April 1993

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

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

Technical Area 3
Advanced Transportation System Studies
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.
Objectives

J-25 Restart Study
• J-2S Restart Program Plan
• Throttling Assessment
• J-2S Background
• J-2S Study Approach
• J-2S Baseline

Agenda
J-2S Baseline
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 chilldown 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.
30,858 sec
6 Engines, 2/3 Tests, Production Configuration Testing Experience

Description

Including accessories

8,200 lb

Basic engine dry weight (lb)

8,225 lb

Engine mixture ratio calibration O/F (15 oz)

6.5:1

Nozzle stagnation (psia)

1,200

Nominal chamber pressure (psia)

426

Nominal vacuum specific impulse (sec)

265,000

Performance & Weight

J-25 Basic Engine Features

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

J-25 Restart Study
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.
High Value/Low Risk Changes Sought

- Address all outstanding J-25 development concerns
- Maintain original structural margins of J-25 engines
- Retain full form/fit/function of original designs
- Minimal qualification requirements
- High technical maturity
- Rockeydyne experience
- Demonstrated cost/cycle time reduction
- Improvement evaluation guidelines defined

Approach

J-25 Restart Study
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.
Define Program Plan

Assess

Configuration

Review Baseline

High Value?

Yes

State-of-the-Art Practice
Reliability/Operability
Environmental
Obsolescence
Material Substitution
Productivity
Design Modifications

History

No

Hold For Future Study

Low Risk?

Task Flow

J-25 Restart Study
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 flights configuration engines tested a total of 26 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 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 upgrading 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.
(Thruster uprating to 320 Kip (analytical only)

Nozzle extensions (analytical only)

- Powered idle mode
- Maintenance
- Throttling operation
- Life extension to 12,000 sec/30 starts between overhauls
designed (as partially demonstrated)
Features beyond model spec requirements
Development completed -- Ready for qualification

- >6' 600 sec, low thrust (idle mode)
- <21' 400 sec, maintainance
- 265 tests (sea level & vacuum)
- 6-flight configuration engine built and tested
- Extensive J-25 engine program conducted
- Experimental engine base 1964-1968
- Engine/Component development of J-25 1965-1972

J-25 History
J-25 Restart Study
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 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.
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<td>1</td>
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<td>Altitude simulation test (engine J-2073)</td>
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<td>5</td>
<td></td>
<td>Start-stop tests</td>
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<td>2</td>
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<td>Demonstration of restart capability tests</td>
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<td>1</td>
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<td>Safety &amp; leakage checks</td>
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<td>Start-restart test couples</td>
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<td>16</td>
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<td>Safety limits tests</td>
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<td>Heat exchanger pressurization performance point tests</td>
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<td>Hydrogen tank pressurization performance point tests</td>
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<td>7</td>
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<td>Mainstage performance tests</td>
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<td>5</td>
<td></td>
<td>Mixture ratio control valve calibration point tests</td>
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<td>8</td>
<td></td>
<td>Climbing pattern cycles</td>
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<td>3</td>
<td></td>
<td>Programmed mixture ratio; 470 sec. duration tests</td>
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<td>1503.9</td>
<td>1500</td>
<td>Operating limits and Performance Tests</td>
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<tr>
<td>3807.4</td>
<td>3750</td>
<td>Performed endurance test, required</td>
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<tr>
<td>30</td>
<td>30</td>
<td>Total duration at high mixture ratio</td>
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J-2S Endurance, Safety, and Performance Testing
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-2S Engine Application Investigations

Numerous inquiries have been received & addressed for J-2S engines.
Productivity Assessment
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 feedback 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.
Other components
Flight instrumentation
Ducts, lines, and interfaces
Combustion devices

Other major areas assessed at part level

Engine valvess
Thrust chamber tap-off port
Turbomachinery

Three areas selected for review in greater depth

Interviews with personnel who worked J-2S
Examination of internal documents
Reviews of drawings
All major components examined

Productivity Assessment
J-2S Restart Study
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 Engine Components Evaluation
J-2S Restart Study
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.
Updated tabulation techniques
Noted problems identified during test program
Consulted with J-25 value development engineers
Engine values were examined for operational issues
Incorporated modern producibility techniques
Component stood to benefit from improved thermal modeling
Document indicated the test configuration was costly & time consuming
Thrust chamber tap-off port reviewed for durability & producibility
Applicability of NLS turbopump producibility effort
Recent rebuild and modification of MK-29 under IR&D
MK-29 turbopump experience in J-2 linear engine
Turbo machinery history reviewed for more data

In-Depth Producibility Review
J-25 Restart Study
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.
• Update electronics (old parts no longer available)
  • Adopt precision end point tooling for ducts
  • Machine cells/multi-purpose tooling
  • Casting/Forging Improvements
  • Laser operations
  • Robotics and numerical control machining
  • Implement state-of-the-art fabrication methods

General Recommendations
J-2S Restar Study
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.
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 castable. The film coolant manifold feeder holes will still have to be machined.
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.
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
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.
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.
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.
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.
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.
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 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.
Solid Propellant Turbine Starter (SPTS)

J-2S Restart Study

- Study should be performed for more modern Initiator
- NSI baseline
- Initiator
  - Baseline configuration - build to print
  - Alternate grains require additional study
  - Hercules Inc. owns formulation of RD-135 propellant

- Solid propellant canister
  - NASA standard Initiator (NSI)
  - Solid propellant/burst diaphragm canister

- Consists of two separate parts
SOLID PROPELLANT TURBINE STARTER

- Case
- Aft Head
- Aft Plate
- Forward Plate
- Basket
- Propellant
- Initiator (2)
- Detector Link (2)
- Pellets
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.
Minor Change to Dynamic Seals
- Stable Ball Bearing Carrier, Preload & Anti-Rotation System
- Stiffen Pump End Bearing Support

Replace Machined Impeller with Casting, P/N 7R045511-7

Same as current drawing (P/N461500) except:

- Proposed Restauration Configuration

- Cast Impeller - was Three Piece Machined From Forgings
- Potential Productivity Improvements
  - Loss of Bearing Support Pilot
  - Loss of Bearing Preload
  - "Cocking" Ball Bearing Carrier & Anti-Rotation Key
  - Pump End Ball Bearing Unloading
  - Corrected with Redesign, Validated with Tests
  - Inducer Suction Performance & Blade Fatigue

Problems Noted During Test

- Impeller - from Forged Ti-5Al-2.5Sn E11 to Cast Ti-6Al-4V E11
- Materials

FUEL TURBOPUMP (MK29-F/P/N461500)
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.
Minor Changes to Dynamic Seals - Vendors no longer in business

Use successful basic MK-290 configuration

Proposed Restart Configuration

None Identified

Potential Productivity Improvements

No Significant Issues were Incurred

Problems Noted During Test

No Changes Required

Materials

Oxidizer TurboPump (MK29-O PN460430)
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.
Double Wall Bellows

Torque Ring

FUEL INLET DUCT

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

ALTERNATIVE

MAINTAINING A VACUUM IN THE JACKET HAS BEEN TROUBLE-SOME

ASSEMBLY ALIGNMENT IS NOT EASY

DESIGNED FOR A MATCHED SPRING RATE WITH THE OXIDIZER INLET DUCT

A LARGE NUMBER OF PRECISION PIECES

NO MATERIALS PROBLEMS
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).
TOURNE RING

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

ALTERNATIVE

ASSEMBLY ALIGNMENT IS NOT EASY
A LARGE NUMBER OF PRECISION PIECES
NO MATERIALS PROBLEMS

OXIDIZER INLET DUCT

SPHERICAL BEARING
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 oversized ducts and accepting the associated weight penalty.
UP TO DATE STRESS ANALYSIS LEADING TO AN OPTIMUM DESIGN

ALTERNATIVE

NO MATERIAL PROBLEMS

FUEL DISCHARGE DUCT
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

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

ALTERNATIVE

NO MATERIAL PROBLEM
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

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

ALTERNATIVE

NO MATERIAL PROBLEM
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.
Alternative

No material problem

Idle mode duct
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.
UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

ALTERNATIVE

NO MATERIAL PROBLEM

OXIDIZER TURBINE BYPASS
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

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

ALTERNATIVE

OXIDIZER TURBINE

FUEL TURBINE
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

NOZZLE MANIFOLD

UP-TO-DATE STRESS ANALYSIS LEADING TO OPTIMUM DESIGN

ALTERNATIVE

FOR INTEGRATED HEAT EXCHANGER

SEE FIGURE

NO MATERIAL PROBLEM
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

Fuel turbine inlet

Tapoff manifold

Up-to-date stress analysis leading to optimum design

Alternative

Redesign of hot gas tapoff system has only an end point effect

No material problem
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.
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.
NOTE: DETAIL DWGS NOT ON MICROFICHE & CANOGA - DWGS MAY NOT EXIST

IDENTIFIED POTENTIAL PRODUCIBILITY IMPROVEMENTS

(USED ON MFY, MOV, FBY, HGTY, & IMY)

NAS-27480 POSITION TRANSDUCER REVIEWED - STILL PRODUCABLE

PROPELLANT UTILIZATION VALUE: ELECTRIC MOTOR ACTUATOR OBSOLETE

VALUE WAS REDESIGNED, BUT NOT FABRICATED

HOT GAS CHECK VALUE: SYSTEMS IMPROVED TIGHTER LEAKAGE REACT

IDENTIFIED MAJOR DESIGN CHANGES

7075 T73 APPROVED FOR USE IN DRY

MOST HOUSINGS WERE 3-D MACHINED 7075 AL ALLOY

IDENTIFIED MAJOR SUBCOMPONENT MATERIALS

J-2S COMPONENT PLAN DATABASE

POTENTIAL FABRICATION AND RECOMMENDED TRADE STUDIES ENTERED INTO

FUNCTIONAL DESCRIPTIONS, MATERIALS, DESIGN CHANGE ASSESSMENT,'"
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 can 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.
For better machining characteristics
BUTTERFLY - DIE FORGING - EVALUATE 431 CRES AND OTHER MATERIALS
HOUSING - DIE FORGING OR CASTING

Potential Productivity Improvements

- SHAFT SEAL AND GATE SEAL LEAKAGE
- ERGATIC POSITION INDICATOR OUTPUT
- SHAFT BEARINGS - REDESIGN INCREASED THICKNESS
- THERMAL CRACKING OF HOUSING AT THIN SECTION ON UPTREAM SIDE OF

Problems

- SHAFT AND ACTUATOR SEALS - MYLAR SHEET
- BUTTERFLY SEALS - KEL-F SHEET - HEAT FORMED
- ACTUATOR PISTONS - A-286
- SHAFT ROLLER BEARINGS - 440 C
- BUTTERFLY AND SHAFTS - INCO 718
- HOUSING - 7075 ALUMINUM ALLOY - 3D MACHINED

Materials

MAIN FUEL VALVE 41320
MAIN FUEL VALVE
99-411320

SEQUENCE OUTLET
SEQUENCE POPPET
SEQUENCE INLET
SEQUENCE VALVE ASSY
SPRING
LINK
OPENING PORT
BUSHING
PISTON
GUIDE
HOUSING
FLOW
CLOSED PORT
SEAL
BEARING
ACTUATOR SHAFT
IDLER SHAFT
GATE
RETAINER
TRANSUDER

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S-C-8
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.
For better machining characteristics
- Butterfly - Die Forging - Evaluates 431 Cases and Other Materials
- Mylar Shaft Seals - Improved Sealing Capability
- Housing - Die Forging or Casting

Potential Productivity Improvements
- Problem Resolved
  - Butterfly Seal Failure on Short Tests - Seal Thickness Increased

Problems
- Actuator Seals - Mylar Sheet
  (Former)
- Butterfly and Shaft Seals - Kel-F Sheet (Butterfly Seal Heart)
- Actuator Pistons - 4.286
- Shaft Roller Bearings - 440 C
- Butterfly and Shafts - Inco 718
- Housing - 7075 Aluminium Alloy - 3D Machined

Materials

Main Oxidizer Valve 41225
MAIN OXIDIZER VALVE
99-411225

- CLOSING PORT
- OPENING PORT
- COMPENSATOR
- LINK
- DRIVE SHAFT
- GATE
- FLOW
- SEAL RETAINER
- TRANSUDER
- IDLER SHAFT

S-C-12

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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.
update electric motor design

potential producibility improvements

reduce hydraulic torque
decrease thickness of gate at edge of flow holes to
and calking
increase clearance of rotating parts to eliminate rubbing
high threshold voltage and failure to respond

problems

shaft roller bearings - 440 C (not verified)
butterfly and shafts (not verified)
housing - aluminium casting (not verified)

materials

propellant utilization valve 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.
Easier machining material for butterfly and shafts
Die forging for butterfly
Casting for housing and caps

Potential productivity improvements
Requirements and costs at relatively low pressure
None. The design is simple; does not have rigorous sealing

Problems
Shaft and actuator seals - mylar sheet
Butterfly seals - Kel-F - heat formed
Actuator pistons - A-286
Shaft roller bearings - 440 C
Butterfly and shafts - Inco 718
Housing - 7075 aluminum alloy - 3D machined

Materials
Fuel bypass valve 41180
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.
REVIEW MATERIALS AND USE OF DIE FORGINGS
VALUE TO VALUE FLOW VARIATION WHEN CLOSED
CHANGE IN VALUE CLOSED LEAKAGE CAUSED BY THERMAL EFFECTS AND
INITIALLY REQUIRED A SEAL. A SEAL WAS ADDED BECAUSE OF LARGE
INVESTIGATE NEED FOR A BUTTERFLY TO HOUSING SEAL (3-2) DID NOT
EVALUATE WEIGHT REDUCTION HOUSING AND GATES

POTENTIAL PRODUCTIVITY IMPROVEMENTS
DISTORTION - REDESIGN NOT TESTED
SEIZED SHAFT BEARINGS - HOUSING REDESIGNED TO REDUCE THERMAL
SMALLER DIAMETER
BUTTERFLY/HOUSING INTERFERENCE - GATE REWORKED TO
VALUE DID NOT GO FULL CLOSED

PROBLEMS
SHAFT BEARINGS - HAYNES 25
BUTTERFLY AND SHAFT - RENE 41
HOUSING - INCO 625

MATERIALS

HOT GAS TAPPOE VALUE 557824
FLOW

BEARING (2)

SEAL ASSY

SHAFT

BEARING

SLEEVE

PISTON

BODY ASSY

STOP

OPENING PORT

CLOSING PORT

TRANSDUCER

BEARING ASSY

HOUSING

Hot Gas Tapoff Valve

99-557824
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.
POTENTIAL PRODUCIBILITY IMPROVEMENTS

- Machined KEL-F shaft seals replaced by sheet KEL-F

PROBLEMS

- Actuator seals - Mylar sheet
- Shaft seals - KEL-F sheet
- Ball seal - Machined KEL-F
- Actuator piston and shaft roller bearings - 440 C
- Ball and shafts - INCO 718
- Housing - 7075 aluminium alloy

MATERIALS

IDLE MODE VALUE 411385
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.
Design study of poppet
Design study to reduce the number of parts
Casting for housing

Potential productivity improvements

The KEL-F and makes retention difficult
In thermal coefficients may produce unacceptable stresses in
Molded KEL-F poppet head is a potential problem. The difference
Leakage

Problems

Poppet - 321 cross with molded KEL-F head
Bellows - INCO 718
Housing - 321 cross

Materials

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.
Review Design for Forging and Casting Applications
Review Materials and Update
Potential Productivity Improvements
None Recorded in Engine Test Summary
Problems
(Not Verified)
Materials

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.
Coatings for Poppet and Seat
Investigate Anti-Galling Materials & Low Friction Surface

Reduces Friction and Improves Reliability
Problem of Hanging Open By Eliminating Metal to Metal Rubbing.
Add Shrink Fit Teflon Sleeve on Poppet Stem. This May Eliminate
Eliminate Threads and Use Structural Weld

Potential Productivity Improvements
None

Problems
Other Materials - Crees or Nickel Alloys (Not Verified)

Seal - Teflon Bar

Materials

Helium Fill and 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.
Review the requirements and do a design trade study.

- On a poppet check valve but it was not fabricated.
- The HGCV allowable leakage were in work. A design was released.
- System design changes to detect ignition detection and reduce.

Potential productivity improvements:

- The springs shielded from the hot gas.
- Released. The flapper edge thickness was to be increased and
- Design concepts were studied to resolve the problem but not
- Flapper cracked in thin section near outer edge.
- Springs lost load due to high gas temperature.

Problems:

- Spring (2 read) - (not verified)
- Shaft (not verified)
- Flapper (2 read) - (not verified)
- Housing - (not verified)

Materials:

Hot gas check valve 309065
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 - TEFOLON BAR

- PROBLEMS
  - REVERSE LEAKAGE
  - HUNG OPEN

- POTENTIAL PRODUCIBILITY IMPROVEMENTS
  - ELIMINATE THREADS AND USE STRUCTURAL WELD
  - ADD SHRINK FIT TEFOLON 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
MISCELLANEOUS CHECK VALVES

55775-11 LOCATIONS

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

55775-11 LOCATIONS

OXIDIZER PUMP INTERMEDIATE SEAL
CHECK VALVE

ALL FILTERS 10 MICRON

POPPET

BODY

TEFLON SEAL

SEAT ASSY

S-1-3
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 - TEFOLON BAR

- PROBLEMS
  - REVERSE LEAKAGE
  - HUNG OPEN

- POTENTIAL PRODUCIBILITY IMPROVEMENTS
  - ELIMINATE THREADS AND USE STRUCTURAL WELD
  - ADD SHRINK FIT TEFOLON 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
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.
Effectiveness - using results of studies performed between 1968-1971
an analysis of design, cost, schedule, operations, and mission
agreed impact to design, cost, schedule, operations, and mission
sensor performance, etc.
needs, would present no technical difficulty in terms of environment,
upgrade to higher thrusts, although perhaps altering measurement

FLEXIBILITY AND TRADEOFFS

configuration changes will need to be documented
interfacing will have to be studied and the numerous resulting
moderitization of hardware used for ports, sealing, and electrical
625 should be suitable for J-2S applications
commonly used housing material for flight instrumentation, inconel
throughout exploration, due to extensive SSME LOX-H experience
materials compatibility issues (for metals and non-metals) are

MATERIALS AND INTERFACE CONSIDERATIONS

• offers improvements over the original parts (which are no longer in
  availability within cost and schedule constraints
  instrumentation which meets the requirements of the J-2S is readily

TECHNOLOGY STATUS

Flight Instrumentation Summary
J-2S Restart Program
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.
<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Measurement Package</th>
<th>Connector Type</th>
<th>Connector Code</th>
<th>Tap No.</th>
<th>Tap Range</th>
<th>Temperature Type</th>
<th>Temperature Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>OXIDIZER TURBINE INLET</td>
<td>Fuel Turbine Inlet</td>
<td>Type Resistance</td>
<td>7126</td>
<td>448/419°F</td>
<td>2.0</td>
<td>517/5°F</td>
<td>N55-773233</td>
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<td>OXIDIZER TURBINE INLET</td>
<td>Fuel Turbine Inlet</td>
<td>Type Resistance</td>
<td>7124</td>
<td>425/430°F</td>
<td>2.0</td>
<td>517/5°F</td>
<td>N55-7721155</td>
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<td>OXIDIZER TURBINE INLET</td>
<td>Fuel Turbine Inlet</td>
<td>Type Resistance</td>
<td>7122</td>
<td>420/200°F</td>
<td>2.0</td>
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<tr>
<td>OXIDIZER TURBINE INLET</td>
<td>Helium Tank</td>
<td>Type Resistance</td>
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<td>420/200°F</td>
<td>2.0</td>
<td>517/5°F</td>
<td>N55-7721151</td>
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<tr>
<td>MAIN FUEL INJECTION DUAL</td>
<td>Main Fuel Injection; Dual</td>
<td>Type Resistance</td>
<td>7131</td>
<td>425/100°F</td>
<td>2.0</td>
<td>517/5°F</td>
<td>N55-77441</td>
</tr>
</tbody>
</table>

**Note:**
- **SYSTEM:** 1-2S FLIGHT AND RELATED INSTRUMENTATION
- **SENSOR PART NO:** J-ON
<table>
<thead>
<tr>
<th>Sys</th>
<th>Measurement</th>
<th>%</th>
<th>Range</th>
<th>Connector</th>
<th>Electro</th>
<th>Code</th>
<th>Tap POV</th>
<th>Tap PFE</th>
<th>Type</th>
<th>Sensor</th>
<th>Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

J-2S Flight and Related Instrumentation
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.
I

element coupled to an electrical bridge consists of a mechanical force summing element, 25 static pressure sensor

currently available designs based upon improved technology for either static pressure (ypical; strain

gage type) or dynamic pressure (piezoelectric)

RC7001
RC7002

SBM TTB

KEW pressure sensor design experience may also apply numerous custom designs completed and hot-fired on SSM E TTB

Synergy with ongoing programs

Housing material is Inconel 625

Qualification requires structural analysis specific to J-25T forwarded custom designs (e.g.; Stahlham, CCC, Enduro, Dynamic, Kistler, etc.)

Outer envelopes may resemble SSM E light sensors; direct retrofit or straight-

Similar parts available for pressure measurement needs

Instrumentation--Pressure Sensors

J-2S Restart Program
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.
Numerous custom designs completed and hot-fired on SSME TTB

Synergy with ongoing programs

- Housing material is Inconel 625
- Forward custom designs (from e.g., Rosemount, Tayco, ARL, etc.)
- Outer envelopes resemble SSME LIIghil sensors: direct retrofit or straight-
- Similar parts available for temperature measurement needs

Instrumentation—Temperature Sensors

J-2S Restart Program
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.
Instrumentation--Flow Sensors

J-25 Restart Program

Synergy with ongoing programs

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

Performance monitoring, mixture ratio control, and throttling all possible through trade study for NLS (up to 8300 gpm) and similar applications performed.
- Alternatively, conventional turbine type volumetric flowmeters in use on SSME mounting assessment, cryogenic vibration testing to take place in 1993.
- In development on Technology Testbed for SSME (cryogenic flow testing).

SSME uses similar technology, straightheads, and pickup coils, consisting of rotor assembly, low volumetric, liquid flow transducer, original J-25 turbine-type,

Modern noninvasive, ultrasonic flowmeter, analogically with flowrate velocity (speed of sound), which varies difference between upstream and downstream using piezoelectric transducers to sense the flow rate.

Flow measurements, system analysis studies done for NLS and OTV.
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.
Synergy with ongoing programs

- Use of two speed sensors can provide torque information nonintrusively
- Trade study for NLS (in conjunction with torque measurement) in progress
- Progress, supporting near term hot-fire tests
- Currently in development on Technology Testbed for SSME (fabrication in progress)

Performance and hardware health

- Preserves structural integrity of turbo pump while providing a measure of
  integrity of turbo pump (such as a speed nut)
- Simple and robust; nonintrusive provided that magnets can be embedded
- New technology a viable replacement for original speed sensor

Instrumentation--Speed Sensors
J-2S Restart Program
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.
- Skin Temperature Sensors (SSME RCI.1624 or RCI.1751)
- Thermocouples (SSME RCI.1675, RFE.1699, RFE.1700, or RFE.1719)
- Proximity Sensors (SSME RCI.1690, RFE.1691, or RFE.1712)
- Accelerometers (SSME RCI.1701 and RFE.1701)

Evolution of engine performance and component condition
Parts also available for noncritical measurements -- for developmental

Valve Position Sensor technology from SSME, NLS, Alfas, and Key
Ignition Detection Technology based upon experience with SSME and Alfas

Equivalent parts available for ignition detection and position

Other Sensor-Related Components
J-25 Restart Program
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
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.
A 886 cubic inch tank is available which exceeds

This is a 700 cubic inch tank

No material problem
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 mechanism since it was never used because all six J-2S engines were well within thrust alignment specifications.
GIMBAL BEARING
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.
Both Interfaces May Have To Be Redesigned To Mate With Vehicle

No Obvious Mechanical Change

Fluid Line Interface

Update Electrical Connections To State-of-The-Art

Electrical Interface

Interface Panels
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.
NO STABILITY PROBLEM WITH THE TWO TUBE DESIGN

HEAT EXCHANGER

OXIDIZER TURBINE EXHAUST DUCT
This chart summarizes 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.
<table>
<thead>
<tr>
<th>No Change</th>
<th>Various Pressures R Out for Specfic Application</th>
<th>Misc. Tubes &amp; Hoses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>H/G Tap-out Dust</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>411080</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>308040</td>
</tr>
<tr>
<td>1</td>
<td>Cross-Over Dust</td>
<td>307714</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>307715</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>411081</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>411079</td>
</tr>
<tr>
<td>1</td>
<td>Use Precision End Point Tooling</td>
<td>411077</td>
</tr>
<tr>
<td>*</td>
<td>Redesign Complety</td>
<td>409899</td>
</tr>
<tr>
<td>*</td>
<td>Fuel in Dust</td>
<td>409900</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>Ducts</td>
</tr>
<tr>
<td>1.4</td>
<td>Update Dynamic Seals</td>
<td>460430</td>
</tr>
<tr>
<td>1.2.3.4</td>
<td>Update Impeller, silicon &amp; modry bags, 8 update dynamic seals</td>
<td>MK-29 Fuel T/P</td>
</tr>
<tr>
<td>1.2.3.4</td>
<td>Turbomachinery</td>
<td>MK-29 Ox T/P</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No Change</th>
<th>Spec/Change</th>
<th>ASL System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Update Initiator and Propellant</td>
<td>651349</td>
</tr>
<tr>
<td>2</td>
<td>Use castings to replace welded structures.</td>
<td>Nozzle/Chamber</td>
</tr>
<tr>
<td>2</td>
<td>Full length nozzles jacket with brazed mantolds.</td>
<td>T/C-Off Pornt</td>
</tr>
<tr>
<td>2.3</td>
<td>Use castings to replace por. mantolds &amp; J-Tubes.</td>
<td>T/C-Off Pornt</td>
</tr>
<tr>
<td>1.2</td>
<td>Use castings for body to eliminate welds. Free post.</td>
<td>Trust Chrm. Assy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component / Drawing</th>
<th>Number of Changes from Basic Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mod Type</td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Component</th>
<th>Number</th>
<th>Changes from Basic Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/S OK Press Switch</td>
<td>N45-27423</td>
<td>Redesign</td>
</tr>
<tr>
<td>Various Sensors</td>
<td>Various Sensors</td>
<td>Redesign</td>
</tr>
<tr>
<td>Flow Sensors</td>
<td>Various Sensors</td>
<td>Redesign</td>
</tr>
<tr>
<td>Temp Sensors</td>
<td>Various Sensors</td>
<td>Redesign</td>
</tr>
<tr>
<td>Pressure Sensors</td>
<td>Various Sensors</td>
<td>Redesign</td>
</tr>
<tr>
<td>Inst. Package</td>
<td>704647</td>
<td>Redesign</td>
</tr>
<tr>
<td>Ign. Del. Probe</td>
<td>500750</td>
<td>Eliminated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Number</th>
<th>Changes from Basic Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Structure, Teflon poppet, sleeve, elimination, filter</td>
<td>557751</td>
<td>Redesign</td>
</tr>
<tr>
<td>Weld Structure, Teflon poppet, sleeve, elimination, filter</td>
<td>557755</td>
<td>Check Valve</td>
</tr>
<tr>
<td>Check Valve</td>
<td>309065</td>
<td>Redesign</td>
</tr>
<tr>
<td>Check Valve</td>
<td>557751</td>
<td>1.4.4 Check Valve</td>
</tr>
<tr>
<td>Check Valve</td>
<td>557755</td>
<td>1.4.4 Check Valve</td>
</tr>
<tr>
<td>Check Valve</td>
<td>55822</td>
<td>1.4.4 Check Valve</td>
</tr>
<tr>
<td>Die Forged Parts</td>
<td>558325</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Relief Valve</td>
<td>407875</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>East Housing, ReDESIGNED Poppet</td>
<td>407875</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>East Housing, Teflon seal, sleeve, cast ball, revised seal</td>
<td>41389</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Top-of-Valve</td>
<td>557824</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Valve skirt, seat and cap, die forged button of 4.31 CR5S</td>
<td>411750</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Valve skirt, seat, die forged button of 4.31 CR5S</td>
<td>411750</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Fuel Bypass Valve</td>
<td>2.3.4 Valve</td>
<td>2.4 Relief Valve</td>
</tr>
<tr>
<td>Main Ox Valve</td>
<td>411225</td>
<td>2.3.4 Valve</td>
</tr>
<tr>
<td>Main Fuel Valve</td>
<td>411320</td>
<td>2.3.4 Valve</td>
</tr>
</tbody>
</table>

**Notes:**
- No change — No recommended change.
- 1 - Productivity; 2 - Fabrication Techniques; 3 - Material Substitution; 4 - Reliability/Operability Enhancements
- Redesign instead.
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.
<table>
<thead>
<tr>
<th>Component Dwg.</th>
<th>Number Changes From Basic Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Recommended Modifications**

- 1 - Redesign/Reconfiguration
- 2 - Fabrication Techniques
- 3 - Material Substitution
- 4 - Reliability/Operability Enhancement

- No Change
- No changes
- Interface Panel
- Replace Helium Tank
- Replace HEIC Vent w/ larger valve, and filter, cast housings
- No Change
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 redzings 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.
Adjust interfaces for specific vehicle

Review hot gas check valve if longer life is desired

Propellant inlet ducts (wrap-arounds would reduce engine cost)

Electronics and sensors to provide desired H/S/CMS

Component redesigns desired to match specific applications

11 Reliability/operability enhancements

12 Material substitutions

20 Changes in fabrication technique (i.e., castings, die forging, etc.)

24 Changes for producibility (no change in form/fit/function)

Describable changes identified

All processes are still possible

No material changes required

Only engine electronics absolutely require replacement

Could be produced to existing drawings
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.
Excellent correlation seen between data and engine model
Approx. 1000 psi
Increased LOX post pressure drop reduces Pc to

0:1 throttling limited by injector stability
6:1 throttling is feasible with baseline configuration

Conclusions

Balance model
Determine changes required for 0:1 throttling with engine
Anchors analytical models with data
Review J-25 6:1 throttling data

Approach

Define impacts of throttling modifications
Define modifications required for throttling up to 1:0:1

Objectives

10:1 Throttling Examination
J-25 Restart Study
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

**Diagram:**
- **MCC INJ**
- **DELP / Pc (%)**
- **PERCENT NOMINAL THRUST (%)**
- **MINIMUM TESTED 6:1**
- **LOX INJ**
- **FUEL INJ**

**Graph Details:**
- X-axis: MCC INJ - DELP / Pc (%)
- Y-axis: PERCENT NOMINAL THRUST (%)
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.
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.
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.
Good Model Prediction/Data Correlation Seen

J-2S Restart Study
J-25 Restart Program Plan
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.
Propellant costs will not be included.

Engine and component hot fire test Rock etende facility modifications and costs will be identified for both drawings and specifications.

The restart planning will be based on review and update of existing study objective.

Co-location of assembly and test facilities should be a future engine assembly.

Program restart plans presume the use of Rock etende facilities for single engine certification only will be addressed.

Cost effective

Existing government resources will be utilized when feasible and

"Engine Restart" is considered to be a requirement

30 starts/3750 seconds for J-2S

Engine life requirement will not exceed previously established
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.
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 Program Schedule

**J-2S Restart Study**

**Total Non-Recurring Cost = $245M**

<table>
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**Note:** Shown in constant FY92 dollars.

**TA-3-00398**
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.
10-YR PRODUCTION UNIT COST (M $2S)

TOTAL QUANTITY PRODUCED (N)

RATE (UNITS PER YEAR)

J-25 ENGINE
PREDICTED PRODUCTION COSTS
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

- Cer test profiles TBD
- Cer test to full life
- Cerity two engines after development
- Demonstrated "corners of operating box"
  - Varied PV settings
  - Inlet pressure variations
  - Altitude and sea level
- Accurate test experience at all operating levels
- Demonstrate repeatable performance with previous data
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.
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**Baseline J-2S Engine Test Matrix**

**J-2S Restart Study**
J-2S Restart Study
Conclusions

This study provided the confidence needed to state without doubt 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 from 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
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.