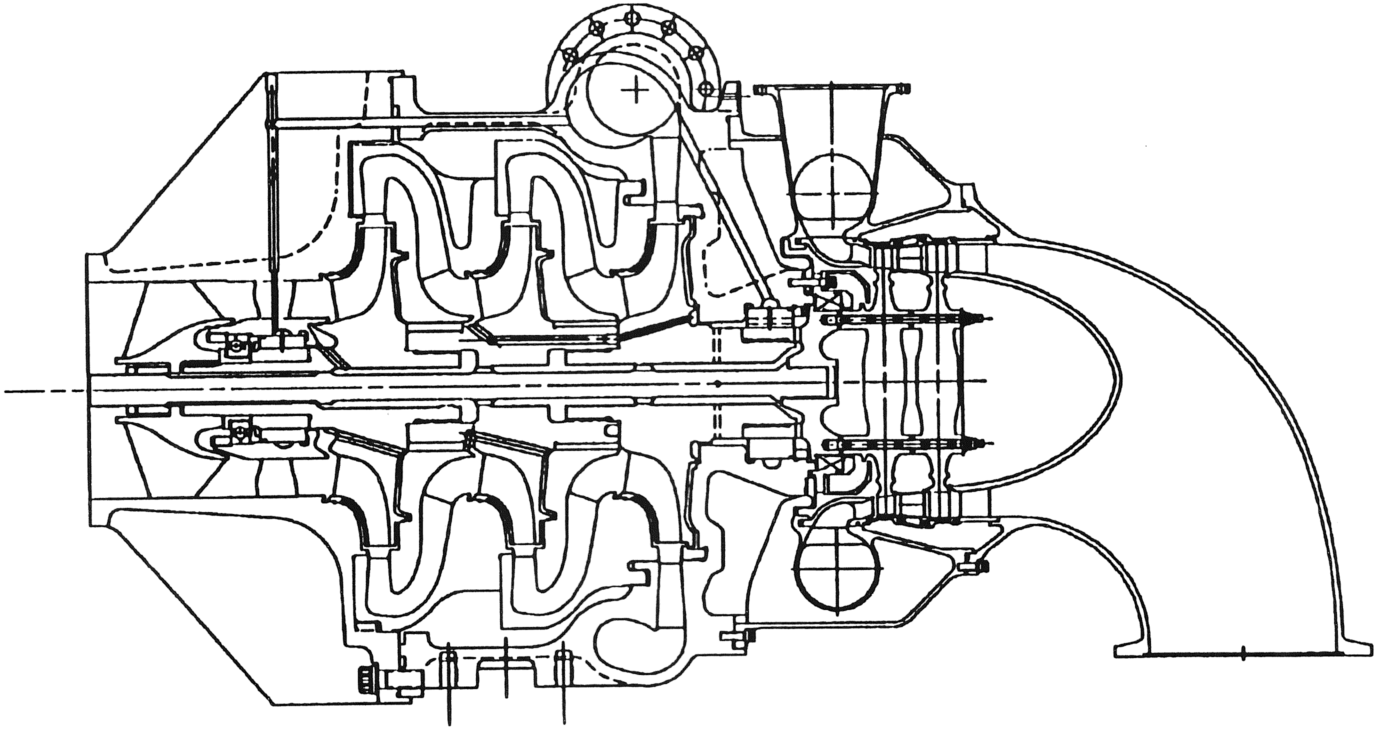
FUTURE PLANS

- **Design**
  - Complete preliminary design
    - Aerodynamic, hydrodynamic & rotordynamic definition
    - Structural analyses of major components
    - Produce layouts for initiating procurement of long lead hardware
  - Complete retrofittable hydrostatic bearing design

- **Fabrication**
  - Initiate procurement of long lead hardware
    - Cast structural housings
    - Ball bearings
    - Cast impellers

- **Significant Future Milestones**
  - Spin test fine grain cast impeller
  - Complete fine grain Inco 718 material characterization
  - Rig test cryogenic ball bearings

FUEL TURBOPUMP



COMPONENT CHARACTERISTICS

- **Robust structural margins**
  - 10% development margin
  - Three stage pump for adequate head rise margin
  - Moderate design turbine inlet temperatures
  - 50% inducer inlet NPSP margin
  - Hydrostatic bearings to provide load control and life margin
  - Excellent rotordynamic control and flexibility
- **Simple, Low cost design approach**
  - 63 unique parts with blisk turbine design
  - 11 major castings
  - Turbine discs and blades integrally machined
  - Minimum number of interfaces
  - Single intermediate pressure hydrogen sealing flange
  - No welding for component integration
  - Simplified design for low cost assembly
  - Positive face type lift-off seal eliminates boattail leakage

OPERATING PARAMETERS

RPL Values

Fuel Turbopump

Parameter	Values
Pump Parameters:	
Inlet Pressure, psia	45
Inlet Temperature, R	37.5
Inlet Flowrate, lbsm/sec	195.78
Discharge Pressure, psia	3,969
Rotor Speed, rpm	24,404
Turbine Parameters:	
Inlet Pressure, psia	2,189
Inlet Temperature, R	1,600
Inlet Flowrate, lbsm/sec	66.04
Pressure Ratio	4.087
Power, Horsepower	54,989

FUEL TURBOPUMP TRADE STUDIES

Trade	Resolution	Rationale
Bearing placement	Selected pump end clutching bearing Selected inlet mounted hydrostatic bearing	Reduces rotor position variation Facilitates hydrostatic bearing feed Increases critical speed margin
Turbine Manifold/Nozzle design	Selected separate strut	Separates nozzle casting from manifold Carries inlet pressure loading
Pump dynamic seal concept	Lift-off seal selected	Eliminates prelaunch LH_2 leakage Acceptable operating leakage
Splines/Curvics	Splines for pump components Curvics for turbine discs	Both acceptable Geometry constraints favor selected approach
Main housing design concept	Selected integral diffuser/volute design	Eliminates one casting Improves load transfer Reduces weight & size
Turbine disc/shaft configuration	Chose integrally bladed separate disks	Low cast approach Individual blade development for backup

FUEL TURBOPUMP ADP PLANNED ACTIVITY

Advanced Development Programs Provided Component Technology

- **Task 1301.01 Fuel Turbopump Technology / Rocketdyne**
  - **Hydrostatic bearing technology**
    - Test H/S Bearing in HFC-134a in Jan-Feb 1992
    - Test H/S Bearing in LH2 in Mar-April 1992
  - **Titanium impeller casting technology**
    - Intermediate size J-2 impeller properties by mid-FY92
    - Full size casting process verification and properties by end-FY92
  - **HEE resistant, corrosion resistant turbine disc**
    - Modified A-286 forging and heat treat optimization by end FY92
  - **Inducer-stator wake dynamics**
    - Model test with laser velocimeter in water by end FY 92
    - Model pump hardware designed and fab in-process for air test by end of FY92
  - **Firtree blade mounted turbine wheel backup design**
    - Design and ECM process & material properties studies in FY92

FUEL TURBOPUMP ADP PLANNED ACTIVITY

Advanced Development Programs Provided Component Technology

- **Task 1202.01 Fuel Turbopump Technology / Aerojet**
  - **NC machined impeller**
    - Complete fab of 8 - blade impeller
    - Fab 6+6 blade impeller
    - Spin test 6+6 impeller
  - **Tilting Pad Hydrostatic Bearing**
    - Subscale test article design, fab, and test
    - Near-full-scale test article design and fab
    - Test preparations (Rocketdyne rig)
  - **Hot section fabrication optimization**
    - Manifold casting technology
    - Nozzle fab and holographic vibration test
    - Materials study and characterization
  - **Turbine Blisc development**
    - Fab process definition and fab of 1 rotor
    - Holographic vibration test
    - Proof spin test

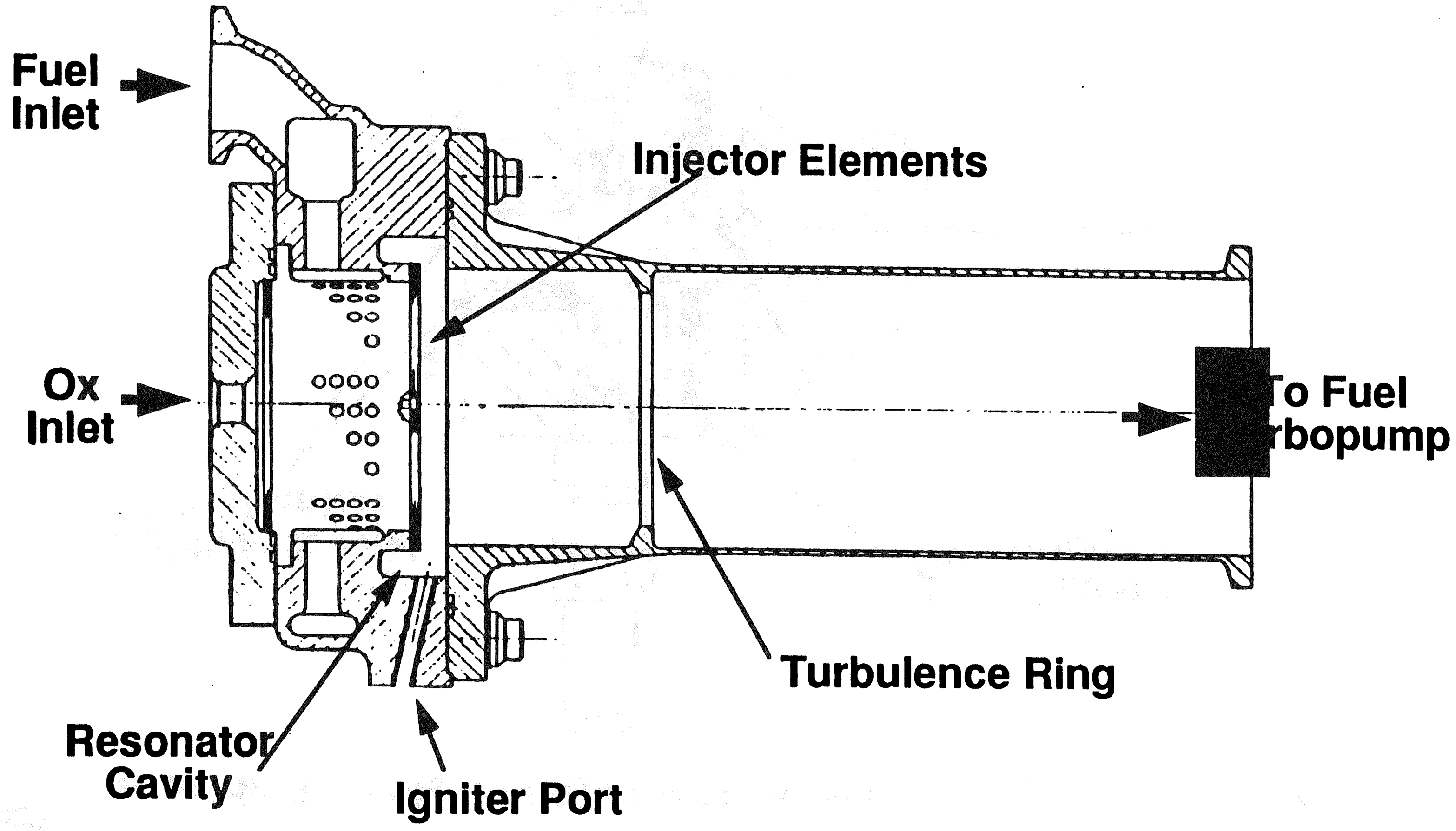
FUEL TURBOPUMP PLANNED ACTIVITY

- **Trade studies to be completed**
    - Turbine Shaft to pump shaft interface
    - Balance piston design range and capacity trades
    - Improved specific impulse design studies
    - Clutching bearing CFD model for operational loads data
    - Manifold/Nozzle configuration
    - Bearing leakage mixing control and utilization

- **Expectations by December 1992 PDR**
    - Complete FTP design layout
    - Perform design analysis on layout configuration
    - Detail design main pump housing

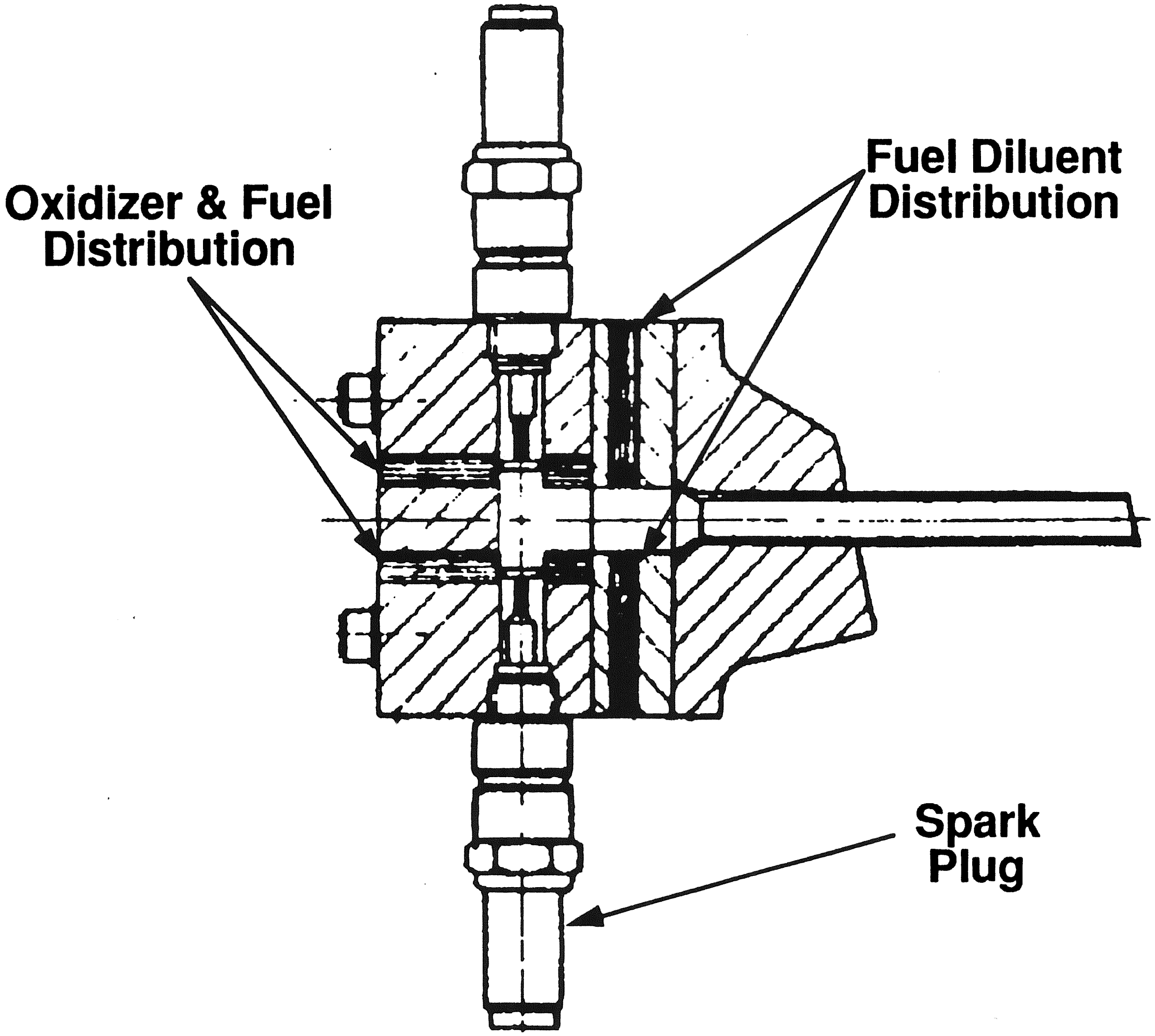
GAS GENERATOR

Provide Accurate, Uniform Temperature to Drive Fuel Turbopump



IGNITER

Provide Reliable Ignition for Main Injector and Gas Generator



Oxidizer & Fuel Distribution

Fuel Diluent Distribution

Spark Plug

SIGNIFICANT TRADE STUDY RESULTS

Gas Generator/Igniter

Trade	Resolution	Rationale
• Mixing approach	• Turbulence ring	• Maturity (Titan, LOX/RP preburner)
• Chamber compatibility	• Generous wall gap	• Low cost (uncooled chamber)
• LOX manifold configuration	• Minimize dribble volume	•Transient MR control; chug stability
• Combustion stability aids	• Acoustic cavities	• Reliability
• Igniter position	• Side-mounted	• Reliable ignition; transient MR control
• Spark provisions	• Spark plug & exciter separate	• Low cost
• Igniter commonality	• Same for gas generator & injector	• Low cost
• Redundancy	• Dual plugs & exciters	• Reliability

GGA/IGNITER OPERATING PARAMETERS

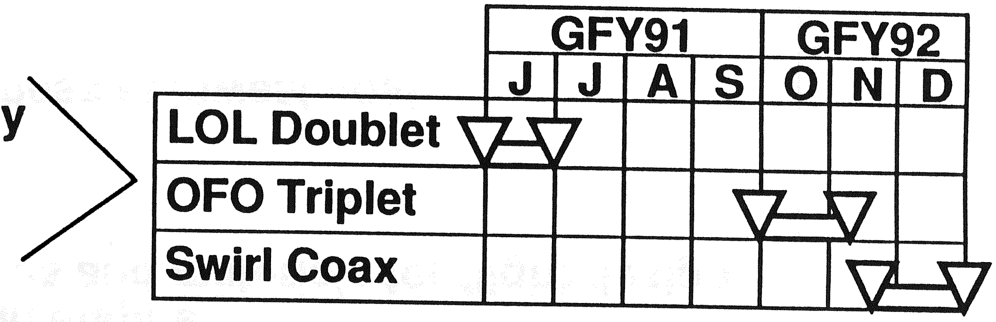
Parameter	Gas Generator Values	Igniter Values
Mixture Ratio	0.88	0.81
Fuel Circuit		
Inlet Pressure	3020 psia	315 psia
Inlet Temperature	73°R	530°R
Flowrate	33.6 lb/sec	0.0638 lb/sec
Oxidizer Circuit		
Inlet Pressure	2788 psia	367 psia
Inlet Temperature	183 °R	530°R
Flowrate	29.5 lb/sec	0.0509 lb/sec
Chamber Pressure	2232 psia	280 psia
Exit Pressure	2189 psia	
Exit Temperature	1600°R	1460°R

GGA/IGNITER ADP CONTRIBUTIONS

Provides Operating Reliability Assessment for Early Risk Reduction

Task 1302 LOX/Hydrogen Combustion Devices Design and Demonstration

- Design and fabricate workhorse gas generators and igniters
- Igniter operability mapping - 2/91
- GGA pattern evaluation:
  - Thermal compatibility
  - Temperature uniformity
  - Throttling
  - Transients
  - Stability



- Evaluate extended range testing for tank head start - 1992
- Assess characterization of J-2D gas generator
- Fabrication process development & materials characterization - 1992

GAS GENERATOR/IGNITER FUTURE PLANS

Trade Studies to be Completed

- Interfaces to fuel turbine and engine
- Finalize fabrication processes and materials for flight design

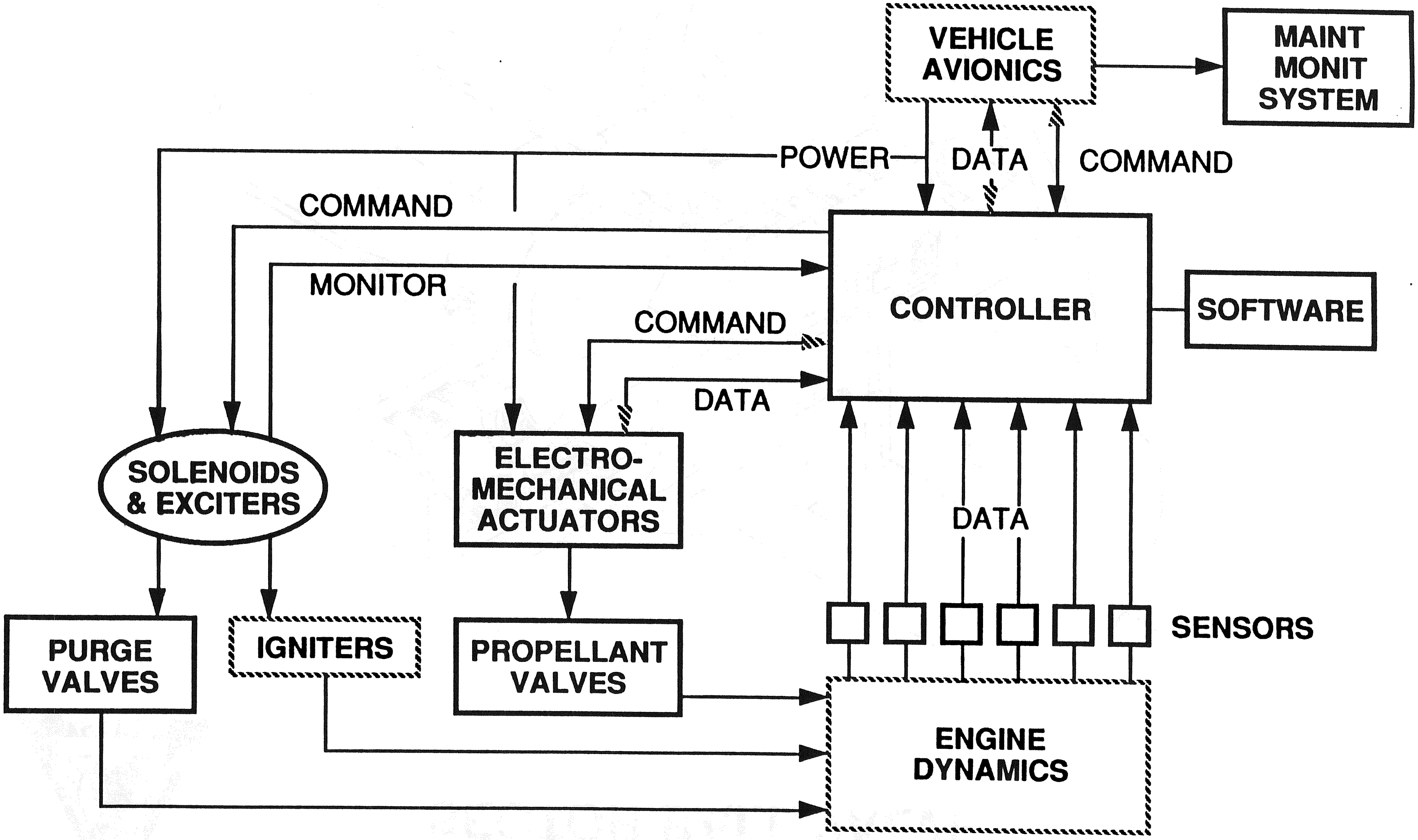
Design Emphasis

- Achieve operational robustness at lowest cost

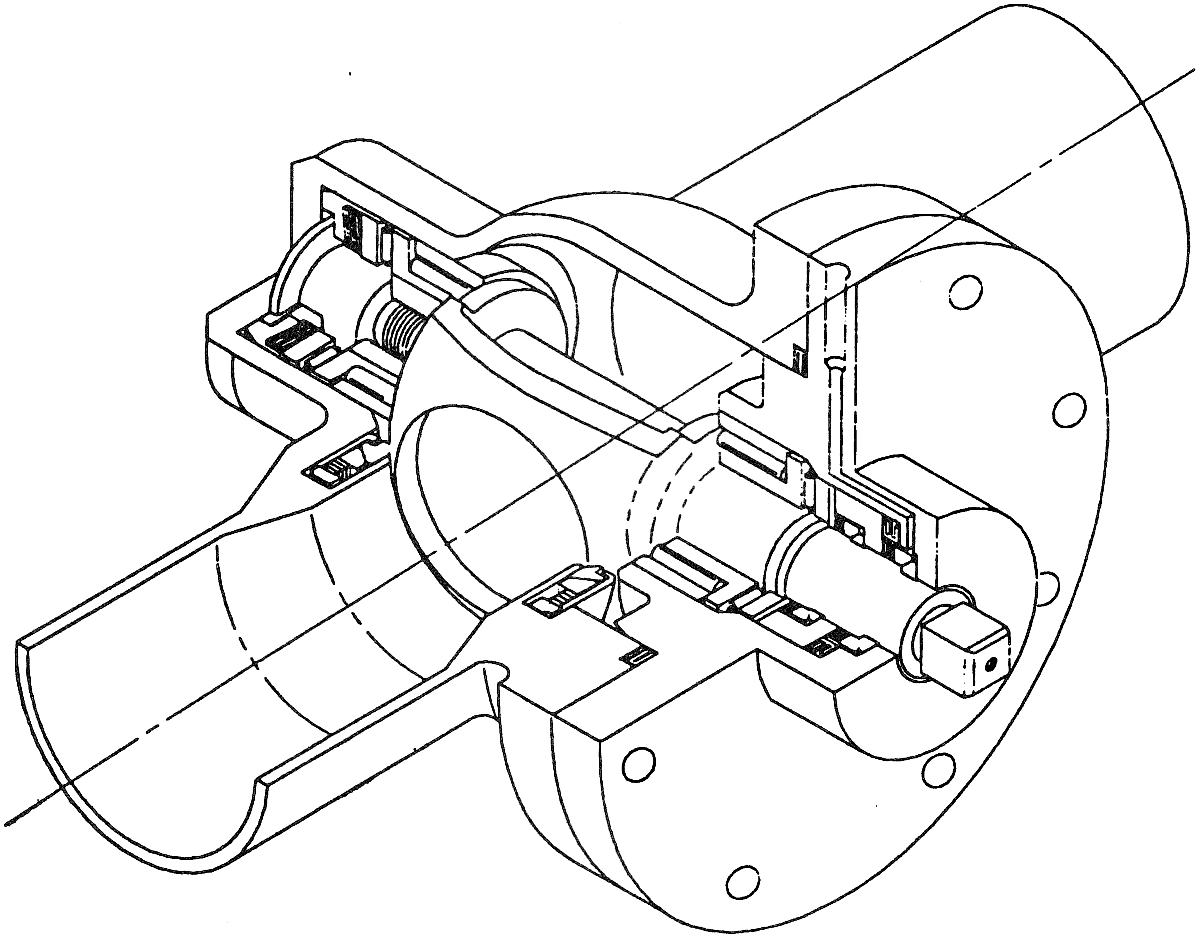
Expectations by October 1991

- Baseline fabrication processes and materials based on substantiated costs
- Initial hot fire operability demonstrations

ENGINE CONTROL SYSTEM



SECTOR BALL VALVE



SECTOR BALL VALVE CHARACTERISTICS

- **Continuous contact downstream seal**

  Simplifies seal configuration

  Similar in design to highly reliable SSME, ASE and RS-44 valve shaft seals

- **Minimizes hydraulic torque**

  Due to blade type design

  Results in reduced actuator requirements
    Lower cost actuator design
    Reduces electrical power requirements

- **Single flange line replaceable elements**

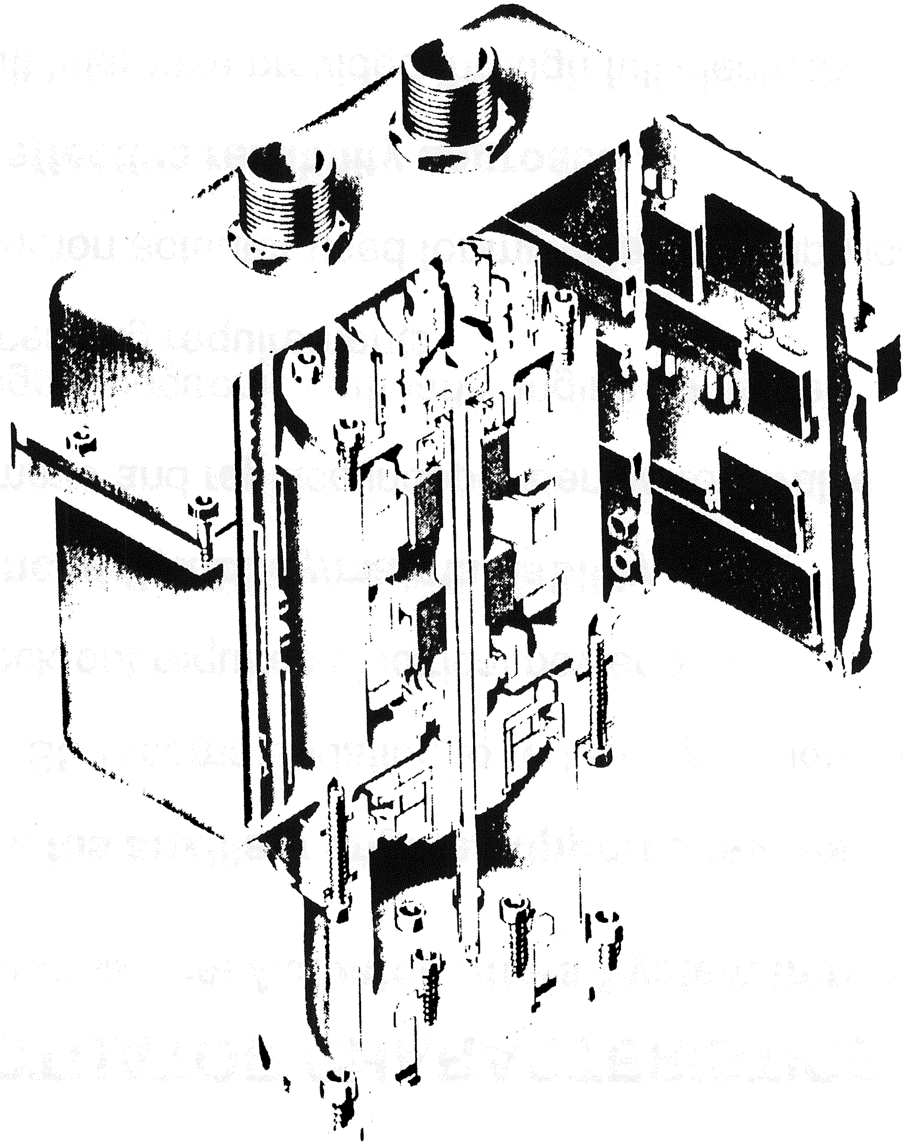
  Greatly simplifies design

  Improves maintainability

PROPELLANT VALVE OPERATING PARAMETERS

Parameter	MOV	MFV	GGOV	GGFV
• **Environment**				
• Fluid type	LOX	LH2	LOX	LH2
• Flow rate (lb/sec)	1143.8	160.6	30.9	35.2
• Inlet temperature (°R)	181	75	182	78
• Inlet fluid pressure	3212	3969	2950	3188
• Max shaft torque (lb-in)	3300	1547	100	100
• **Design characteristics**				
• Full open ΔP (psid)	135	135	135	135
• Ball diameter (in)	5.2	5.2	2.1	2.1

PROPELLANT EFFECTOR (ACTUATOR)



ACTUATOR CHARACTERISTICS

Electromechanical Actuator Offers System Improvements

- **Eliminates auxiliary engine support systems**

  OEPSS recommendation to reduce operational costs

  Check-out requires electrical power only

- **Enhanced flexibility/maintainability**

  Remove and replace independently from valve

  Integral electronics offloads engine controller processing requirements

  ☆ → Common actuator used for multiple valve applications

- **Cost effective reliability approach**

  Fault tolerance provided through full electrical redundancy

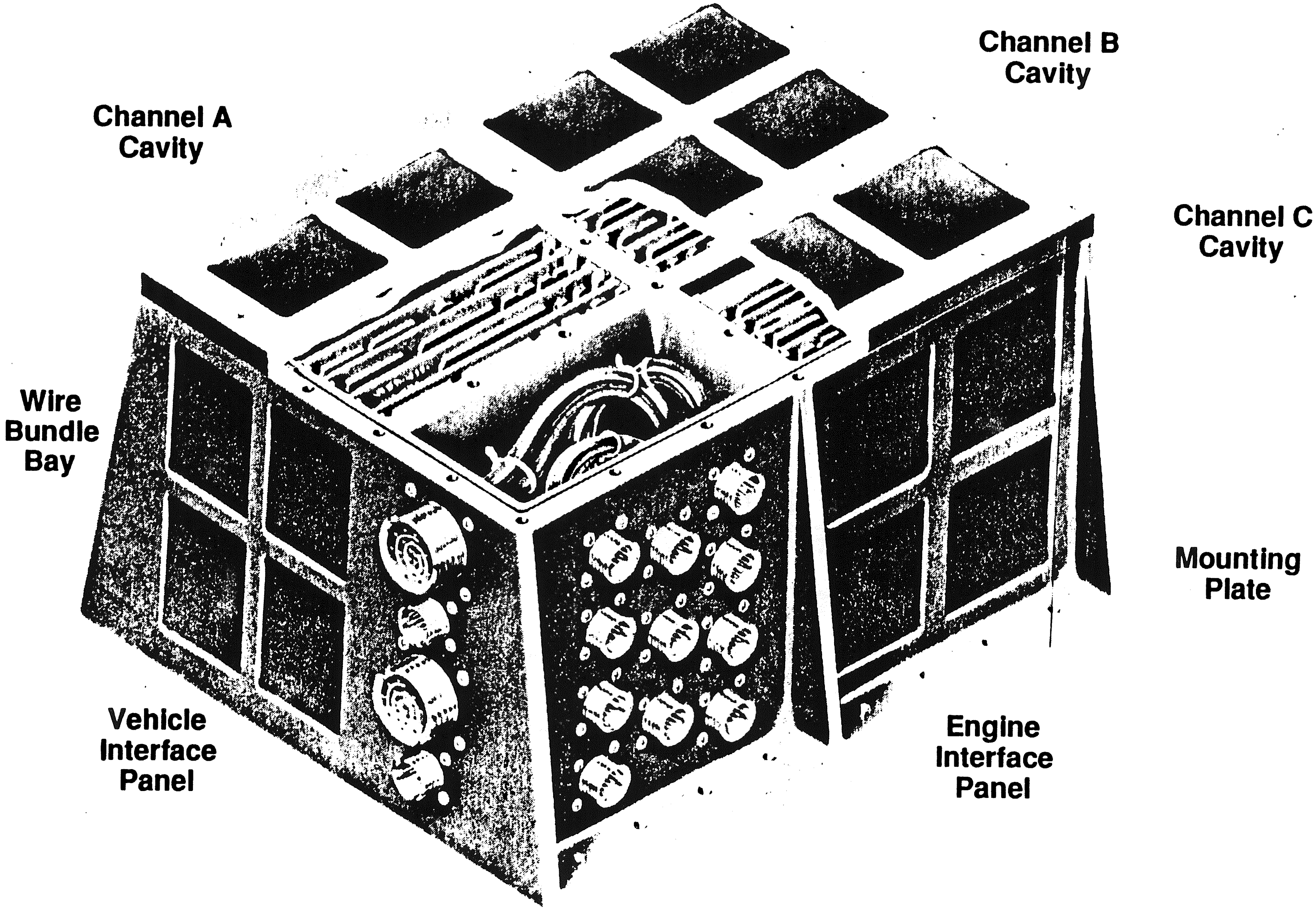
  Simplified actuator/engine controller interface

OPERATING PARAMETERS

Parameter	**Value**
• **Interface** (dual redundant)	
Power Bus	TBD Vdc* @ TBD Amps
Command & Data Bus	1 MBit/sec (MIL-STD-1553B)
• **Performance**	
Output Torque (max)	
MOV	3300 in-lb
MFV	1547 in-lb
Position	
Accuracy/Holding	± 1 Degree of Command Position
Backlash	< 0.5 Degree on Output
Response Time	TBD msec (transient analysis ongoing)
Duty Cycle	90° CW - 10 Min. Hold - 90° CCW
Stability	Stable Over All Operating Ranges

* Source Voltage Study On-Going

ENGNE CONTROLLER



CONTROLLER CHARACTERISTICS

Engine Controller Design Supports All Program Objectives

- **Reliability**
  - Fault tolerance provided through redundancy
    - Triplex processing allows majority voting
    - Duplex vehicle and engine power, command & data bus
- **Cost**
  - Modular controller functions reduce unique parts
  - High level software language (Ada) improves reusability
- **Performance**
  - Autonomous control capability (vehicle inhibit possible)
  - Onboard checkout and status monitoring - ready signal

OPERATING PARAMETERS

Parameter	Value
• **Interfaces**	
Vehicle:	
Power Bus	28 Vdc (MIL-STD-1539NC)
Command & Data Bus	1 MBit/sec (MIL-STD-1553B)
Engine:	
Effectors	Common 28 Vdc*
Sensors	Unconditioned output signal (e.g. Vdc)
• **Performance**	
Processor:	
Clock Frequency	20 MHz
Throughput	7-20 MIPS
Address Space	4 Gigabytes
Memory:	
Processing	1 Megabytes of high speed memory (plus EPROM, Non volatile RAM)
Storage	2 Megabytes of flash memory

* Solenoids And Igniters Only

SOFTWARE CHARACTERISTICS

Architecture Focused On Reducing Life Cycle Cost

- **High level Ada language**

  Embodies modern software design methodologies

  Targeted for large real-time system domains

- **Modular design approach**

  Well defined and tightly constrained functional interfaces

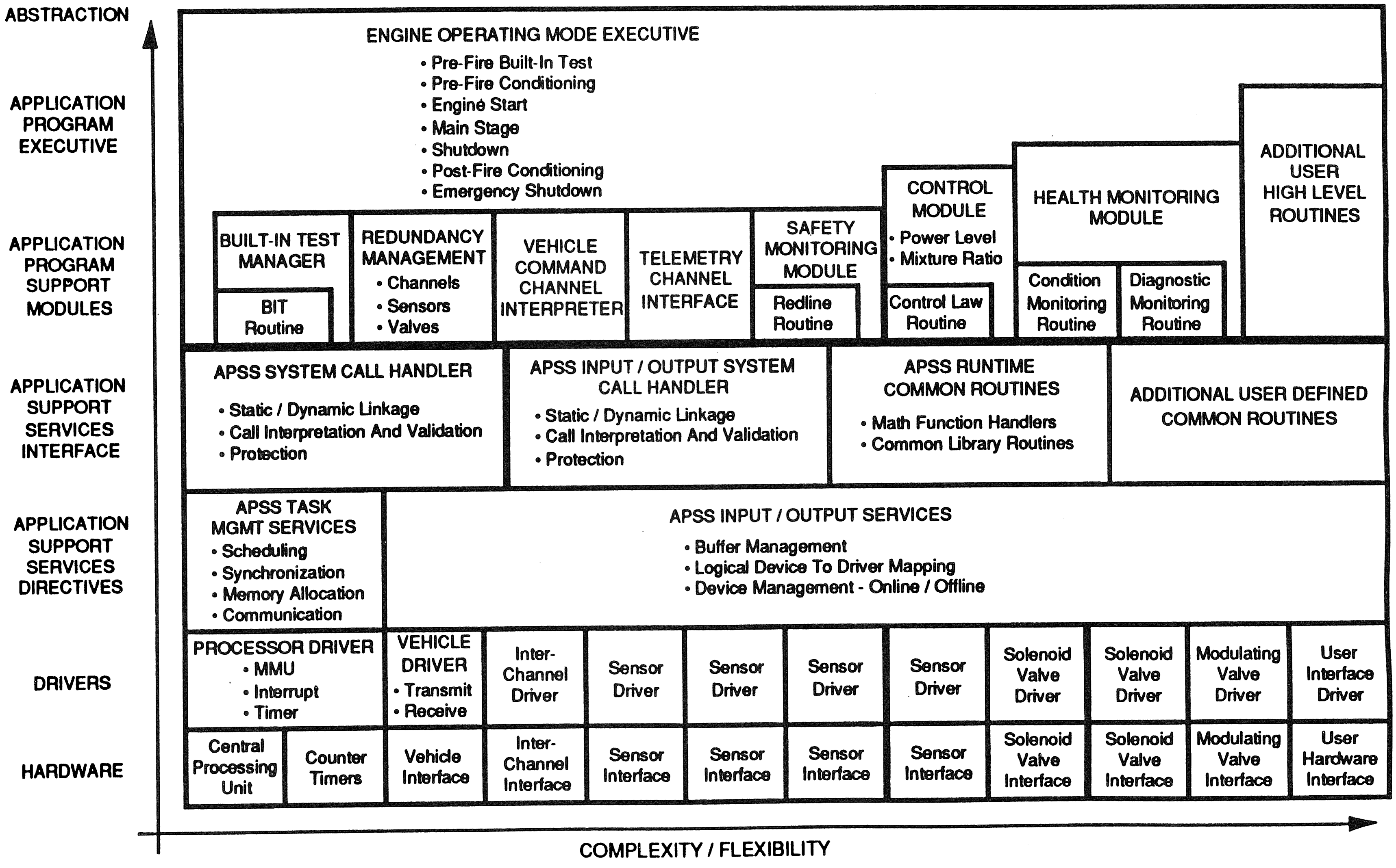
  Minimizes recurring cost for software updates

- **Incremental development of software functions**

  Highest risks addressed first

  Functional framework for early identification of bugs

SOFTWARE ARCHITECTURE



ABSTRACTION

APPLICATION PROGRAM EXECUTIVE

ENGINE OPERATING MODE EXECUTIVE
- Pre-Fire Built-In Test
- Pre-Fire Conditioning
- Engine Start
- Main Stage
- Shutdown
- Post-Fire Conditioning
- Emergency Shutdown

ADDITIONAL USER HIGH LEVEL ROUTINES

APPLICATION PROGRAM SUPPORT MODULES

BUILT-IN TEST MANAGER
- BIT Routine

REDUNDANCY MANAGEMENT
- Channels
- Sensors
- Valves

VEHICLE COMMAND CHANNEL INTERPRETER

TELEMETRY CHANNEL INTERFACE

SAFETY MONITORING MODULE
- Redline Routine

CONTROL MODULE
- Power Level
- Mixture Ratio
- Control Law Routine

HEALTH MONITORING MODULE
- Condition Monitoring Routine
- Diagnostic Monitoring Routine

APPLICATION SUPPORT SERVICES INTERFACE

APSS SYSTEM CALL HANDLER
- Static / Dynamic Linkage
- Call Interpretation And Validation
- Protection

APSS INPUT / OUTPUT SYSTEM CALL HANDLER
- Static / Dynamic Linkage
- Call Interpretation And Validation
- Protection

APSS RUNTIME COMMON ROUTINES
- Math Function Handlers
- Common Library Routines

ADDITIONAL USER DEFINED COMMON ROUTINES

APPLICATION SUPPORT SERVICES DIRECTIVES

APSS TASK MGMT SERVICES
- Scheduling
- Synchronization
- Memory Allocation
- Communication

APSS INPUT / OUTPUT SERVICES
- Buffer Management
- Logical Device To Driver Mapping
- Device Management - Online / Offline

DRIVERS	PROCESSOR DRIVER • MMU • Interrupt • Timer		VEHICLE DRIVER • Transmit • Receive	Inter-Channel Driver	Sensor Driver	Sensor Driver	Sensor Driver	Sensor Driver	Solenoid Valve Driver	Solenoid Valve Driver	Modulating Valve Driver	User Interface Driver
HARDWARE	Central Processing Unit	Counter Timers	Vehicle Interface	Inter-Channel Interface	Sensor Interface	Sensor Interface	Sensor Interface	Sensor Interface	Solenoid Valve Interface	Solenoid Valve Interface	Modulating Valve Interface	User Hardware Interface

COMPLEXITY / FLEXIBILITY

ENGINE FLIGHT SENSORS

The Flight Instrumentation Compliment Performs Several "Functions" For The Engine System

SAFETY

- Real-time monitoring to prevent catastrophic failure (start command through shutdown)

CONTROL

- Determine engine pre-start readiness
- Effect engine operation (non-safety)

MAINTENANCE MONITORING

- Tracking & trending analysis
- Identification & isolation of failures

ENGINE FLIGHT SENSORS

Minimum Instrumentation List* - Safety & Control Only

PRESSURE

FTP Pump Inlet
OTP Pump Inlet
OTP IPS Purge
Main Chamber
Oxid Purge
Fuel Purge

TEMPERATURE

FTP Pump Inlet
FTP Turb Inlet
OTP Pump Inlet

SPEED/DISPLACEMENT

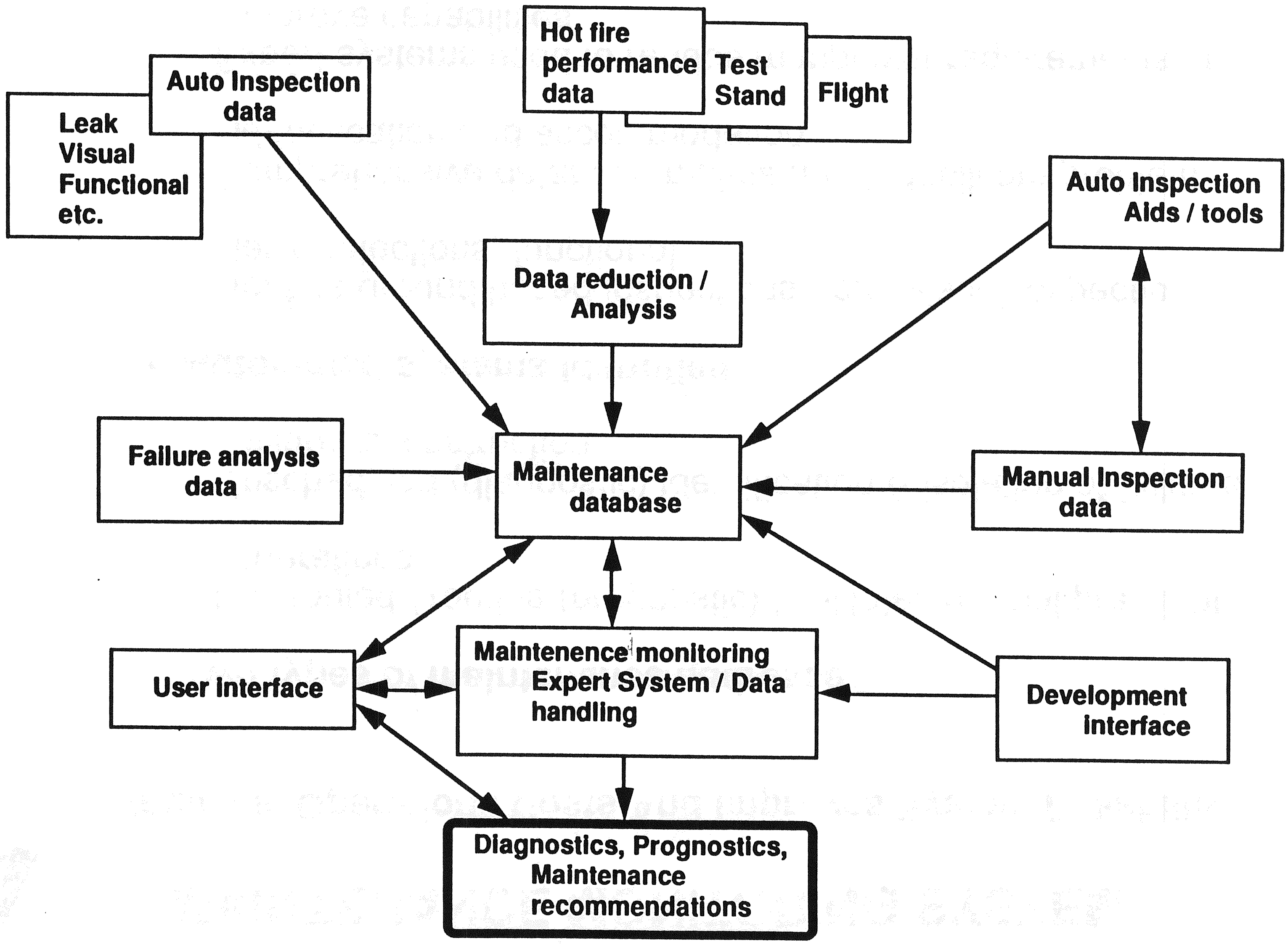
FTP Shaft
OTP Shaft

POSITION

Main Fuel Valve
Main Oxid Valve
GG Valves
Turb Bypass Valve

* Studies To Determine Maintenance Monitoring Sensor Requirements Are On-Going

MAINTENANCE MONITORING SYSTEM



Leak
Visual
Functional
etc.

Auto Inspection data

Hot fire performance data

Test Stand

Flight

Data reduction / Analysis

Auto Inspection Aids / tools

Failure analysis data

Maintenance database

Manual Inspection data

User Interface

Maintenence monitoring Expert System / Data handling

Development interface

Diagnostics, Prognostics, Maintenance recommendations

MAINTENANCE MONITORING SYSTEM

Reduces Operations Costs And Improves System Reliability

- **Two types of maintenance addressed**
  - Scheduled / routine (prognostic) facilitates normal pre-flight operations
  - Unscheduled (diagnostic) identification & isolation of failures / failure reconstruction
- **Automated systems identified**
  - Routine ground based inspections - e.g. visual inspections, leak detections, functional
  - Comprehensive database maintained to facilitate problem identification and accommodation
  - Expert systems used to reduce manpower requirements and improve capabilities

MAINTENANCE MONITORING SYSTEM

Trade Studies Will Identify Components / Technologies

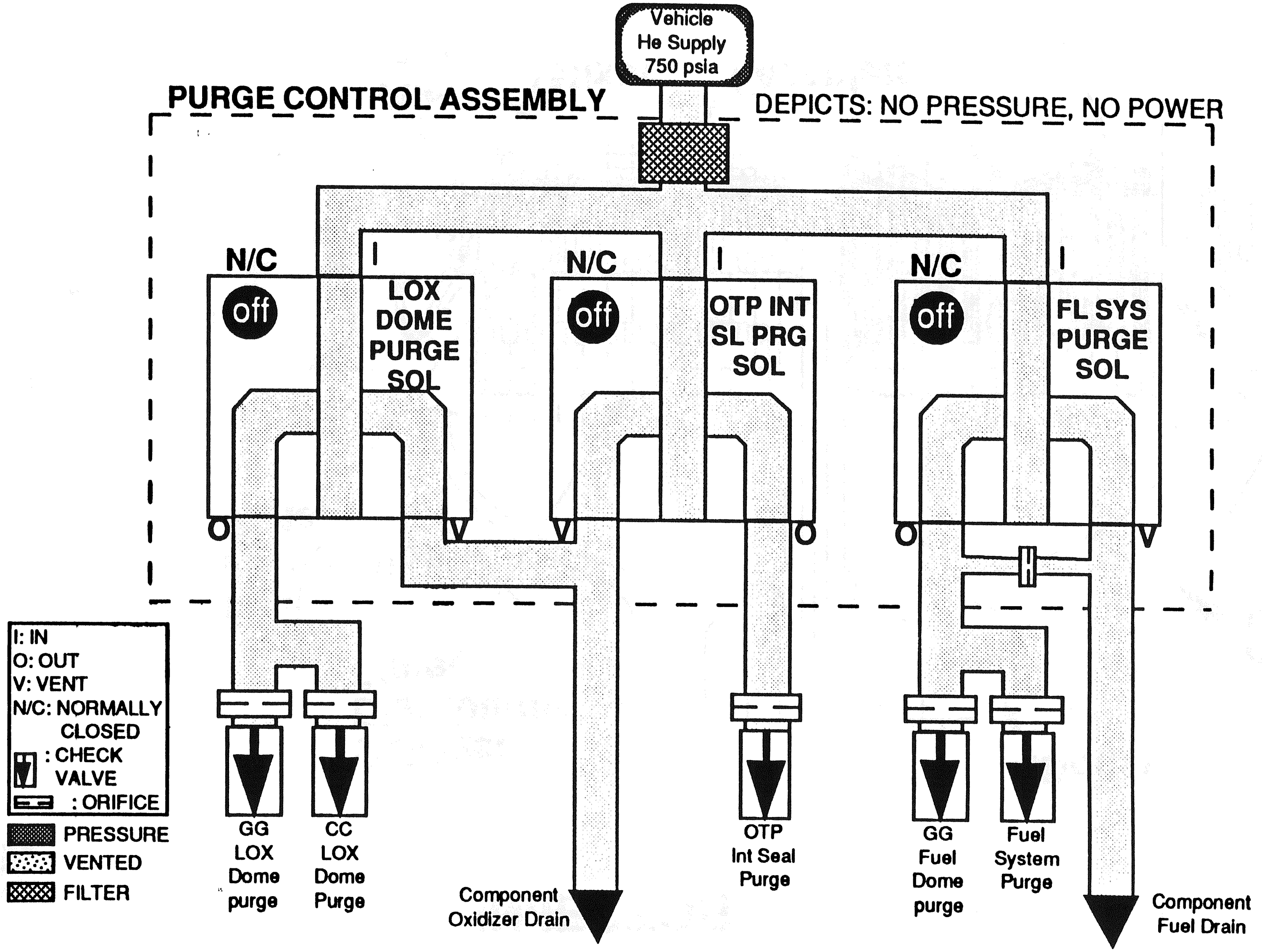
- Flight sensors needed for tracking and trending and failure reconstuction
- Ground based sensors / systems to improve launch operations and reduce time and costs
- Database and Expert Systems to facilitate routine operations analyses and improve life prediction / maintenance forecasting

PNEUMATIC CONTROL ASSEMBLY

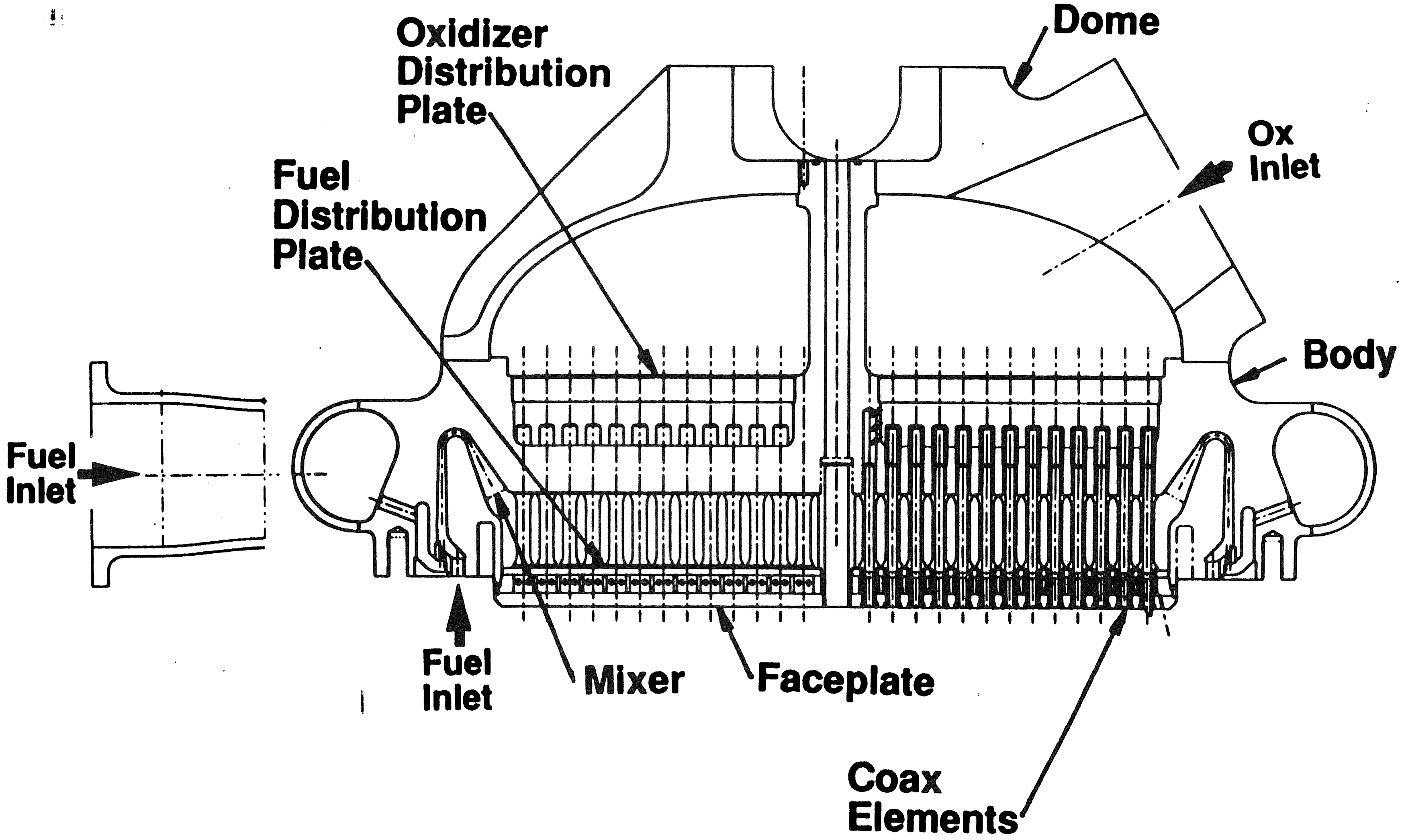
Features

- **Pneumatic Control Assembly (PCA)**
    - Three 4-way solenoid valves
        - Balanced pressure valves
        - Smaller actuators, less current
    - Six sonic orifices
        - CC LOX dome, GG LOX dome, fuel system, GG fuel dome, OTP intermediate seal & fuel drain system
        - Installed in output manifold of PCA
- **Five low pressure lines**
    - Safer if line damaged
- **Five inline check valves**
    - Installed near component being purged
    - High delta P to eliminate possible chatter

PNEUMATIC CONTROL ASSEMBLY



INJECTOR

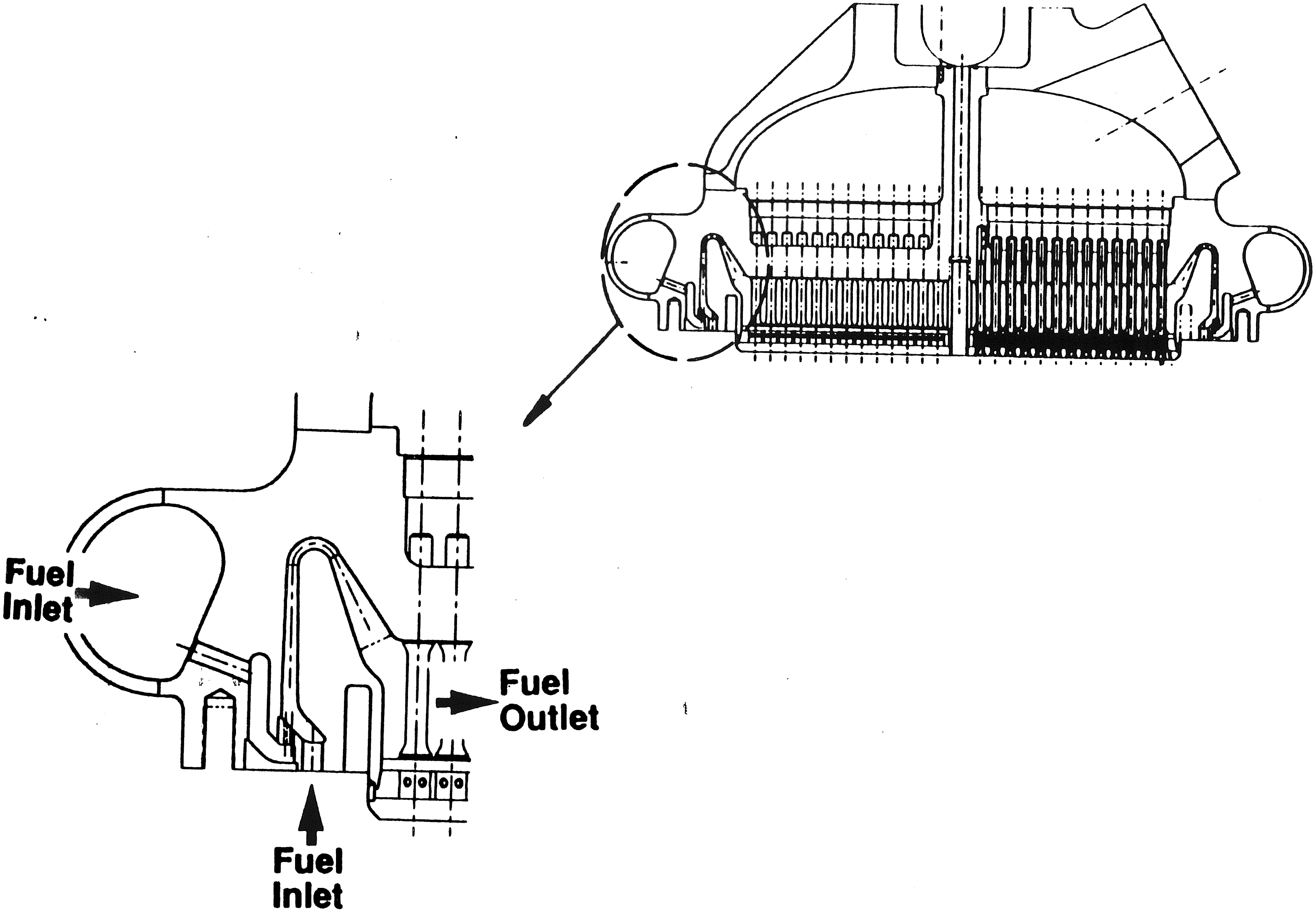

Oxidizer Distribution Plate
Dome
Ox Inlet
Fuel Distribution Plate
Body
Fuel Inlet
Fuel Inlet
Mixer
Faceplate
Coax Elements

SIGNIFICANT TRADE STUDY RESULTS

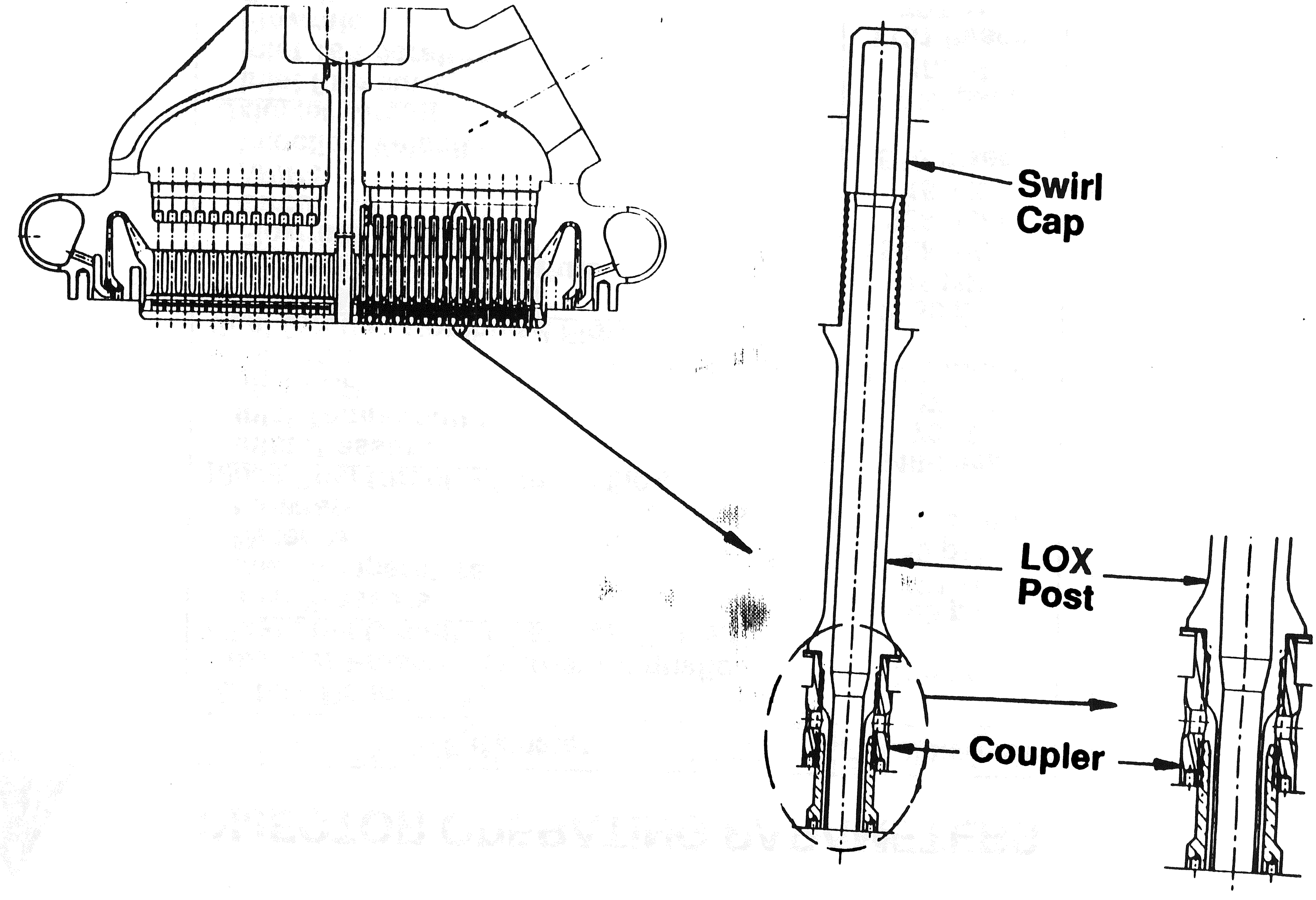
Injector/Mixer

Trade	Resolution	Rationale
• Body fabrication	• Sand-cast INCO 625	• Lowest cost
• Mixer type	• Integral; jet pump	• Higher reliability; low cost • Low ΔP; uniform MR & temperature
• LOX post configuration	• Machined; brazed installation	• Low cost; easy repair
• LOX distribution plate	• Perforated sheet	• Uniform distribution
• Dome fabrication	• Centrifugal-cast INCO 718	• Lowest cost
• Body / dome joint type	• Welded	• Light weight; no maintenance
• Fuel distribution plate	• Rigimesh	• Lowest cost; uniform distribution
• Faceplate fabrication	• Rigimesh	• Lowest cost
• Injection element	• Swirl coax; 546 elements	• Lower ΔP • Low cost

MIXER



INJECTOR ELEMENT



INJECTOR OPERATING PARAMETERS

Parameter	Value
Mixture Ratio (TCA)	7.08
Chamber Pressure (Throat Stagnation)	2250 psia
Mixer Fuel Circuit - Chamber Coolant	
Inlet Pressure	2709 psia
Inlet Temperature	421°R
Mixer ΔP	50 psi
Flowrate	45.5 lb/sec
Mixer Fuel Circuit - Bypass Flow	
Inlet Pressure	3485 psia
Inlet Temperature	73°R
Mixer ΔP	827 psi
Flowrate	114.3 lb/sec
Fuel Circuit - Combined Flow	
Mixer Outlet Pressure	2658 psia
Mixer Outlet Temperature	191°R
Flowrate	159.8 lb/sec
Circuit ΔP	339 psia
ΔP/Pc	15.1%
Injection Velocity	660 ft/sec
Oxidizer Circuit	
Inlet Pressure	3026 psia
Inlet Temperature	183°R
Flowrate	1131 lb/sec
Circuit ΔP	707 psi
ΔP/Pc	31.4%
Injection Velocity	200 ft/sec
Injection Velocity Ratio	3.3
Face Pressure	2319 psia

INJECTOR ADP CONTRIBUTIONS

Provide Early Risk Reduction

Task 1301/2 LOX/Hydrogen Combustion Devices Design and Demonstration

TASK 1304 LOX/H2 Injector Stability Demonstration

- Evaluate operability features
  - Injection element
    - Swirl coax
    - Shear coax
    - Size (thrust/element)
  - Chamber wall cooling
    - Outer row MR bias
    - Outer row LOX post scarf
    - Fuel film cooling
  - Combustion stability aids
    - No stability aids
    - Baffles
    - Acoustic cavities

Interactive effects on performance, thermal compatibility, & combustion stability

- Subscale injectors - initial testing complete

	GFY90			GFY91				
Test Article	J	A	S	O	N	D	J	Features
PW 40K - MSFC			■	■				Swirl coax; MR bias, scarf, & FFC
AJ 40K - MSFC					■	■		Swirl coax; acoustic cavities; FFC
AJ 100K				■	■			Swirl coax; FFC; with & w/o acoustic cavities

INJECTOR ADP CONTRIBUTIONS (Cont.)

- Scheduled testing will resolve technical issues

	GFY92							GFY93				
Test Article	M	A	M	J	J	A	S	O	N	D	J	Features
AJ 100K									■	■	■	Swirl coax; FFC; with & w/o acoustic cavities
AJ 580K - MSFC	■	■										Swirl coax; FFC; no stability aids
PW 580K - MSFC				■	■	■						Swirl coax; scarf; no stability aids
RD 580K - MSFC								■	■	■		Shear coax; baffles; MR bias

- Point of departure design for current effort

INJECTOR FUTURE PLANS

Trade Studies to be Completed

- Finalize interfaces to chamber and engine
- Optimize chamber compatibility features
  - Wall temperature & mixture ratio
  - Scarf versus MR bias versus FFC
- Support system performance versus cost and risk trades

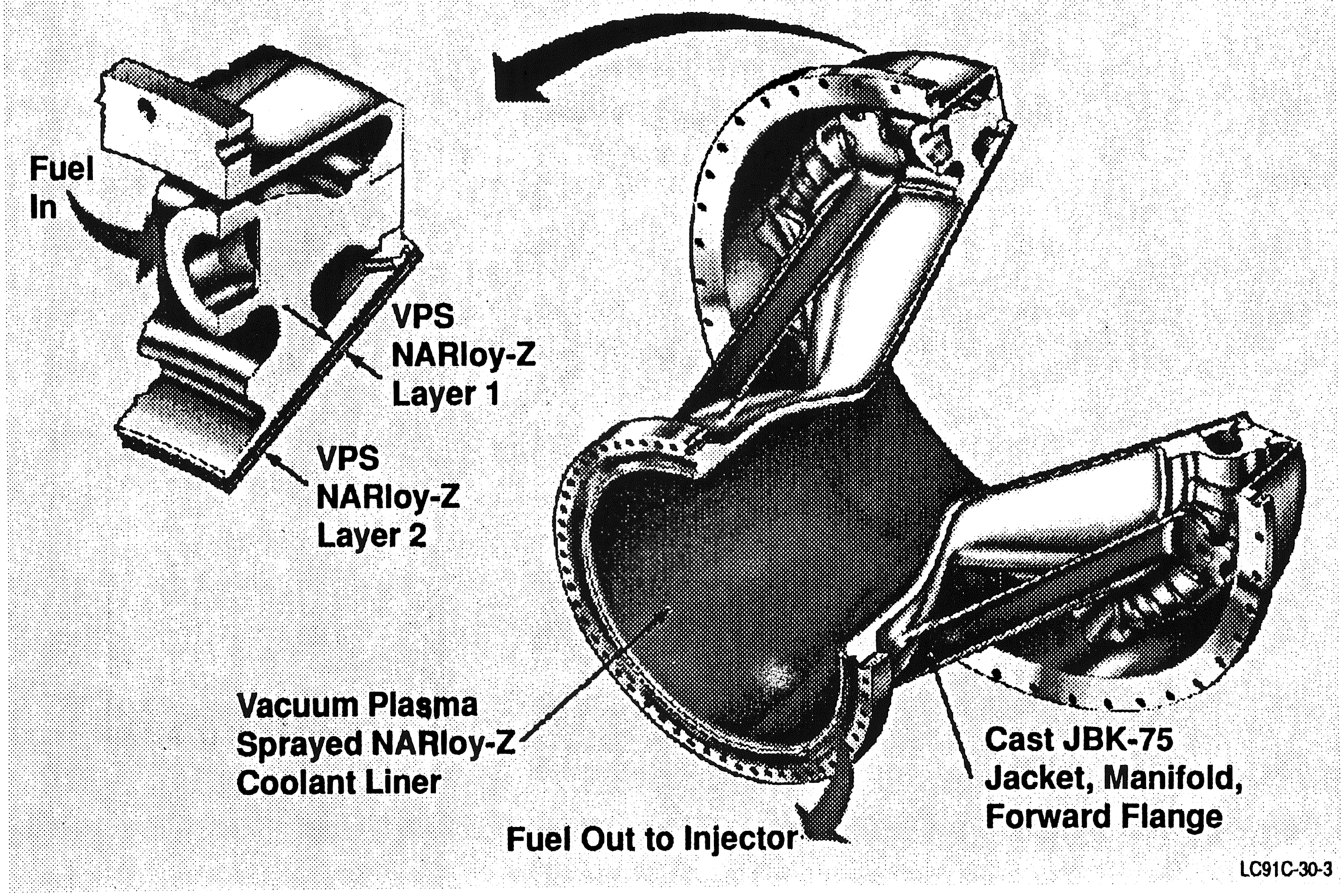
Design Emphasis

- Initiate detailed combustion, hydraulic, thermal, & structural analyses

Expectations by January 1992

- Complete trades
- Start development for low-cost castings
- Finalize expanded technology test program to resolve technical and cost reduction issues

CAST JACKET/VPS LINER COMBUSTION CHAMBER



COMPONENT CHARACTERISTICS

- **Structure**
  - Single low cost, highly reliable casting
  - 8 braces provide access and inspection benefits
- **Aft manifold**
  - Closed out by simple forged ring for inspectability
    - Ultrasonically inspected through wrought material
    - High process margin beam weld
- **Coolant liner**
  - Vacuum plasma sprayed (VPS) NARloy-Z material enables use of low cost casting
  - Coolant exits directly into injector to eliminate costly manifold and ducting
- **Design life**
  - Based primarily on LCF, creep ratcheting and fracture mechanics

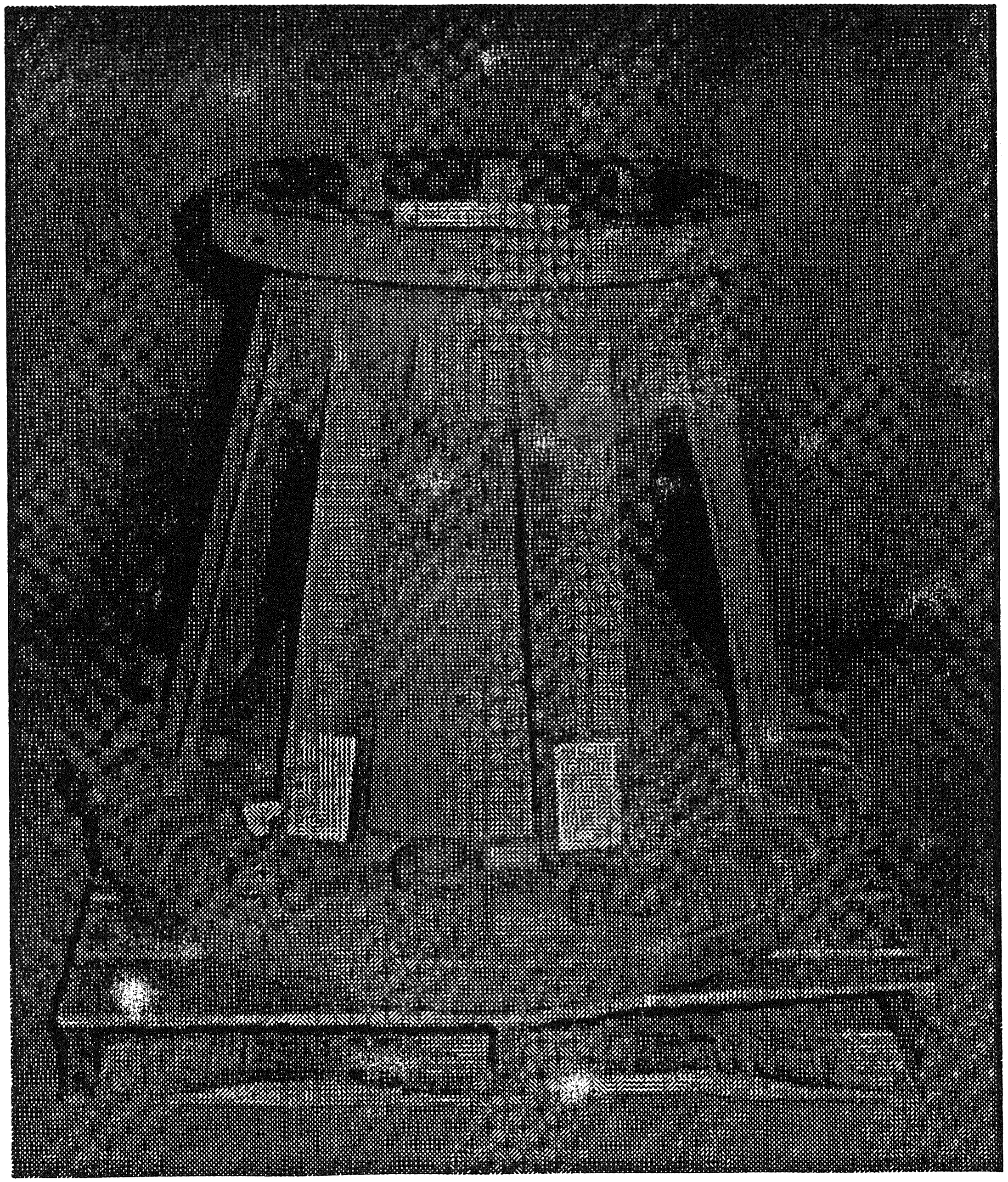
OPERATING PARAMETER

Combustion Chamber

Parameter	Values
● **Interface**	
● Inlet pressure	3803 psia
● Outlet pressure	2705 psia
● Inlet temperature	77°R
● Outlet temperature	510°R
● **Internal**	
● Maximum Q/A	73 BTU/sq in. sec
● Maximum wall temperature	980 °F
● Length	33.3 in
● Throat diameter	13.1 in

COMBUSTION CHAMBER TRADES

Trade	Resolution	Rationale
Cast Jacket Material	JBK-75 selected	• Thermal expansion compatibility • Good strength to weight ratio • Reasonable cost
Aft Manifold Closeout	I.D. beam welded ring selected	• Improves jacket castability and inspectability • Automated welding repeatability • High reliability
Jacket Thrust Structure	Eight-brace design selected	• Easier inspection with improved accuracy • Easier in-process welding and access
Coolant Liner Channel Filler	VPS iron selected	• Leaching characteristics • Machinability
Nozzle Attachment	Flexible cylinder selected	• Thermal strains accommodated • Non-binding operation • Certainty of tight fit at hot gas seal



COMBUSTION CHAMBER ADP CONTRIBUSTIONS

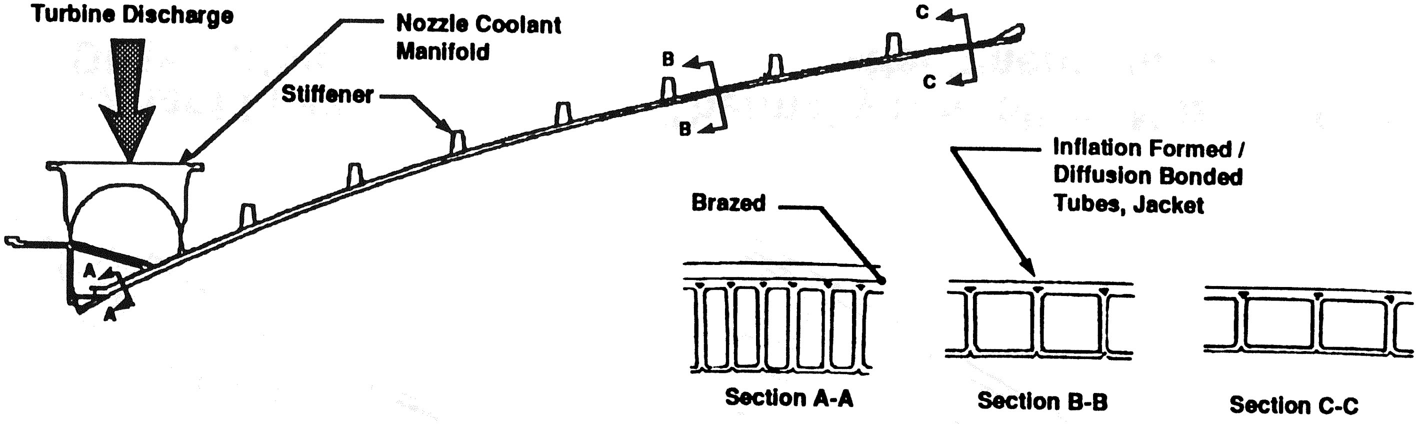
Advanced Development Program Provided Component Technology

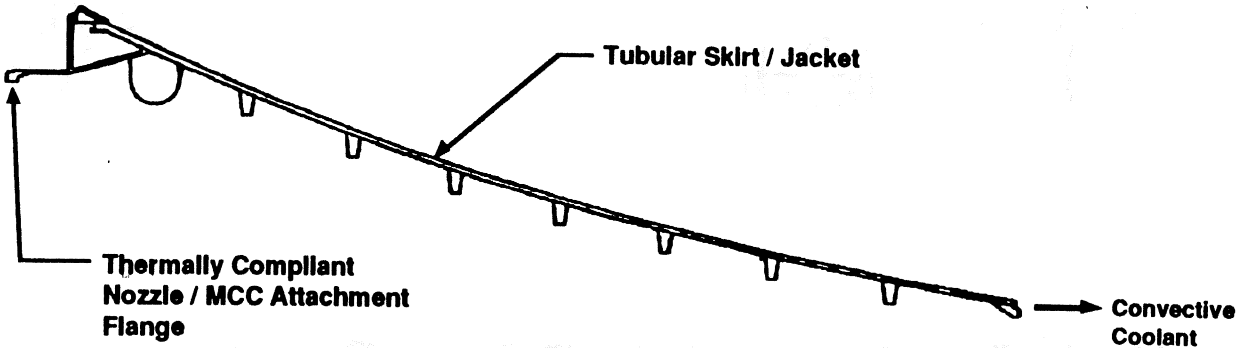
- **Task 1203.01, LOX/H_2 TCA and GGA**
  - VPS NARloy-Z development and scaleup
    - Preliminary VPS NARloy-Z properties obtained
    - Demonstrate an acceptable channel filler
    - Demonstrated HIPed cold wall in cast throat - 4/92
    - Develop I.D. spray gun & produce initial I.D. material properties - 6/92
    - Fabricate 80% size simulators - 5/92
  - JBK-75 jacket casting tooling and mockups
    - Aft manifold mockup casting poured
    - Full-size jacket mockup #1 poured
    - Metallurgical and NDE evaluation of jacket - 11/91
    - Full-size jacket mockup #2 poured and evaluated - 3/92
    - Effect of thermal cycles on large casting microstructure and material properties
- **Task 1304.01, Combustion Chamber**
  - Full-size combustion chambers using LIDB and EDNi/Co fabrication
    - Unit #1 - final machine closeout in work - deliver - 11/91
    - Unit #2 - currently on hold - 8/92

COMBUSTION CHAMBER PLANNED ACTIVITIES

- **Trade studies to be completed**
  - Parameter trade studies in support of engine optimization studies
  - Interfaces to injector and nozzle
- **Design emphasis**
  - Improve producibility of liner features
  - Improve jacket castability by thinning heavy sections
  - Incorporate lessons learned from VPS cast throat and 80% size simulators
  - Evaluate impact of higher thrust
- **Expectations by December 1992 PDR**
  - Provisions established for accommodating adjacent component interfaces in jacket casting
  - Incorporate lessons learned from cast jacket mockups
  - Complete deliverable cast jacket design & order permanent casting tooling
  - Complete HIPed cold wall & VPS hot wall in cast throat
  - Complete second jacket mockup casting & begin casting Design of Experiments parts
  - Complete agreed to "Outputs & Expectations" for PDR-1

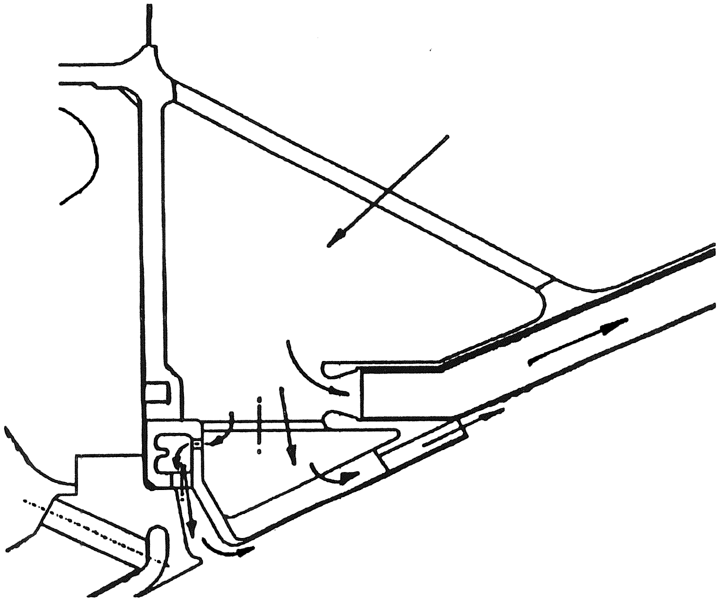
FILM / DUMP COOLED NOZZLE



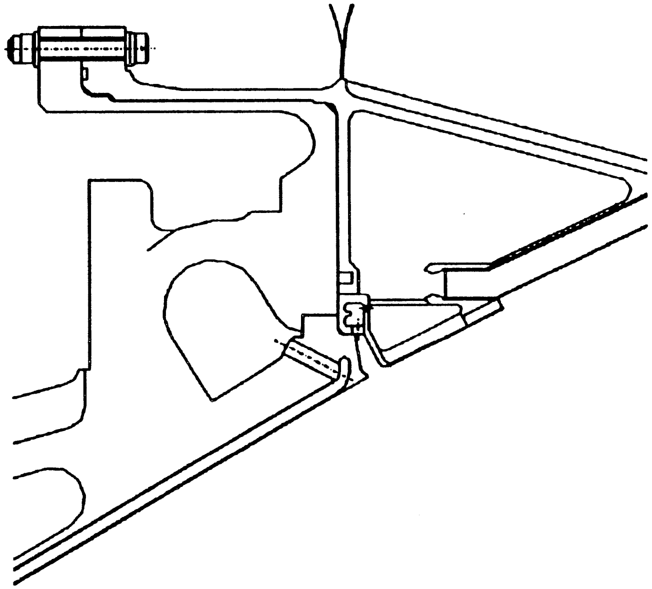


All Nozzle Materials
are INCO 625

FILM / DUMP COOLED NOZZLE (Cont.)



Coolant Flow Distribution



Thermally Compliant Nozzle / MCC Attachment Flange

NOZZLE CHARACTERISTICS

- **Film / convectively dump cooled - durability**
  - Supersonic film injection parallel to wall
  - Cast film injector for lower cost
- **Tubular skirt and jacket assembled with no welds or brazes - higher reliability**
  - 540 non-precision tubes - lower cost
  - Jacket fabricated from welded sheet - inspectable
  - Formed and bonded in single operation - lower cost
- **Nozzle coolant manifold brazed to jacket - lower operational cost**
  - Precision cast - lower cost
  - Film coolant flow injector is cast feature - lower cost
- **Thermally compliant nozzle / chamber attachment flange - higher reliability**
  - Allows thermal growth, provides structural support - higher reliability
- **All components are made from same alloy : INCO 625 - higher reliability, lower cost**
  - Moderate strength, high temperature alloy
  - Processing issues due to thermal growth minimized

NOZZLE OPERATING PARAMETERS

PARAMETER	VALUE
• INTERFACE	
INLET PRESSURE	295 psia
EXIT PRESSURE	87 psia
INLET TEMPERATURE	1190° R
EXIT TEMPERATURE	1476° R
FLOW	66.5 lb / sec
• INTERNAL	
AREA RATIO	45:1
NUMBER OF PASSAGES	540
MAXIMUM WALL TEMPERATURE	1985° R (AT MDC)
FORWARD DIAMETER (AR = 7:1)	34.3 in.
AFT DIAMETER	87.0 in.
LENGTH	87.0 in.

SIGNIFICANT TRADE STUDIES

Nozzle

Trade	Resolution	Rationale
• Coolant flowpath geometry	• Revised to reduce pressure drop	• Lower gas generator flow required, improves cycle
• Coolant flow split	• 38% primary film, 7% secondary film, 55% convective	• Optimize cooling effectiveness
• Exit area ratio	• Revised to 45:1	• Improved performance with acceptable cost & weight increase
• Skirt fabrication process	• ADP fab trials	• Ensure high reliability, low cost skirt fabrication
• Nozzle / chamber attachment flange	• Thermally compliant 'L' flange	• Provides thermal growth capability and structural support
• Throttling impact to nozzle cooling	• Turbine temperature 200°R lower at reduced power	• Ensure nozzle is designed for worst case operating point

NOZZLE ADP CONTRIBUTIONS

- **Subscale (40K) Calorimeter Nozzle**
  - Design complete, fabricate (3/92), test (8/92)
  - DOE test approach where practical
  - Provides nozzle skirt cooling assessment
    - Primary and secondary film injection
    - Heat transfer and computational fluid dynamics design code validation

- **Trades**
  - Percentage of flow used in film injection
  - Primary vs. secondary film injection
  - Primary film injection method
    - Sonic vs supersonic

- **Selection criteria**
  - Wall temperature
  - Coolant ΔP impact
  - Film injector cost
  - Nozzle efficiency

NOZZLE ADP CONTRIBUTIONS (Cont.)

- **Nozzle skirt fabrication studies**
  - DOE used throughout where appropriate
  - Phase 1 - process requirements and sensitivities (1/92)
  - Phase 2 - size scale up (6/92)

- **Trades**
  - Three tubular concepts, non-precision tubes
    - Inflation form / diffusion bond
    - High velocity oxygen / fuel (H2) spray
    - Low cost brazing (risk mitigation)
  - Three sheetmetal construction concepts
    - Explosion form, laser weld
    - Laser weld, inflation form
    - Diffusion bond, inflation form

- **Selection criteria**
  - Process compatible with design and quality requirements
    - Control, capable, margin scale-up
    - Inspectable, repairable
  - Cost
    - Facilities, tooling, recurring
  - Reliability, durability, operability / maintainability assessments

FUTURE NOZZLE PLANS

- **Trade studies to be completed**
  - Film / convective dump cooled vs. partial film / radiation cooled - reliability, cost, weight
  - Nozzle coolant manifold, full vs. partial casting - reliability, cost
  - Nozzle coolant manifold torous vs. volute - reliability, cost ,weight
  - Combustion chamber / nozzle interface - reliability, cost, weight

- **Design emphasis**
  - Solidify requirements
    - Cycle balance
    - IICD, ICEI, ARD
  - Initiate preliminary design and thermal, aerodynamic and structural analyses

- **Important milestones**
  - Establish Component Development Team activities, October '91
  - Initial down select of skirt fabrication method, January '92
  - Initiate preliminary design
  - Conduct Design Concept Review. 2nd Quarter FY 92
  - Complete subscale calorimeter nozzle testing, August '92

STATUS REPORT ON VEHICLE/ENGINE STUDIES

Engine Support Description	Task No.	Status
Provide an STME installation drawing	3-P-001 3-P-006 3-P-013	Completed
Provide STME dry weight, gimbaled center of gravity and moments of inertia, and side loads	3-P-013 3-P-014	Completed
Provide STME LH2 and LOX heat leak data for prestart conditions	3-P-018 3-P-033	Completed
Provide STME estimated LOX leakage through the LOX pump inter-propellant seal	3-P-018	Completed
Provide STME propellant weights at shutdown	General Studies	Completed
Provide STME weight, cost,* and dimensions vs. thrust (550K - 800K)	General Studies	Completed
Provide STME proposed maintenance concepts	3-P-061	Completed
Provide STME heat exchanger operating characteristics for GO2 and GHe	3-P-027	Completed
Provide STME required purges		Nearing Completion

STATUS REPORT ON VEHICLE/ENGINE STUDIES

Engine Support Description	Task No.	Status
Provide STME start and shutdown requirements (NPSP and flow rate vs. time, . . .)	3-P-017 3-P-018 3-P-019 3-P-031 3-P-033	Start Completed Shutdown Nearing Completion
Provide STME weight, cost, and powerhead dia. vs. LOX and LH2 NPSP requirements	3-P-017 3-P-031	Nearing Completion
Evaluate the impact of equal pump inlet diameters to support MPS component commonality requirements study	3-P-016	Nearing Completion
Provide STME 'cold' turbopump weights at chilldown	3-P-018 3-P-033	Nearing Completion
Define STME filter reuqirements	3-P-018 3-P-033	Still Working
Provide STME maintenance cost to support propulsion module recovery design features study	3-P-002 3-P-003	No Work Started
Evaluate the impact of an open vs. closed propulsion compartment	3-P-004	No Work Started