Advanced Transportation System Studies

Technical Area 3

Alternate Propulsion Subsystem Concepts
NAS8-39210
DCN 1-1-PP-02147

J-2S Restart Study
Task Final Report
DR–4

April 1993

Rockwell International
Rocketdyne Division

TA3–0337

J-2S Restart Study
Objectives

Contract No. NAS8-39210, which contained a J-2S Restart Study Task, was awarded to Rocketdyne by NASA-MSFC in April 1992. A kickoff meeting was held 2 September 1992 at MSFC to discuss and refine the study approach and work scope. It was agreed that the primary focus of this NRA study would be to resolve the configuration and process issues associated with a production restart of a J-2S engine. The results or the study would then provide the necessary foundation for the detailed manufacturing and test plans and non-recurring and recurring cost estimates that are needed to complete the effort to reinitiate production of the J-2S engine system.

The objectives of this study were to assess what design changes would be required to reinitiate production of the J-2S engine for use as a large high energy upper stage engine, as it was designed for, or the possible use as a boost stage engine. The study was to assess design changes required to perform per the J-2S model specification, manufacturing changes required due to obsolescence or improvements in state-of-the-practice, availability issues for supplier provided items, and to provide cost and schedule estimates for this configuration.

The study also requested to examine the feasibility of using the J-2S in a deep throttling application. Studies for vehicles requiring deep throttling were reviewed and it was found that the required throttling range for these applications was between 10:1 and 5:1. Since the J-2S had been successfully tested to 6:1 throttling at an altitude test facility at AEDC, the task was taken to determine what changes were required to achieve 10:1 throttling, if that extreme condition should be required in the mission duty cycle. The modeling calculations were then correlated with actual test data to validate the models used.

J-2S Restart Study
Objectives

- Determine what is required to initiate J-2S engine production
  - Design changes
  - Manufacturing changes
  - Availability of supplier provided items
  - Schedule
  - Cost

- Examine feasibility of throttling J-2S
  - Calculate system impacts of providing up to 10:1 throttling
  - Tie calculations to previous test data

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Agenda

- J-2S Baseline
- J-2S Study Approach
- J-2S Background
- Producibility Assessment
- Throttling Assessment
- J-2S Restart Program Plan

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J-2S Baseline

J-2S Restart Study
J-2S Basic Engine Features

The J-2S (J-2 Simplified) Engine was originally developed as a follow on contract for the J-2 Saturn vehicle upper stage engine. The intent of the study was to not only provide performance upgrades to the engine but to greatly simplify the production and operation of the engine. The task used the same design and development team as the J-2 to produce this engine.

The nominal vacuum thrust of the engine is 265,000 pounds while providing a specific impulse of 436 seconds with a 40:1 nozzle expansion ratio. Baseline operation was at a mixture ratio of 5.5, oxidizer to fuel, with the capability to operate at mixture ratios of 5.0 and 4.5 upon command for optimized propellant utilization during the mission. All engine interfaces were located such that the engine could be used as a direct substitute for the J-2 engine. The engine cycle was changed to a tap-off cycle to eliminate the gas generator. Throttling capability was added as an option for applications other than the Saturn Program. The engine also included a feature for low thrust operation known as "Idle Mode" which was to be used for propellant tank settling, on orbit maneuvering, and rapid engine childown prior to firing.

This engine system was validated with 6 flight configuration engines in 273 tests for a total operating experience of 30,858 seconds. Upon the termination of the J-2S program, the engine was ready to go into certification for flight operations.

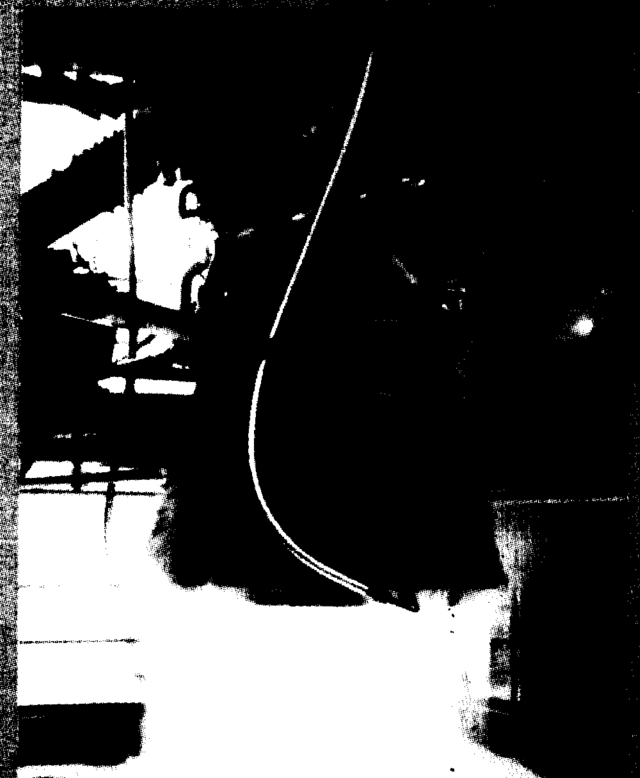
J-2S Basic Engine Features

Performance & Weight

• Nominal vacuum thrust (lb)	265,000
• Nominal vacuum specific impulse (sec)	436
• Chamber pressure (psia) (nozzle stagnation)	1,200
• Engine mixture ratio calibration O/F	5.5:1
• Basic engine dry weight (lb)	3,235
• Engine dry weight (lb) (including accessories)	3,800

Description

- Pump-fed liquid propellant rocket engine
- Propellants – liquid oxygen & liquid hydrogen
- Tap-off turbine drive cycle
- Tubular-wall thrust chamber, regen cooled
- Nozzle area ratio – 40:1
- Separate oxidizer & fuel turbopumps
- Throttling capability
- Low-thrust operating capability



Testing Experience
Production Configuration*

6 Engines, 273 Tests,
30,858 sec

*R&D configuration totalled 10,756 sec

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J-2S Restart Study
Baseline Study Configuration

This study retains the previous thrust level of the engine at 265,000 pounds of vacuum thrust, even though analytical effort has suggested that the engine is capable of being easily uprated to over 320,000 pounds of thrust. Propellant utilization control for real time operation at mixture ratios of 5.5, 5.0, and 4.5 was also retained. Two versions of the J-2S were configured. One for the S-II stage with single start capability and one for the S-IVB stage with three start capability. This study examined both of these configurations and focused primarily on the three start configuration since it provided the greatest operating flexibility for possible applications. The Idle mode operating capability was retained as well since the features of propellant settling, orbital maneuvering, and rapid engine chill would justify the added complexity on most applications.

The study also baselines the use of low risk design and process improvements to take advantage of 1990's technology. The major area of emphasis was in the area of producibility, since the J-2S was only manufactured as a development engine, therefore not ever mass produced. An area identified as a potential problem was the acceptability of some materials and processes used during the 1960's which are no longer environmentally acceptable. The J-2S manufacturing process was reviewed for any required environmental changes (none were identified). Also during the study, the reliability and operability of components were reviewed to assess if any of the problems seen during the J-2S test series could be easily solved using experience gained from subsequent programs. All identified improvements were incorporated into the engine baseline.

J-2S Restart Study
Baseline Study Configuration

- Use J-2S model specification
    - 265 Klb vacuum thrust
    - Propellant utilization control
    - Three starts per mission
    - Idle mode operation

- Recommend design and process improvements
    - Producibility
    - Environment
    - Reliability/operability

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J-2S Study Approach

J-2S Restart Study
Approach

At the outset of the study improvement groundrules were defined for the investigators. These were imposed to assure that no proposed changes would invalidate the extensive development effort already invested in the engine configuration. Only previously demonstrated cost and cycle time reduction techniques were allowed such as incorporation of castings or numerical control machining. Only technologies which had been applied at Rocketdyne were acceptable, since the scope of the study was limiting and validation of any other process technology was not possible. Only changes with high technical maturity were accepted to assure lengthy process development would not be required. Only those processes with minimal qualification requirements were acceptable since it was considered important to keep restart cost and schedule to a minimum. It was also decided that original form, fit, and function were to be retained for engine components with the only exception being the engine interface itself, which could be modified for any specific application. Original structural margins were also to be retained since the potential application is undefined at the moment and it was thought to be desirable to retain the engines "man-rating". Also all development concerns of each of the components was to be addressed so that the restart program would not be initiated with any known problems.

The constant focus of this study was to insert all identified high payoff, low risk changes.

J-2S Restart Study
Approach

- Improvement evaluation groundrules defined
  - Demonstrated cost/cycle time reduction
  - Rocketdyne experience
  - High technical maturity
  - Minimal qualification requirements
  - Retain full form/fit/function of original designs
  - Maintain original structural margins of J-2S engines
  - Address all outstanding J-2S development concerns

High value/low risk changes sought

J-2S Restart Study
Task Flow

The initial task in the study was for the investigators to review the J-2S configuration and to become reacquainted with the engines history and available documentation. Documents were organized in a room to provide a central knowledge library for team member use throughout the study. Personnel who participated on the original J-2S program were consulted on numerous occasions throughout the study.

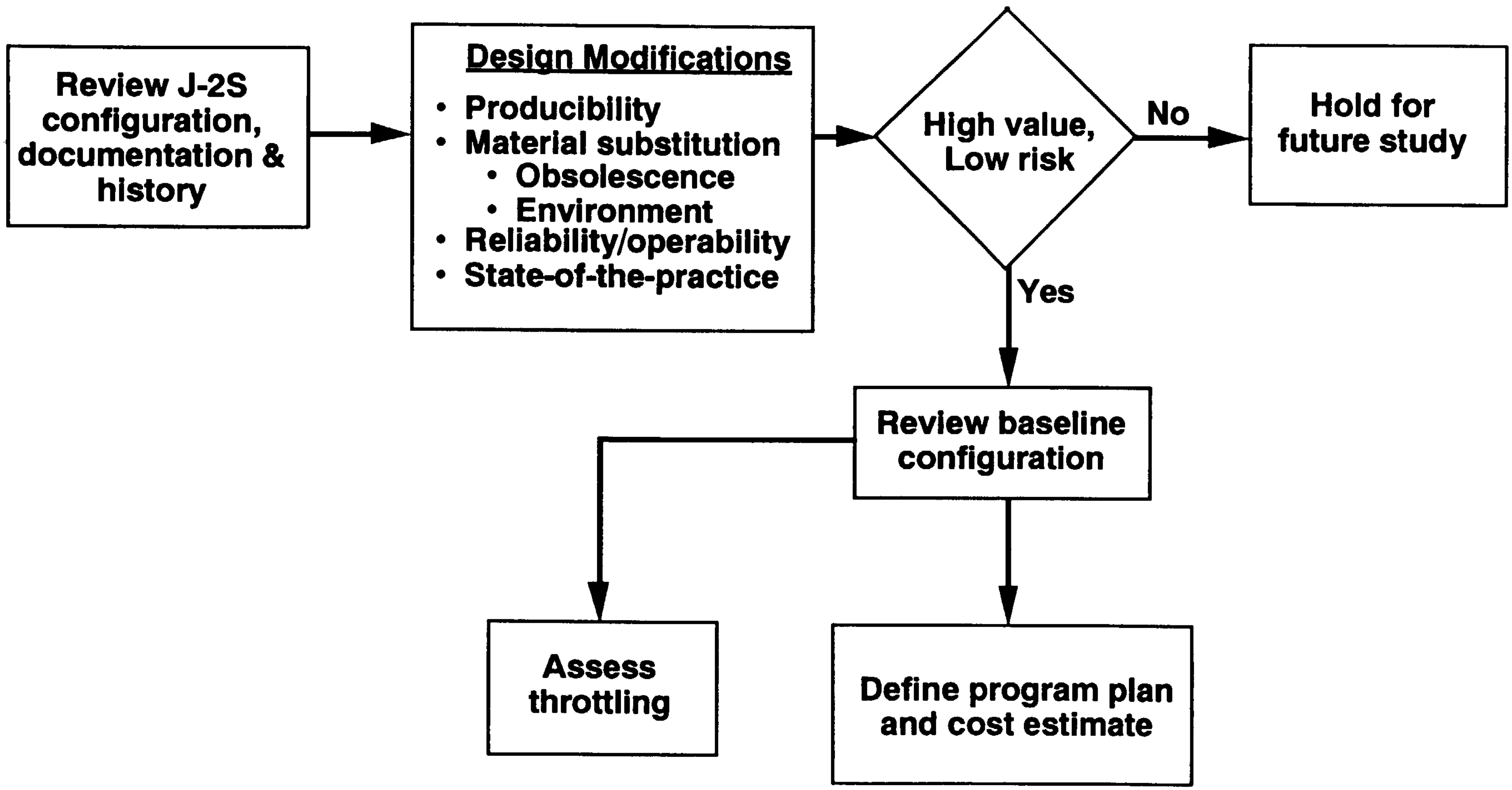
After team members reviewed historical documents, each of the component specialists examined their areas to propose design modifications to address producibility material substitution from either obsolescence or environmental need, reliability/operability issues, and to insert processes that are current state of the practice. These changes were evaluated based on the study approach groundrules.

Each of the proposed modifications were evaluated on the bases of being low risk while providing high added value to the engine system. Those modifications which appeared to add high value but also introduced considerable additional risk were identified for future study. The remaining changes were added to the baseline configuration.

The baseline configuration was then used to define a program plan and cost estimate for the restart program. All testing and costs are consistent with the configuration defined during the producibility program.

In parallel, the 10:1 throttling examination was performed to identify changes required to perform a large throttle ratio. The modeling for this task was not significantly affected by the results of the producibility study.

J-2S Restart Study
Task Flow



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J-2S Background

J-2S Restart Study
J-2S History

The J-2S engine and components were developed between 1965 and 1972 and the effort was based on experimental engines tested between 1964 and 1968 (the J-2X engine series). The J-2S program consisted of six flight configuration engines tested a total of 265 times at both sea level and vacuum conditions. This test total included over 21,400 seconds of mainstage duration and over 6,600 seconds of low thrust idle mode operation. At the completion of the program the engine was fully developed and ready to begin qualification for flight.

A number of features that were beyond the basic model specification were also examined during the program. Life extension of this nominally expendable engine was demonstrated to 12,000 seconds and 30 starts between overhauls. Throttling operation was also demonstrated in two ways. One engine was successfully throttled to 6:1 at AEDC with satisfactory results. Also development was initiated on a powered idle mode which provided throttling in the region between normal idle mode (approx. 5% nominal thrust) and the 6:1 regime. Analytical effort was also performed to examine nozzle extensions for increased performance and uprating the engine to over 320,000 pounds vacuum thrust. The uprating used the same principles used for Atlas and Delta engine upgrades, structural strengthening of key components and chamber pressure increase. No other changes would be required to achieve this higher power level.

An engine qualification was proposed, and rejected, in 1972 for the basic J-2S. It was to be a 36 month program requiring one engine plus a spare and would demonstrate endurance, operation at limits, and engine performance. Unfortunately this readiness for flight coincided with the demise of the Saturn Program and the J-2S was never qualified or ever flown.

J-2S Restart Study
J-2S History

- Engine/component development of J-2S 1965-1972
    - Experimental engine base 1964-1968
    - Extensive J-2S engine program conducted
        - 6-flight configuration engines built and tested
            - 265 tests (sea level & vacuum)
                - >21,400 sec. mainstage
                - >6,600 sec. low thrust (idle mode)
        - Development completed -- ready for qualification
    - Features beyond model spec requirements designed (& partially demonstrated)
        - Life extension to 12,000 sec/30 starts between overhauls
        - Throttling operation
            - Mainstage
            - Powered idle mode
        - Nozzle extensions (analysis only)
        - Thrust uprating to 320 Klb (analysis only)

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J-2S Restart Study

J-2S Schematic

The J-2S, with S standing for simplified, changed from the classic gas generator cycle of the time to a unique tap-off engine cycle. This cycle allowed the elimination of the gas generator by supplying hot gas for the turbines from the combustion chamber, diluted considerably with liquid hydrogen. This simplification eliminated some of the timing difficulties associated with the start-up of multiple combustion devices.

The oxidizer in this cycle is pumped to pressure and ducted to the injector. The fuel is pumped to pressure and used to cool the combustion chamber and nozzle and then sent to the injector. Turbine drive gas is tapped off through a set of ports form the combustion chamber and immediately diluted with some of the cold hydrogen from the chamber coolant circuit. This warm hydrogen and steam is used to power the high pressure ratio turbines and is then ducted back to the nozzle at a suitable location to be expanded with the rockets exhaust plume.

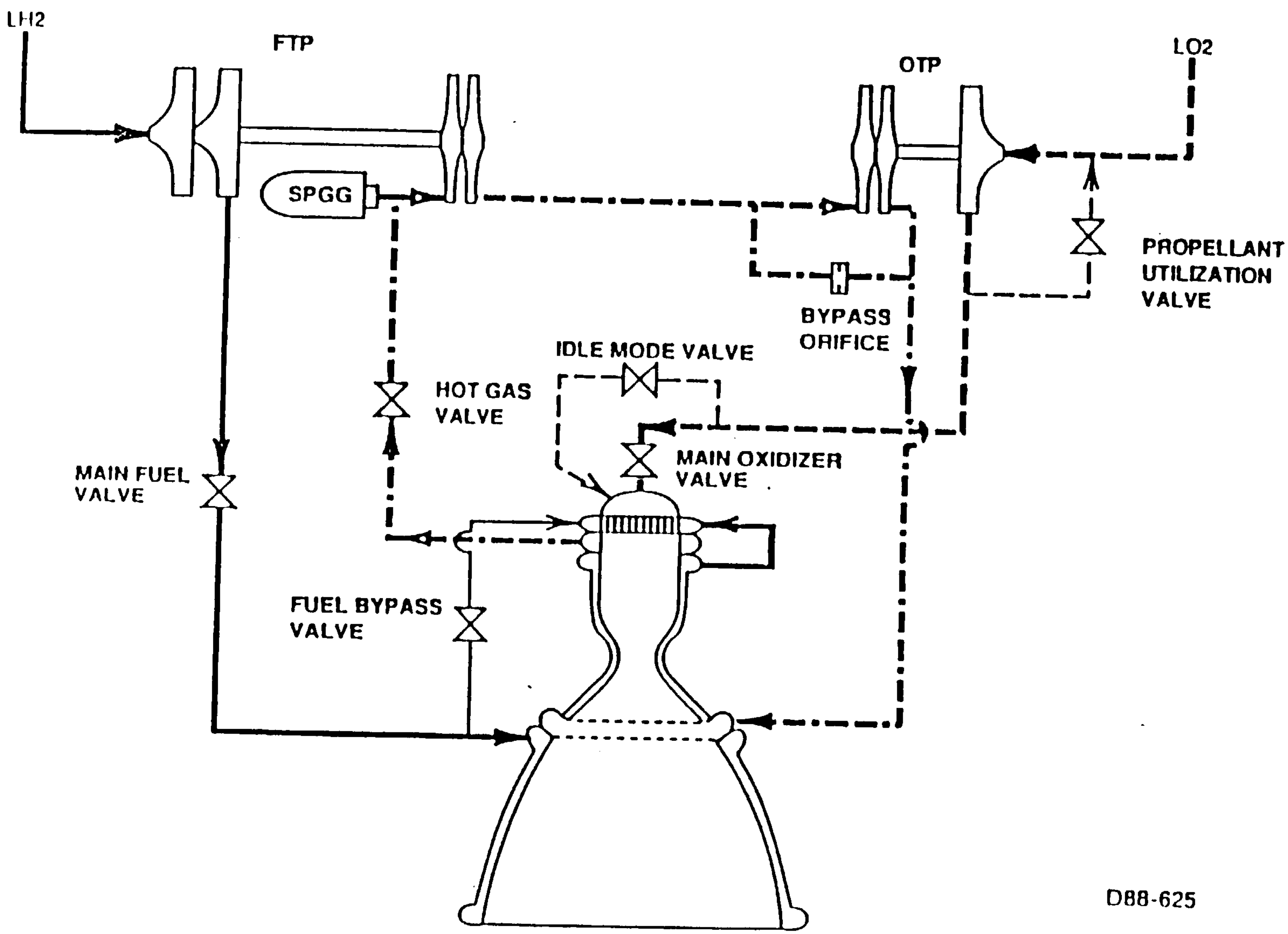
The engine start was driven by a solid propellant gas generator which was electronically initiated at the proper moment of the start sequence. These solid propellant turbine starters were arranged in a manifold of three units for those configurations requiring multiple starts. Each cartridge was fired in sequence and did not require protection from the ignition of the adjoining cartridges.

Propellant utilization mixture ratio control was provided by a valve which varied oxygen recirculation flow around the oxidizer pump. For lower mixture ratio, more oxidizer was simply recirculated.

Idle mode was made possible by adding an injector manifold which only passed oxidizer through the center rows of the injector, thus maintaining a stable pressure drop in each of these elements even during the low propellant flows seen during operation in this low thrust mode. The valve is shown in the schematic.

Throttling was simply accomplished by closing down the hot gas valve, thus reducing the turbines' available power. The effectiveness of this technique was verified in hot-fire test.

J-2S SCHEMATIC



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J-2S Restart Study

J-2S Endurance, Safety, and Performance Testing

This chart summarizes the types and quantity of endurance and operating limits testing required for the J-2S engine to enter qualification along with what testing was performed on the engine.

All engine requirements were satisfied during the development test program.

J-2S Endurance, Safety, and Performance Testing

	Required	Demonstrated
Endurance Tests		
Total tests	30	30
Total seconds	3750	3807.4
Total duration at high mixture ratio	1500	1503.9
Operating Limits and Performance Tests		
Programmed mixture ratio; 470 sec. duration tests	3	3
Gimbaling pattern cycles	8	8
Mixture ratio control valve calibration point tests	5	5
Mainstage performance tests	4	7
Heat exchanger pressurization performance point tests	2	2
Hydrogen tapoff pressurization performance point tests	1	1
Safety limits tests	16	16
Start-restart test couples	2	2
Safety & leakage checks	1	1
Demonstration of restart capability tests	2	2
Start-stop tests	As necessary	5
Altitude simulation test (Engine J-2073)	1	1

J-2S Restart Study

J-2/J-2S Engine Application Investigations

Since before the end of the J-2S development program, there have been a number of applications which have examined the engine as a possible candidate. Detailed inputs for the engine were submitted to the early Space Shuttle examinations as well as the early phases of the Advanced Launch System Program. For each of these, a tailored capability version of the J-2S was proposed.

Other studies have not been as specific but have addressed broad mission classes. For these investigations specific engine requirements were not available but rough order of magnitude estimates of what would be required to restart engine production and qualification were provided.

J-2/J-2S Engine Application Investigations

- Numerous inquiries have been received & addressed for J-2/J-2S engines
  - Specific programs
    - Mission definition input
    - Unique requirements
      - Technical
      - Schedule -- development & production
      - Cost -- non-recurring & production
    - Examples:
      - J-2S for Space Shuttle Orbiter (71/72)
      - J-2S for ALS (88)
  - Generic/derivative engine data
    - Undefined (i.e., broad class missions)
    - Non-specific requirements
      - Derivative engines/potential features
      - Cost/schedule parametrics
    - Examples
      - J-2S for potential MMC application (89)
      - Rocketdyne Engine Data Package (92)

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Producibility Assessment

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J-2S Restart Study
Producibility Assessment

As part of the review of each of the major components, the responsible engineers and their teams reviewed the drawings to assure full understanding of how the part was previously made along with an examination of internal letters referring to operational and production issues with each of the parts. In many of the components interviews were conducted with personnel actually involved in the design, production and development of the hardware to obtain first hand feed back of the shortcomings and lessons learned from experience. In several cases retired personnel consented to assist in these studies.

Three areas were selected for greater depth of study since documents either indicated greater concern for these parts at the end of the development program or less depth of documentation was actually available in the area. Turbomachinery was examined since this is an area of traditional concern in rocket engines and there was some record of early fuel turbopump issues seen in the historical documentation. The thrust chamber tap-off port was also examined in greater depth since this is the only device of its kind ever tested and early program records indicated problems with erosion. It was felt that any issues with this part had to be fully understood prior to reinitiating production. Finally the engine valves were examined in greater depth since several operational issues were identified along with the fact that several of the drawings were missing from the storage locations.

Along with these "in-depth" examinations every major component of the engine was evaluated by the team to determine a baseline configuration.

J-2S Restart Study
Producibility Assessment

- All major components examined
  - Reviews of drawings
  - Examination of internal documents
  - Interviews with personnel who worked J-2S
- Three areas selected for review in greater depth
  - Turbomachinery
  - Thrust chamber tap-off port
  - Engine valves
- Other major areas assessed at part level
  - Combustion devices
  - Ducts, lines, and interfaces
  - Flight instrumentation
  - Other components

J-2S Engine Components Evaluation

For the component evaluation, the engine system was divided into the major subsystems and assigned to responsible engineers for study. Bob Saxelby of Advanced Combustion Devices examined the combustion devices, supported by Irving Kaith of Advanced Systems Design on the tap-off port evaluation and Joe Trom also of Advanced Combustion Devices on the Solid Propellant Turbine Starter examination. Turbopumps were examined by Dan Shea of Advanced Rotating Machinery Projects supported by Brian Lariviere, project engineer on the Mk-29FD IR&D study. Ducts were evaluated by Irving Kaith and Valves were done by Mike Cochran of Valves and Controls. Flight instrumentation was evaluated by Sonia Balcer of Rocketdyne's Advanced Instrumentation Group. Miscellaneous components were evaluated by the responsible engineer who had the greatest familiarity with the component.

Each of the presented components were examined and a baseline configuration established.

J-2S Restart Study

J-2S Engine Components Evaluation

- J-2S Engine Sys.
  - Combustion Devices
    - TCA 99-210620
    - Injector
    - Tap-off Port
    - Nozzle/ Chamber
    - Manifolds, fuel & turb. exhaust
    - ASI System 651349 652050
    - SPTS Cartridges
  - Turbopumps
    - Mk-29 Fuel Turbopump 99-461500
    - Mk-29 Ox. Turbopump 460430
  - Ducts
    - Fuel Inlet Duct 409900
    - Oxidizer Inlet Duct 409899
    - Fuel Disch. Duct 99-411078
    - Oxidizer Disch. Duct 99-411077
    - Fuel Bypass 99-411079
    - Idle Mode Duct 411081
    - Misc. Tubes & Flex Hoses
    - Ox Turb Bypass 307715
    - Cross-over Duct 307714
    - Turbine Exhaust 308040
    - Hot Gas Tap Off 99-411080
  - Valves
    - MFV 99-411320
    - MOV 99-411225
    - PU Valve 99-251455
    - Fuel Bypass Valve 99-411180
    - Tap-off Valve 99-557824
    - Idle Mode Valve 99-411385
    - Anti-Flood Valve 99-407875
    - Relief Valve 558325
    - Check Valves 558022 309065 557755 557751
  - Flight Instrumt. System
    - Ign. Detector Probe 500750
    - Instrument. Package 99-704641
    - Pressure X-ducers
    - Temperature Sensors
    - Flowmeters
    - Speed X-ducers
    - Mainstage OK Press. Sw.
  - Misc. Components
    - Pneum. Cont. Package 99-558330
    - Helium Tank NA5-260212
    - Gimbal Bearing 208900
    - Interface Panels
    - Heat Exchanger 307885
    - ECA Package 99-503670

J-2S Restart Study
In-Depth Producibility Reviews

The turbomachinery configuration was reviewed since additional history was available on these components. The Mk-29 turbopumps were used after the J-2S Program on the Linear Aerospike Engine program. Also the Mk-29F has recently been disassembled, modified, and rebuilt under Rocketdyne's Mk-29FD IR&D Program. This was an opportunity to take recent pump build experience and recent producibility effort done under the NLS Program to form a solid configuration baseline with personnel very experienced in this particular hardware and working on a similar producibility improvement goal.

The thrust chamber tap-off port was both a durability and producibility concern. Documents and personnel recollection indicated that the previous port configuration was very difficult and time consuming to produce. Also records indicated that this configuration had life limiting erosion issues early in the test program. This was the opportunity to solve both of these issues by introducing modern producibility techniques if applicable along with a configuration that could be designed for durability using modern thermal modeling techniques.

Drawings for several of the valves could not be located and several documents indicated that problems were experienced during the development program. To address these issues a retired Rocketdyne Valve engineer was brought in to provide valuable historical perspective on this task of defining a restart baseline. All previous test problems were able to be identified and state-of-the-practice solutions found. It was determined that the valves that are missing drawings would have had to been redrawn to incorporate improvements for operation and producibility.

J-2S Restart Study
In-Depth Producibility Reviews

- Turbomachinery history reviewed for more data
  - MK-29 turbopump experience in J-2 linear engine
  - Recent rebuild and modification of MK-29F under IR&D
  - Applicability of NLS turbopump producibility effort
- Thrust chamber tap-off port reviewed for durability & producibility
  - Documents indicated the test configuration was costly & time consuming
  - Component stood to benefit from improved thermal modeling capability
  - Incorporated modern producibility techniques
- Engine valves were examined for operational issues
  - Consulted with J-2S valve development engineers
  - Noted problems identified during test program
  - Updated fabrication techniques

J-2S Restart Study
General Recommendations

Several recommendations appeared to be universal in the study. The incorporation of robotics and numerical control machining to replace previously manual operations would be implemented. This provides lower part cost and greater part-to-part repeatability. The use of laser measurement and inspection techniques allows greater precision of flaw detection. Replacing simplistic geometry forged and welded parts with net shape castings and forgings greatly reduces the process flow of long lead parts. The use of machine cells and multi purpose tooling will eliminate the queuing times and minimize the overall tooling costs. Adopt precision end point tooling for ducts where the J-2S was previously built with custom fitted ducting due to its low production rate.

It was also found that all of the electronic parts required updating simply because the formerly used parts are no longer available. New electronic parts have better performance and cost much less, aside from the fact that they are available.

J-2S Restart Study
General Recommendations

- Implement state-of-the-practice fabrication methods
  - Robotics and numerical control machining
  - Laser operations
  - Casting/forging improvements
  - Machine cells/multi-purpose tooling
  - Adopt precision end point tooling for ducts
- Update electronics (old parts no longer available)

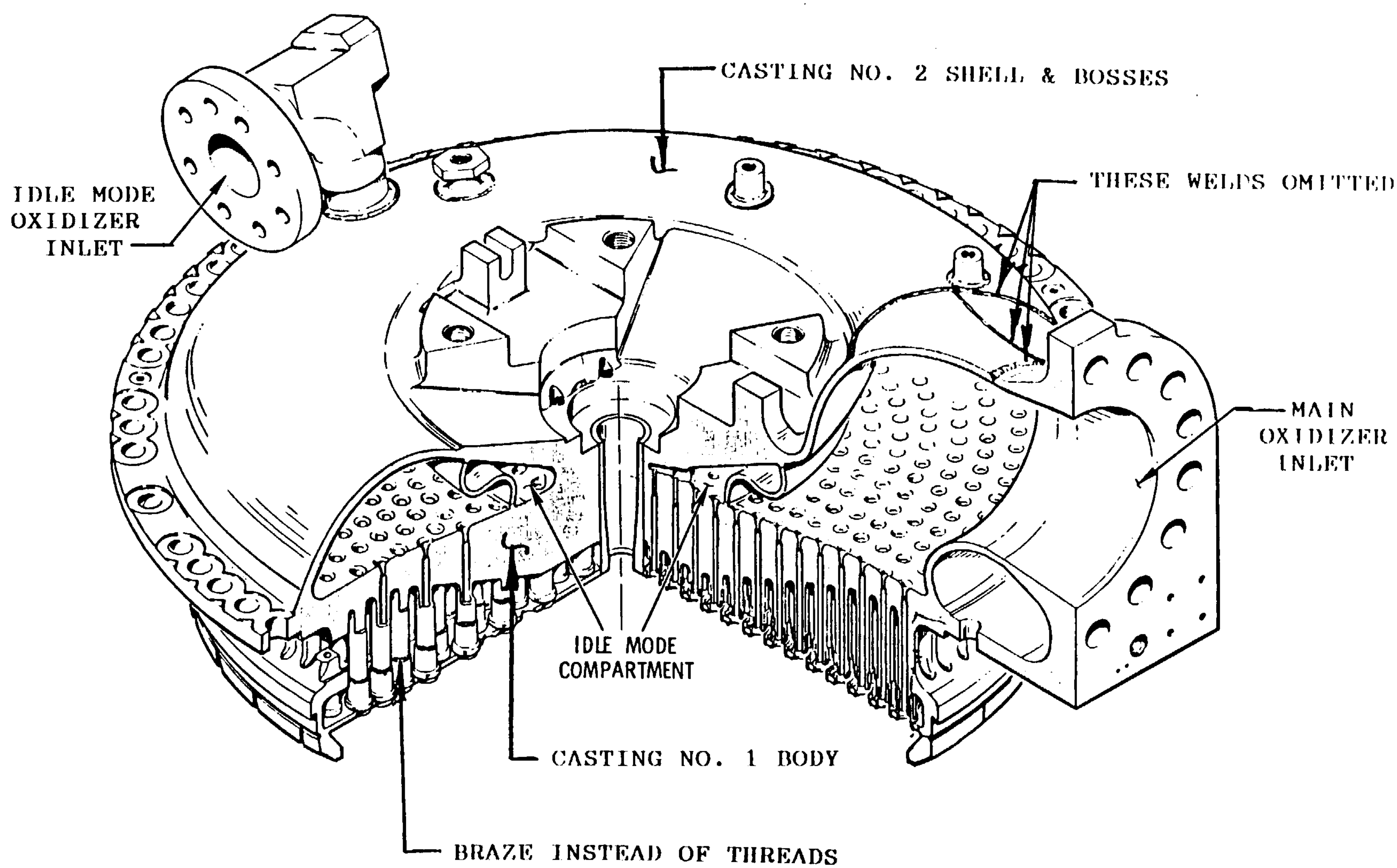
J-2S Restart Study

Two Piece Cast Injector

This chart shows how a two piece cast injector would be implemented. By casting the injector in two halves, a majority of the existing machining operations and several major welds would be eliminated. One part of the casting would be the body which would include the injector mounting flange and the gimbal/ASI mounting structure. The second casting would include the LOX inlet flange, the LOX manifold shell and the ports and bosses located on the shell. The IDLE mode manifold and inlet would still have to be assembled as presently accomplished because of the necessity of providing radial LOX feed holes for the inner two rows of LOX posts.

Fuel sleeves would be attached to the LOX posts by brazing instead of threads to simplify the design. The braze cycle will also take the place of a stress relief function currently performed.

TWO PIECE CAST INJECTOR



J-2S Restart Study
Cast Tap-off Manifold

Casting the tap-off manifold would eliminate two class I welds each more than 70 inches in length and would considerably reduce the machining requirements of the tap-off manifold. The fuel pump mounting balls and clevis and the LOX pump mounting balls would still require final machining along with other critical features but the rough features can be cast. The LOX pump mount would still be weld attached and the shear pin would be unchanged. The fuel tank pressurization outlet with flange would be cast in place as well as the two actuator pockets. The tap-off outlet with flange and turning vane are also castable. The core for the tap-off manifold shell may be retainable by inserting core supports throughout the radial tap-off ports. The ports may not then require subsequent machining. The axial fuel passages located around the periphery of the manifold will also be cartable. The film coolant manifold feeder holes will still have to be machined.

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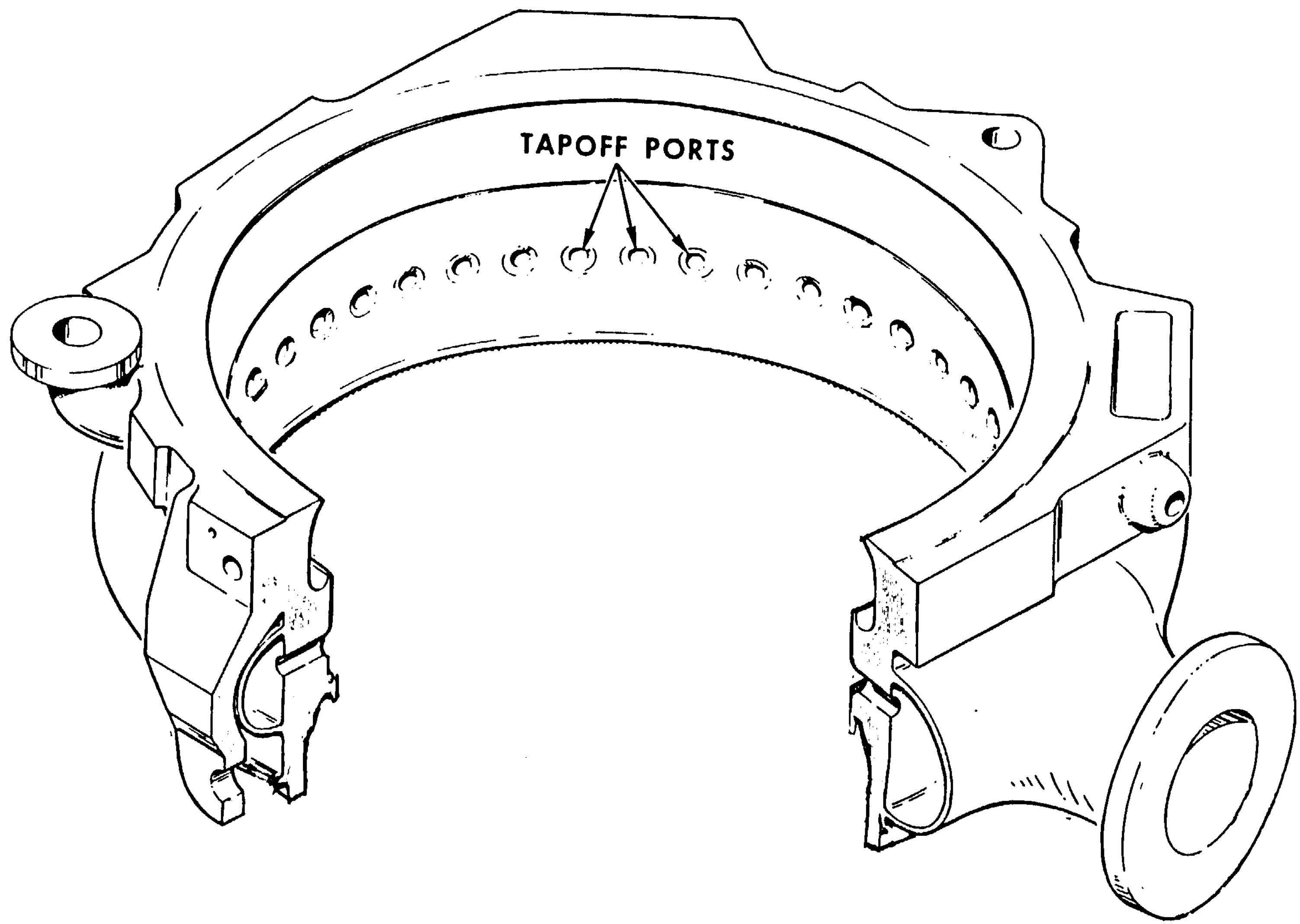
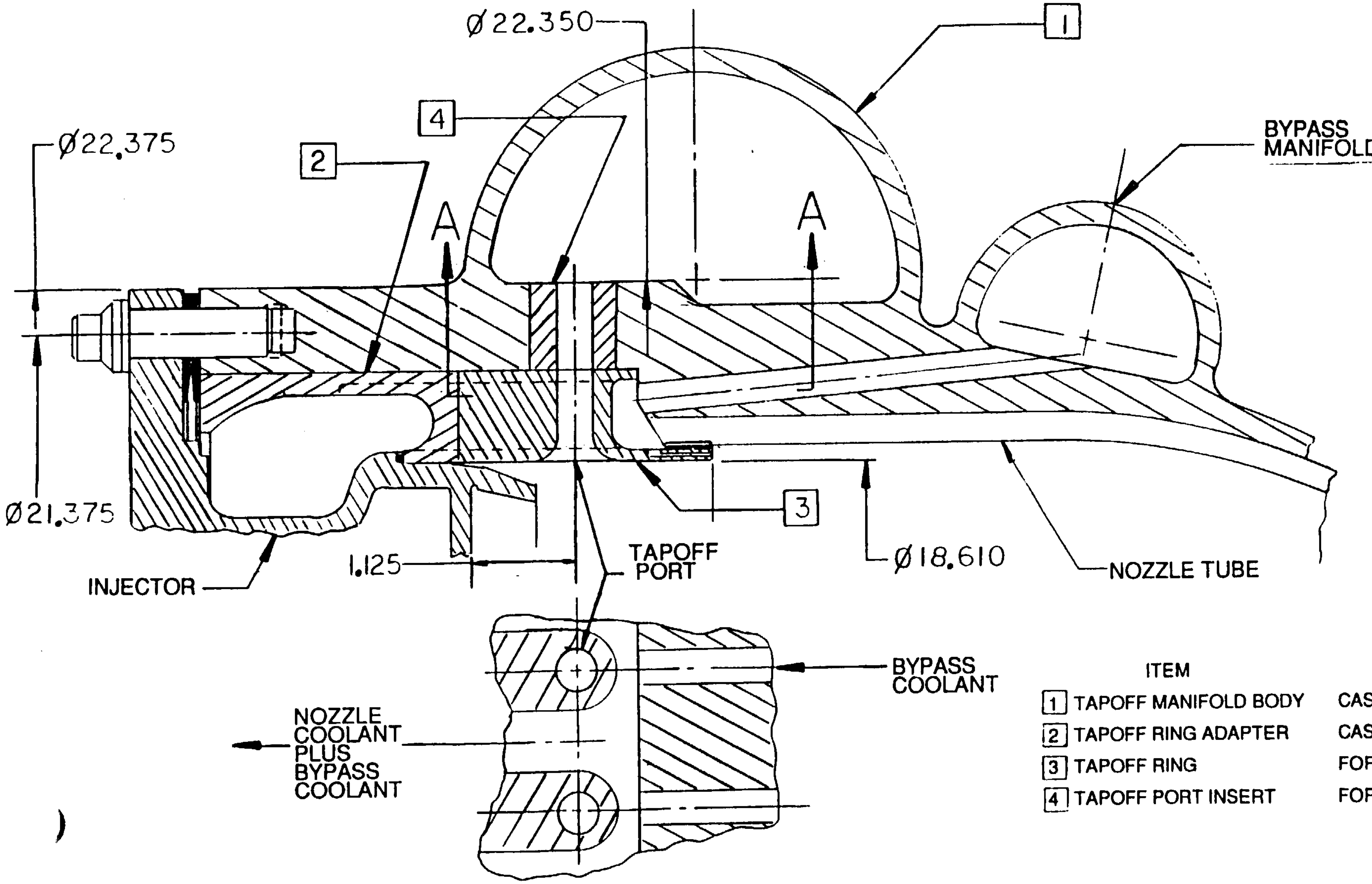
CAST TAPOFF MANIFOLD



J-2S Restart Study
Proposed J-2S Tap-off Manifold Redesign

This cross section of the proposed cast tap-off manifold assembly shows how the port supplies the hot gas into the coolant-rich manifold. The narloy-z lined port is cooled sufficiently by the surrounding chamber coolant flow to operate without erosion or localized melting. Note that the tubes end at the casting and are routed to provide the cooling between the ports (shown in section A-A). This configuration replaces the intricately machined and hand brazed part used during previous testing, greatly simplifying the procedure and providing far greater confidence in production without nonconformances. It should also be noted that the advanced materials used far exceed the capabilities of the 321 CRES material used in the previous work, thus supplying an engine with improved operating margins along with producibility improvements. The structural portions of the casting will be made from JBK-75, a high castability grade of A-286 stainless steel.

PROPOSED J-2S TAPOFF MANIFOLD REDESIGN



SECTION A-A

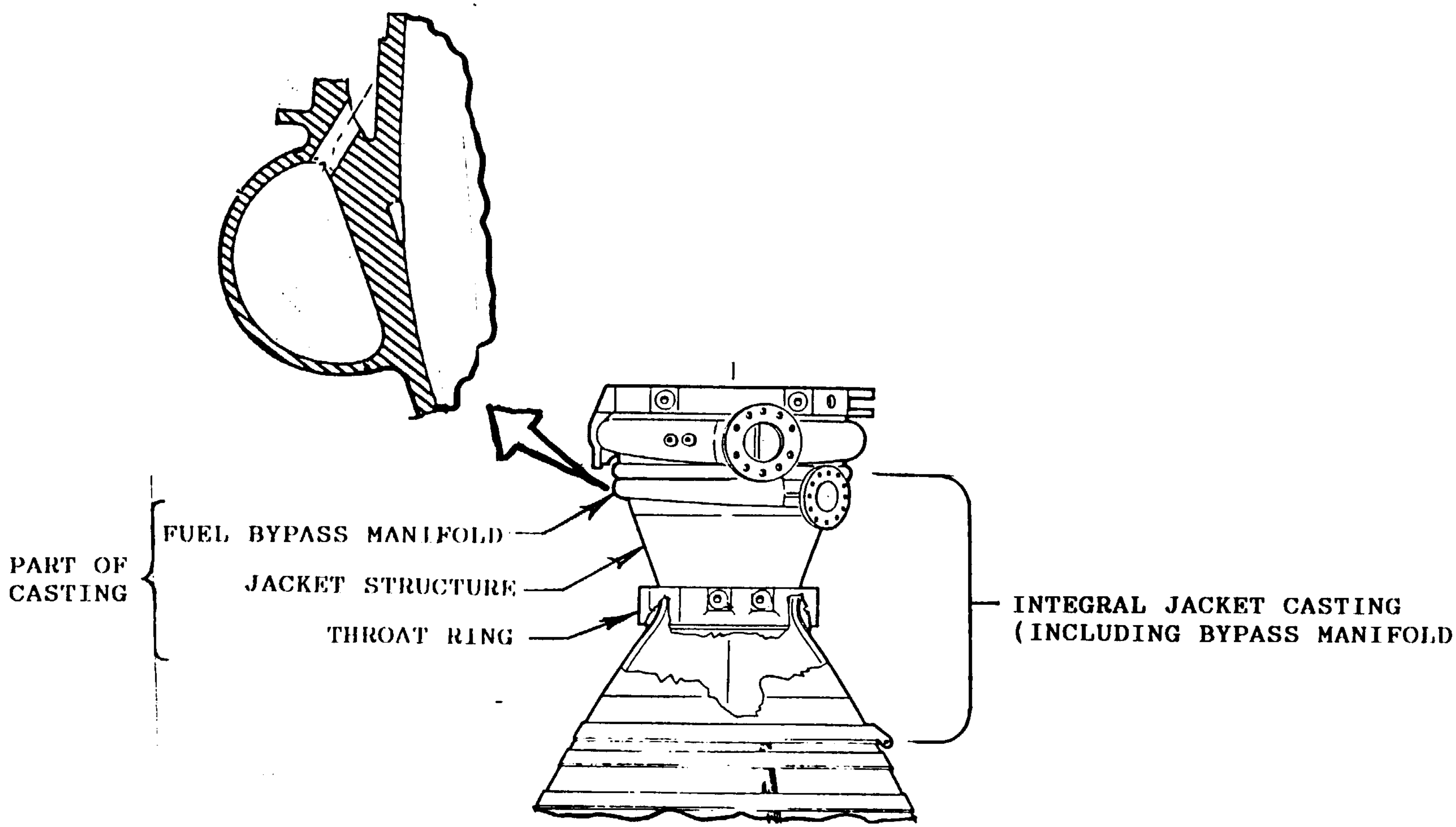
	ITEM	MATERIAL
1	TAPOFF MANIFOLD BODY	CAST JBK
2	TAPOFF RING ADAPTER	CAST JBK
3	TAPOFF RING	FORGED NARLOY-Z
4	TAPOFF PORT INSERT	FORGED NARLOY-Z

J-2S Restart Study

Cast Integral Jacket with Bypass Manifold

Casting the fuel manifold and the jacket integrally would eliminate several major welds and would provide a more structurally satisfactory part. The casting would include the throat ring, actuator strut mounting feature located on the throat ring, bypass manifold with inlet, accessory brackets located on the throat ring and on the jacket end ring such as the -345, -413, and -415 brackets and could include structural reinforcement features such as the -253, -249, and -250 positioned in the throat ring. This cast design will eliminate over 250 inches of welding.

CAST INTEGRAL JACKET WITH BYPASS MANIFOLD



J-2S Restart Study
One Piece Full Jacket to Exit

This configuration allows reducing or eliminating tube to tube braze demands. Brazing can be accomplished using a vacuum bag method which is very satisfactory and uses less complicated tooling setups once tooling is designed. The full jacket provides an additional structural bonus at a modest weight increase.

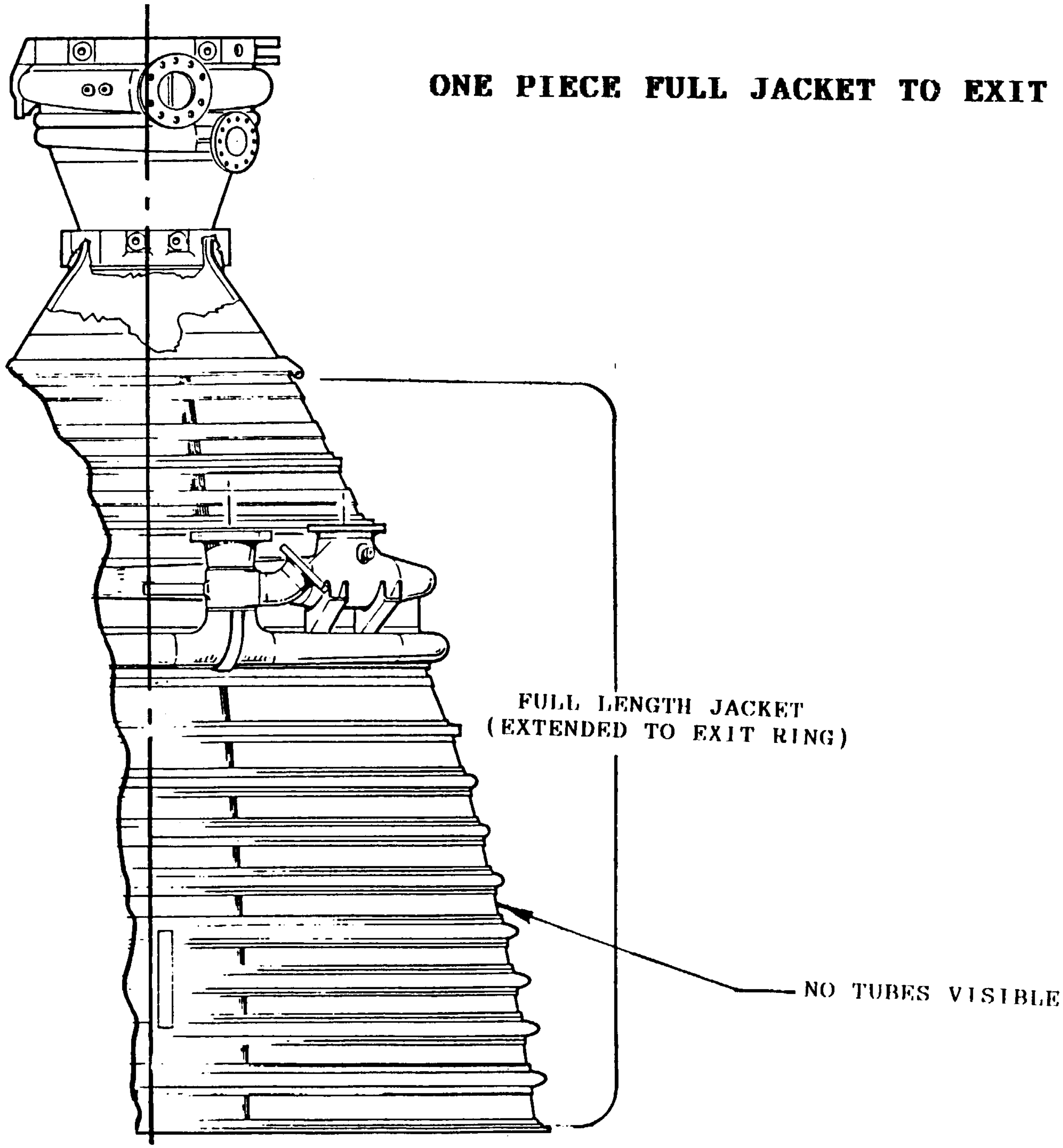
Alternate methods which warrant further study would be:

A) Chem-milled waffled array which eliminates hatbands

B) Honeycomb jacket structure

C) Chem-milled configuration which accommodates rolled tube hatband weld installation.

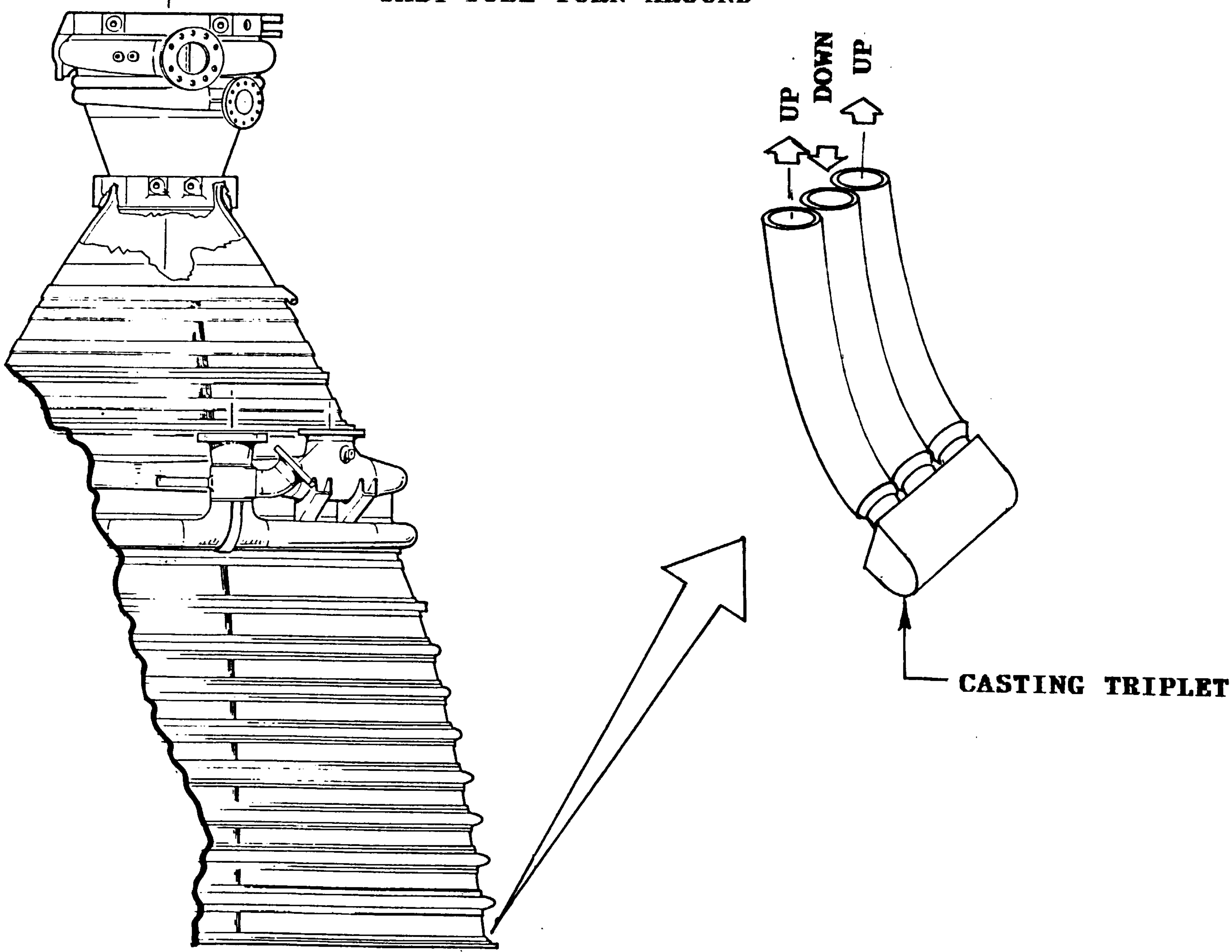
ONE PIECE FULL JACKET TO EXIT



J-2S Restart Study
Cast Tube Turnaround

This change would be done simultaneously with the full length nozzle jacket, otherwise an additional hatband would be required at the aft end. In this configuration, the turnaround manifold is replaced with numerous cast triplets to turn the flow around from the single down-pass tube to the two up-pass tubes. This configuration eliminates the large machined forged rings which require >485 inches of pressure vessel welding.

CAST TUBE TURN-AROUND



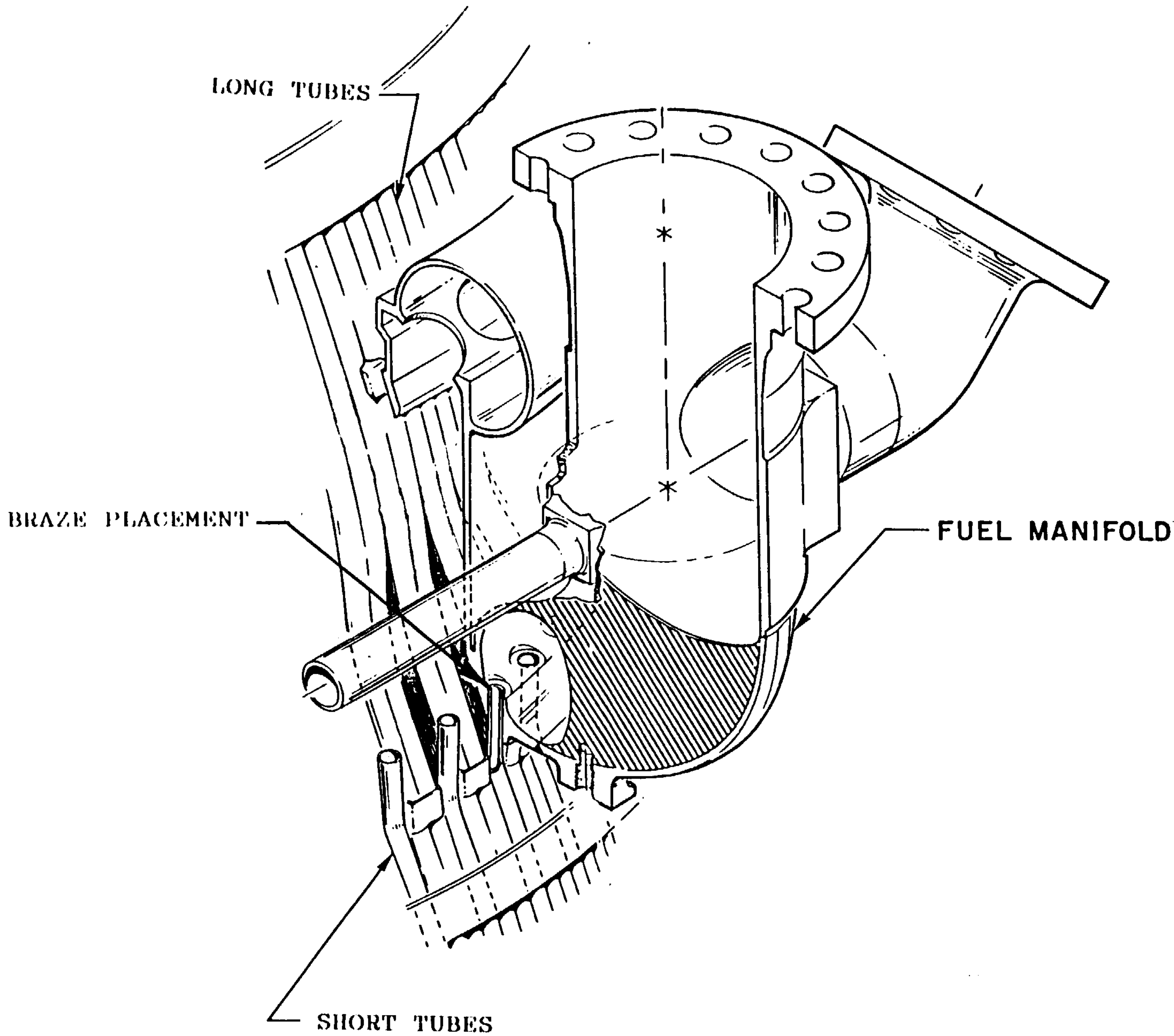
J-2S Restart Study

Cast Fuel Inlet Manifold

Casting the fuel inlet manifold would eliminate two major structural welds (>354 inches). The stiffeners, sideload lugs, bosses, fuel inlet and the outlets located on the inlet neck could be integrally cast thus eliminating several more inches of class I welding. The tube insert holes would still require machining as is presently done.

An alternative cast method would be to cast the outer shell in two half circles, one side including the inlet and both halves including the side load lugs. The two halves would be joined together at two angular locations. The inner ring would still be a machined forged ring and the two large circular welds would still have to be made to complete the assembly.

CAST FUEL INLET MANIFOLD



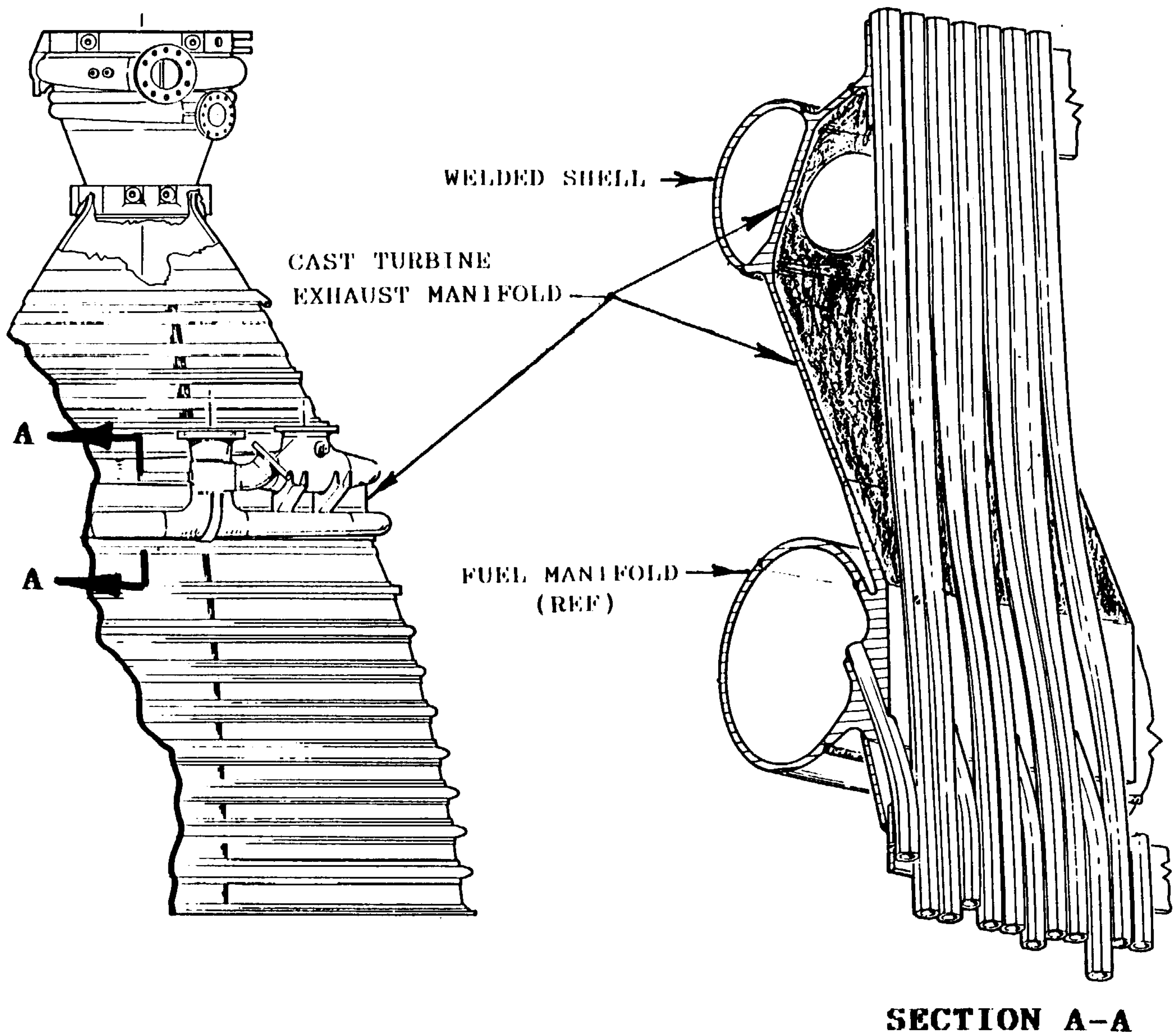
J-2S Restart Study

Cast Turbine Exhaust Manifold

Casting the inner ring portion of the turbine exhaust manifold (P/N 210620-143) would eliminate an expensive machined part and could eliminate several significant welds if the small inlet was included with the ring casting. The large inlet would be cast separately. The small inlet, supports, and flange could be integrated with the -143 ring to eliminate several parts and welds. The -143 ring has a machined tapered land, to which the manifold shell is welded, that is an expensive machining feature that could be cast. The large inlet would be separately cast and would include the -163, -164, -165, -166, -209, and -210 inlet shells, the -184 and -185 gussets, the -183 and -184 stiffeners and the -154 flange. Casting the large inlet would eliminate over 100 inches of class I welding.

Further study will be required to determine if the ninety large holes on the -143 ring can be cast. Also an evaluation of the potential of integrating the casting of the -143 ring on the turbine exhaust manifold with the casting of the fuel inlet manifold is desired.

CAST TURBINE EXHAUST MANIFOLD

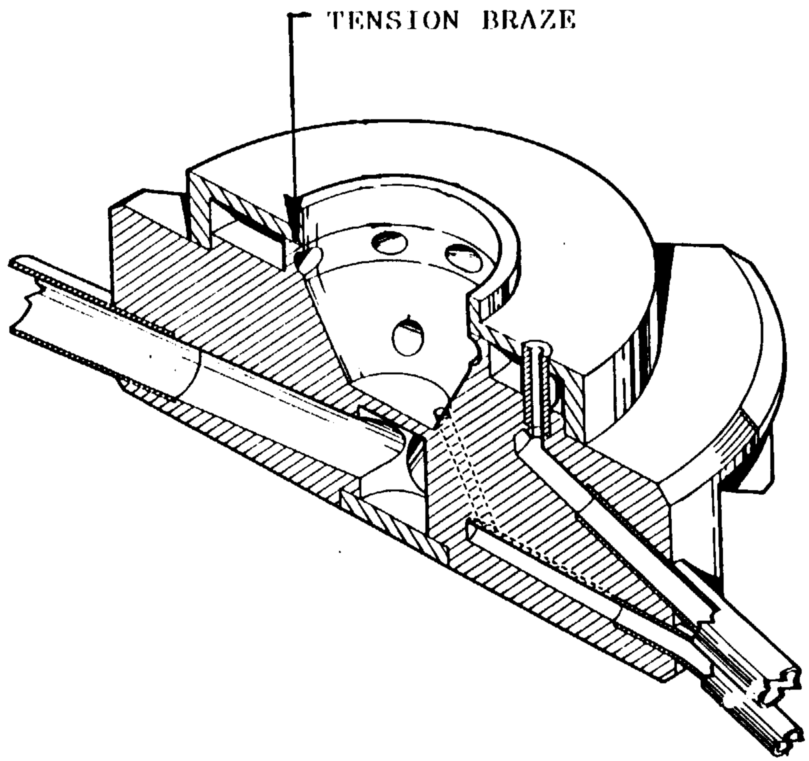


J-2S Restart Study
Augmented Spark Igniter

The Augmented Spark Igniter (ASI) is the device that provides an ignition source for the main injector. As the name implies, a spark source is used to initiate ignition. However, the spark source is “augmented” by the use of an ignition-favorable mixture of hydrogen and oxygen in a small premix chamber. These propellants are ignited by the spark initially, however when the pressure rises to the level that the spark source is quenched, the premix chamber maintains the combustion thus providing a continuous source for the main injector.

The ASI would still be machined in two parts, however the propellant manifold cap will be brazed into place rather than welded. This process will produce a part with lower rework without reducing the quality of the part in operation.

AUGMENTED SPARK IGNITER



J-2S Restart Study

Solid Propellant Turbine Starter (SPTS)

The SPTS consisted of two major subassemblies, the solid grain contained in a canister and the NASA standard initiator (NSI). The canister had a burst diaphragm which kept the grain from prematurely igniting when other SPTS's were activated. Three of these devices were located on a manifold adjacent to the fuel turbopump.

The solid propellant used in the canister was RD-135 formerly made by Rocketdyne's solid rocket division in MacGregor Texas. Since this division was sold to Hercules Inc. the formulation now belongs to them. This grain was found to be completely satisfactory, however should another supplier be desired, a study would b be required to determine what propellant is suitable. This study assumes that the part will be built to print updating propellant if practical.

The J-2S used a NSI with complete success, however this was an operational intensive device. More modern devices are available, however this would require additional study.

J-2S Restart Study
Solid Propellant Turbine Starter (SPTS)

- **Consists of two separate parts**
  - Solid propellant/burst diaphragm canister
  - NASA standard initiator (NSI)
- **Solid propellant canister**
  - Hercules Inc. owns formulation of RD-135 propellant
  - Alternate grains require additional study
  - Baseline configuration - build to print
- **Initiator**
  - NSI baselined
  - Study should be performed for more modern initiator

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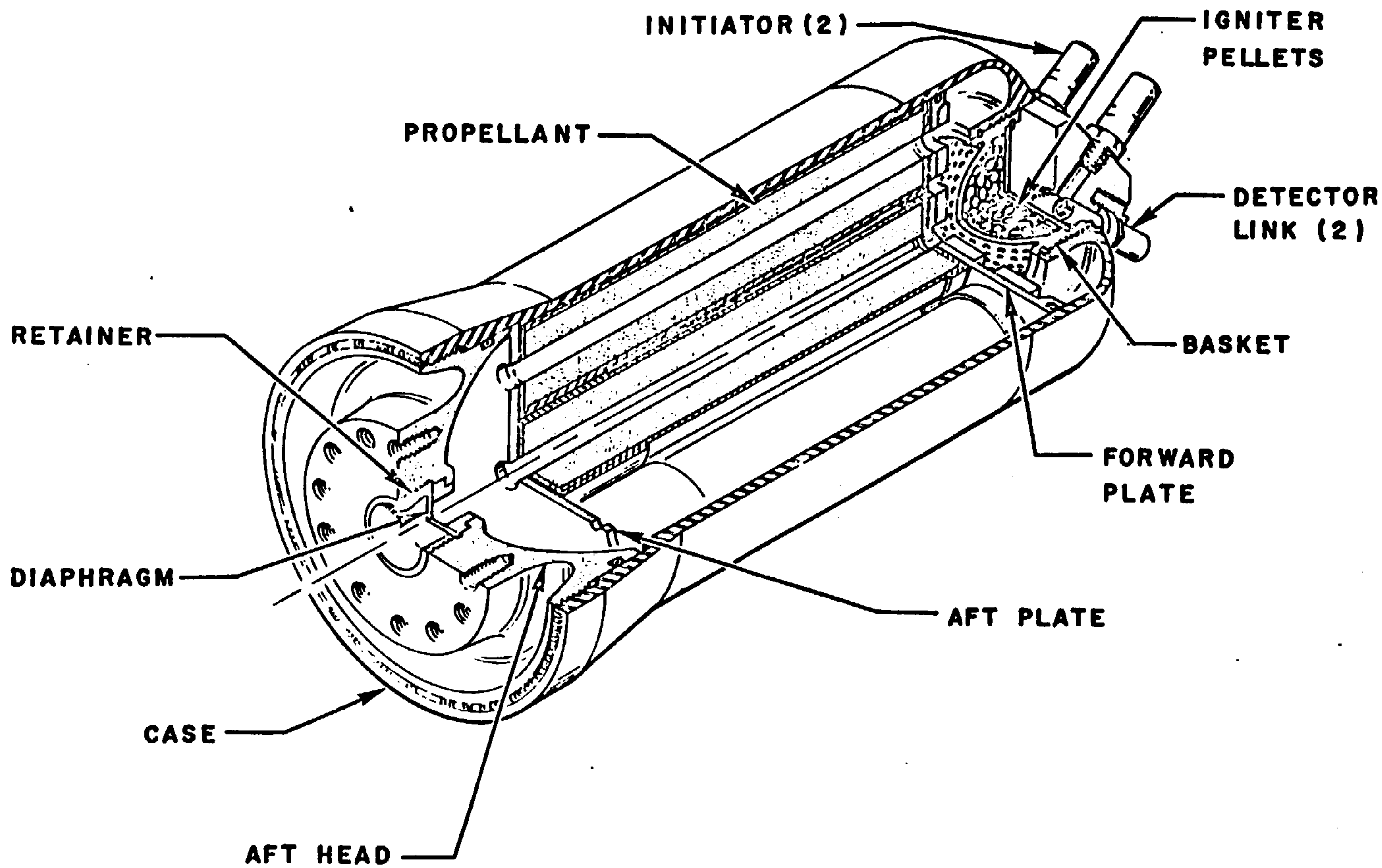
SOLID PROPELLANT TURBINE STARTER



J-2S Restart Study

Fuel Turbopump (MK29-F)

This component was subject to an in-depth study which examined previous operational issues as well as producibility issues. Early testing demonstrated an inducer suction performance problem that resulted in blade fatigue. This condition was corrected by improving the contouring, which was validated in follow-on testing. Another issue found was that the pump end ball bearing experienced unloading characterized by a "cocking" of the ball bearing carrier and anti rotation key. Over extended testing a loss of bearing preload and eventual loss of the bearing support pilot were experienced in some units. This second issue will be addressed by adding a stiffer pump end bearing support along with adding a more modern stable ball bearing carrier, preload and anti-rotation system.

In terms of producibility, the only changes are to replace the current machined forged impeller with a cast titanium impeller, significantly reducing the cost and need for rework. There will be a material change to retain acceptable strength levels.

The final change will be to update dynamic seals with units that are currently available. The manufacturer of the previously used units is no longer producing these products.

FUEL TURBOPUMP (MK29-F P/N461500)

- **Materials**
  - Impeller - from Forged Ti-5Al-2.5Sn ELI to Cast Ti-6Al-4V ELI
- **Problems Noted During Test**
  - Inducer Suction Performance & Blade Fatigue
    - Corrected with Redesign, Validated with Tests
  - Pump End Ball Bearing Unloading
    - "Cocking" Ball Bearing Carrier & Anti-Rotation Key
    - Loss of Bearing Preload
    - Loss of Bearing Support Pilot
- **Potential Producibility Improvements**
  - Cast Impeller - was Three Piece Machined From Forgings
- **Proposed Restart Configuration**
  - Same As Current Drawing (P/N461500) except;
    - Replace Machined Impeller with Casting, P/N 7R045511-7
    - Stiffer Pump End Bearing Support
    - Stable Ball Bearing Carrrier, Preload & Anti-Rotation System
    - Minor Change to Dynamic Seals

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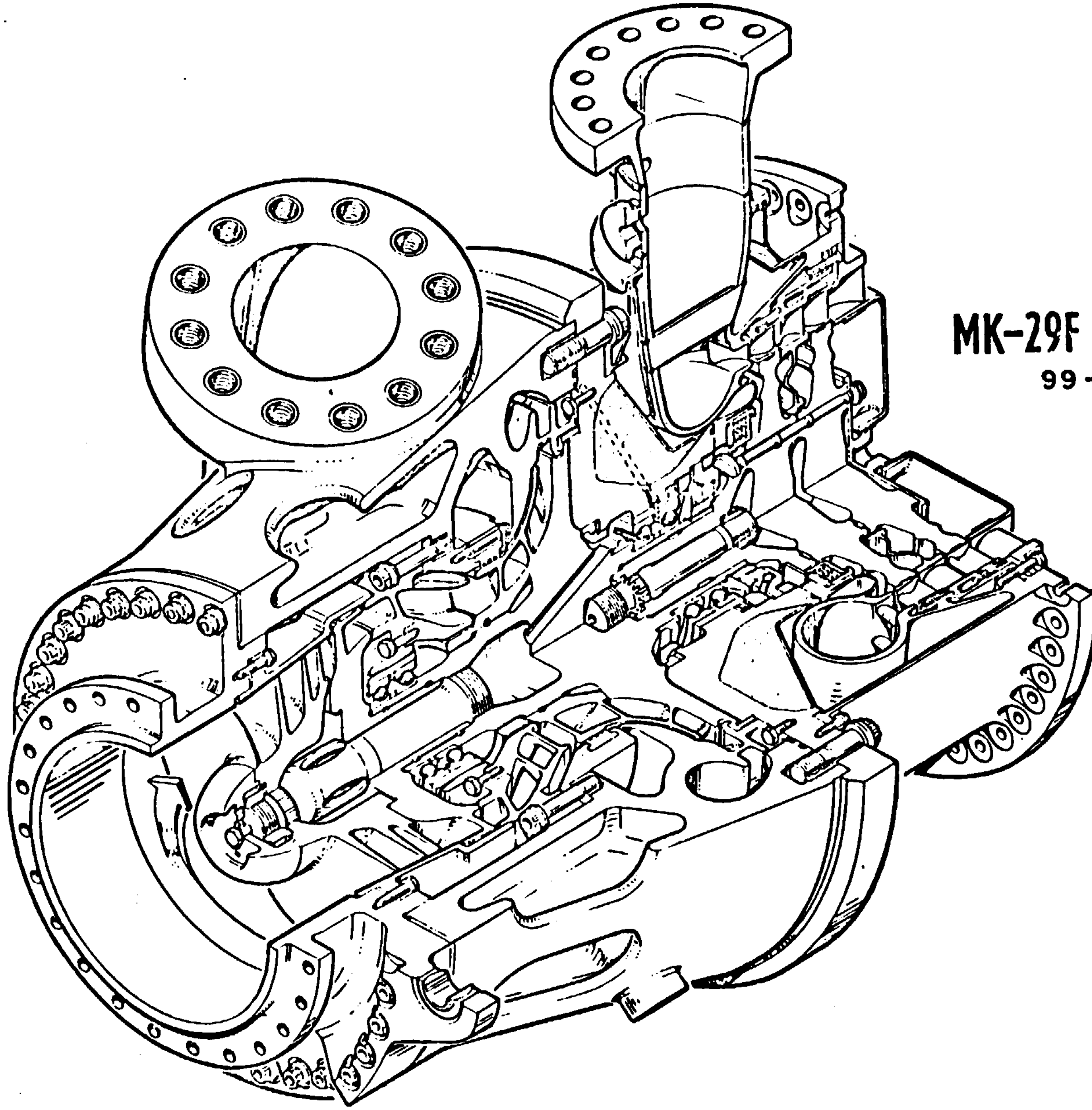

MK-29F TURBOPUMP
99-461500

J-2S Restart Study

Oxidizer Turbopump (MK29-O)

The Mark 29 oxidizer turbopump was perhaps the most successful oxidizer turbopump design in the history of rocket engine design. This seemingly amazing feat is considerably mitigated by the fact that it is a direct derivative of the Mark 15 oxidizer turbopump used on the J-2 engine. Since the Mk-29O was by the same design team, all problems were solved in the previous turbopump design.

The only change proposed for this component is to replace the dynamic seals, since the former vendor is no longer in business. There are numerous vendors who could produce these parts.

OXIDIZER TURBOPUMP (MK29-O P/N460430)

- **Materials**
  - No Changes Required
- **Problems Noted During Test**
  - No Significant Issues were Incurred
- **Potential Producibility Improvements**
  - None Identified
- **Proposed Restart Configuration**
  - Use successful basic Mk-29O configuration
  - Minor Changes to Dynamic Seals - Vendors no longer in business

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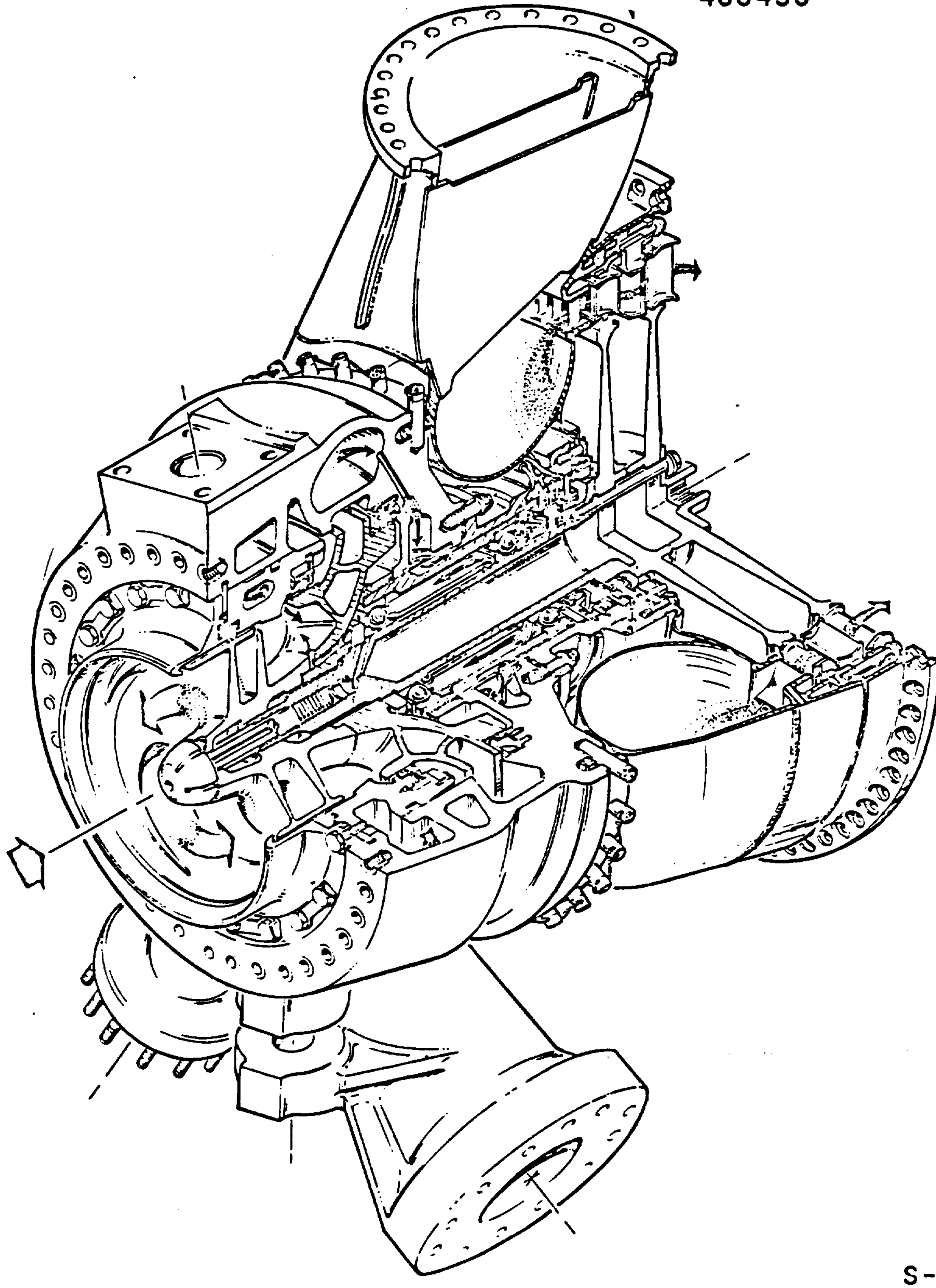
MK-29 OXIDIZER TURBOPUMP

460430



J-2S Restart Study
Fuel Inlet Duct

The fuel inlet duct on the J-2S was a scissors type flexible inlet duct. The previously used configuration present no material issues, however the use and maintenance of this type of inlet duct has historically been labor intensive. The previous configuration is still feasible, however it is recommended that this duct be replaced with a redesign wrap-around duct, which would cost a fraction of the scissors duct (based on recent STME scissors duct studies).

A wrap-around duct (such as the SSME low pressure fuel or oxidizer ducts running from the low pressure pumps to the high pressure pumps) is configured so that multiple smaller bellows provide for gimbal movement rather than a single larger bellows as in a scissors duct (such as the original J-2S). The cost of the longer duct with the much smaller (and lower freedom of movement) bellows is typically much lower than the single large externally tied scissors duct bellows.

FUEL INLET DUCT

NO MATERIALS PROBLEMS

A LARGE NUMBER OF PRECISION PIECES

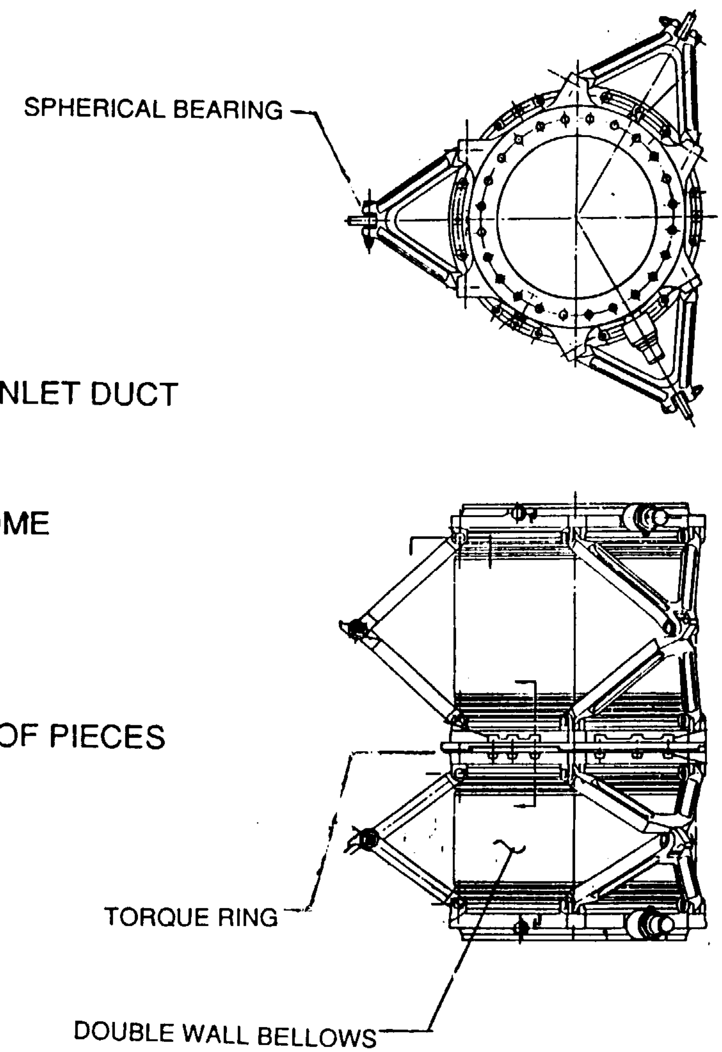
DESIGNED FOR A MATCHED SPRING RATE WITH THE OXIDIZER INLET DUCT

ASSEMBLY ALIGNMENT IS NOT EASY

MAINTAINING A VACUUM IN THE JACKET HAS BEEN TROUBLESOME

<u>ALTERNATIVE</u>

WRAP-A-ROUND DUCT AT LESS COST WITH REDUCED NUMBER OF PIECES AND REDUCED PRECISION REQUIREMENTS

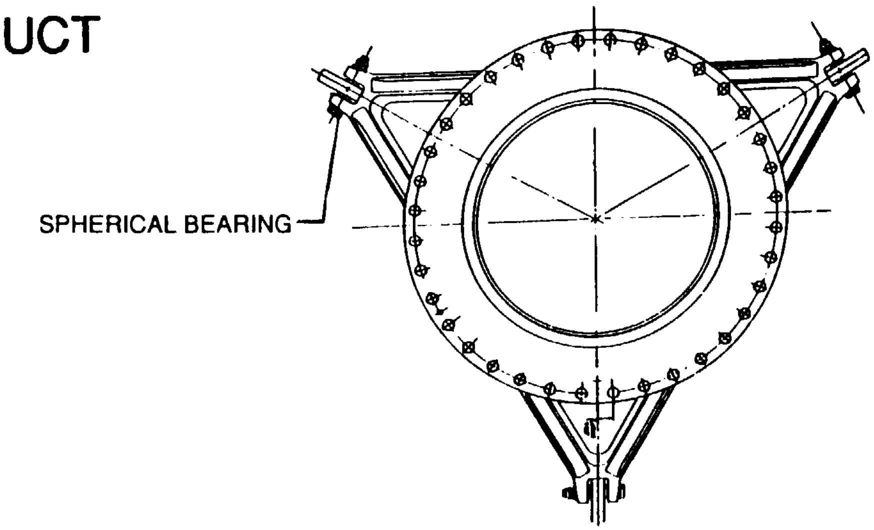


J-2S Restart Study

Oxidizer Inlet Duct

The oxidizer inlet duct on the J-2S was a scissors type flexible inlet duct. The previously used configuration present no material issues, however the use and maintenance of this type of inlet duct has historically been labor intensive. The previous configuration is still feasible, however it is recommended that this duct be replaced with a redesign wrap-around duct, which would cost a fraction of the scissors duct (based on recent STME scissors duct studies).

OXIDIZER INLET DUCT



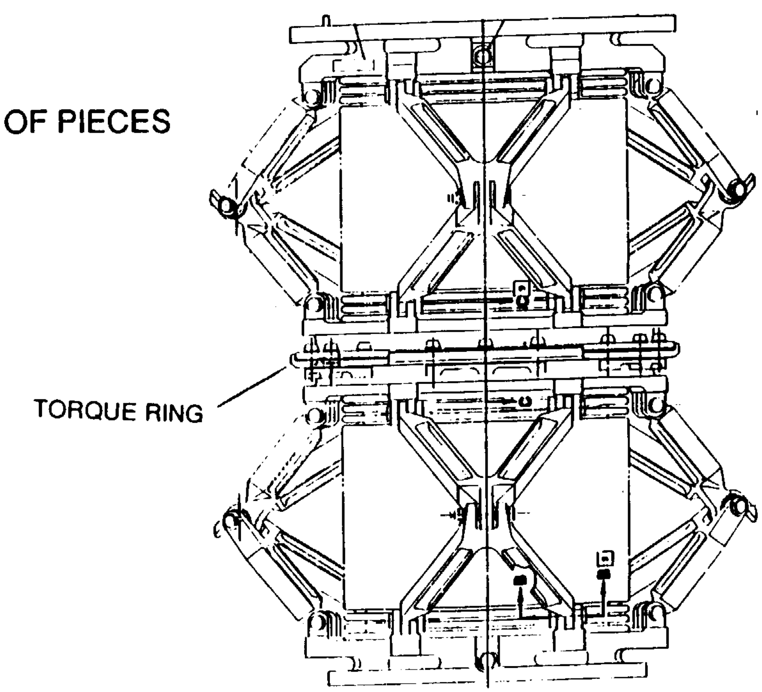
NO MATERIALS PROBLEMS

A LARGE NUMBER OF PRECISION PIECES

ASSEMBLY ALIGNMENT IS NOT EASY

ALTERNATIVE

WRAP-A-ROUND DUCT AT LESS COST WITH REDUCED NUMBER OF PIECES AND REDUCED PRECISION REQUIREMENTS



J-2S Restart Study

Fuel Discharge Duct

This rigid duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts.

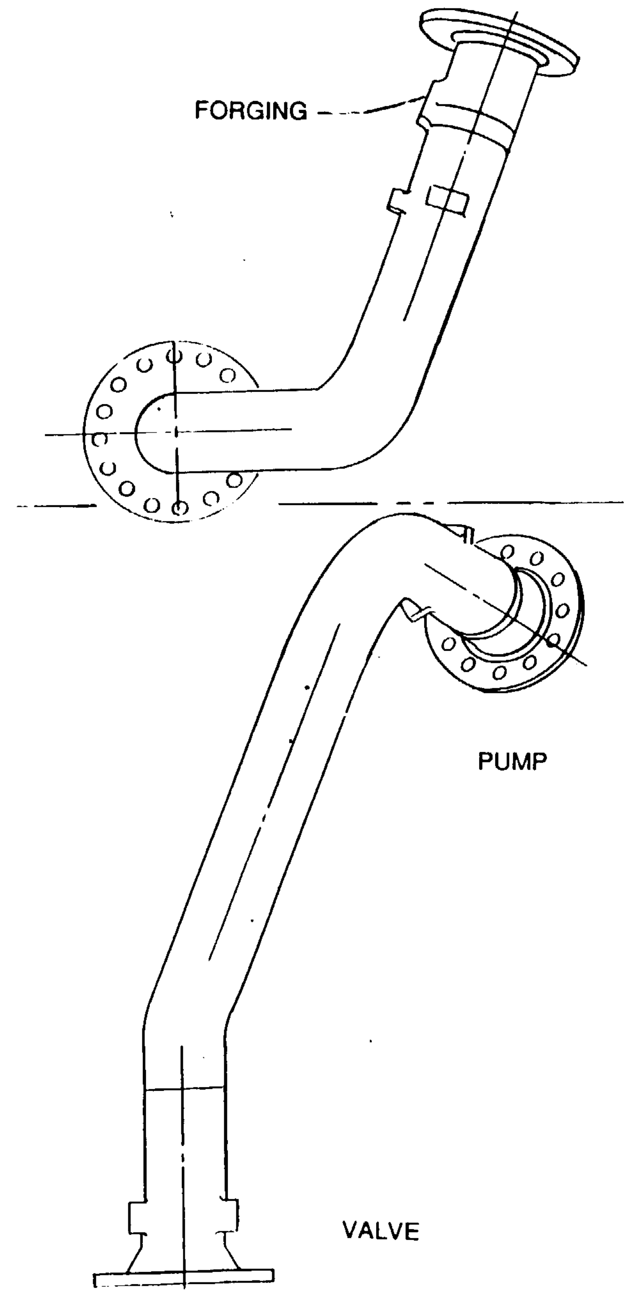
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

FUEL DISCHARGE DUCT

NO MATERIAL PROBLEMS

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO AN OPTIMUM DESIGN



J-2S Restart Study

Oxidizer Discharge Duct

This rigid duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts.

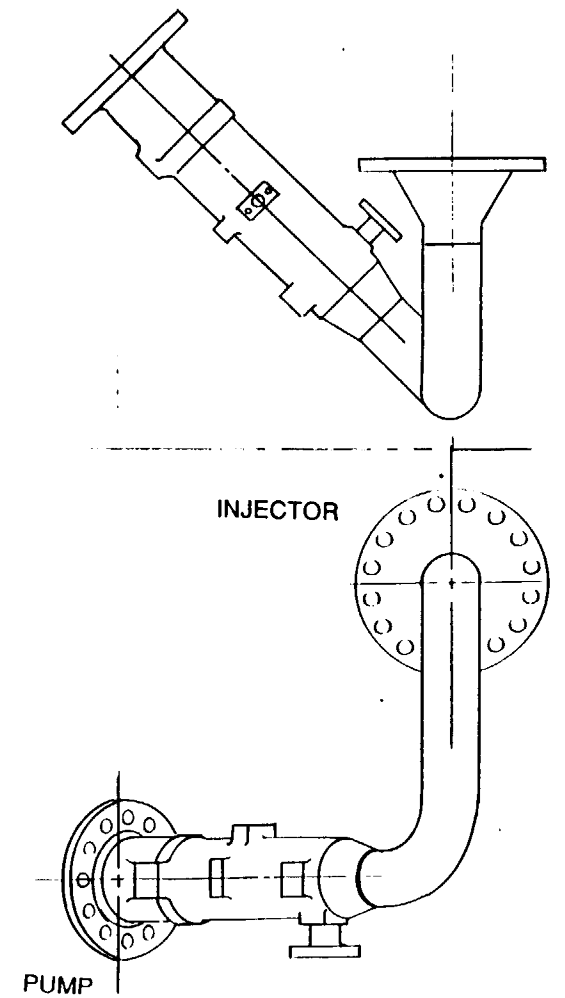
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

OXIDIZER DISCHARGE DUCT

NO MATERIAL PROBLEM

ALTERNATIVE

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study
Fuel Bypass Duct

This rigid duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts.

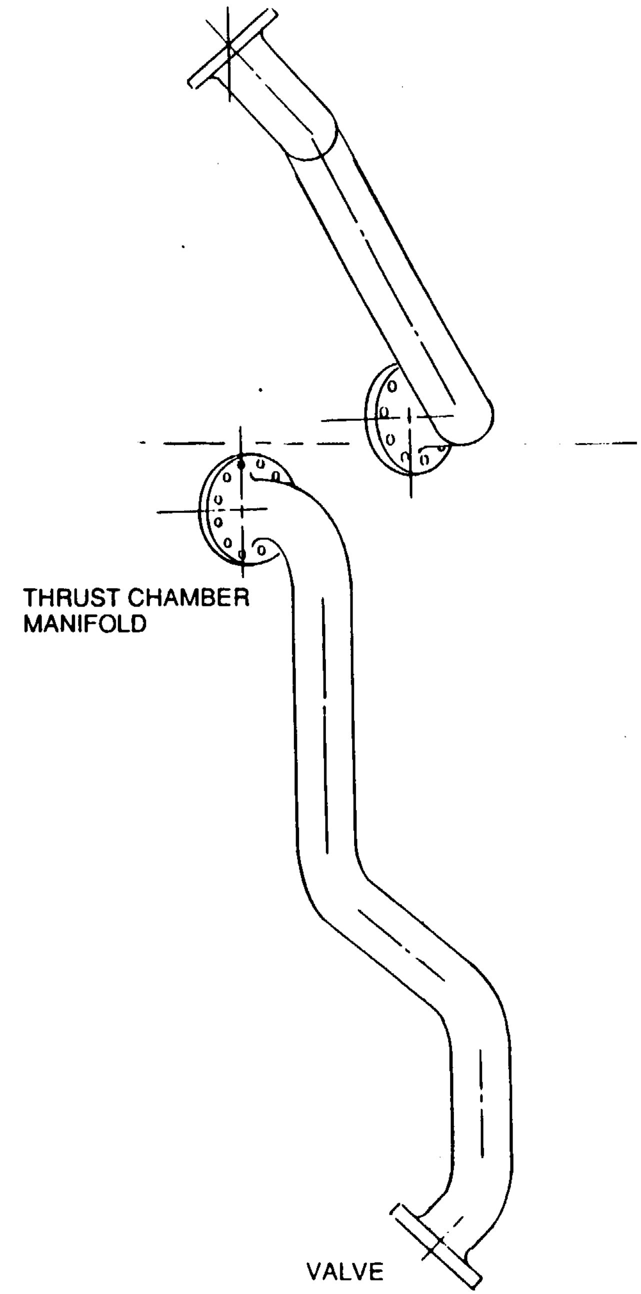
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

FUEL BYPASS DUCT

NO MATERIAL PROBLEM

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study

Idle Mode Duct

This rigid duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts.

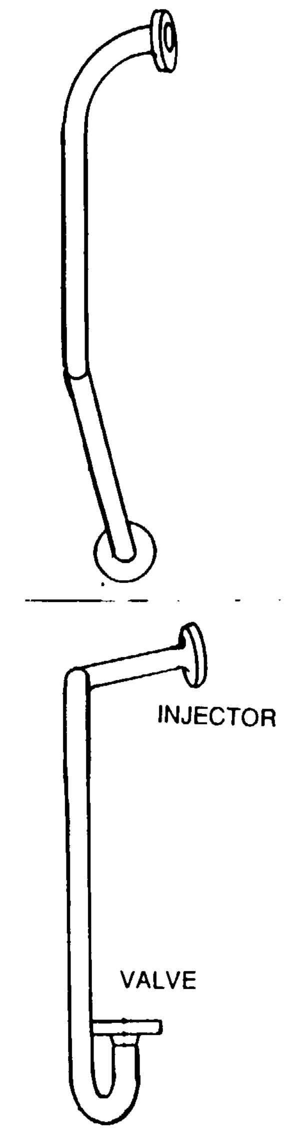
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

IDLE MODE DUCT

NO MATERIAL PROBLEM

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study
Oxidizer Turbine Bypass

This flexible duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts.

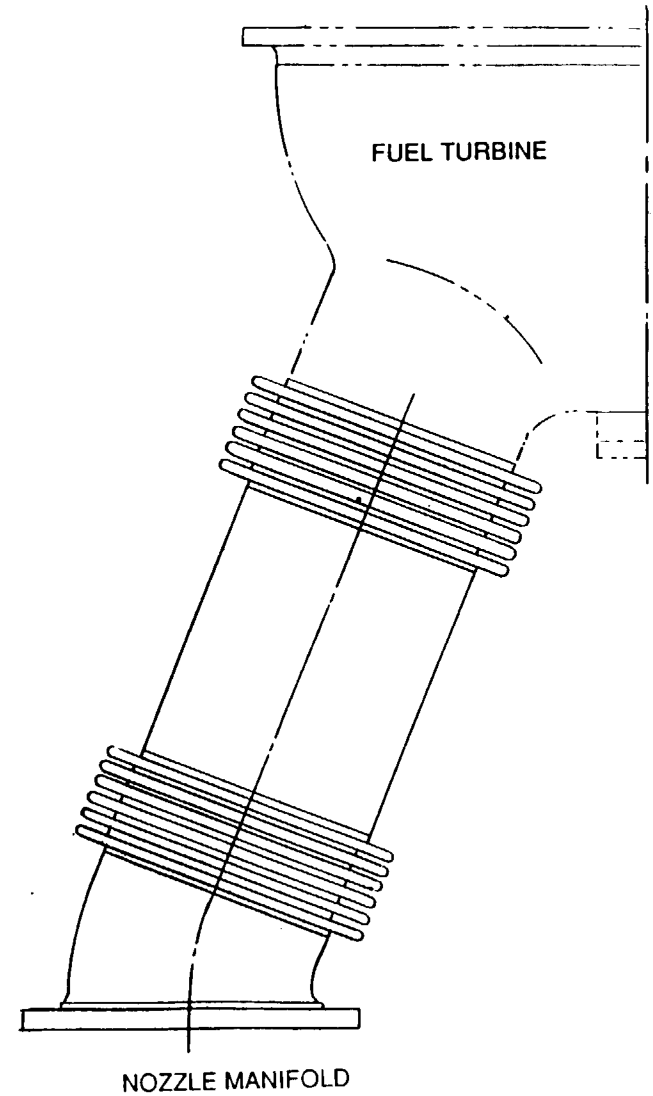
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

OXIDIZER TURBINE BYPASS

NO MATERIAL PROBLEM

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study

Crossover Duct

This flexible duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available.

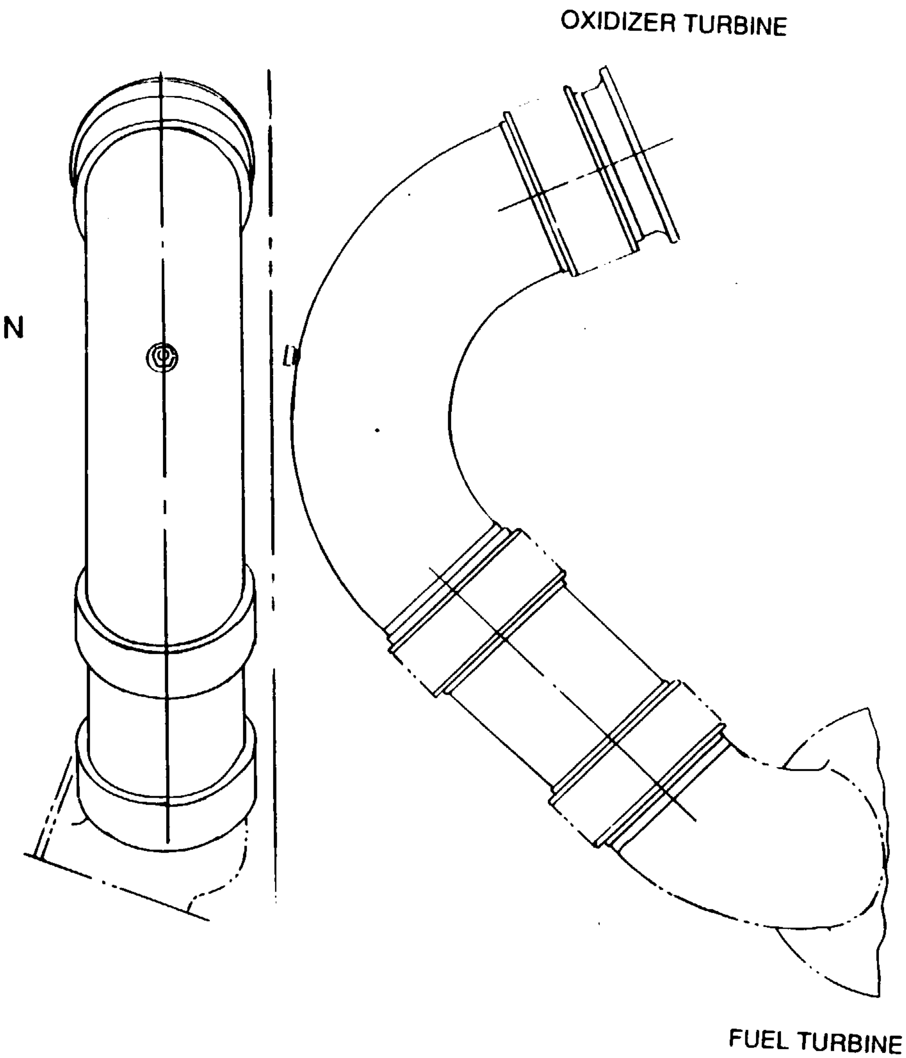
Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

CROSSOVER DUCT

NO MATERIAL PROBLEM

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study

Oxidizer Turbine Exhaust

This flexible duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available.

Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

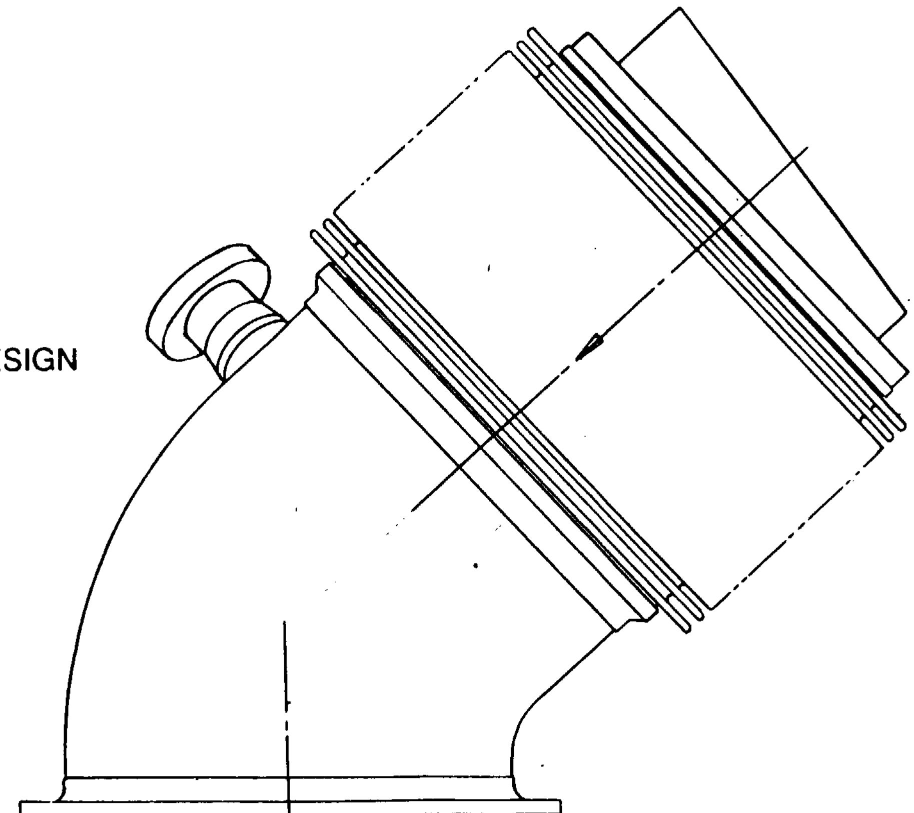
OXIDIZER TURBINE EXHAUST

NO MATERIAL PROBLEM

SEE FIGURE   FOR INTEGRATED HEAT EXCHANGER

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN



J-2S Restart Study

Hot Gas Tapoff Duct

This rigid duct was made from materials still in use today on various propulsion systems therefore no changes are proposed, even though lighter and stronger materials are available. The previous manufacturing process used in the six J-2S engines was to mount the flanges on the engine and perform weld fit-up on the engine. For a greater production volume, the use of precision end point tooling would be used to allow more parallel production of the ducts. The redesign of the hot gas tapoff system will alter the configuration of the inlet flange of this duct slightly from the previously used duct.

Additional study could be performed to structurally optimize the duct, as the configuration of the basic J-2S used overdesigned ducts and accepting the associated weight penalty.

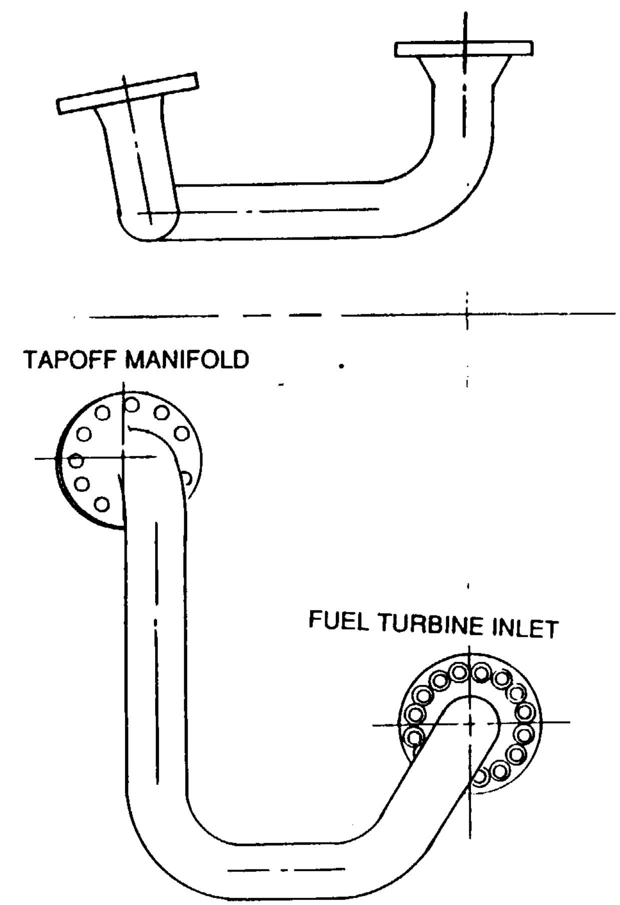
HOT GAS TAPOFF DUCT

NO MATERIAL PROBLEM

REDESIGN OF HOT GAS TAPOFF SYSTEM HAS ONLY AN END POINT EFFECT ON THIS DUCT

<u>ALTERNATIVE</u>

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

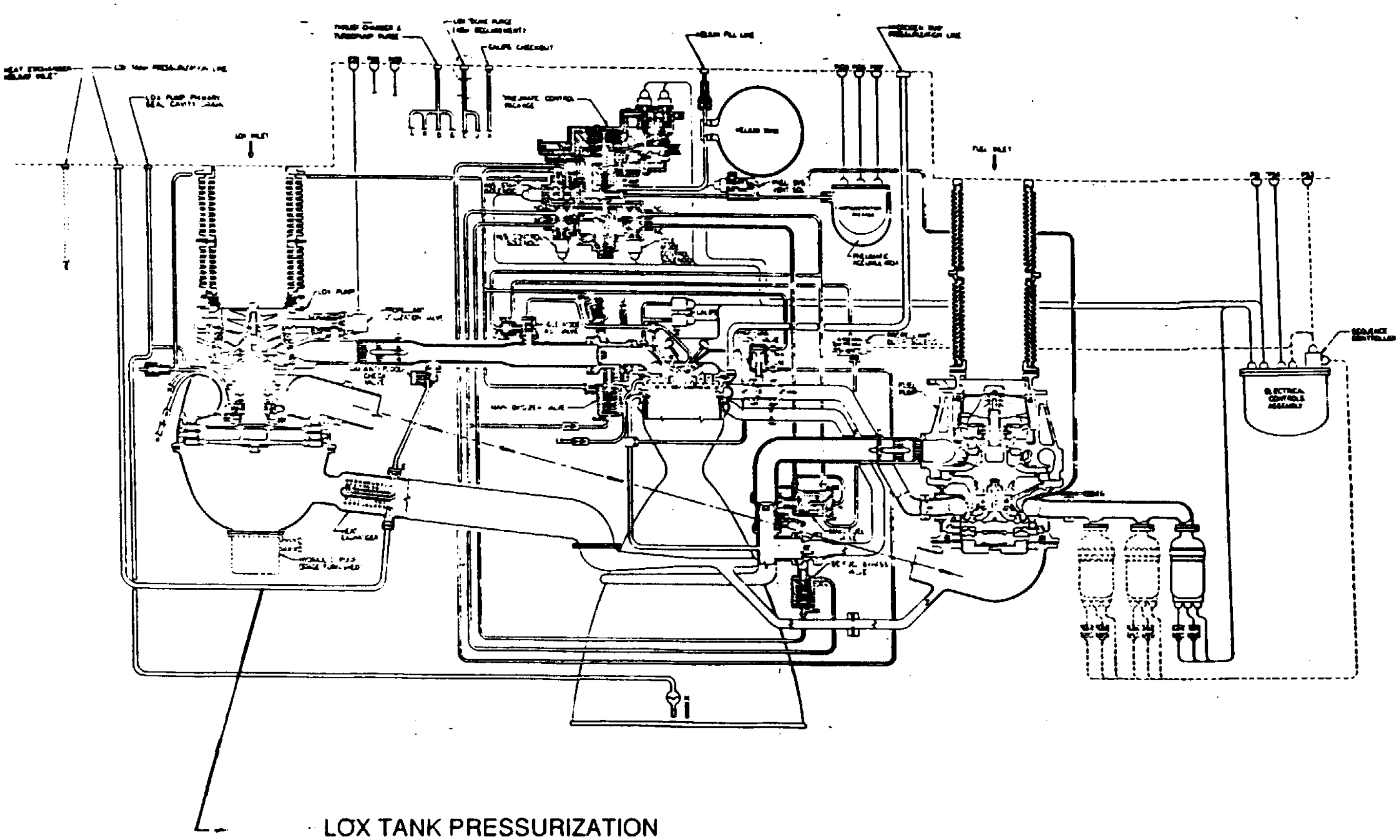


J-2S Restart Study

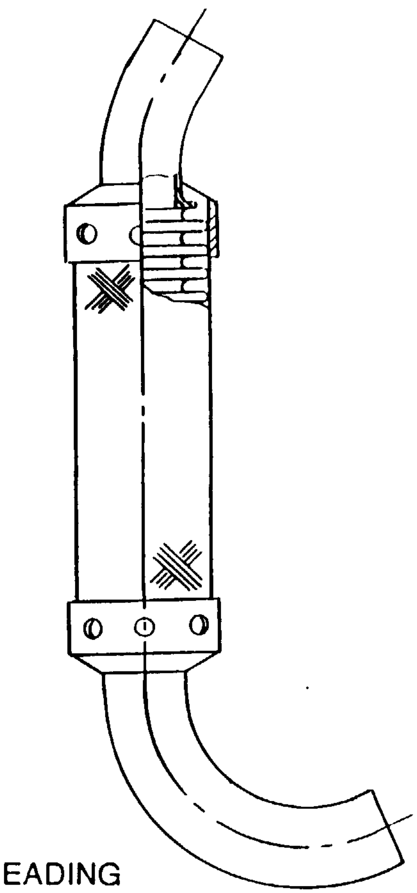
Miscellaneous Tubes and Flex Hoses

Direct replacements are available for all tubes and flex hoses used on the J-2S. Most of the flex hoses would be redesigned to customize the interfaces for any proposed application.

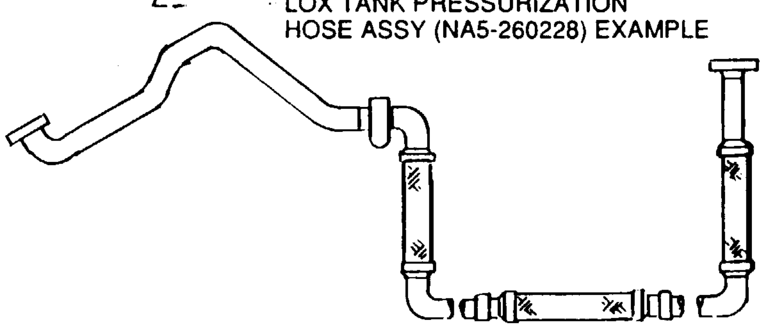
MISCELLANEOUS TUBES AND FLEX HOSES



TYPICAL HIGH PRESSURE
BRAIDED HOSE/BELLOWS ASSY



LOX TANK PRESSURIZATION
HOSE ASSY (NA5-260228) EXAMPLE



55 ITEMS ARE IDENTIFIED UNDER THIS HEADING
INCLUDING 8 HOSE ASSEMBLIES

J-2S Restart Study

J-2S Valve Plan Summary

An in-depth review was performed on the valves and the pneumatic control assembly. Detailed reviews of each part were performed and entered into a database within the valves group.

No significant material issues were found. The housings were made from 7075 aluminum which is still permissible for use in the current engine design requirements handbook at Rocketdyne.

Recommended major design changes are few. The hot gas check valve would be changed to a lower leakage configuration which was redesigned but never fabricated during the J-2S program. The propellant utilization valve electric motor actuator is quite obsolete by current standards, therefore would be replaced. Finally the position transducer used on several valves is still producible, however it is recommended this be replaced by a more modern configuration.

Producibility improvements were identified with numerous parts.

There was some difficulty in finding several of the detailed drawings on microfiche. This suggests that there is a significant possibility that these drawings no longer exist if they are not found at corporate storage. These parts would require some additional work to reinitiate production.

J-2S VALVE PLAN SUMMARY

- **THIRTEEN ENGINE VALVE AND PCA TOP ASSY DWGS REVIEWED**
- **FUNCTIONAL DESCRIPTIONS, MATERIALS, DESIGN CHANGE ASSESSMENT, POTENTIAL FABRICATION AND RECOMMENDED TRADE STUDIES ENTERED INTO J-2S COMPONENT PLAN DATABASE**
- **IDENTIFIED MAJOR SUBCOMPONENT MATERIALS**
  - MOST HOUSINGS WERE 3-D MACHINED 7075 AL ALLOY
  - 7075 T73 APPROVED FOR USE IN DRH
- **IDENTIFIED MAJOR DESIGN CHANGES**
  - **HOT GAS CHECK VALVE:** SYSTEMS IMPOSED TIGHTER LEAKAGE REQMT
    - VALVE WAS REDESIGNED, BUT NOT FABRICATED
  - **PROPELLANT UTILIZATION VALVE:** ELECTRIC MOTOR ACTUATOR OBSELETE
  - **NA5-27480 POSITION TRANSDUCER REVIEWED - STILL PRODUCEABLE (USED ON MFV, MOV, FBV, HGTV, & IMV)**
- **IDENTIFIED POTENTIAL PRODUCIBILITY IMPROVEMENTS**
- **<u>NOTE : DETAIL DWGS NOT ON MICROFICHE @ CANOGA - DWGS MAY NOT EXIST</u>**

J-2S Restart Study

Main Fuel Valve 411320

The materials used to produce this valve are all available and in use today.

Problems experienced during the test program were thermal cracking of the housing at a thin section on the upstream side of the shaft bearings. This an be easily corrected by increasing the thickness at this location. Previous erratic position indication will be resolved by updating the position transducer. Some shaft seal and gate seal leakage was experienced, however this was due to insufficient control in the placement of the seals. This will be corrected by using up-to-date procedures for valve assembly.

Producibility will be improved by casting the aluminum housing and die forging the butterfly with a more easily worked material than INCO 718.

MAIN FUEL VALVE 411320

- **MATERIALS**
  - HOUSING - 7075 ALUMINUM ALLOY - 3D MACHINED
  - BUTTERFLY AND SHAFTS - INCO 718
  - SHAFT ROLLER BEARINGS - 440 C
  - ACTUATOR PISTONS - A-286
  - BUTTERFLY SEALS - KEL-F SHEET - HEAT FORMED
  - SHAFT AND ACTUATOR SEALS - MYLAR SHEET
- **PROBLEMS**
  - THERMAL CRACKING OF HOUSING AT THIN SECTION ON UPSTREAM SIDE OF SHAFT BEARINGS -REDESIGN INCREASED THICKNESS
  - ERRATIC POSITION INDICATOR OUTPUT
  - SHAFT SEAL AND GATE SEAL LEAKAGE
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - HOUSING - DIE FORGING OR CASTING
  - BUTTERFLY - DIE FORGING - EVALUATE 431 CRES AND OTHER MATERIALS FOR BETTER MACHINING CHARACTERISTICS

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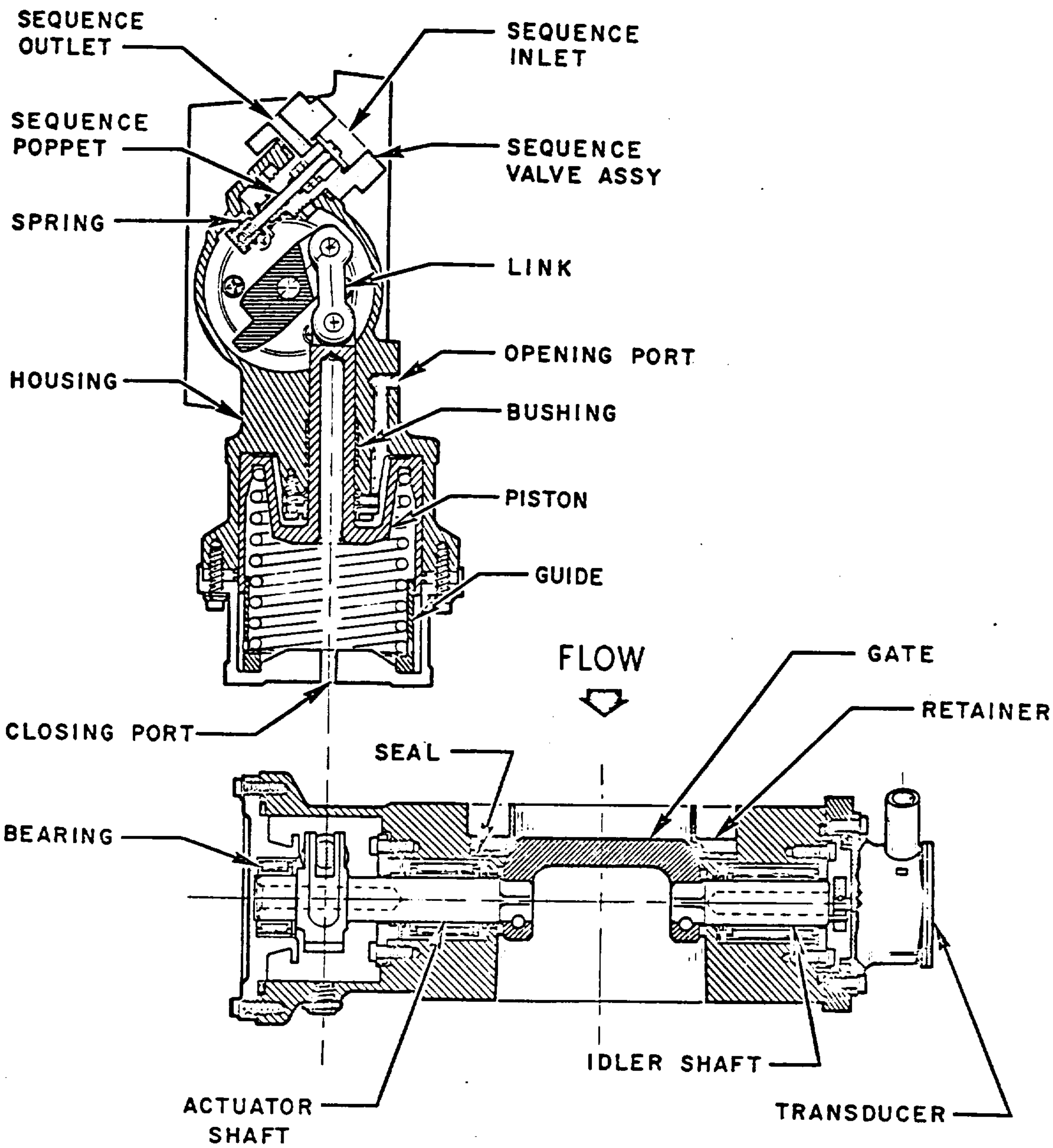
MAIN FUEL VALVE
99-411320



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J-2S Restart Study

Main Oxidizer Valve 411225

The materials used to produce this valve are all available and in use today.

Problems only experienced during the test program was butterfly seal failure on short tests, however this problem was resolved by increasing the seal thickness.

Producibility will be improved by casting the aluminum housing and die forging the butterfly with a more easily worked material than INCO 718. Mylar shaft seals will also be incorporated to improve the sealing capability.

MAIN OXIDIZER VALVE 411225

- **MATERIALS**
  - HOUSING - 7075 ALUMINUM ALLOY - 3D MACHINED
  - BUTTERFLY AND SHAFTS - INCO 718
  - SHAFT ROLLER BEARINGS - 440 C
  - ACTUATOR PISTONS - A-286
  - BUTTERFLY AND SHAFT SEALS - KEL-F SHEET (BUTTERFLY SEAL HEAT FORMED)
  - ACTUATOR SEALS - MYLAR SHEET
- **PROBLEMS**
  - BUTTERFLY SEAL FAILURE ON SHORT TESTS - SEAL THICKNESS INCREASED, PROBLEM RESOLVED
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - HOUSING - DIE FORGING OR CASTING
  - MYLAR SHAFT SEALS - IMPROVED SEALING CAPABILITY
  - BUTTERFLY - DIE FORGING - EVALUATE 431 CRES AND OTHER MATERIALS FOR BETTER MACHINING CHARACTERISTICS

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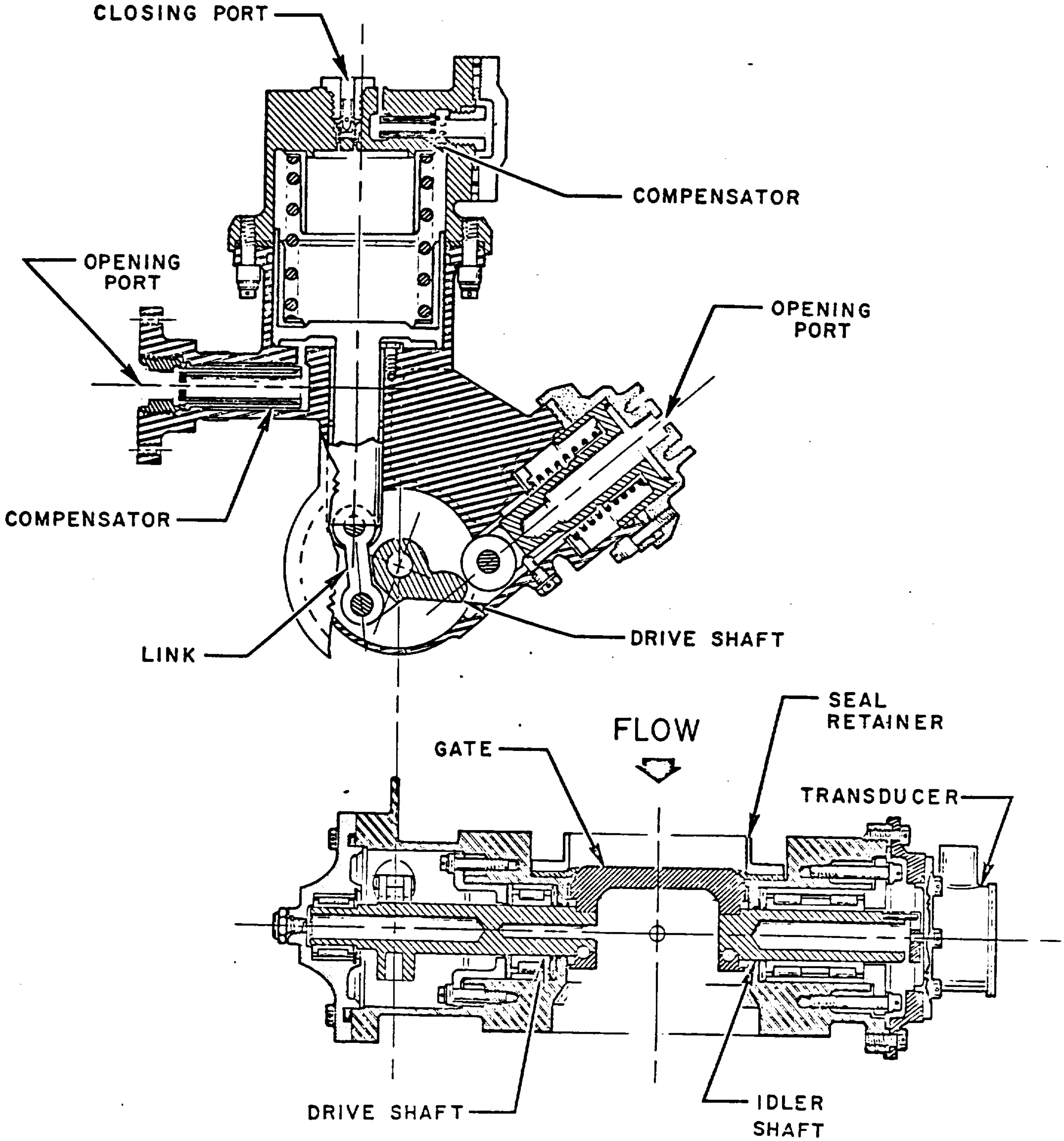
MAIN OXIDIZER VALVE
99-411225



J-2S Restart Study

Propellant Utilization Valve 251455

The detailed drawings for this part could not be found, however numerous reports were examined to perform this study. The materials used are believed to be currently available materials, however the drawings will have to be reviewed to confirm this beyond doubt.

The problems seen in previous testing were high required threshold voltage and failure to respond. This was previously corrected by increasing clearance of rotating parts to eliminate rubbing and galling. Also the thickness of the gate at the edge of the flow holes was decreased to reduce the hydraulic torque requirement.

The electric motor used in this valve would be replaced by an updated configuration.

PROPELLANT UTILIZATION VALVE 251455

- **MATERIALS**
  - HOUSING - ALUMINUM CASTING (NOT VERIFIED)
  - BUTTERFLY AND SHAFTS - (NOT VERIFIED)
  - SHAFT ROLLER BEARINGS - 440 C (NOT VERIFIED)
- **PROBLEMS**
  - HIGH THRESHOLD VOLTAGE AND FAILURE TO RESPOND
    - INCREASED CLEARANCE OF ROTATING PARTS TO ELIMINATE RUBBING AND GALLING
    - DECREASED THICKNESS OF GATE AT EDGE OF FLOW HOLES TO REDUCE HYDRAULIC TORQUE
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - UPDATE ELECTRIC MOTOR DESIGN

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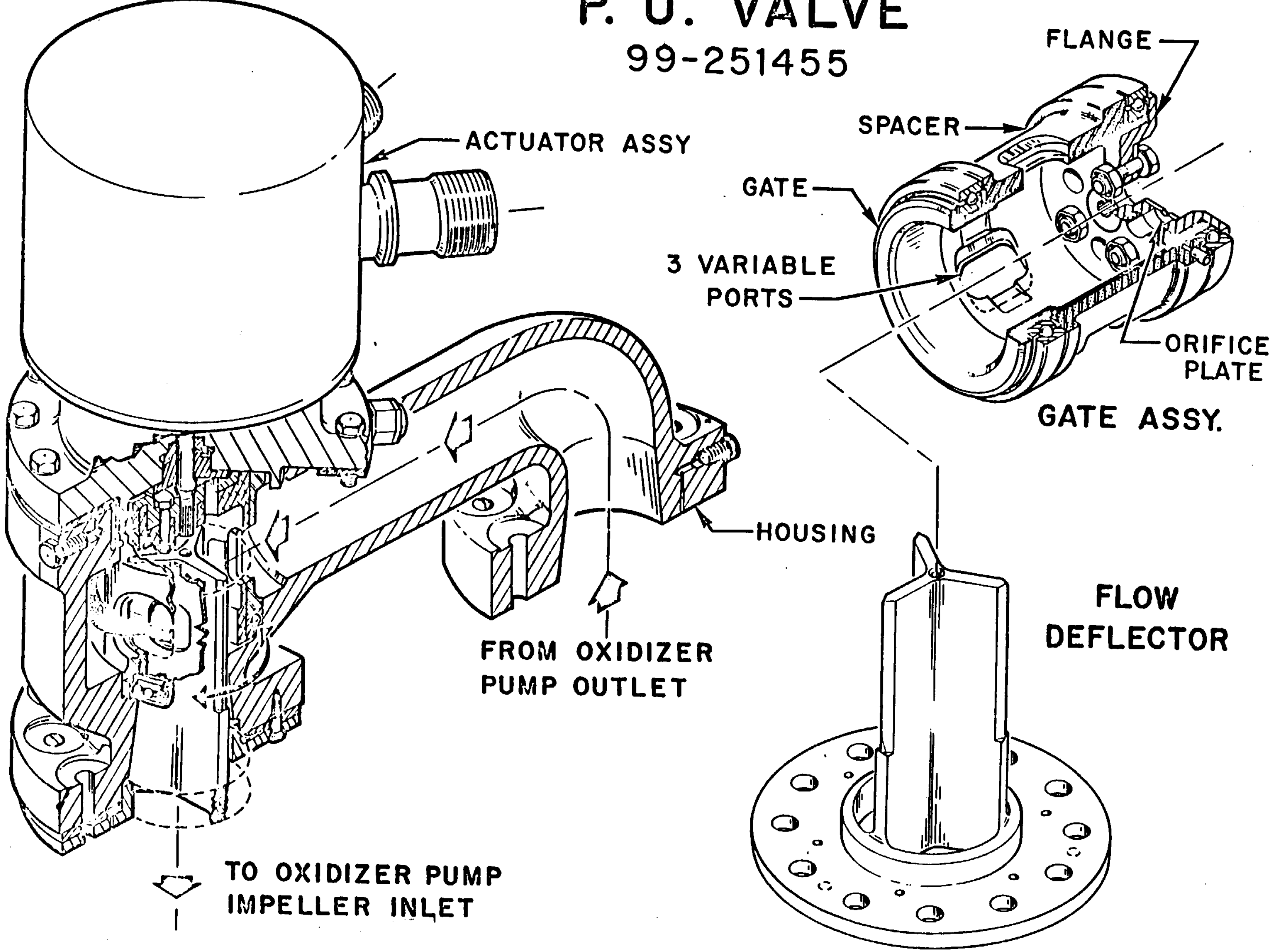
P. U. VALVE
99-251455



J-2S Restart Study

Fuel Bypass Valve 411180

The materials used to produce this valve are all available and in use today.

No problems were experienced with this component at any time of the test program.

Producibility will be improved by casting the aluminum housing and caps and die forging the butterfly and shafts with a more easily worked material than INCO 718.

FUEL BYPASS VALVE 411180

- **MATERIALS**
  - HOUSING - 7075 ALUMINUM ALLOY - 3D MACHINED
  - BUTTERFLY AND SHAFTS - INCO 718
  - SHAFT ROLLER BEARINGS - 440 C
  - ACTUATOR PISTONS - A-286
  - BUTTERFLY SEALS - KEL-F - HEAT FORMED
  - SHAFT AND ACTUATOR SEALS - MYLAR SHEET
- **PROBLEMS**
  - NONE. THE DESIGN IS SIMPLE, DOES NOT HAVE RIGOROUS SEALING REQUIREMENTS AND CLOSES AT RELATIVELY LOW PRESSURE
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - CASTING FOR HOUSING AND CAPS
  - DIE FORGING FOR BUTTERFLY
  - EASIER MACHINING MATERIAL FOR BUTTERFLY AND SHAFTS

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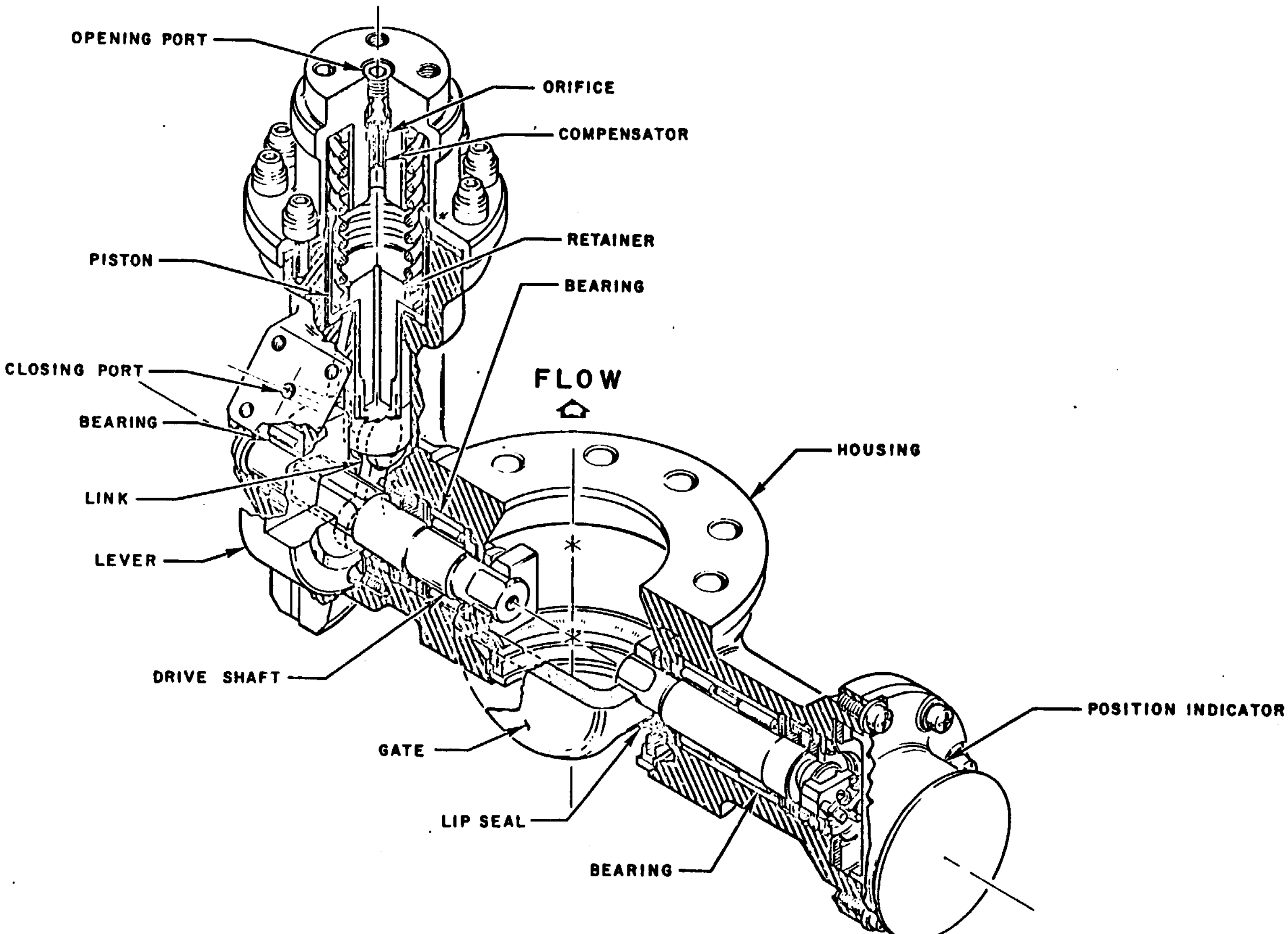
FUEL BYPASS VALVE
99-411180



J-2S Restart Study

Hot Gas Tapoff Valve 557824

The materials used to produce this valve are all available and in use today.

During early testing the valve did not fully close. To correct this situation caused by butterfly to housing interference, the gate was reworked to a smaller diameter which solved the problem on subsequent testing. Another problem appeared on a later engine where the shaft bearings seized. A redesign to reduce thermal distortion of the housing was performed, however this redesign was never tested. Production restart would be with this redesigned configuration.

Additional study is required to evaluate potential weight reductions in the housing and gates. Also the need for a butterfly to housing seal needs to be re-examined after the effects of the reduced warpage hosing are assessed. It may also be wise to reassess materials to determine if more readily available materials would be adequate in this application.

HOT GAS TAPOFF VALVE 557824

- **MATERIALS**
  - HOUSING - INCO 625
  - BUTTERFLY AND SHAFT - RENE 41
  - SHAFT BEARINGS - HAYNES 25
- **PROBLEMS**
  - VALVE DID NOT GO FULL CLOSED
    - BUTTERFLY/HOUSING INTERFERENCE - GATE REWORKED TO SMALLER DIAMETER
  - SEIZED SHAFT BEARINGS - HOUSING REDESIGNED TO REDUCE THERMAL DISTORTION - REDESIGN NOT TESTED
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - EVALUATE WEIGHT REDUCTION HOUSING AND GATES
  - INVESTIGATE NEED FOR A BUTTERFLY TO HOUSING SEAL (J-2 DID NOT INITIALLY REQUIRE A SEAL. A SEAL WAS ADDED BECAUSE OF LARGE CHANGE IN VALVE CLOSED LEAKAGE CAUSED BY THERMAL EFFECTS AND VALVE TO VALVE FLOW VARIATION WHEN CLOSED
  - REVIEW MATERIALS AND USE OF DIE FORGINGS

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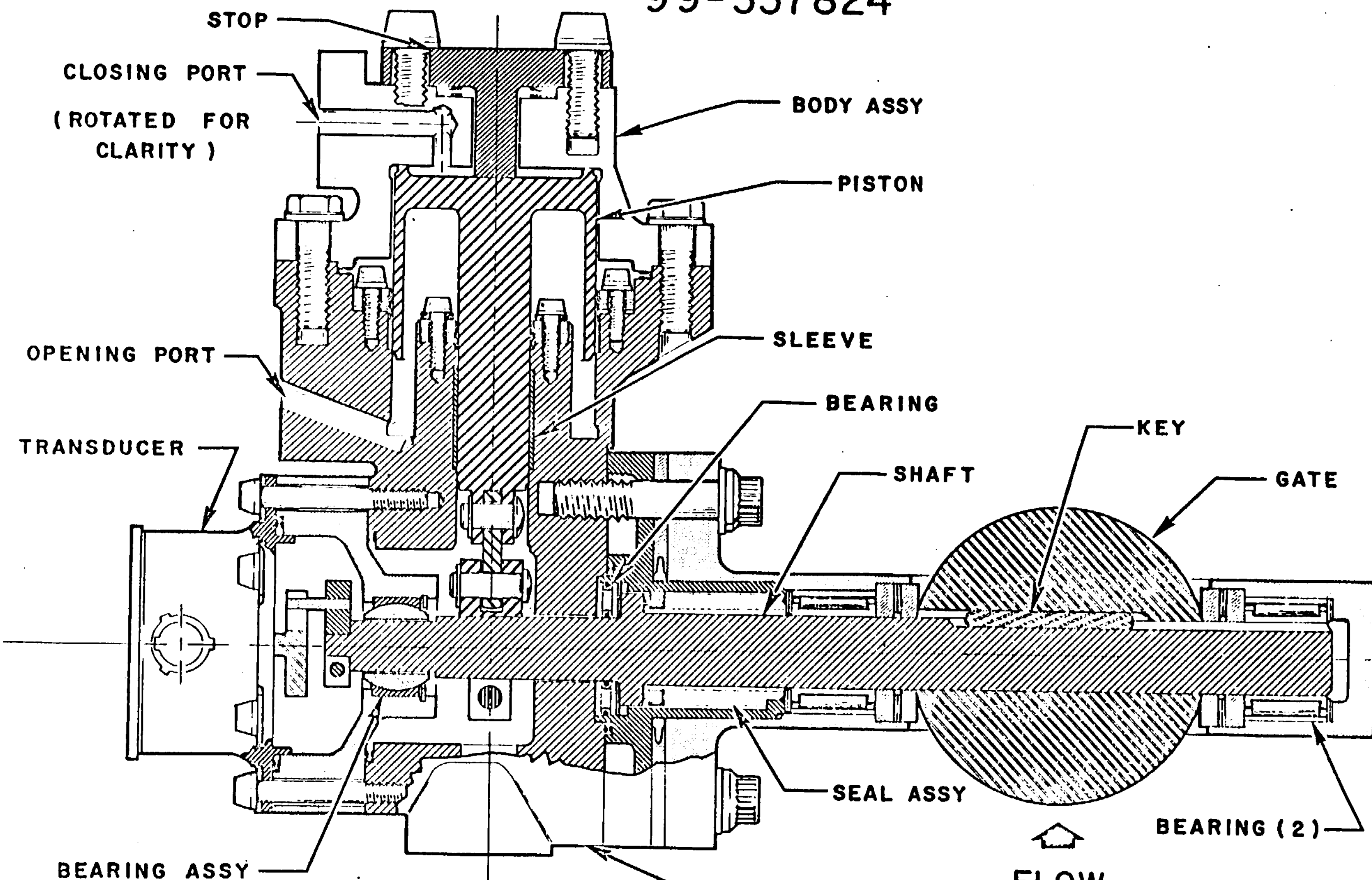
HOT GAS TAPOFF VALVE

99-557824



J-2S Restart Study

Idle Mode Valve 411385

The materials used to produce this valve are all available and in use today.

The only problem identified for this component during the J-2S Program was that there was considerable difficulty in machining the Kel-F shaft seals. This issue was rectified by using a stamped sheet of Kel-F in its place.

Producibility of this part would be enhanced by casting the housing and ball. The ball will still require a welded sleeve for the flow passage. Mylar shaft seals would be used to decrease leakage potential. Finally the bellows and Kel-F seat seal would be replaced by a more producible and reliable wave spring with a vespel seat seal.

IDLE MODE VALVE 411385

- **MATERIALS**
  - HOUSING - 7075 ALUMINUM ALLOY
  - BALL AND SHAFTS - INCO 718
  - ACTUATOR PISTON AND SHAFT ROLLER BEARINGS- 440 C
  - BALL SEAL - MACHINED KEL-F
  - SHAFT SEALS - KEL-F SHEET
  - ACTUATOR SEALS - MYLAR SHEET
- **PROBLEMS**
  - MACHINED KEL-F SHAFT SEALS REPLACED BY SHEET KEL-F
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - HOUSING - CASTING OR DIE FORGING
  - MYLAR SHAFT SEALS - IMPROVED SEALING CAPABILITIES - REQUIRES LOX COMPATIBILITY REVIEW - MYLAR IS USED IN ELV VALVES
  - BALL - HOLLOW CAST BALL WITH WELDED IN SLEEVE FOR FLOW PASSAGE
  - BELLOWS AND KEL-F SEAT SEAL - WAVE SPRING AND VESPEL SEAT SEAL

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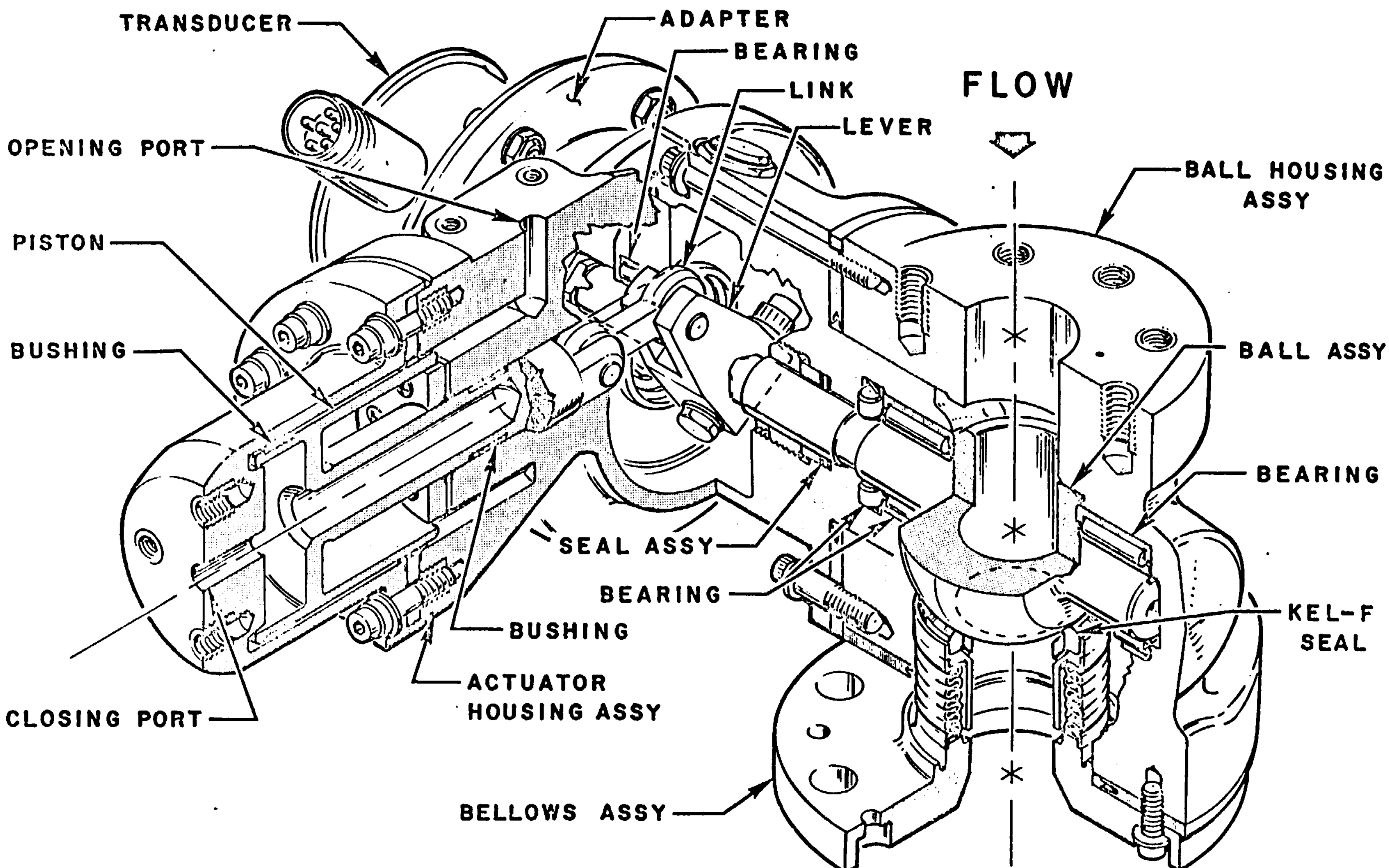
IDLE MODE VALVE

99-411385



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J-2S Restart Study

Anti-Flood Valve 99-407875

The materials used to produce this valve are all available and in use today.

The problems with this valve were few but required additional analysis to resolve. Occasional leakage was noted. This was never a significant problem but was identified as something of a nuisance. Also the molded Kel-F poppet head was identified as a potential problem since the difference in thermal expansion coefficients may produce stresses in the Kel-F that make retention difficult. A follow on design study for the poppet is recommended to resolve these minor concerns

Producibility could be improved by casting the housing and initiating a study to evaluate how part count could be reduced. This study required considerably more analysis than was in the scope of the J-2S restart study.

ANTI-FLOOD VALVE 99-407875

- **MATERIALS**
  - HOUSING - 321 CRES
  - BELLOWS - INCO 718
  - POPPET - 321 CRES WITH MOLDED KEL-F HEAD
- **PROBLEMS**
  - LEAKAGE
  - MOLDED KEL-F POPPET HEAD IS A POTENTIAL PROBLEM. THE DIFFERENCE IN THERMAL COEFFICIENTS MAY PRODUCE UNACCEPTABLE STRESSES IN THE KEL-F AND MAKES RETENTION DIFFICULT
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - CASTING FOR HOUSING
  - DESIGN STUDY TO REDUCE THE NUMBER OF PARTS
  - DESIGN STUDY OF POPPET

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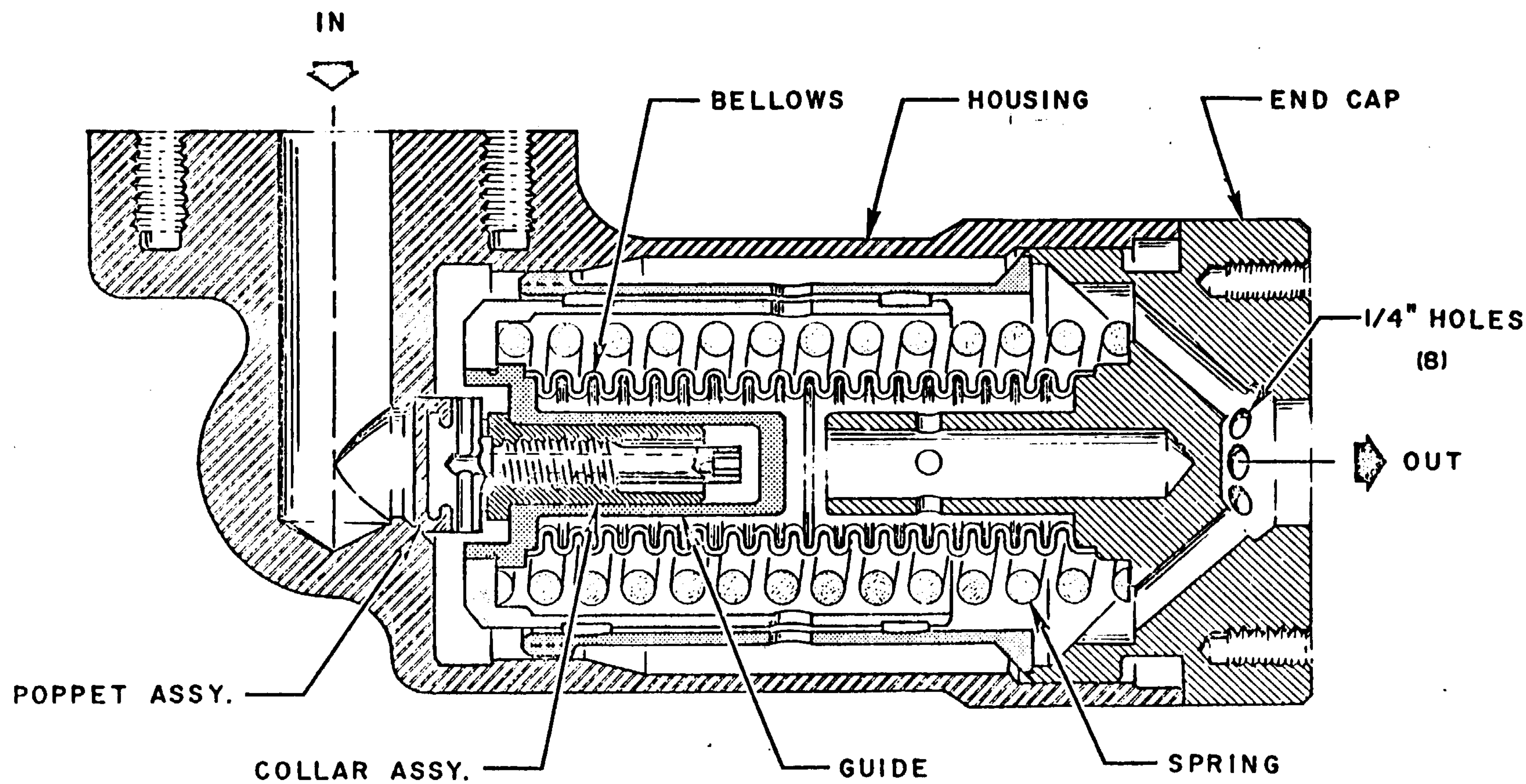
ANTI-FLOOD VALVE

99-407875



J-2S Restart Study

Relief Valve 558325

The materials of this component could not be verified since the drawing of the part was not available, however it is believed that all materials used are currently in use on other programs.

There were no problems with the operation or manufacture of this part that were identified by documentation or recollection.

Prior to restart of production, the drawings would have to be reviewed to verify the materials are acceptable or to potentially update materials with superior materials. A deeper review would be required to accurately determine if this part could benefit from adoption of cast or forged parts.

RELIEF VALVE 558325

- **MATERIALS**
  - (NOT VERIFIED)
- **PROBLEMS**
  - NONE RECORDED IN ENGINE TEST SUMMARY
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - REVIEW MATERIALS AND UPDATE
  - REVIEW DESIGN FOR FORGING AND CASTING APPLICATIONS

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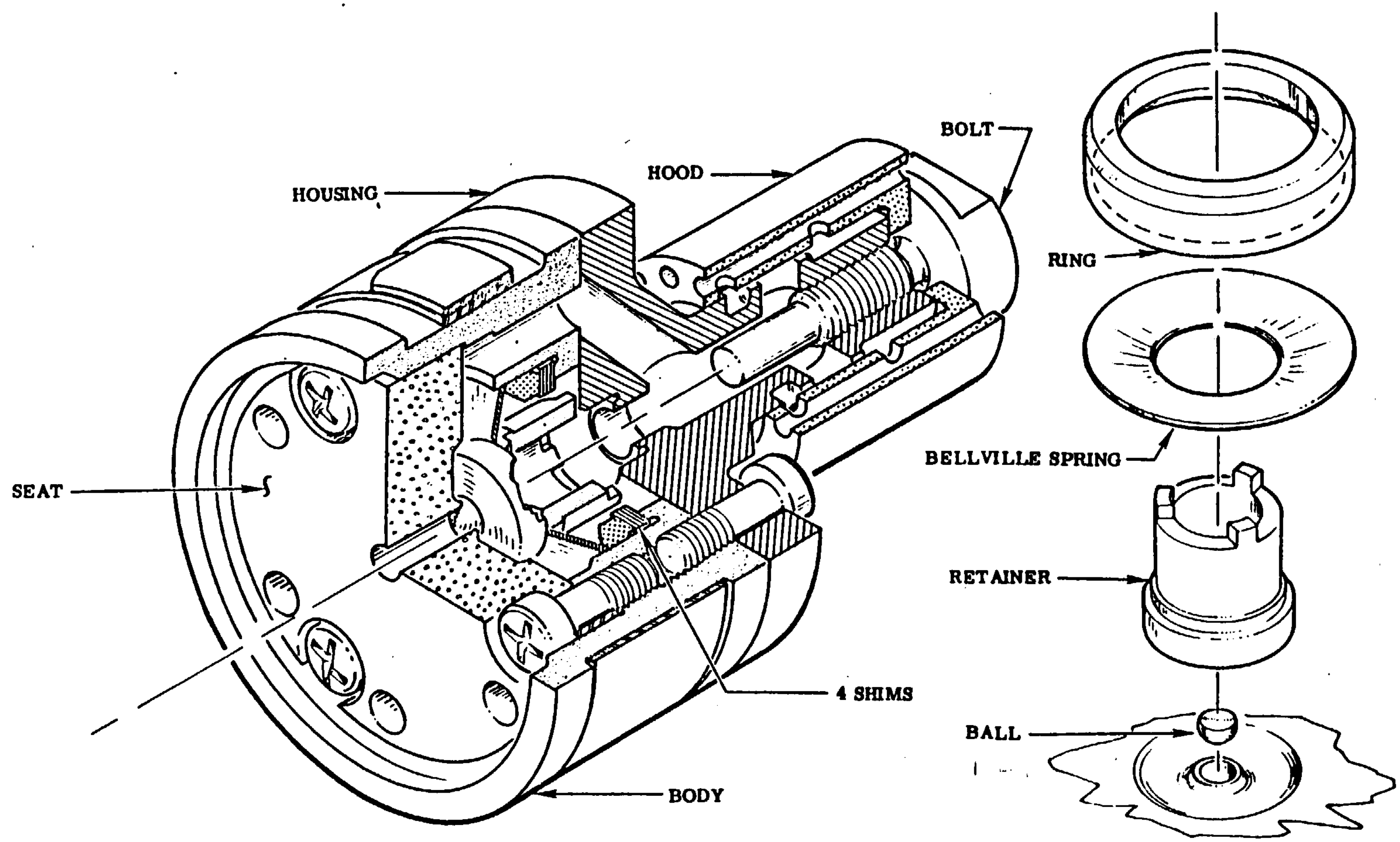
J-2 HIGH PRESSURE RELIEF VALVE

558325



J-2S Restart Study

Helium Fill and Check Valve 558022

The materials used in this part are believed to be commonly used materials today, however the drawing was not available to confirm this.

There were no problems or issues associated with this valve.

Producibility could be improved by eliminating the threads and using a structural weld. Also the addition of a shrink fit teflon sleeve on the poppet would reduce friction and improve part reliability. A follow on effort would be suggested to investigate antigalling materials and low friction surface coatings for the poppet and seat.

HELIUM FILL AND CHECK VALVE 558022

- **MATERIALS**
  - SEAL - TEFLON BAR
  - OTHER MATERIALS - CRES OR NICKEL ALLOYS (NOT VERIFIED)
- **PROBLEMS**
  - NONE
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - ELIMINATE THREADS AND USE STRUCTURAL WELD
  - ADD SHRINK FIT TEFLON SLEEVE ON POPPET STEM. THIS MAY ELIMINATE PROBLEM OF HANGING OPEN BY ELIMINATING METAL TO METAL RUBBING. REDUCES FRICTION AND IMPROVES RELIABILITY
  - INVESTIGATE ANTIGALLING MATERIALS & LOW FRICTION SURFACE COATINGS FOR POPPET AND SEAT

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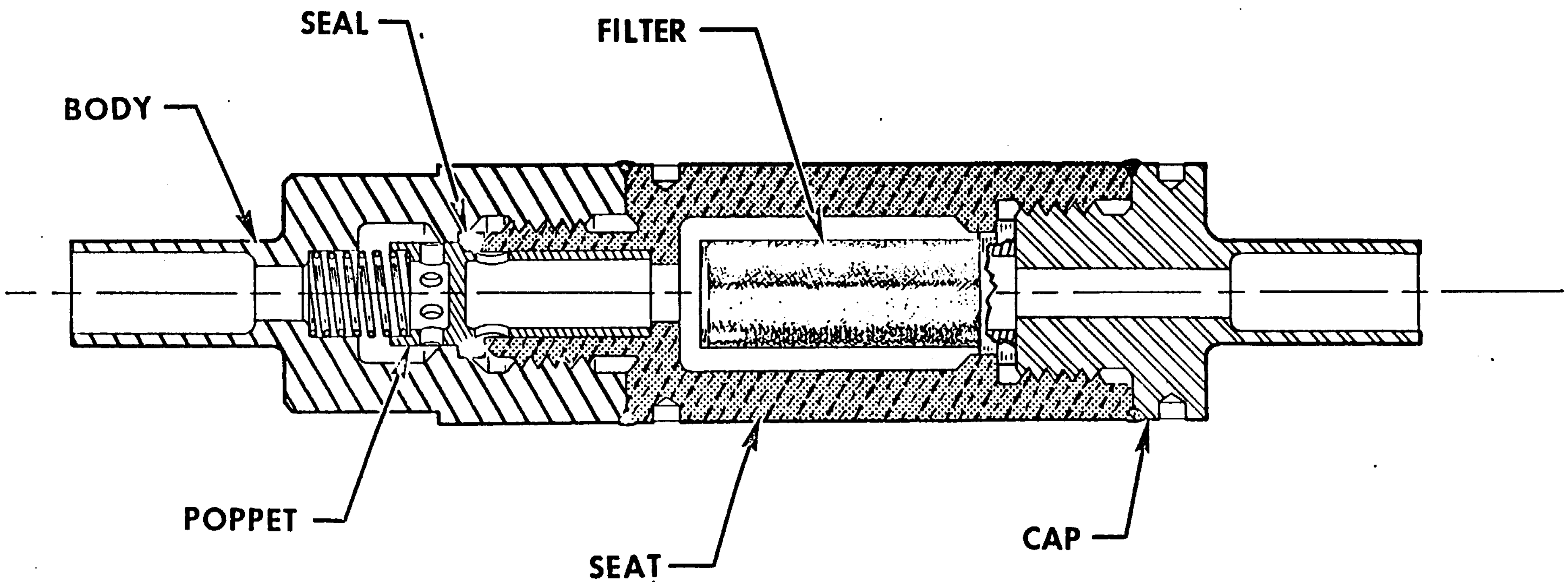
HELIUM FILL CHECK VALVE
558022



J-2S Restart Study

Hot Gas Check Valve 309065

The materials used in this part are believed to be commonly used materials today, however the drawing was not available to confirm this.

Two problems were identified in previous testing, loss of spring load due to high gas temperature and flapper cracking in a thin section near the outer edge. Design fixes were formulated but never released or tested. These improvements increased the flapper edge thickness and shielded the springs from the hot gas.

A valve redesign was released to delete the ignition detection and change leakage allowances. It is recommended that this component be redesigned to incorporate all these improvements.

HOT GAS CHECK VALVE 309065

- **MATERIALS**
  - HOUSING - (NOT VERIFIED)
  - FLAPPER (2 REQD) - (NOT VERIFIED)
  - SHAFT - (NOT VERIFIED)
  - SPRING (2 REQD) - (NOT VERIFIED)
- **PROBLEMS**
  - SPRINGS LOST LOAD DUE TO HIGH GAS TEMPERATURE
  - FLAPPERS CRACKED IN THIN SECTION NEAR OUTER EDGE
  - DESIGN CONCEPTS WERE STUDIED TO RESOLVE THE PROBLEM BUT NOT RELEASED. THE FLAPPER EDGE THICKNESS WAS TO BE INCREASED AND THE SPRINGS SHIELDED FROM THE HOT GAS
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - SYSTEM DESIGN CHANGES TO DELETE IGNITION DETECTION AND REDUCE THE HGCV ALLOWABLE LEAKAGE WERE IN WORK. A DESIGN WAS RELEASED ON A POPPET CHECK VALVE BUT IT WAS NOT FABRICATED
  - REVIEW THE REQUIREMENTS AND DO A DESIGN TRADE STUDY

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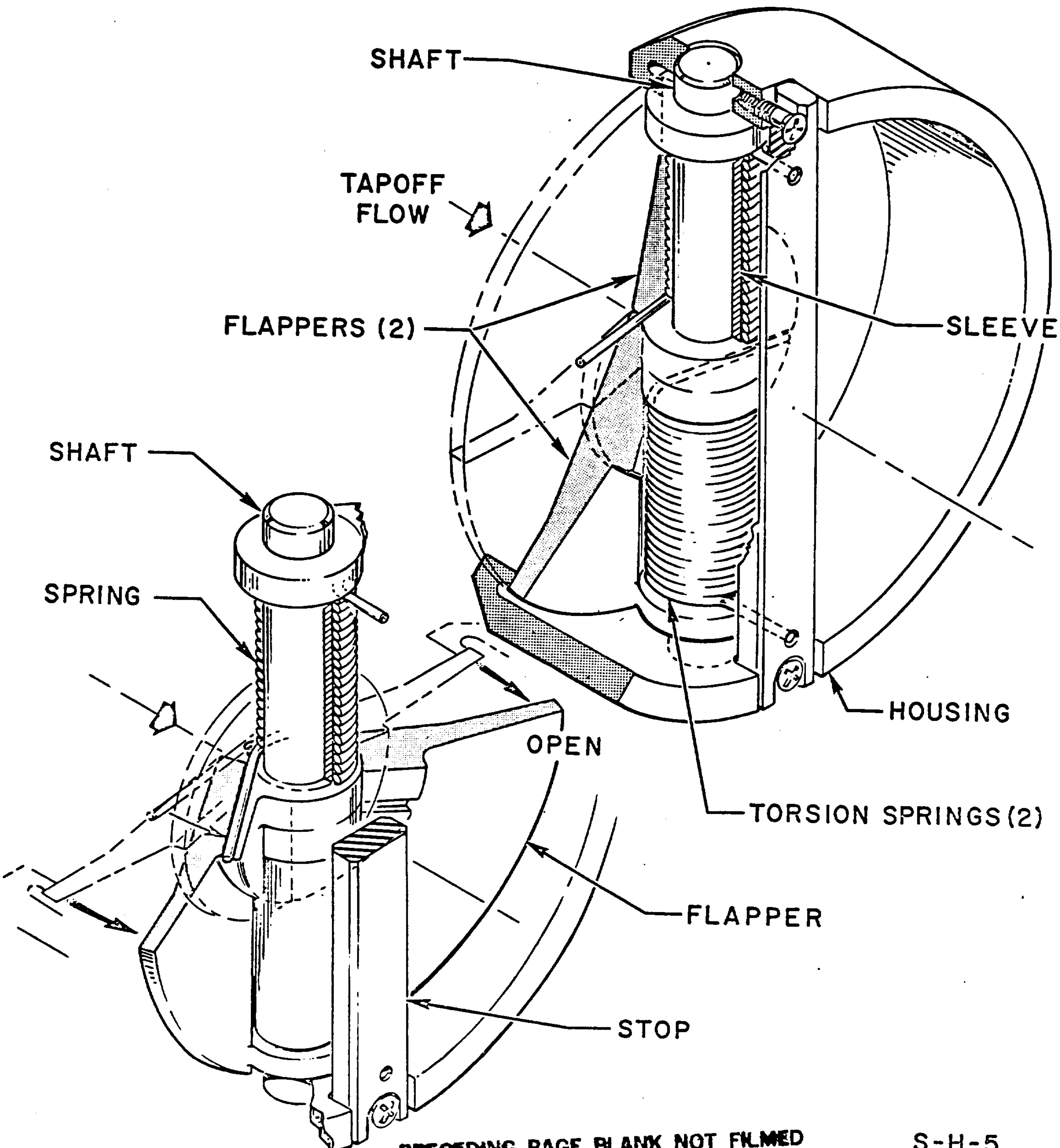
HOT GAS CHECK VALVE

309065



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J-2S Restart Study

1/4 Inch Check Valve 557755

The materials used in this part are believed to be commonly used materials today, however the drawing was not available to confirm this.

Occasional instances of reverse leakage and "hanging open" were experienced with this part. An additional study is required to determine the cause of the reverse leakage, while the hanging open would be solved by adding a teflon sleeve to the poppet stem to reduce friction. This teflon sleeve may be adequate to eliminate the reverse leakage issue.

To aid in producibility, the threads would be eliminated by using a structural weld. Also the filter would be removed in favor of a central pneumatic filter located in the pneumatic control assembly.

Additional investigation is recommended to examine antigalling materials and low friction surface coatings for the poppet and seat.

1/4 INCH CHECK VALVE 557755

- **MATERIALS**
  - BODY, SEAT, POPPET - CRES (NOT VERIFIED)
  - SEAL - TEFLON BAR
- **PROBLEMS**
  - REVERSE LEAKAGE
  - HUNG OPEN
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - ELIMINATE THREADS AND USE STRUCTURAL WELD
  - ADD SHRINK FIT TEFLON SLEEVE ON POPPET STEM. THIS MAY SOLVE PROBLEM OF HANGING OPEN BY ELIMINATING METAL TO METAL RUBBING AND REDUCES FRICTION. REDUCED FRICTION MAY ALSO ALLEVIATE REVERSE LEAKAGE PROBLEMS
  - INVESTIGATE ANTIGALLING MATERIALS & LOW FRICTION SURFACE COATINGS FOR POPPET AND SEAT
  - DEVELOPMENT PROGRAM TO IMPROVE REVERSE LEAKAGE
  - INSTALL SINGLE FILTER IN PURGE SYSTEM AND ELIMINATE THE CHECK VALVE FILTERS

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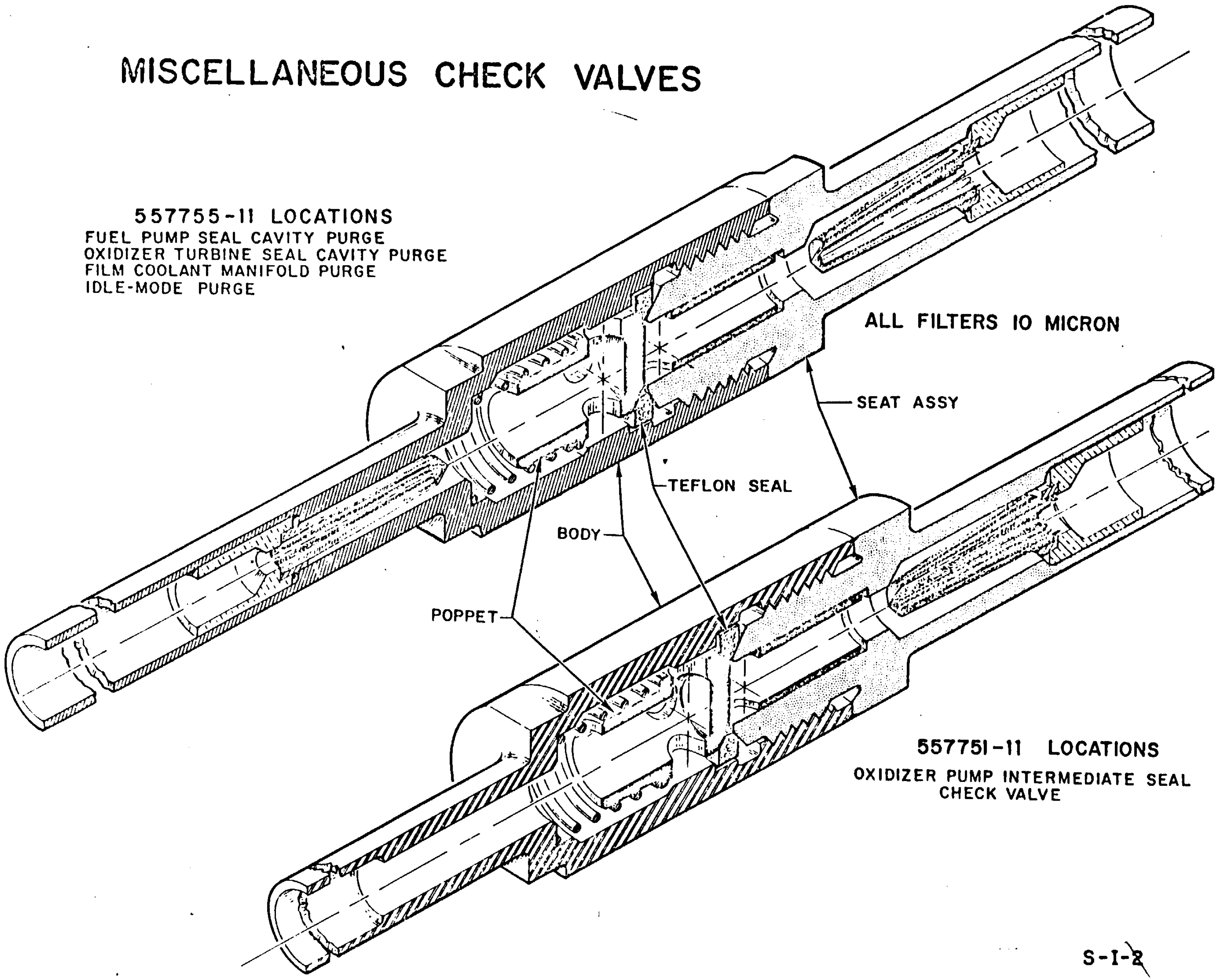
TA3-0124

MISCELLANEOUS CHECK VALVES

557755-11 LOCATIONS
FUEL PUMP SEAL CAVITY PURGE
OXIDIZER TURBINE SEAL CAVITY PURGE
FILM COOLANT MANIFOLD PURGE
IDLE-MODE PURGE



557751-11 LOCATIONS
OXIDIZER PUMP INTERMEDIATE SEAL
CHECK VALVE

J-2S Restart Study

1/4 Inch Check Valve 557751

The materials used in this part are believed to be commonly used materials today, however the drawing was not available to confirm this.

Occasional instances of reverse leakage and "hanging open" were experienced with this part. An additional study is required to determine the cause of the reverse leakage, while the hanging open would be solved by adding a teflon sleeve to the poppet stem to reduce friction. This teflon sleeve may be adequate to eliminate the reverse leakage issue.

To aid in producibility, the threads would be eliminated by using a structural weld. Also the filter would be removed in favor of a central pneumatic filter located in the pneumatic control assembly.

Additional investigation is recommended to examine antigalling materials and low friction surface coatings for the poppet and seat.

1/4 INCH CHECK VALVE 557751

- **MATERIALS**
  - BODY, SEAT, POPPET - CRES (NOT VERIFIED)
  - SEAL - TEFLON BAR
- **PROBLEMS**
  - REVERSE LEAKAGE
  - HUNG OPEN
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - ELIMINATE THREADS AND USE STRUCTURAL WELD
  - ADD SHRINK FIT TEFLON SLEEVE ON POPPET STEM. THIS MAY SOLVE PROBLEM OF HANGING OPEN BY ELIMINATING METAL TO METAL RUBBING AND REDUCES FRICTION. REDUCED FRICTION MAY ALSO ALLEVIATE REVERSE LEAKAGE PROBLEMS
  - INVESTIGATE ANTIGALLING MATERIALS & LOW FRICTION SURFACE COATINGS FOR POPPET AND SEAT
  - DEVELOPMENT PROGRAM TO IMPROVE REVERSE LEAKAGE
  - INSTALL SINGLE FILTER IN PURGE SYSTEM AND ELIMINATE THE CHECK VALVE FILTERS

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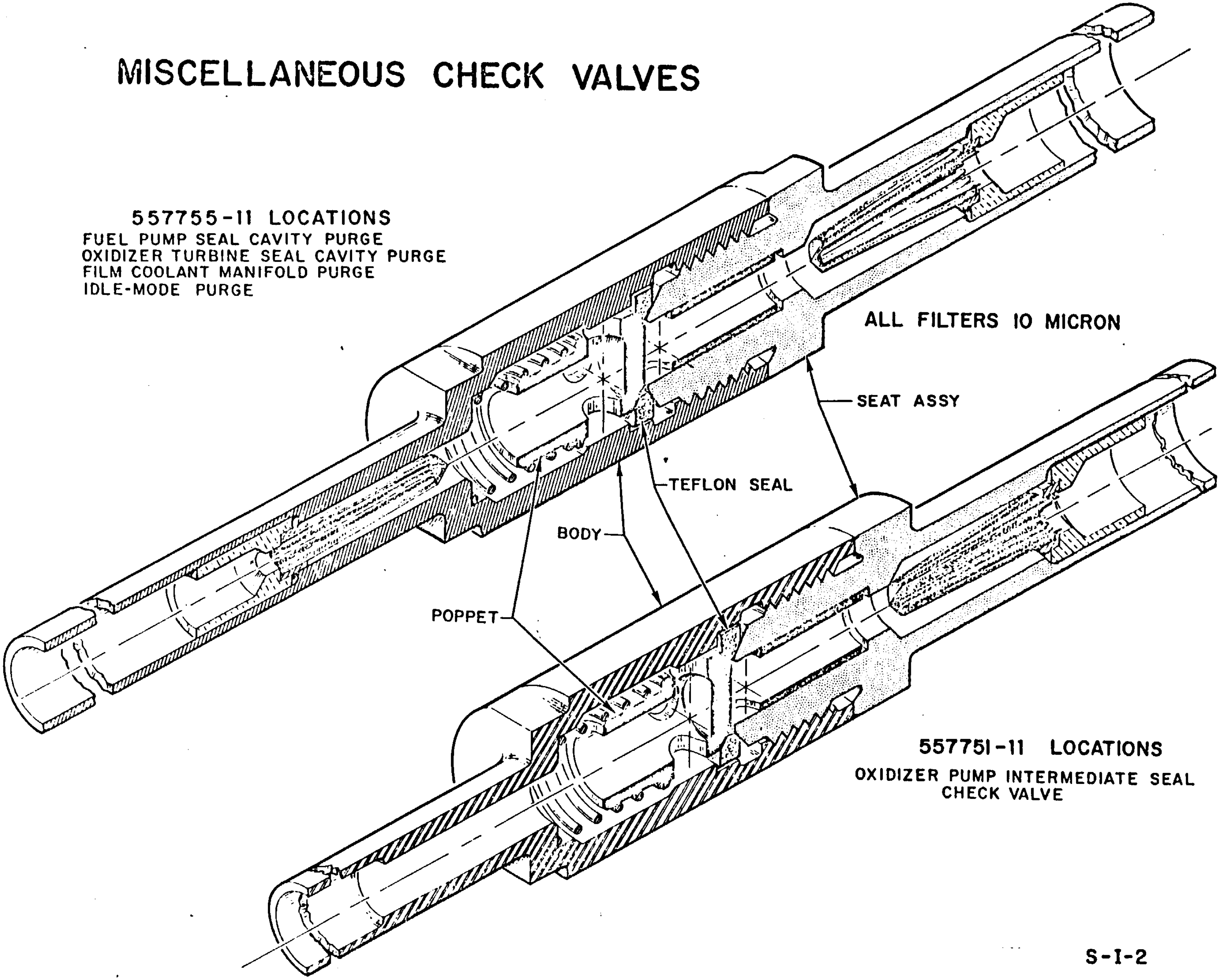
MISCELLANEOUS CHECK VALVES



J-2S Restart Study

Flight Instrumentation Summary

There have been significant gains in instrumentation technology levels since the J-2S program. Instrumentation which meets the needs of the J-2S is readily available within acceptable cost and schedule limitations. These new devices offer numerous improvements over the original parts which are no longer in production nor are they available.

Material compatibility issues are now better understood after the SSME experience base. It is clear that Inconel 625 will be suitable for most J-2S instrumentation material applications. An additional study task may prove beneficial to study port interfacing and sealing configurations based on those lessons learned on the shuttle program.

These instruments are also anticipated to be capable of sustaining system upgrades without requiring replacement in many cases, since environments are not significantly increased.

J-2S Restart Program

Flight Instrumentation Summary

TECHNOLOGY STATUS

- Instrumentation which meets the requirements of the J-2S is readily available within cost and schedule constraints
- Offers improvements over the original parts (which are no longer in production)

MATERIALS AND INTERFACE CONSIDERATIONS

- Materials compatibility issues (for metals and non-metals) are thoroughly explored, due to extensive SSME LOX-H experience
- Commonly used housing material for flight instrumentation, Inconel 625, should be suitable for J-2S applications
- Modernization of hardware used for ports, sealing, and electrical interfacing will have to be studied and the numerous resulting configuration changes will need to be documented

FLEXIBILITY AND TRADEOFFS

- Upgrade to higher thrusts, although perhaps altering measurement needs, would present no technical difficulty in terms of environment, sensor performance, etc.
- Tradeoffs include analyzing the benefits of additional measurements against impact to design, cost, schedule, operations, and mission effectiveness--using results of studies performed between 1968-1971

J-2S Restart Study

J-2S Flight and Related Instrumentation

The following three charts list the proposed J-2S flight instrumentation suite for the J-2S restart program. This list includes the previously used sensor part number, the sensor type, the tap code for the port, the electrical connector they were wired to, measurement range, accuracy, name of measurement, and subsystem designator in the literature. This list is based on instrumentation desired for operation on a S-IVB stage and is therefore subject to alteration depending on the specific proposed application and required level of health and condition monitoring.

J-2S FLIGHT AND RELATED INSTRUMENTATION

PART NO.	SENSOR TYPE	TAP Code	Electrical Connector	RANGE	%	MEASUREMENT	Sys
NA5-27412T10T	Pressure	Tap CG1	J137	0-1500 psia	1.0-1.5	Thrust Chamber #1; signal term. at vehicle interface	P
NA5-27412T10T	Pressure	Tap CG1	J138	0-50 psia	1.0-2.5	Thrust Chamber #2 (Idle Mode Pc); signal terminated at vehicle interface	P
NA5-27412T35T	Pressure	Tap NN1	J139	0-5000 psia	2.0-2.5	Helium Tank #1; signal terminated at vehicle interface	P
NA5-27412T15T	Pressure	Tap PF3	J135	0-2500 psia	2.0-2.5	Fuel Turbopump Discharge; signal terminated at vehicle interface	P
NA5-27412T20T	Pressure	Tap PO3	J136	0-2500 psia	2.0-2.5	Oxidizer Turbopump Discharge; signal term. at vehicle interface	P
NA5-27412	Pressure	Tap TG1	J138	25-46 psia	2.0-2.5	Fuel Turbine Inlet; signal terminated at package	P
NA5-27412	Pressure	Tap NN1	J187	0-5000 psia	2.0-2.5	Helium Tank #2; signal terminated at vehicle interface	A
NA5-27412	Pressure	Tap NN2	J183	0-750 psia	2.0-2.5	Helium Regulator Outlet; signal terminated at package	A
NA5-27412T2T	Pressure	Tap TG3	J192	39-53 psia	2.0-2.5	Oxidizer Turbine Inlet; signal terminated at package	A
NA5-27412T1T	Pressure	Tap TG4	J186	0-100 psia	2.0-2.5	Oxidizer Turbine Exhaust; signal terminated at package	A

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J-2S FLIGHT AND RELATED INSTRUMENTATION

PART NO.	SENSOR TYPE	TAP Code	Electrical Connector	RANGE	%	MEASUREMENT	Sys
NA5-27441	Temperature, Resistance Type	Tap CFT2	J131	-425/+100°F	2.0	Main Fuel Injection; Dual Channnels	P
NA5-27215T3	Temperature, Resistance Type	Tap NNT1	J122	-200/+200°F	2.0	Helium Tank	P
NA5-27215T5	Temperature, Resistance Type	Tap PFT1	J124	-425/+390°F	2.0	Fuel Turbopump Discharge (2 channels, A&B)	P
NA5-27215T5	Temperature, Resistance Type	Tap POT3	J125	-300/-250°F	2.0	Oxidizer Turbopump Discharge (2 channels, A&B)	P
NA5-27323T3	Temperature, Resistance Type	Tap TGT1	J126	-424/-418°F	2.0	Fuel Turbine Inlet	P
NA5-27323T3	Temperature, Resistance Type	Tap TGT3	J127	-298/-284°F	2.0	Oxidizer Turbine Inlet	P
NA5-27324T4	Temperature, Resistance Type	Tap TGT4	J128	0 to + 1000 °F	2.0	Oxidizer Turbine Outlet	P
NA5-27315	Temperature, Resistance Type	Tap n/a	J2	-200/+200°F	2.0	Electrical Control Assembly	P
NA5-27315	Temperature, Resistance Type	Tap n/a	J103	-200/+200°F	2.0	Primary Flight Instrumentation Package	P

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J-2S FLIGHT AND RELATED INSTRUMENTATION

PART NO.	SENSOR TYPE	TAP Code	Electrical Connector	RANGE	%	MEASUREMENT	Sys
NA5-27328	Speed	Tap PFV	J112	0–33,000 rpm	2.0	Fuel Turbopump	P
NA5-27382	Speed	Tap POV	J113	0–12,000 rpm	2.0	Oxidizer Turbopump	P
NA5-27331	Flow, Volumetric	Tap PFF	J110	1000–11,000 gpm	2.0-10	Engine Main Fuel	P
NA5-27331	Flow, Volumetric	Tap POF	J111	1500–36,000 gpm	2.0-10	Engine Main Oxidizer	P
NA5-27285	Position	Tap n/a	J114	0–100%	2.0	Main Fuel Valve	P
NA5-27285	Position	Tap n/a	J115	0–100%	2.0	Main Oxidizer Valve	P
NA5-27307	Position	Tap n/a	J116	0–100%	2.0	Hot Gas Tapoff Valve	P
NA5-27285	Position	Tap n/a	J117	0–100%	2.0	Fuel Bypass Valve	P
NA5-27285	Position	Tap n/a	J120	0–100%	2.0	Idle Mode Valve	P
NA5-27306	Position	Tap n/a	J119	0–100%	2.0	Mixture Ratio Control Valve	P
704095	Integration	Tap n/a	Tap n/a	control voltage	2.0	Primary Flight Instrumentation Package	P
500750	Event	Tap n/a	Tap n/a	8 ± 2 volts range 0/5	2.0	ASI Ignition Detector Probe	P
NA5-27453	Switch	Tap n/a	Tap n/a	20ms	on-off	Mainstage OK Detector Switch #1	P
NA5-27453	Switch	Tap n/a	Tap n/a	20ms	on-off	Mainstage OK Detector Switch #2	P

J-2S Restart Study

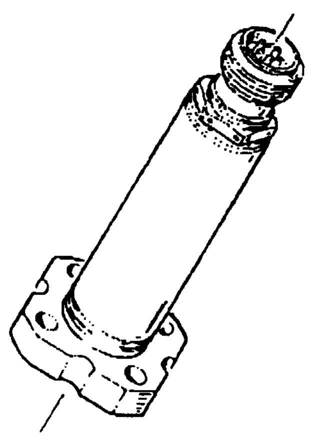
Instrumentation - Pressure Sensors

There are many similar parts available to replace the J-2S static pressure sensors. The physical operating principle is unchanged, however the advances improve on accuracy, durability, and robustness (especially in the area of thermal compensation). Replacement with a new sensor will require some structural analysis, however if SSME type parts are used, operating margins will be quite satisfactory.

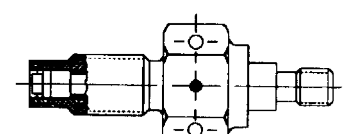
There are a number of ongoing programs that have synergy with the development of J-2S instrumentation, most notably the SSME Technology Test Bed. There may also be some advanced technology available form Kinetic Energy Weapon work going on for various branches of the military.

J-2S Restart Program
Instrumentation--Pressure Sensors

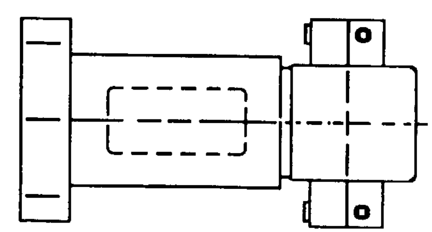
- **Similar parts available for pressure measurement needs**
  - Physical principle unchanged but design implementation much advanced
  - Outer envelopes may resemble SSME flight sensors; direct retrofit or straight-forward custom designs (e.g., Statham, CCC, Endevco, Dytran, Kistler, etc.)
  - Qualification requires structural analysis specific to J-2S
  - Housing material is Inconel 625
- **Synergy with ongoing programs**
  - Numerous custom designs completed and hot-fired on SSME TTB
  - KEW pressure sensor design experience may also apply

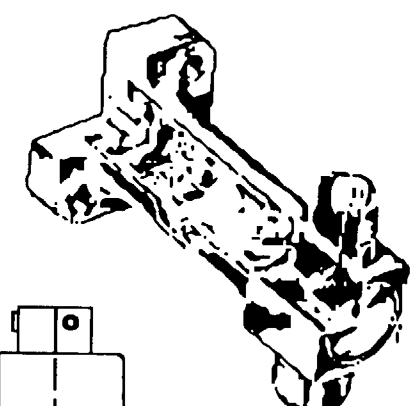


Original J-2S static pressure sensor consists of a mechanical force summing element coupled to an electrical bridge



8RE1704; SSME TTB





RC7001 and others

Currently available designs based upon improved technology for either static pressure (typical; strain gage type) or dynamic pressure (piezoelectric)

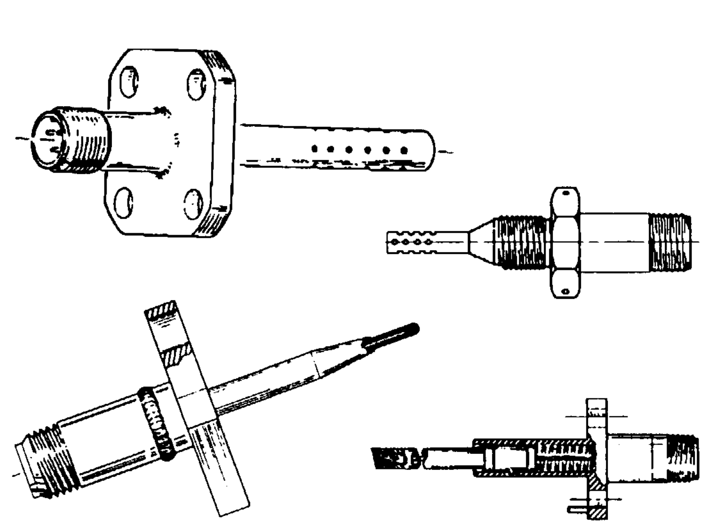
J-2S Restart Study

Instrumentation - Temperature Sensors

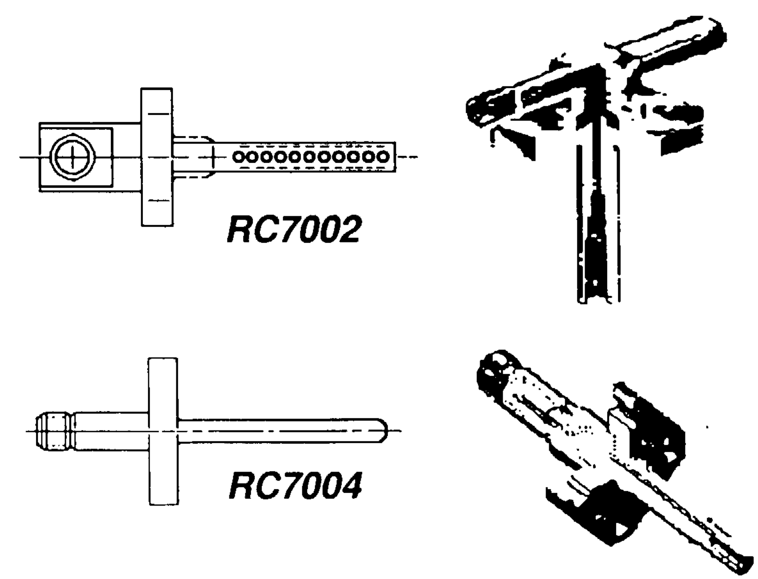
Temperature sensors are available in a number of shapes, sizes, and ranges that would apply to the J-2S. Numerous qualified suppliers exist with ongoing product improvement programs which allow suitable replacements for the J-2S sensors to be found rather easily.

J-2S Restart Program
Instrumentation--Temperature Sensors

- **Similar parts available for temperature measurement needs**
    - Basic technology unchanged with incremental producibility improvements
    - Outer envelopes resemble SSME flight sensors; direct retrofit or straight-forward custom designs (from, e.g., Rosemount, Tayco, ARI, etc.)
    - Housing material is Inconel 625
- **Synergy with ongoing programs**
    - Numerous custom designs completed and hot-fired on SSME TTB



Original J-2S temperature sensors for bearings, hot-gas, and liquid oxygen; platinum resistance type with 3-wire termination



Currently available designs based upon similar technology (RTDs) for both hot gas and cryogenic applications

J-2S Restart Study

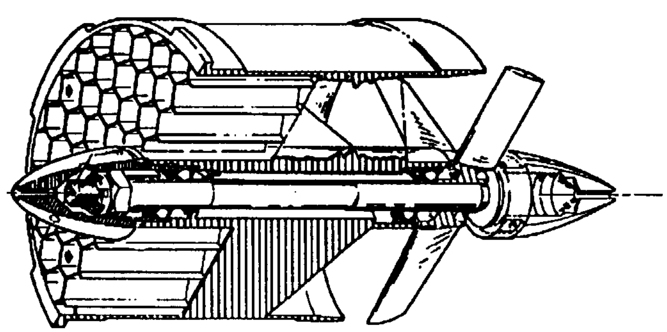
Instrumentation - Flow Sensors

Flow sensor technology has advanced greatly since the J-2S program in the mid 1960's. The J-2S used turbine type flowmeters built into the high pressure propellant ducts. More modern non-intrusive systems are available which offer significant benefits in reliability, safety, and performance over the old configuration. This technology update must be examined in greater detail, but it offers a vast improvement over the previously used measurement devices.

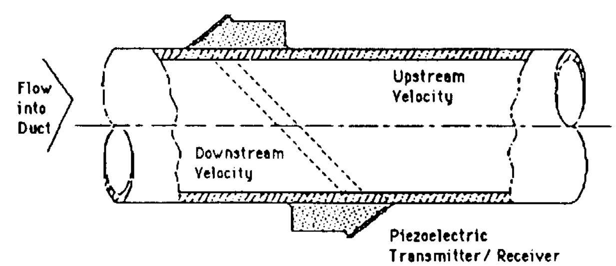
J-2S Restart Program
Instrumentation--Flow Sensors

- **New technology a viable replacement for original flow transducer**
  - Simple and robust; no moving parts
  - Preserves system efficiency (no pressure drop)
  - Operationally efficient (easy to install, no maintenance)

- **Synergy with ongoing programs**
  - In development on Technology Testbed for SSME (cryogenic flow testing, mounting assessment, cryogenic vibration testing to take place in 1993)
  - Alternatively, conventional turbine type volumetric flowmeters in use on SSME
  - Trade study for NLS (up to 8300 gpm) and similar applications performed
  - Performance monitoring, mixture ratio control, and throttling all possible through flow measurements (system analysis studies done for NLS and OTV)



Original J-2S turbine-type, volumetric, liquid flow transducer, consisting of rotor assembly, flow straighteners, and pickup coils. (SSME uses similar technology.)



Modern nonintrusive, ultrasonic flowmeter, using piezoelectric transducers to sense the difference between upstream and downstream velocity (speed of sound), which varies analytically with flowrate

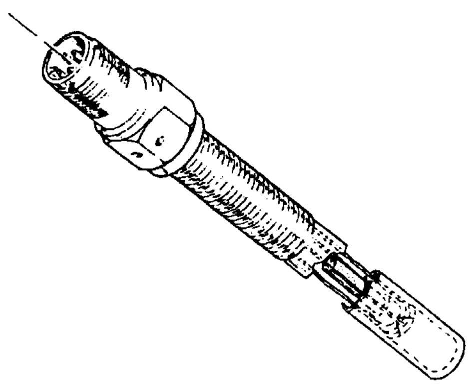
J-2S Restart Study

Instrumentation - Speed Sensors

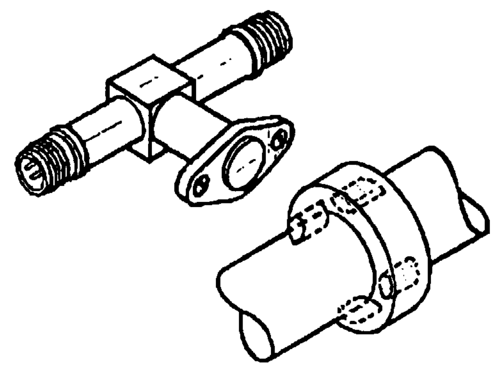
Two turbopump speed sensor options are available. The SSME type magnetic pick-up is baselined to replace the J-2S magnetic pick-up configuration, since it is available and provides higher signal quality. A second configuration is recommended for study. This is the non-intrusive sensor developed under the SSME Technology Test Bed program. This system has the benefit of eliminating potential interference problems between the rotor and the sensor.

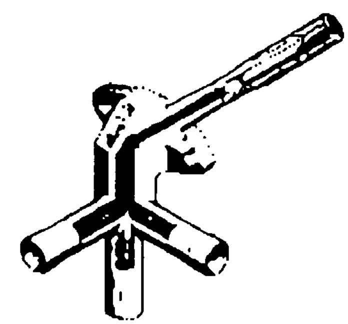
J-2S Restart Program
Instrumentation--Speed Sensors

- **New technology a viable replacement for original speed sensor**
  - Simple and robust; nonintrusive provided that magnets can be embedded in a rotating element (such as a speed nut)
  - Preserves structural integrity of turbopump while providing a measure of performance and hardware health
- **Synergy with ongoing programs**
  - Currently in development on Technology Testbed for SSME (fabrication in progress, supporting near term hot-fire tests)
  - Trade study for NLS (in conjunction with torque measurement) in progress
  - Use of two speed sensors can provide torque information nonintrusively



Original J-2S magnetic probe and pickup coils; respond to speed-dependent variations in electromagnetic flux





RC7005

Modernized SSME version--
Nonintrusive at left,
Existing SSME flight sensor at right

J-2S Restart Study

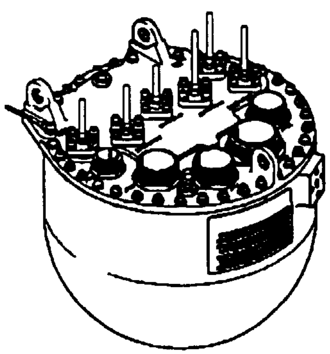
Other Sensor-Related Components

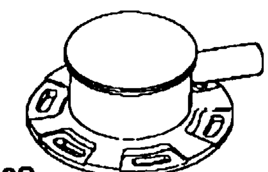
Equivalent or superior parts are available for ignition detection and position measurement from other ongoing rocket engine programs. Specific components would have to be selected for this application. Parts are also available for any added measurements should they be desired, such as accelerometers, proximity sensors, thermocouples and skin temperature sensors.

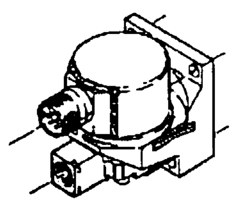
Sensor availability supports any number of potential health and condition monitoring architectures for the J-2S program, whatever the application may be.

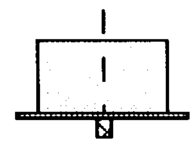
J-2S Restart Program
Other Sensor–Related Components

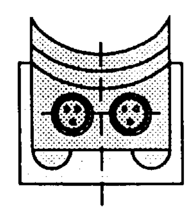
- **Equivalent parts available for ignition detection and position measurement**
  - Ignition Detection technology based upon experience with SSME and Atlas
  - Valve Position sensor technology from SSME, NLS, Atlas, and KEW
- **Parts also available for noncritical measurements-- for developmental evaluation of engine performance and component condition**
  - Accelerometers (SSME Flight and Testbed RES7001
  - Proximity Sensors (SSME Testbed 8RE1690, 8RE1691, or 8RE1702)
  - Thermocouples (SSME Testbed 8RE1675, 8RE1699, 8RE1700, or 8RE1719)
  - Skin Temperature Sensors (SSME RC1624 or RC1751)

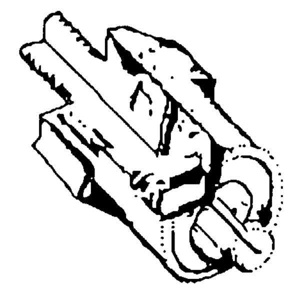

Primary Flight Instrumentation Package


Original J-2S Valve Position Transducer


Original J-2S Mainstage OK Pressure Switch


Angular Position Transducer SSME RES1258; Kavlico or MPC


Skin Temperature Sensor SSME TTB RES1345, Rosemount


Accelerometer SSME RES7001

J-2S Restart Study

Pneumatic Control Assembly 99-558330

The detail drawing for this component was not available for the review, however all indications were that it was made from aluminum. This will be verified when the drawing is retrieved.

Problems associated with this component were isolated instances of solenoid leakage while deactuated, failure to regulate pressure within the specified bounds, and long helium tank venting time.

The proposed change to the component would be to replace the helium tank vent valve with a larger capacity valve to reduce venting time. Additional study should be given to review and update materials and then examine if any benefit could be gained from converting the machined body to either a forging or casting.

PNEUMATIC CONTROL ASSEMBLY 99-558330

- **MATERIALS**
  - HOUSING - ALUMINUM (NOT VERIFIED)
- **PROBLEMS**
  - SOLENOID LEAKED WHILE DEACTUATED
  - FAILED TO REGULATE
  - EXCESSIVE HELIUM TANK VENTING TIME
- **POTENTIAL PRODUCIBILITY IMPROVEMENTS**
  - REPLACE HELIUM TANK VENT VALVE WITH LARGER CAPACITY FOUR-WAY SOLENOID VALVE TO REDUCE VENTING TIME
  - REVIEW MATERIALS AND UPDATE
  - REVIEW DESIGN FOR FORGING AND CASTING APPLICATIONS

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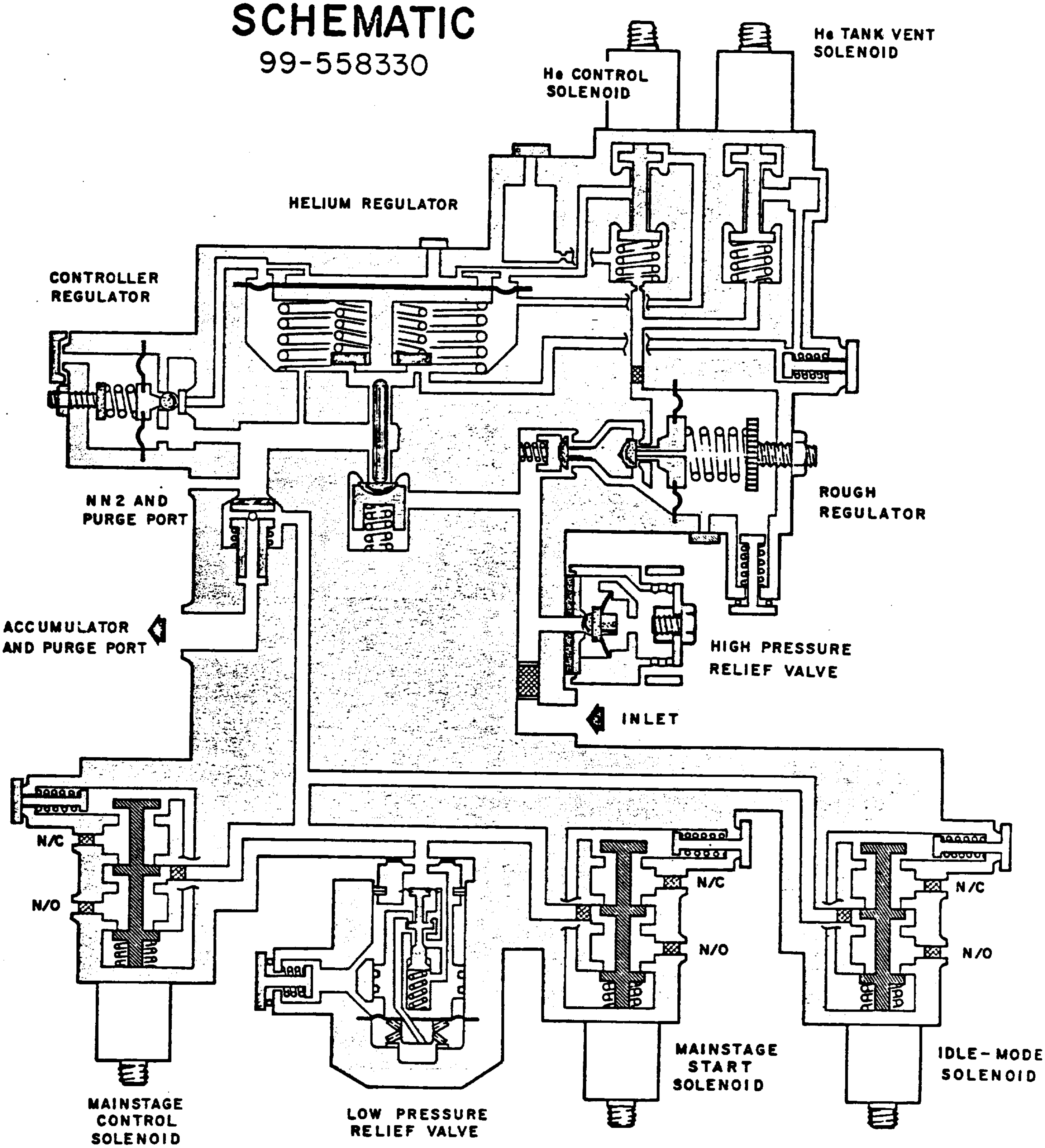
PNEUMATIC PACKAGE SCHEMATIC

99-558330



J-2S Restart Study

Helium Tank

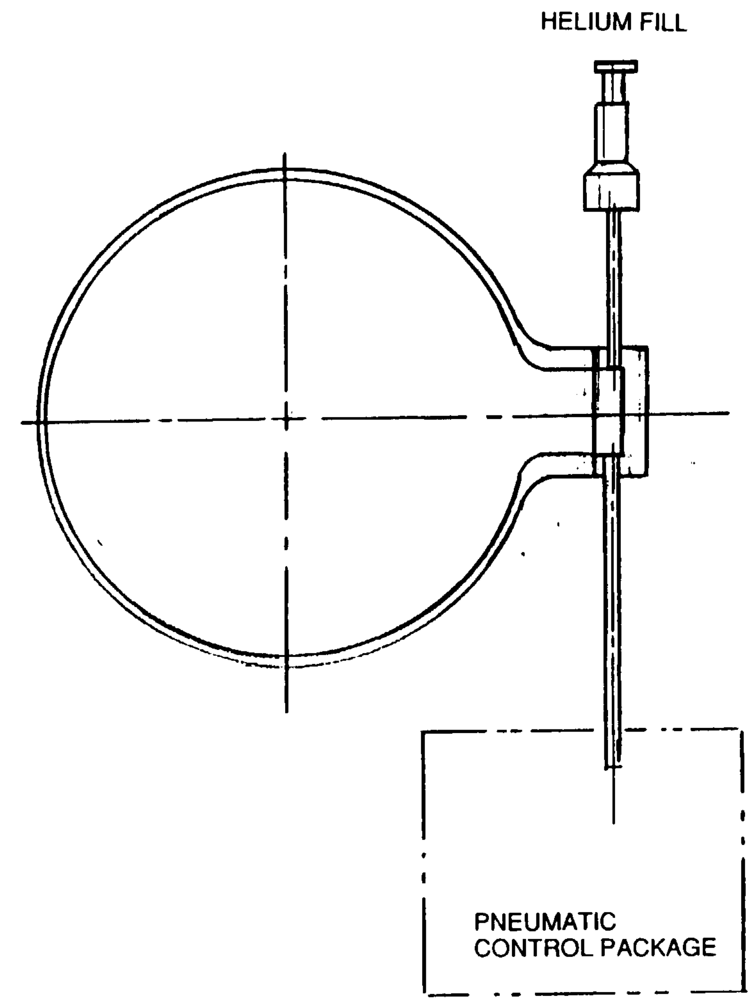
There were two helium tanks used on the J-2S program, one for the S-II configuration and a larger one for the S-IVB configuration (with multiple restarts). Replacement tanks are available from the original supplier PSI Inc. and from Brunswick Corp. These new tanks exceed the capacity and pressure ability while decreasing the weight of the component. Tank size will have to be determined based on the proposed application, however this study is baselining the larger S-IVB configuration.

HELIUM TANK

NO MATERIAL PROBLEM

THIS IS A 700 CUBIC INCH TANK

A 886 CUBIC INCH TANK IS AVAILABLE WHICH EXCEEDS
OPERATING PRESSURE
PROOF PRESSURE
BURST PRESSURE



J-2S Restart Study

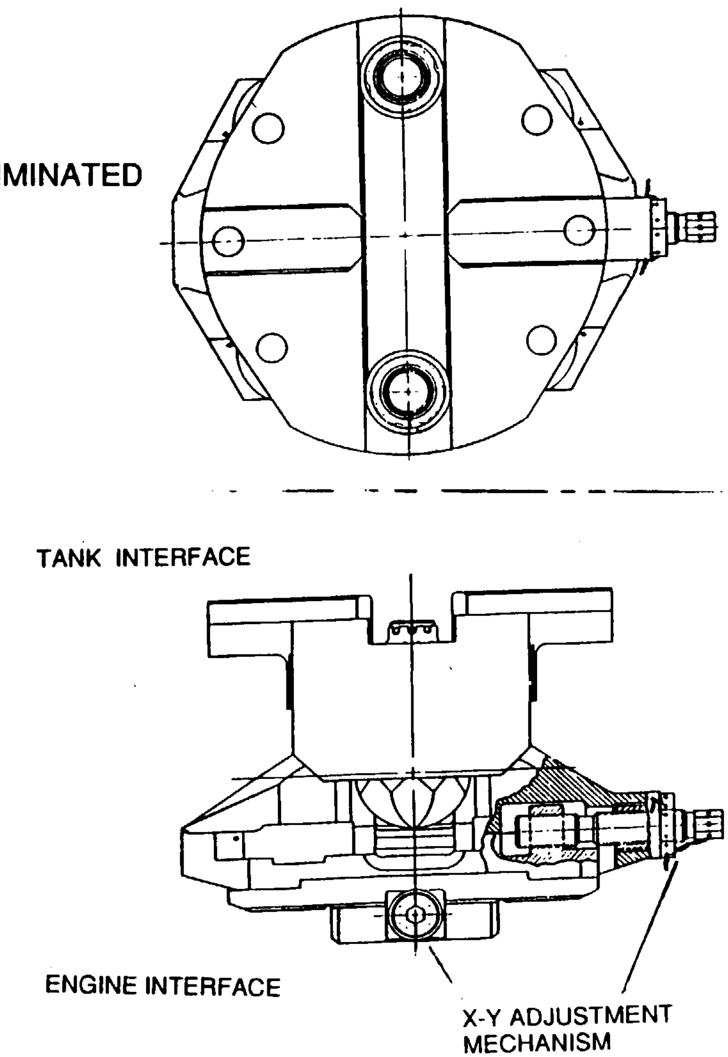
Gimbal Bearing

There were no issues identified with the gimbal bearing. All materials and manufacturing processes are still in use. The only producibility improvement suggested was to eliminate the X-Y thrust alignment mechnanism sine it was never used because all six J-2S engines were well within thrust alignment specifications.

GIMBAL BEARING

NO MATERIAL PROBLEM

ACCORDING TO A PRIOR REPORT THE X-Y MECHANISM CAN BE ELIMINATED SINCE ALL OF THE ENGINES WERE WITHIN THRUST ALIGNMENT SPECIFICATION WHEN THE GIMBAL WAS SET AT ITS NULL POINT.

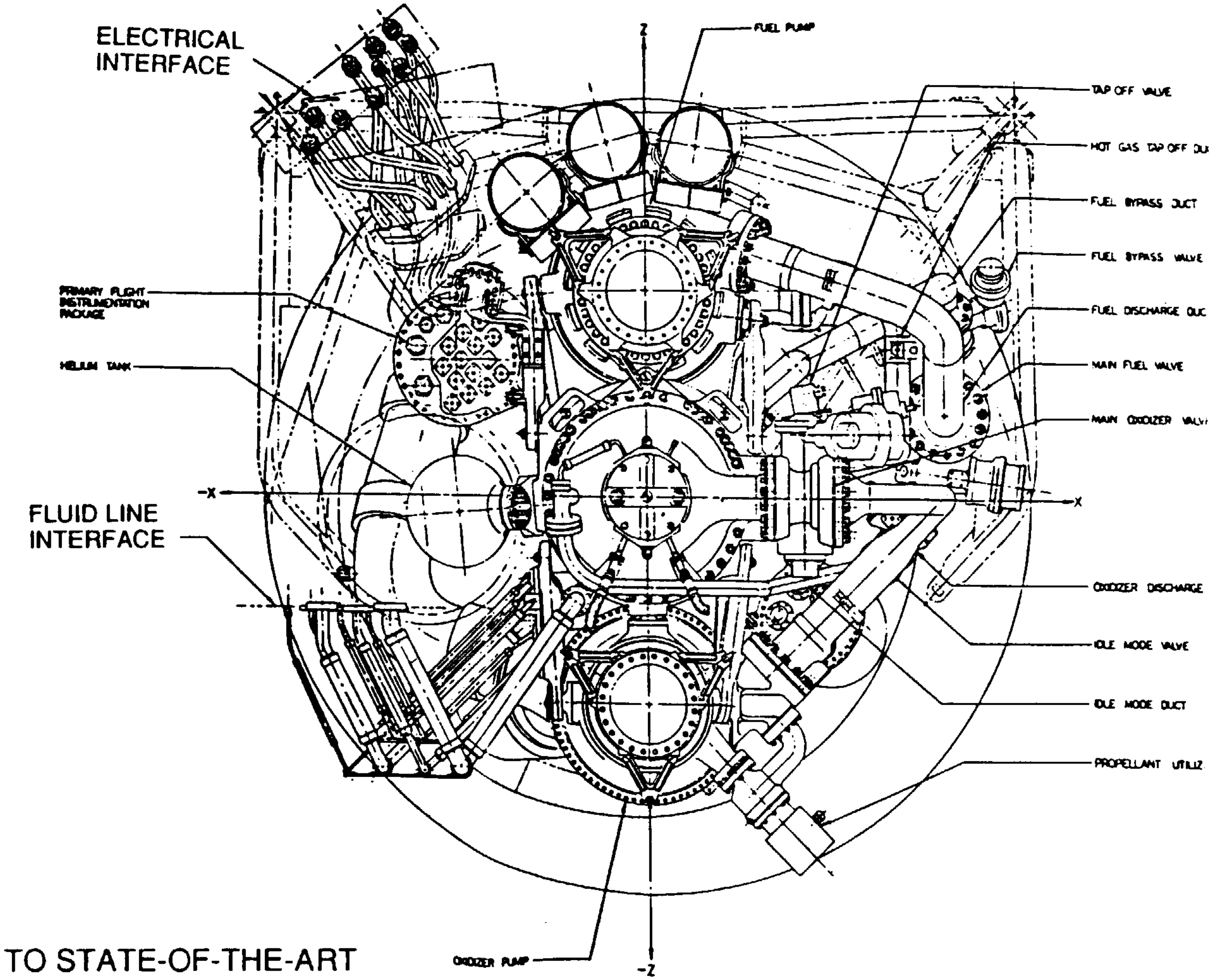


J-2S Restart Study

Interface Panels

These panels would be redesigned to meet the interfaces of the proposed application. The fluid line interfaces would require no change, however the electrical connector type should be updated to an improved configuration.

INTERFACE PANELS



ELECTRICAL INTERFACE

UPDATE ELECTRICAL CONNECTORS TO STATE-OF-THE-ART

FLUID LINE INTERFACE

NO OBVIOUS MECHANICAL CHANGE

BOTH INTERFACES MAY HAVE TO BE REDESIGNED TO MAT E WITH VEHICLE

J-2S Restart Study

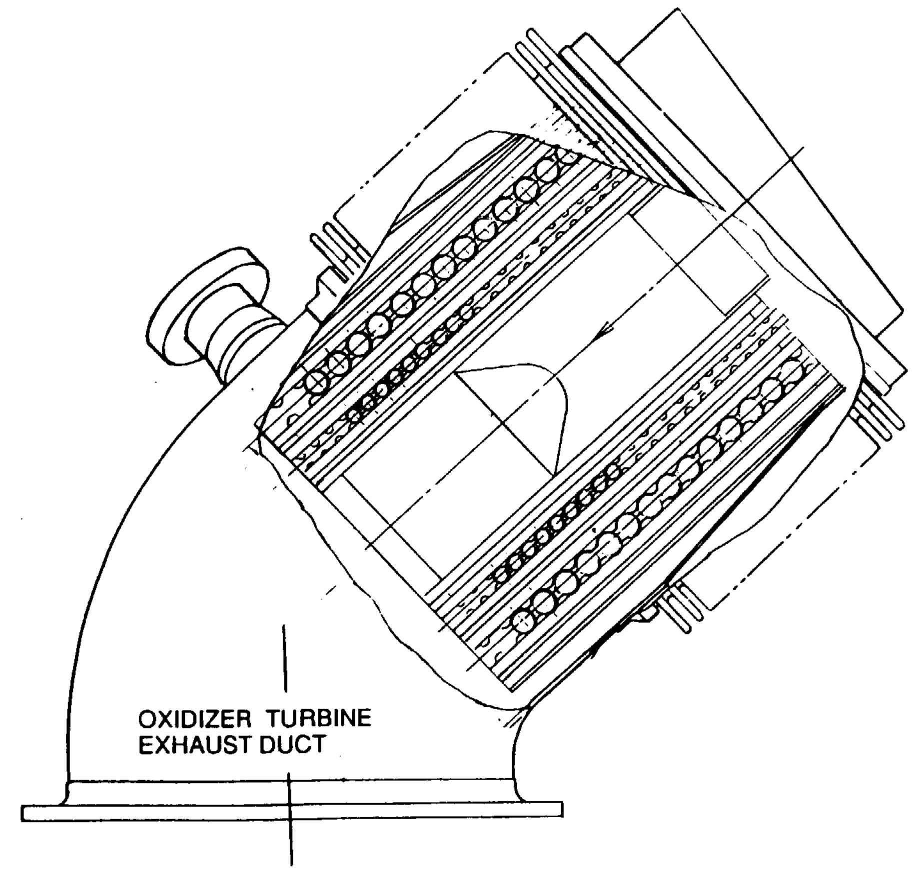
Heat Exchanger

The heat exchanger for oxidizer tank repressurization, if required for the proposed application, is located in the oxidizer turbine exhaust duct. A similar unit experienced flow instability in the J-2 engine program, however this was alleviated by going to a bifurcated two tube design, similar to that used in the SSME today. An option for further study would be to examine the use of a tapered tube heat exchanger design like that proposed for SSME product improvement.

HEAT EXCHANGER

NO MATERIAL PROBLEM

NO STABILITY PROBLEM WITH THE TWO TUBE DESIGN



J-2S Restart Study
Recommended Modifications

This chart summarize the proposed restart configuration of the J-2S engine based on the work performed during the producibility assessment. For each of the major components listed, the applicable drawing number is shown and a brief summary of the changes made to each component.

Recommended Modifications

Component	Dwg. Number	Changes from basic drawing	Mod Type**
Combustion Devices			
Thrust Cham. Assy	210620		
Injector		Use castings for body to eliminate welds. Braze posts.	1,2
Tap-Off Port		Use casting to replace port, manifolds, & J-Tubes.	2,3
Nozzle/Chamber		Full length nozzle jacket with brazed manifolds.	2
Manifolds		Use castings to replace welded structures.	2
ASI System	651349	Machine and braze assembly.	1
SPTS Cartridges	Spec	Update initiator and propellant	No Change
Turbomachinery			
Mk-29 Fuel T/P	461500	Cast impeller, stiffen & modify brgs., & update dynamic seals	1,2,3,4
Mk-29 Ox T/P	460430	Update dynamic seals	1,4
Ducts			
Fuel In Duct	409900	Redesign completely	*
Ox In Duct	409899	Redesign completely	*
Fuel Disch. Duct	411078	Use precision end point tooling	1
Ox Disch. Duct	411077	Use precision end point tooling	1
Fuel Bypass Duct	411079	Use precision end point tooling	1
Idle Mode Duct	411081	Use precision end point tooling	1
Ox Turb B/P Duct	307715	Use precision end point tooling	1
Cross-over Duct	307714	Use precision end point tooling	1
Turb Exh. Duct	308040	Use precision end point tooling	1
H/G Tap-off Duct	411080	Use precision end point tooling	1
Misc Tubes & Hoses	Various	Reassess routing for specific application	No Change

* Redesign instead.
** 1 – Producibility; 2 – Fabrication Technique; 3 – Material Substitution; 4 – Reliability/Operability Enhancement.
No Change – No recommended change.

J-2S Restart Study
Recommended Modifications

This chart summarize the proposed restart configuration of the J-2S engine based on the work performed during the producibility assessment. For each of the major components listed, the applicable drawing number is shown and a brief summary of the changes made to each component.

Recommended Modifications

Component	Dwg. Number	Changes from basic drawing	
Valves			
Main Fuel Valve	411320	Cast housing, die forged butterfly of 431 CRES	2,3,4
Main Ox. Valve	411225	Cast housing, mylar shaft seals, die forged butterfly of 431 CRES	2,3,4
Prop Util. Valve	251455	Update motor design	4
Fuel Bypass Valve	411180	Cast housing and caps, die forged butterfly of 431 CRES	2,3
Tap-off Valve	557824	Elminate butterfly seal, use die forged parts	2
Idle Mode Valve	411385	Cast housing, mylar shaft seals, cast ball, revised seat	1,2,4
Anti-Flood Valve	407875	Cast housing, redesigned poppet	2
Relief Valve	558325	Die forged parts	2
Check Valve	558022	Weld structure, teflon poppet sleeve	1,4
Check Valve	309065	Redesign	1
Check Valve	557755	Weld structure, teflon poppet sleeve, eliminate filter	1,4
Check Valve	557751	Weld structure, teflon poppet sleeve, eliminate filter	1,4
light Instrumentatio			
Ign. Det. Probe	500750	Eliminated	Eliminated
Instr. Package	704641	Redesign	*
Pressure Sensors	Various	Redesign	*
Temp. Sensors	Various	Redesign	*
Flow Sensors	Various	Redesign	*
Speed Sensors	Various	Redesign	*
Valve Pos x-ducers	Various	Redesign	*
M/S OK Press Switch	NA5-27453	Redesign	*

* Redesign instead.
** 1 – Producibility; 2 – Fabrication Technique; 3 – Material Substitution; 4 – Reliability/Operability Enhancement.
No Change – No recommended change.

J-2S Restart Study
Recommended Modifications

This chart summarize the proposed restart configuration of the J-2S engine based on the work performed during the producibility assessment. For each of the major components listed, the applicable drawing number is shown and a brief summary of the changes made to each component.

Recommended Modifications

Component	Dwg. Number	Changes from basic drawing	
llaneous Component			
Pneum Cont. Pack.	558330	Replace He tk vent w/ larger valve, add filter, cast housings	2,4
Helium Tank	NA5-260212	Replace with in production unit	1
Gimbal Bearing	208900	Eliminate alignment mechanism	4
Interface Panels	Various	Redesign for specific application	No Change
Heat Exchanger	307885	No changes	No Change
ECA Package	503670	Redesign with modern electronics	*

* Redesign instead.
** 1 – Producibility; 2 – Fabrication Technique; 3 – Material Substitution; 4 – Reliability/Operability Enhancement.
No Change – No recommended change.

J-2S Restart Study
Producibility Summary

An interesting conclusion of the study was that the J-2S could be produced entirely from existing drawings, with the exception of replacing the obsolete, outdated, and unavailable electronics. This is a sharp contrast from other restart efforts conducted at Rocketdyne. All of the materials used are still available for use as are the manufacturing processes.

While the engine could be produced using the existing prints, a number of low risk, high payoff changes have been identified. Twenty four component changes to aid in producibility have been identified that do not alter form, fit, or function. In addition to this, another twenty changes in fabrication technique were identified such as the use of modern castings or die forgings to produce previously labor intensive components. The use of fabrication techniques, along with the existence of known superior materials, yield a recommendation to perform 12 material substitutions. Finally, eleven reliability or operability enhancing changes were identified by the team. Such changes incorporate now proven technologies that were not available during the time of J-2S design.

Several complete component redesigns were identified which would be defined as a function of intended application. The electrical control and sensor architecture would be modified to incorporate condition monitoring and health monitoring capability appropriate to the intended application. Also the propellant inlet scissor ducts would be replaced with much less costly wrap-around ducts if the interfaces of the application allow it. Since this engine has the potential of operating in applications requiring long life, the hot gas check valve would be redesigned to provide improved life margin over those units tested, although this is not necessarily required for an expendable application. Engine interfaces would also be adjusted to provide a more efficient design than that used in previous testing.

TA3-0394A

J-2S Restart Study
Producibility Summary

- Could be produced to existing drawings
  - Only engine electronics absolutely require replacement
  - No material changes required
  - All processes are still possible
- Desirable changes identified
  - 24 changes for producibility (no change in form/fit/ function)
  - 20 changes in fabrication technique (i.e., castings, die forging, etc.)
  - 12 material substitutions
  - 11 reliability/operability enhancements
- Component redesigns desired to match specific applications
  - Electronics and sensors to provide desired HMS/CMS
  - Propellant inlet ducts (wrap-arounds would reduce engine cost)
  - Revise hot gas check valve if longer life is desired
  - Adjust interfaces for specific vehicle

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Deep Throttling Assessment

J-2S Restart Study
10:1 Throttling Examination

This portion of the restart study examined what modifications would be required to throttle the J-2S engine to as high as 10:1, a considerable increase from the tested 6:1 throttling. The study also defined what impacts would result from these modifications.

At the outset of this study, the data taken on engine J-115 at AEDC on throttling tests down to 6:1 throttling levels was examined to determine if satisfactory operation had been observed to that level. Then this data was compared to the off-design code J-2S engine power balance model to demonstrate accuracy of the model. Throttling cases were run at several points (1.7:1, 3:1, 5:1, 6:1, and 10;1) to establish operating trends.

It was found that the model agreed very well with the test data all the way to the 6:1 previously tested. As shown on a later chart, in throttling to 10:1 the oxidizer injector element pressure drop to chamber pressure ratio dropped to about 2 percent of Pc which is below the rule-of-thumb minimum stability criteria of about 5 percent (although this particular engine design was stable at 3 percent in test). If such deep throttling were desired, it would be possible to increase the oxidizer element orifice resistance to allow stable operation at the low power level. This would require an oxidizer orifice resistance increase. If the turbine tapoff flow were held constant, then the chamber pressure would be reduced to approximately 1000 psi. Alternately, the tapoff flow could be increased and the pump discharge pressure increased to maintain the current chamber pressure. Early studies were performed that indicated that the turbopumps could be uprated to high enough chamber pressures to deliver 320,000 pounds of thrust merely by increasing the thickness of structural housings. This pump discharge pressure increase capability is more than adequate to insure stability.

Turbomachinery performance at the 10:1 operating level appears acceptable based on the 6:1 experience, however this study did not address the secondary coolant and seal flows which may still require some additional modification. These results have a high degree of confidence due to the previous test data and its excellent correlation with the engine model.

J-2S Restart Study
10:1 Throttling Examination

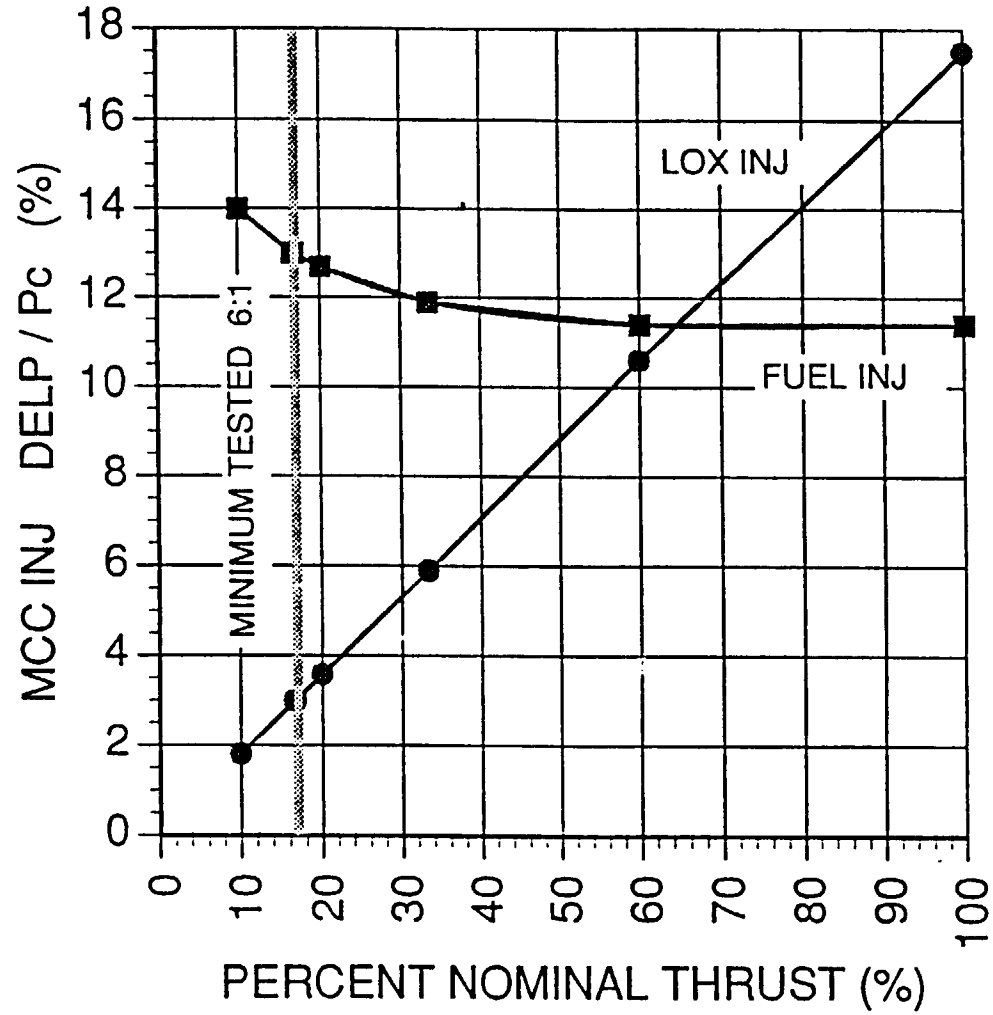
- Objectives
  - Determine modifications required for throttling up to 10:1
  - Define impacts of throttling modifications
- Approach
  - Review J-2S 6:1 throttling data
  - Anchor analytical models with data
  - Determine changes required for 10:1 throttling with engine balance model
- Conclusions
  - 6:1 throttling is feasible with baseline configuration
  - 10:1 throttling limited by injector stability
    - Increased LOX post pressure drop reduces Pc to approx. 1000 psi
  - Excellent correlation seen between data and engine model

J-2S Restart Study

Main Injector Pressure Drop vs. Power Level

This chart shows the limiting factor in throttling the J-2S engine. The data was produced by using the J-2S engine balance off-design code. As the engine is throttled the fuel injector retains its pressure drop to chamber pressure ratio, ensuring injector stability from the chug mode. Note however that the LOX injector pressure drop to chamber pressure ratio drops to very low levels. By general rule of thumb, a 5 percent ratio is required to ensure stability with specific testing required to validate any point below that. The J-2S was operated with stability at a 6:1 throttle point, however it is proper to assume that this represents it's lowest stable operating point without further testing since it was operated at about 3 percent during the 6:1 throttling point. It is possible that further testing would indicate stable operation at the lower 10:1 throttling setting, however without such test data it is recommended that to go to 10:1 throttling, the oxidizer injector orifice resistance should be increased.

J-2S Restart Study
Main Injector Pressure Drop vs. Power Level

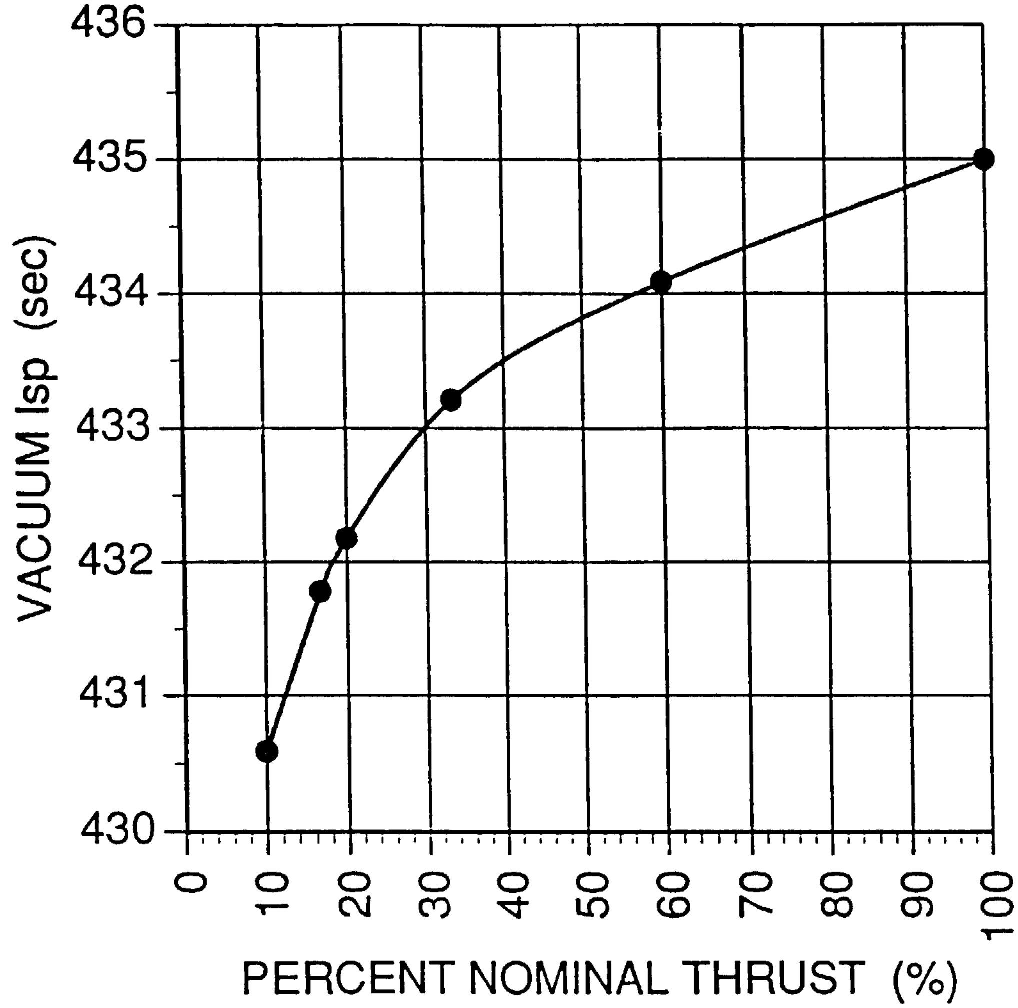


10:1 Throttling requires increased LOX injection pressure drop

J-2S Restart Study
Engine Performance vs. Power Level

This chart merely points out that the delivered vacuum specific impulse of the engine does not suffer significantly from deep throttling. The performance reduction seen is driven by reductions in turbopump operating efficiencies at the off-design conditions. The data was produced using the J-2S engine balance off-design code.

J-2S Restart Study
Engine Performance vs. Power Level

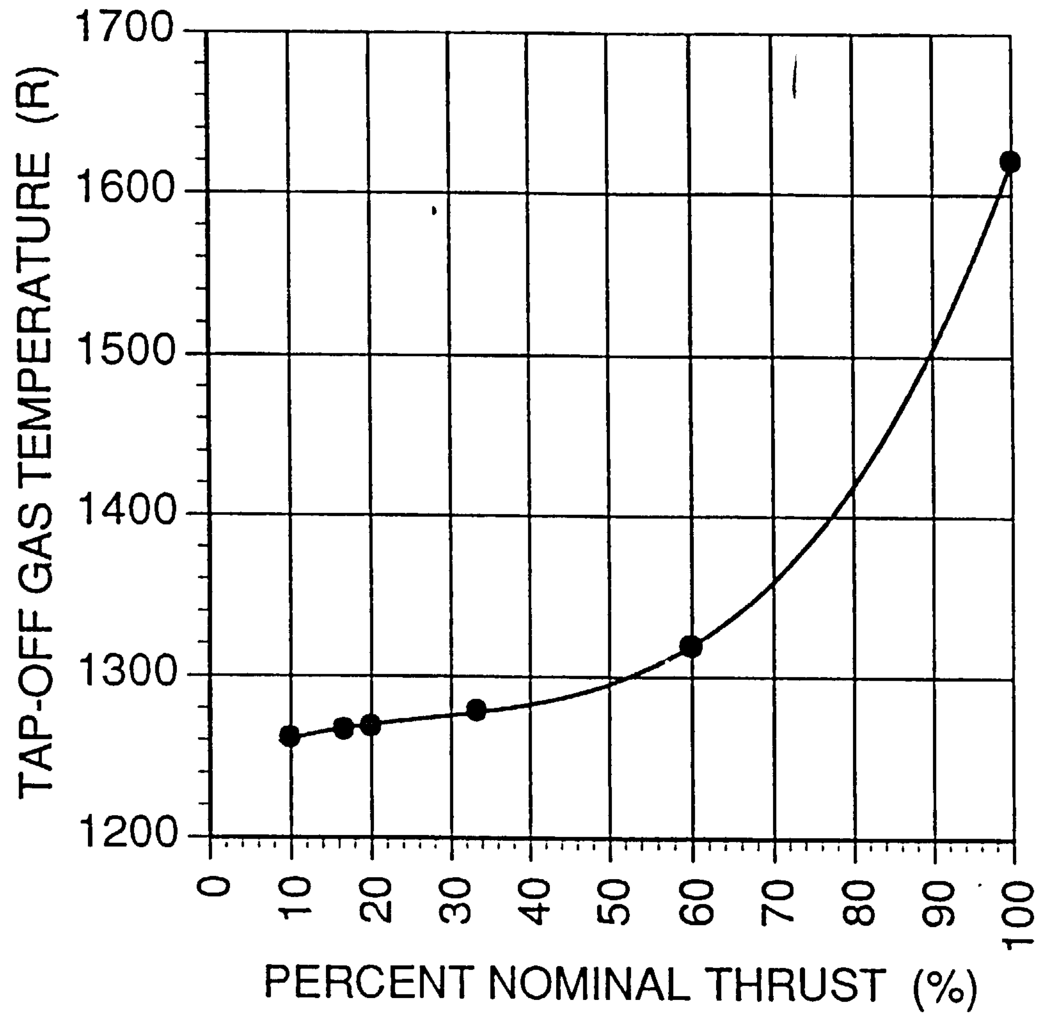


Throttling does not significantly decrease engine performance

J-2S Restart Study
Turbine Inlet Temperature vs. Power Level

This chart shows how the tap-off cycle maintains satisfactory turbine temperatures over the entire throttling range. Other engine cycles tend to reduce turbine inlet temperatures to low enough levels that either ice (in the case of GG and staged combustion cycles) or that turbine power availability (in the case of expander cycles) becomes a concern. Even at the 10:1 extreme condition the temperature remains fairly stable at 1260 °R. The data was produced using the J-2S engine balance off-design code.

J-2S Restart Study
Turbine Inlet Temperature vs. Power Level



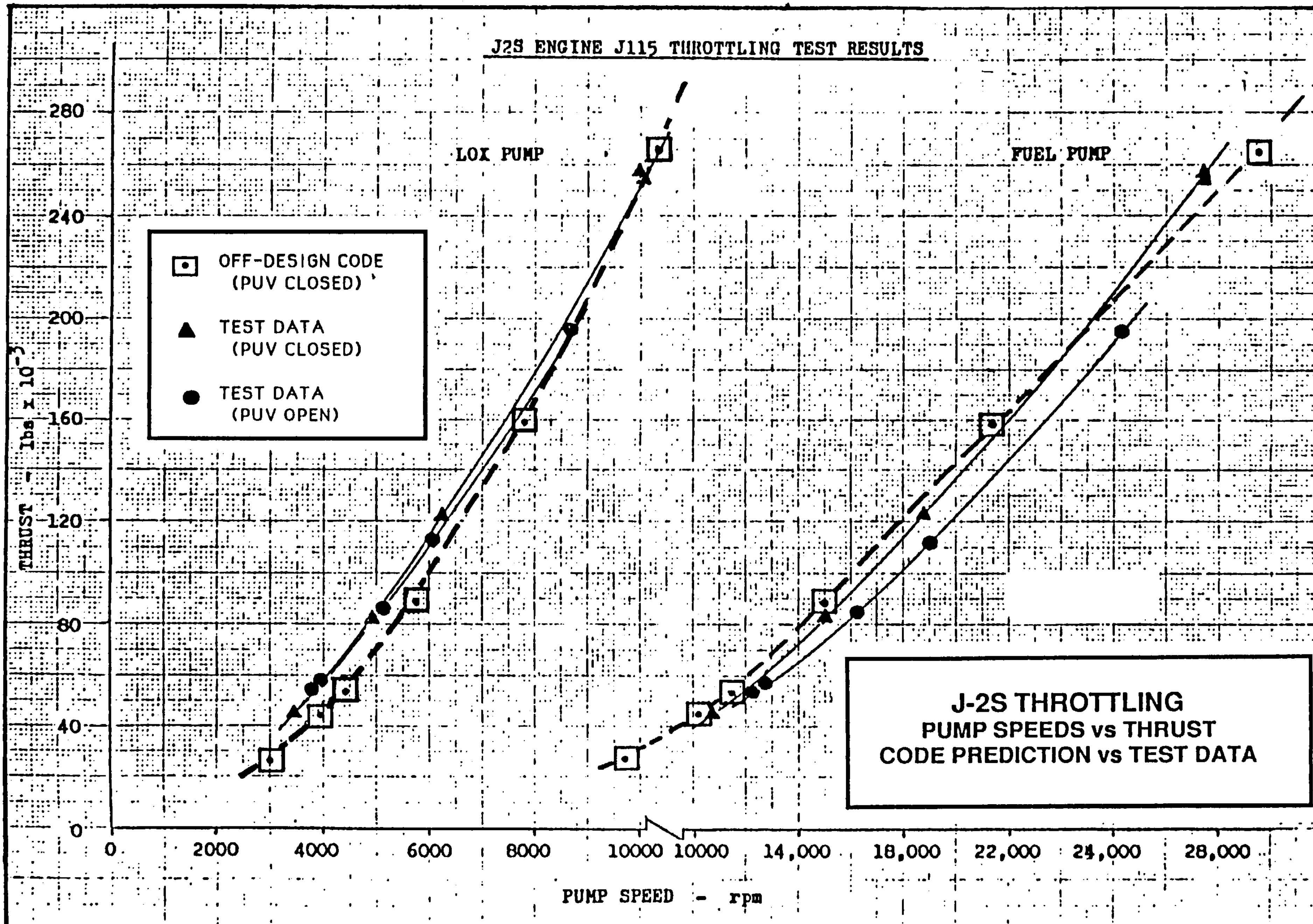
At throttled conditions temperature remains acceptable

J-2S Restart Study

Good Model Prediction/Data Correlation Seen

This chart overlays the off-design engine power balance model predictions with actual deep throttling data taken with the J-2S. The turbopump operating conditions, similar to other parameters, were very well predicted by the code. This gives confidence in the resolution of the modeling capability used for this study. This code is available for future J-2S modeling effort.

J-2S Restart Study
Good Model Prediction/Data Correlation Seen



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J-2S Restart Program Plan

TA3-0407

J-2S Restart Study

Program Plan Groundrules and Assumptions

For the purposes of this study, it was assumed that the engine life requirement would be the same as the original J-2S model specification which called for 30 starts and 3750 seconds of operation. It was also assumed that in-flight restarts would be a requirement so the engine is configured for three starts on a mission. The planning assumed that government facilities would be used wherever they were available and cost effective. A limitation placed on this planning was to limit certification to single engine configurations so that this work would not be configuration dependent. This means that additional effort would be required for clustered applications since nozzle thermal protection and main propulsion test article testing are not included. For the purpose of cost estimating, the use of Rocketdyne facilities and engine assembly were presumed which did not account for any gains to be had in colocating production and test facilities. The planning used for production restart assumes the existing drawings and specifications would be updated rather than transferring the drawings and specifications to electronics based systems. Modifications to Rocketdyne facilities have been identified and estimated for areas where such testing is to occur. Finally, the cost of the propellants have not been included in the estimates since this is highly dependent on facility configuration, test program, and test location. Details of costs and engine tests are shown on later charts.

J-2S Restart Study

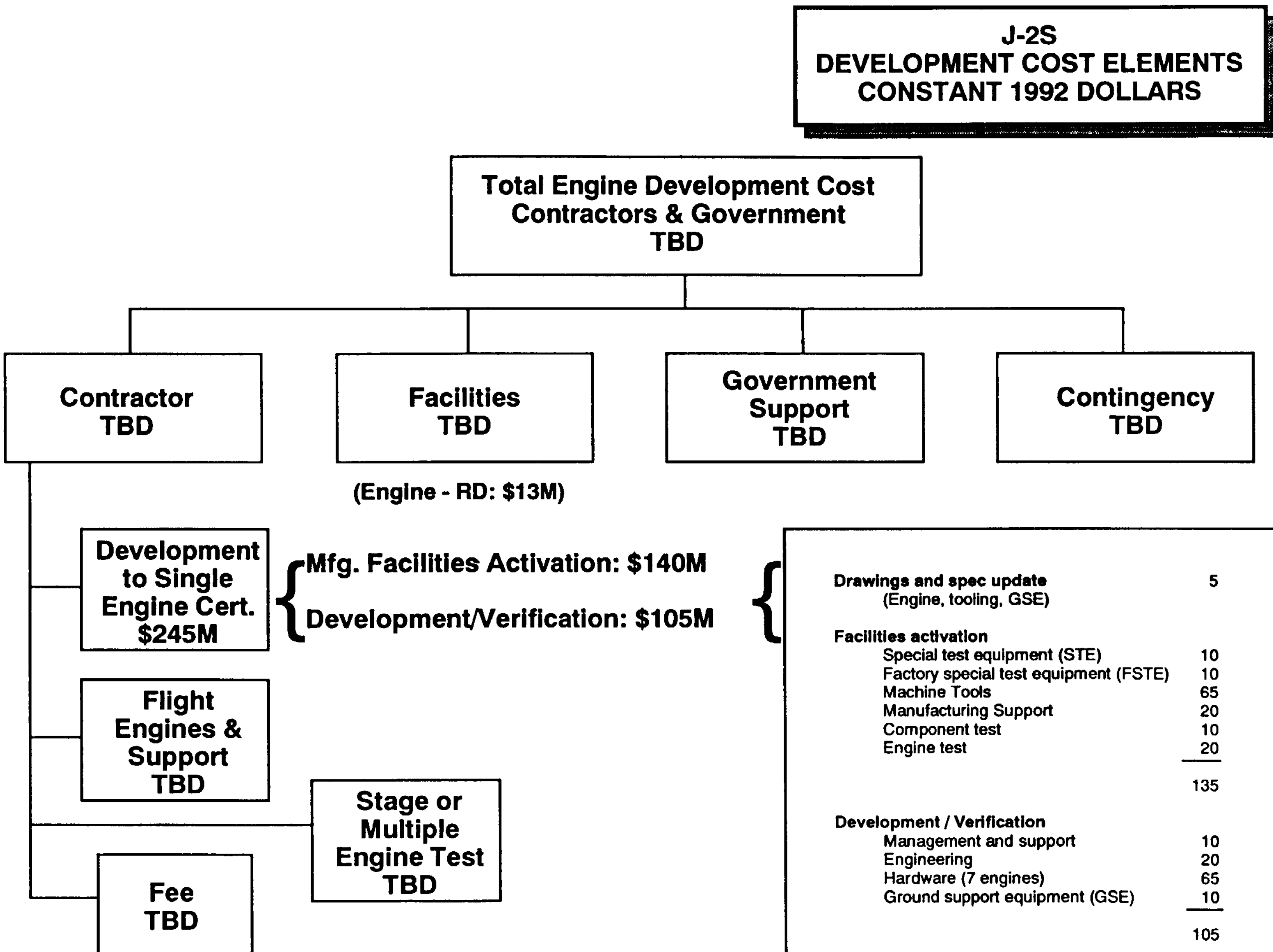
Program Plan Groundrules and Assumptions

- Engine life requirement will not exceed previously established 30 starts/3750 seconds for J-2S
- "Engine Restart" is considered to be a requirement
- Existing government resources will be utilized when feasible and cost effective
- Single engine certification only will be addressed
- Program restart plans presume the use of Rocketdyne facilities for engine assembly
    - Co-location of assembly and test facilities should be a future study objective
- The restart planning will be based on review and update of existing drawings and specifications
- Rocketdyne facility modifications and costs will be identified for both engine and component hot fire test
- Propellant costs will not be included

J-2S Restart Study
Development Cost Elements

This chart shows what cost elements are included in the non-recurring cost estimate. The cost shown is for contractor effort required to achieve single engine operation certification. Estimates for flight engines are provided later in this briefing as a function of quantity produced and yearly production rate. There is no fee associated with these estimates. Estimates for clustered engine application must be tied to a specific configuration to account for thermal protection and MPT testing requirements.

Facility costs are highly dependent on location, who was conducting the work, and other factors. An estimate is provided for the refurbishment of a Rocketdyne test facility which could perform the desired testing. Government support is not estimated nor is a contingency fund.



Drawings and spec update	5
(Engine, tooling, GSE)	
Facilities activation	
Special test equipment (STE)	10
Factory special test equipment (FSTE)	10
Machine Tools	65
Manufacturing Support	20
Component test	10
Engine test	20
	135
Development / Verification	
Management and support	10
Engineering	20
Hardware (7 engines)	65
Ground support equipment (GSE)	10
	105
Total	245

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J-2S Restart Study
J-2S Restart Program Schedule

The program schedule assumes a go-ahead is given at the start of fiscal year 1994 with money released in mid fiscal year 1993 to initiate long lead procurement. This effort accounts for the progress made towards restart by this study. System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR) are shown taking place during the first two years of the program. Hardware fabrication is initiated at the start of fiscal year 1995 with component test preceding this by six months using existing hardware. System level testing is initiated during the last quarter of fiscal year 1996 and completing certification midway through fiscal year 1998. The delivery dates of the six development engines and the two certification engines are shown. The funding is shown on a yearly basis in constant fiscal year 1992 dollars.

Engineering includes all design, drawing update, analysis of redesigned components, component and system level test data review and discrepancy/anomaly resolution. Management and support includes program management, schedule and cost reporting, and customer coordination. Manufacturing support includes all manufacturing planning, quality control, and engine assembly oversight. Long lead procurement includes all castings and nozzle tubes. Tooling preparation and hardware fabrication includes the effort required to produce the component piece parts and assemble the engines.

J-2S Restart Study

J-2S Restart Program Schedule

Task	FY92	FY93	FY94	FY95	FY96	FY97	FY98
Program Milestones			SRR (Q1), PDR (Q2)	CDR (Q2)	D1 (Q4)	D2, D3, D4, D5, C1, C2	
					Engine Deliveries	Engine Deliveries	
Mk-29FD w/ hydrostat. bearing	RD IR&D	RD IR&D					
MSFC NRA	$50K	$50K					
Engineering			$6M	$6M	$3M	$3M	$2M
Management & Support			$3M	$3M	$3M	$3M	$1M
Manufacturing support			$3M	$7M	$8M	$3M	
Long lead procurement		$1M					
Tooling preparation (incl. STE)			$15M	$40M	$30M		
Hardware fabrication (incl. GSE)				$25M	$35M	$15M	
Component testing			$1M	$4M	$4M	$1M	
Engine testing					$3M	$10M	$7M
	$50K	$1.05M	$28M	$85M	$86M	$35M	$10M

Note: Shown in constant FY92 dollars

Total Non-recurring Cost = $245M

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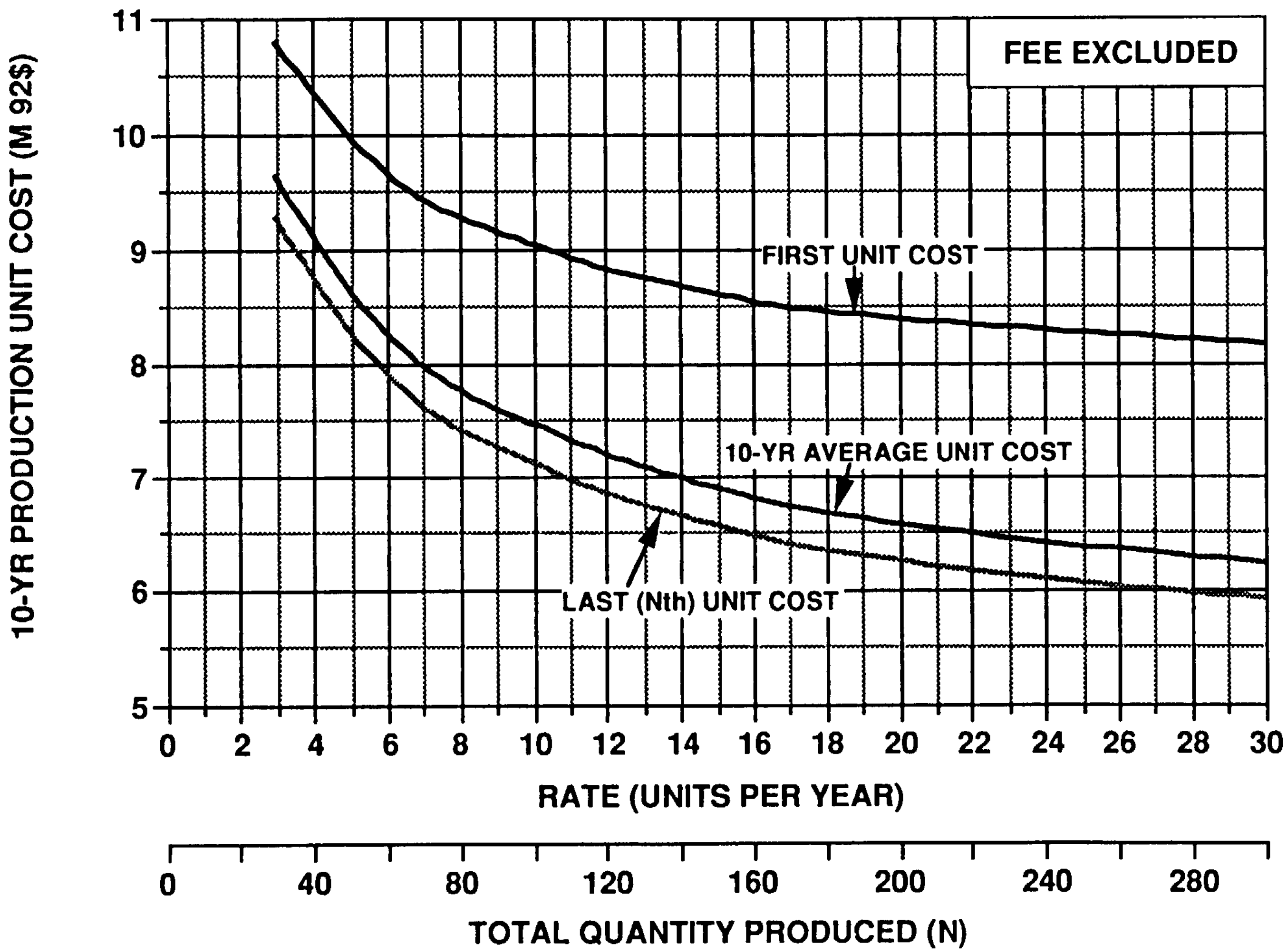
J-2S Restart Study
Predicted Production Costs

This chart shows the predicted production costs as a function of rate in units per year and total quantity produced assuming the established Rocketdyne learning curve. The three curves, from top to bottom, show first unit cost, 10 year production average unit cost, and last (or Nth) unit cost. These curves are for cost only and do not include fee or contingency.

This cost estimate is based on historical J-2S fabrication touch labor escalated to FY 1992 wrap rates at Rocketdyne's production facilities. This estimate does not account for the recommended producibility improvements listed under the producibility assessment. Effort that was beyond the scope of this study in the areas of manufacturing planning and cost estimating would be required to incorporate the results.

PREDICTED PRODUCTION COSTS
J-2S ENGINE



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Rocketdyne Division

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J-2S Restart Study
Test Philosophy

When formulating a proposed test matrix, a logical "test philosophy" was formulated to justify the number of tests and engines required for the restart program. This approach produces a very conservative test matrix that provides an extremely high confidence level in success.

The real requirement for any "development" engines for any restart program is to demonstrate repeatable performance with previous data and within a selected sampling of new production engines. In order to be completely valid, the program must accrue test experience at all anticipated operating levels. The proposed matrix examines altitude and sea level performance, inlet pressure variations, varied propellant utilization valve settings, as well as operation at all corners of the operating box. The conservative testing assumed verifies that the engines being produced are traceable to the original engines in all operation conditions.

Upon completion of the "development" phase, two engines will undergo a qualification/certification test series to demonstrate full life capability on flight configuration engines. While the life requirement is taken directly from the J-2S model specification, the test profiles themselves should be reflective of the mission profile of the proposed application.

Test Philosophy

- Demonstrate repeatable performance with previous data
- Accrue test experience at all operating levels
  - Altitude and sea level
  - Inlet pressure variations
  - Varied PV settings
  - Demonstrated "corners of operating box"
- Certify two engines after development
  - Cert test to full life
  - Cert test profiles TBD

J-2S Restart Study
Baseline J-2S Engine Test Matrix

This chart shows how a conservative engine development testing can examine all pertinent operating points using the proposed four development engines and two qualification/certification engines. This matrix presumes that either an altitude simulation facility, similar to that previously used at AEDC, or a diffuser nozzle is available for the test program. The total tests required to perform this matrix is 210 tests for a total duration of approximately 25,000 seconds. This is compared to the J-2S development program which required 273 tests and 30,858 seconds.

Four of the six engines will be tested to the model specification life of 3750 seconds while two will undergo extended testing to 5000 seconds. This is only a preliminary test matrix which takes a very conservative approach to verifying the flight readiness of the engine.

Testing is shown at sea level as well as at simulated altitude (using a diffuser or the AEDC J-4 facility). Altitude testing is included to demonstrate that all engine operating parameters can be related to the sea level results, thus validating the extensive sea level test matrix.

The test objectives represent broad categories of interest. Start and cutoff transient testing will revalidate the pressure ladder sequencing and establish timing limits for this control scheme. Mainstage performance testing will verify analysis on delivered engine thrust, specific impulse, and operating mixture ratio. Endurance/durability testing will demonstrate that component life is adequate. Mixture ratio control testing will check the operation of the propellant utilization system. Idle mode testing will examine operation at tankhead low thrust idle mode to ensure stability and characterize performance. Safety limits testing will be performed to demonstrate all margins are being satisfied. Gain factors testing will be performed to anchor analytical models and set up guidelines for future engine trim reorificing. Combustion stability verification will use injector mounted bombs to demonstrate that the injectors adequately damp induced instabilities. Gimbal testing will be performed to ensure proper operation of this system and to verify dimensional tolerances during this operation. Stage tank pressurization testing will verify that the engine autogenous pressurization will meet stage demands. Start-restart capability testing will demonstrate the engine's ability to perform in-flight restarts without the need for manual servicing. Engine qualification testing will be performed on two engines to clear the production line for flight operations.

J-2S Restart Study

Baseline J-2S Engine Test Matrix

Hot Fire Test Objectives (A)	Engine 1	2	3	4	5	6
Start & Cutoff Transient	S	S	S/A	S	S	S/A
Mainstage Performance	✔	✔	S	✔	✔	S
Endurance/Durability		✔	✔	✔	✔	✔
Mixture Ratio Control	✔	✔	✔	✔	✔	✔
Idle Mode (B)	✔	✔	S/A	✔	✔	S/A
Safety Limits Testing		✔	S/A	✔	✔	S/A
Gain Factors	✔		✔	✔	✔	✔
Combustion Stability		✔		✔		
Gimbaling			S	✔	✔	S
Stage Tank Pressurization	✔		S/A	✔	✔	S/A
Start-restart Capability		✔	S/A	✔	✔	S/A
Qualification					✔	A
TESTS	30	45	30	45	30	30
SECONDS	3750	5000	3750	5000	3750	3750

(A): S – sea level or site test
A – vacuum altitude simulation

(B): T – tank head idle mode

Preliminary

210 tests
25,000 sec.

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J-2S Restart Study
Conclusions

This study provided the confidence needed to state without doubt the the J-2S production could be reinitiated within reasonable costs and schedules. No significant technical issues were identified in either the producibility study or in the review of previous technical data. Areas of potential cost reduction were identified which could be quantified to a greater extent with further manufacturing planning. The proposed schedule can be met with no foreseeable impacts.

All of the design changes are sound technically and thus prudent risks. Many of the processes examined have already been applied to restarts of Expendable Launch Vehicle engines such as those used on Atlas and Delta launch vehicles. The changes provide reductions in cost, schedule, operability concerns, reliability concerns, or, as in the case of many of the changes, address all of these issues. Finally the testing required to fully validate the proposed changes is completely within the scope of the test series, which would probably be applicable even if no changes were made form the original J-2S drawings.

The investigation team is confident that the feasibility of the J-2S production restart has been proven. A team is now in place at Rocketdyne and it is ready to begin when a need is identified.

J-2S Restart Study
Conclusions

- Feasibility of J-2S production restart demonstrated
  - No technical issues found
  - Could be produced to existing drawings
    - Only engine electronics absolutely require replacement
    - No material changes required
    - All processes are still possible

- Significant cost reduction potential identified
  - 24 Changes for producibility (no change in form/fit/function)
  - 20 Changes in fabrication technique (i.e., castings, die forging, etc.)

- 23 Other desirable changes identified
  - 12 Material substitutions
  - 11 Reliability/operability enhancements

- All recommended changes are prudent risks
  - Mitigated by ELV experience
  - Justified by benefits
  - Verification test impact within scope of existing plan

J-2S restart production feasibility demonstrated

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13. ABSTRACT *(Maximum 200 words)*

The objectives of this study were to assess what design changes would be required to reinitiate production of the J-2S engine for use as a large high energy upper stage engine. The study assessed design changes required to perform per the J-2S model specification, manufacturing changes required due to obsolescence or improvements in state-of-the-practice, availability issues for supplier provided items, and provided cost and schedule estimates for this configuration.

This study provided the confidence that J-2S production could be reinitiated within reasonable costs and schedules. No significant technical issues were identified in either the producibility study or in the review of previous technical data. Areas of potential cost reduction were identified which could be quantified to a greater extent with further manufacturing planning. The proposed schedule can be met with no foreseeable impacts.

The results of the study provided the necessary foundation for the detailed manufacturing and test plans and non-recurring and recurring cost estimates that are needed to complete the effort to reinitiate production of the J-2S engine system.

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