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STATUS REPORT

SATURN 1750 LB. THRUST ULLAGE ROCKET ENGINE (MARQUARDT MODEL NO. MA 118-XAB)

THE Marquardt CORPORATION

VAN NUYS, CALIFORNIA

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STATUS OF SATURN 1750 LB. THRUST ULLAGE ROCKET ENGINE

1.0 SUMMARY OF ENGINE STATUS

Development of this engine was conducted by Marquardt under Douglas CPIF Subcontract 62-229. The scope of this contract included five phases; Development, Design Evaluation Test, Pre-Flight Rating Test (PFRT-7 engines), Reliability Demonstration Test (RDT-12 engines) and End Item Deliveries (23 engines). The contract was initiated on November 19, 1962, and was terminated on April 23, 1964, just as the DET test phase was beginning, due to a change in NASA requirements. Successful completion of the Development phase led to a joint TMC/DAC design freeze meeting on January 21, 1964. All hardware for the DET phase was fabricated, as was some PFRT hardware. Test firing of DET Engine #1 was completed on April 6-7, 1964. A photograph of this engine configuration is shown in Figure 1.

The status of the engine development, with respect to the critical requirements of DAC Specification Control drawing 1A39598, is shown in Table I. Engine characteristics are more completely defined in model Specification 6027. A further summary of status for the thrust chamber, injector, and valve is presented in the following paragraphs. Table II lists the percentage completion of hardware and testing at the time of termination.

2.0 THRUST CHAMBER SUMMARY

2.1 Summary

The thrust chamber has demonstrated capability of satisfying the specification duty cycle of 90 seconds with a mean time to failure of approximately 260 seconds. Static and vibration tests have indicated structural adequacy of the thrust chamber under all specification environmental requirements. Fabrication techniques have been developed which provide good repeatability and high quality.

2.2 Description

The DET thrust chamber characteristics are as follows:

(a) $L^* = 24$
(b) Contraction Ratio = 1.84
(c) Expansion Ratio - 20
(d) Chamber pressure = 100 psia
(e) Thrust = 1750#
(f) Constant diameter throat for 1 inch length.

The DET thrust chamber (Figure 2) features an oriented refrasil phenolic ablative liner for chamber, throat and exit bell that is overwrapped with parallel to centerline refrasil phenolic insulating layer. A high strength fiberglass is then wrapped on the ablative unit, and the fiberglass is securely attached to the steel injector attach fitting and the aluminum main engine mount fitting by means of wave shaped structural joints. A silicone rubber "O" ring is located between the ablative overwrap structure and the injector attach fitting to preclude gas leakage at the structural joint.

2.3 Evolution of Design

Combustion considerations that contributed to the selection of ablative liner material, orientation and thickness are as follows.

2.3.1 Material Selection

U. S. Polymeric FM 5067 and Fiberite MX 2646 ablative materials were extensively used for liner and insulating overwrap during the development program. These materials exhibited equivalent erosion resistence in the chamber wall and throat, however, MX 2646 was selected because of superior fabrication properties and fewer procurement problems.

2.3.2 Material Orientation

The 45° to gas flow ablative orientation resulted in low char depth and good erosion qualities. Liner orientation in the bell, which changes with respect to the engine centerline, remains constant at approximately 45° to the gas stream. The 90° orientation at the head end reduces delamination at the injector interface.

2.3.3 Thickness of Liner

The oriented ablative liner thickness in the chamber and bell was established as the erosion plus char depth that resulted from 200 seconds of firing. This thickness is 0.6" in the chamber. The 92 second Douglas specification requirement produces approximately 2/3rds of the above char depth. The remaining uncharred liner thickness inhibits delamination to the parallel wrap interface, and establishes a reliability pad required to achieve the specified .9998 value. The predicted (and demonstrated) burnout time is approximately 260 seconds.

The ablative parallel wrap thickness was established (1) to provide adequate insulation to keep the fiberglass overwrap below the char temperature and (2) to keep the outer wall temperature below 400°F during soak following the 28.6 second firing required by the Douglas specification or an extrapolated 500°F for space conditions in a 160°F environment. The addition of an external 1/4 inch fiberglass insulation blanket reduces the outer wall temperature to below 300°F. Chamber wall temperature at the end of 28 seconds firing remains below 150°F.

2.4 Experience

Three DET configuration thrust chambers have been satisfactorily tested to specification duty cycle, and finally to destruction, a total of 800 seconds firing with a minimum failure time of 250 seconds. The specification thrust requirements were met for each test. In addition to the aforementioned tests, an additional 1800 seconds of combustion testing has been accumulated on the materials of construction used in the DET configuration. These tests were conducted at sea level conditions but the information gained was of value in making the selection of materials for the DET configuration.

2.5 Structural Status

2.5.1 Overwrap Structure

The fiberglass structural overwrap of the thrust chamber consists of alternating layers of phenolic impregnated unidirectional fiberglass cloth oriented longitudinally, and circumferentially wound phenolic impregnated fiberglass roving. This system provides for straightforward analysis of axial and hoop loads. A considerable amount of testing has been done to establish the design allowables of this geometry for axial tension, compression, and hoop loadings as well as transverse and interlaminar shear, bearing, etc. Tests were conducted at temperatures ranging from ambient to as high as 700°F. In general, temperature affects load conditions that are dependent upon resin such as interlaminar shear, and do not affect the hoop strength which is dependent largely on the glass fibers. "E" glass and the higher strength "S" glass were tested. "S" glass is used for roving because of its higher fiber strength in hoop tension. "E" glass is used for cloth because in compression higher strength is not achieved.

2.5.2 Injector Attach Fitting

The injector attach fitting is a heat treated type 17-4 stainless steel forging. A double wave joint configuration has been employed to join the structural fiberglass overwrap to the fitting and transfer axial loads. This configuration resulted from testing several alternate designs. Ref. Figure 2.

The layers of wound roving are progressively terminated approaching the joint so the axial cloth layers at the joint act together to transfer load across the inclined plane to the fitting. The resulting radial load is resisted by the external layers of wound roving. Small scale and full scale static compression and tension tests as well as post fired thrust chamber pressure tests to destruction have been conducted to establish the structural integrity of the joint. Joint slippage starts at near the proof pressure load and increases approximately linearly with load to failure (at roughly 5 times the proof load). The joint is tested at a pressure slightly higher than proof during fabrication. A maximum of .005" residual deflection is allowed before finish machining the injector interface.

2.5.3 Main Engine Mount Ring

The main engine mount ring is a heat treated aluminum forging. It is attached to the fiberglass structural overwrap by means of the same wave form joint described above. A heavier buildup of wound roving over the joint provides greater stiffness to resist vibratory loads. The critical load condition results from the vibration requirement of the Douglas procurement specification 1A39598. This generates reversing axial loads across the joint resulting from vibratory bending of the bell. Vibration of development chambers of the final configuration demonstrated the capability of the joint to withstand the specification vibration requirement with no joint failure. Resonance occurred at approximately 160 cps at 19 g input with a maximum of 180 g's registered by accelerometers on the bell. During fabrication, the joint will be static proof tested to a load based on the maximum engine thrust at which no joint deflection will be allowed.

2.6 Fabricability Status

Three methods are employed in the fabrication of the various thrust chamber ablative components from phenolic impregnated silica fabric.

Method I: Throat billets are fabricated from die-cut (cookie) shapes, stamped out of the pre-preg material and placed on a mandrel in individual layers to the desired billet length.

Method II: The combustion chamber mid-section is fabricated from pre-preg fabric tape wound on a mandrel at an orientation of 45^{o} to the mandrel axis and debulked with a high pressure roller as the wrapping progresses. The exit bell is fabricated in the same manner except that the orientation of the wrap changes from a 45^{o} to mandrel axis angle to a 15^{o} angle (45^{o} to engine exhaust gas flow) by a special (patent applied for) technique resulting in a very uniform transition of directional lay.

Method III: The forward section of the combustion chamber utilizes a combination of methods I and II. The material at the chamber entrance is oriented at 90° for one-inch, then changes direction to 45°, and is fabricated from die-cut cookies (Method I) of specified sizes in combination. The remaining length is applied using tape (Method II).

Components made by Methods I and III are formed and cured in a heated and closed die fixture and compacted (debulked) in a hydropress at specified pressures to result in the proper density. Components made by Method II are encased in rubber and cured in hydroclaving equipment. Cycling is controlled by time-oriented cams.

2.7 Quality Status

2.7.1 Cookie Laminate Versus Tape Wrapping

To fabricate components that must demonstrate a reliability value of .9998 or better, continuous state-of-the-art research in the development of advanced technical and production concepts would justify some discussion of certain significant considerations given to assure the quality of the combustion chamber.

Fabrication Methods I and III described above, while more costly due to increased material requirements, are considered justifiable since the technique provides uniformity in material orientation without wrinkling and in addition, the critical resin content and billet density can be more precisely controlled with repeatability assured during production.

2.7.2 Post Cure

Early in the development program, delaminations and cracks were experienced in the fabrication of detail components which was recognized as being due to mold shrinkage. When parts which have not been "post cured" are heated during subsequent processing, a resulting mold shrink is experienced. In the build-up of a thrust chamber, the several layers are applied in separate operations and completely cured after each application. This requires the various components to be subjected to several heating and cooling cycles. To prevent cracks and delaminations from occurring during subsequent buildup, the detail components are dimensionally stabilized by a post-curing process in an oven at controlled temperatures for 48 hours minimum.

2.7.3 Marquardt IR Index

Material control procedures are important in the fabrication of components from "pre pregs" resin impregnated fabrics from the time of receipt to the time of fabrication. Early in the development program, these materials were judged mainly on the basis of tests for flow, volatiles, resin content, and subjectivity by the "feel" of the material. These tests are not entirely adequate nor are the precise testing techniques clearly defined by nationally accepted standards.

It has been shown that the Chang Index, first reported by J. C. H. Chang in Modern Plastics, April 1961, is not applicable to all phenolic resin systems for the determination of cure advancements in pre-pregs (B-staging). However, this technique was recognized as having potential and was further developed at Marquardt to characterize all of the materials (phenolic impregnated silica and glass fabrics, and glass rovings) used in the fabrication of the DET thrust chamber. This material control procedure has been named the "Marquardt Index" Control. This index is the numerical difference in percent transmission at 13.2 and 12.2 microns, with absorbance ratios at 13.2 μ versus 12.2 μ and 12.2 μ versus 9.8 μ. It is measured by extracting the uncured resins from the pre-preg materials and examining them by use of a Beckman IR-5 Infrared Spectrophotometer.

3.0 INJECTOR STATUS

3.1 Injector Status Summary

The DET injector has successfully demonstrated adequate margin for the specification duty cycle. Average Isp efficiency has been shown to be 91.8%. Baffle erosion is satisfactory for the intended application. In general, the injector development has reached a state where it exceeds all specified requirements.

3.2 Description of DET Injector

The DET injector pattern consists of two concentric rings of equally spaced doublets with 48 doublets in each ring and a central quad for valve dumps. The impingement included angle for the doublets is 70° and for the central quad element is 90°. Propellant flow thru the central quad amounts to 10% of the total propellant flow. Welded to the injector face are ten non-symmetrically spaced baffles to stop the tangential instability experienced with non-baffled injectors of this design. The steel baffles are cooled by directing a .017 inch diameter fuel stream at the center and upon each side of the baffle. This fuel cooling flow amounts to approximately 8% of the total fuel flow.

3.3 Evolution of Design

The basis for the selection of the injection pattern was uniform heat release across the combustion chamber cross sectional area. Thus, the injection rings were positioned at centroids of area. Earliest injectors of this type had 16 doublets in each ring. This small number of doublets caused grooving of the combustion chamber walls and the design gradually evolved to the present 48 doublets in each ring. Efficiency of this type of injector has consistently been higher than single ring designs both with and without splash plates.

During the latter stages of the injector development it became apparent that a tangential mode of combustion instability was resulting in heavy erosion rates at the injector end of the combustion chamber. To reduce or eliminate this instability, five baffles were added to the injector face in a non-symmmetrical pattern. The five baffles greatly reduced but did not completely eliminate the erosion, so five additional baffles were added and this completely eliminated the combustion chamber erosion. Other methods (acoustic dampeners and higher contraction ratios) of eliminating instability were tested and found to be only conditionally satisfactory. Baffling was selected over these because the confidence in the baffling was higher than for the other methods, and because of the weight penalty of 9 lbs. with the higher contraction ratio.

3.4 Experience

This injector configuration has successfully completed 1,451 seconds (with 123 starts and stops) of combustion time and has not shown any severe chamber erosion due to tangential combustion instability previously experienced with this type of injector without baffles. Vibration levels experienced with this configuration are only 1/10 magnitude of those experienced in the previous injectors. Average Isp efficiency for this injector configuration is 91.8% with a high of 93% and a low of 91%. Baffle erosion does occur with this design, but the erosion rate is such that at the end of combustion runs in excess of 265 seconds (accumulated) the engine remains stable. At the end of a 92 second specification duty cycle, the erosion is very slight. At combustion times of approximately 300 seconds, sufficient erosion has occurred to the baffles and the throat of the engine that the engine is only conditionally stable at that time.

3.5 Structural Considerations

3.5.1 Thermal Stability of Injector Face

Because of the high temperatures of the face exposed to combustion and the relatively cool manifold components and thrust chamber attach flange, early injector configurations were very unstable. This was due to thermal stresses growth of the hot face which resulted in loading the cold flange in hoop tensions and yielding the hot face in compression. Cooling of the injector produced a shrinkage and cupping of the outer flange and cracking of the bottom of the impingement Vee grooves. The DET injector design has corrected this condition by: (a) changing the material from type 321 stainless to heat treated 17-4 material, which has a lower thermal expansion coefficient and higher strength with which to resist thermal stresses and (b) re-designing the hot face of the injector to a flat plate and locating the injector attach flange in line with the hot face. A development injector of this improved design has undergone 1,256 seconds of firing without warpage.

3.5.2 Ability to Resist Chamber and Manifold Pressures

A DET type injector was burst tested attached to a thrust chamber and withstood over 1100 psi without failure. Proof pressure in the injector manifold is 350 psi.

3.6 Fabricability Status

3.6.1 The DET injector is a composite of details welded together to form an integral unit containing two separated compartments or manifolds. Each manifold distributes a fluid (oxidizer or a fuel) thru two concentric patterns of equally spaced orifices oriented such that impingement of the fluids occurs are a predetermined distance from the injector interface.

The face plate detail is the major component in the fabrication of the injector assembly. It is precisely machined from a controlled, radial grain, upset forging of 17-4 Cres conforming to AMS-5643. Because of the complexity of this detail, only precision machine equipment and highly skilled operators are utilized in the many and varied operations required to produce it. Again, because of complexity, only limited production techniques are considered applicable. The face plate contains four groups of 48 equally spaced orifices. Each group is of a different hole size with a tolerance of ± .001 of the nominal diameter specified and at an angle which precludes any possibility of using multiple spindle, hole producing equipment. While this technique requires 192 separate drilling operations and four different setups, no problems are being encountered in producing the tolerances as specified. The front face configuration of the injector lends itself to utilizing the cam-trace method of producing this surface.

Earlier development injector configurations made of 321 stainless steel did present a problem in drill breakage. As many as 12 to 15 dozen drills were used in producing a single part. This required an additional operation to remove the broken drills with eloxing equipment. Considerable care in this setup was required to maintain size and hole alignment. Several development configurations, (limited to one or two of a type) were furnace brazed using a high temperature nickel alloy. Because of the limited number of units, not enough experience was gained per unit to produce a leakproof assembly that would yield the high reliability requirements of specification. Subsequent material change to 17-4 pH and the acquisition of special high speed steel drills of an English make reduced the drill breakage problem to that which is considered normal in producing holes of the size, quality, and quantities required in each part. The injector material was changed for reasons of material stability (lower expansion coefficient and higher strength properties) and because of previous experience with brazed assemblies and this prompted the decision to change to welding. Special tooling requirements are minimal. Welding, heat treat and locating fixtures are required, in addition to the cam-trace template referred to above.

3.7 Quality Status

Materials used in the fabrication of the injector head assemblies are procured to Military Specifications (MIL-Specs) or Aeronautical Material Specifications (AMS) as applicable. Material Certifications for chemical and physical properties are required of all suppliers. Materials, after being received and inspected, are kept in bond and issued to manufacturing departments by material order requests.

Detail parts are machined by conventional methods such as turning, milling, shaping and drilling, they are deburred, inspected and identified by part number, change letter and by a manufacturing sequence or lot number. An assembly parts list (APL) is then issued which lists parts by number, serial, lot, etc. to complete the assembly. All machined parts are passivated, cleaned, and placed in clean plastic bags.

Assembly of these parts is accomplished by set-up and welding. The assembly is pressure tested after welding and then processed thru a complete heat treat cycle. X-Ray and dye-penetrant inspection is performed before and after heat treat processing, then the flange area is finish machined. The assembly is then flow checked per Marquardt Test Specification (MTS) 0589 after which it is propellant cleaned per a Marquardt Process Specification. The injector is then assembled with a set of two each oxidizer and fuel valves on a steel (boiler-plate) combustion chamber for acceptance testing per MTS 0517.

After having passed acceptance testing (MTS 0517), the assembly is again processed to be propellant clean. It is then double-bagged, identified, and together with the record log book, placed in stores and held for the next assembly.

4.0 VALVE STATUS

4.1 Valve Status Summary

The basic DET design has proven to be adequate (as shown in the Valve Summary of Experience) with the exception of one problem which arose as a consequence of reducing engine chamber pressure from 150 to 100 psi and supply pressure from 230 to 180 psi at DAC direction. The ΔP across the valve was lower than originally expected and, as a result, the second stage piston furnished just enough power to make full opening of the valve only marginal. When care is exercised to ensure that other parameters (injector ΔP, calibrating orifice ΔP's, and tank pressure) are nominal, the valves open fully. When these parameters vary slightly from nominal, the ΔP across the valve may be reduced and the valve will not always open fully. As DET hardware fabrication was already underway, this problem could not be easily remedied; however, in the PFRT valve design, the second stage piston area was increased to furnish greater power at the same low ΔP. Otherwise, the DET valves have proven their ability to furnish a good leak tight seal and to open and close in less than 150 ms, using one-third less power than the maximum allowable.

Sixteen (16) Redundant Valve Assemblies were fabricated for the DET program, all of which have passed valve acceptance testing. Twelve of the valve assemblies are awaiting DET engine running and four have already completed support of engine runs and are now awaiting DET component tests.

4.2 Description

The DET valve is a two stage, co-axial solenoid pilot operated, hydraulic powered valve, as were previous valves constructed during the development of the 1750 pound thrust engine. The specification requirement is for eight valves per engine arranged in a quad redundant scheme. The selected approach was to construct the pair of valves required to be in series as one component, called a "Redundant Propellant Valve Assembly". A DET valve set has a weight of 11.5 pounds and fits into an envelope 10 inches in diameter by 4½ inches in depth, consistent with original program plans. It may be noted that a significant portion of this 11.5 pounds is contributed by conoseal inlet and vent passage flanges. This vent passage is not a functional part of the valve but is utilized in filling the vehicle's propellant tanks.

Operating Principle

Electrical power is used to actuate the valve. In order to keep the power requirement low and maintain good response, a two stage design was chosen for the 1750 pound thrust engine's propellant valves. Only the pilot stage uses electrical power. The second stage is actuated by differential pressure across the closely fitted piston (second stage poppet) after the pilot stage has opened, reducing the pressure behind the piston. Flow through the pilot stages enters the combustion chamber through the injector's center doublets.

4.3 Evolution of Design

The evolution of the valve design is shown in Figure 3. A trade-off study of valving concepts was conducted at the start of Marquardt's 1750 pound thrust engine program. The first phase of the trade-off consisted of evaluating several types of valves, i.e. ball, gate, poppet, etc. This study led to the selection of a poppet valve as the basic valving concept. The second setup was a comparison of bi-propellant valves versus single propellant valves. Since there were no known bi-propellant valve concepts in which the probability of a catastrophic failure due to leakage paths could be eliminated, it was decided that the valve should be a single propellant valve. The most significant criteria for selection were the arrangement of a quad-redundant fuel valve set and a quad redundant oxidizer valve set into a relatively small envelope that would operate on less than 1.3 amps per valve and still furnish propellant for a 1750 pound thrust engine in the required response times. As the final step in the tradeoff study, three candidate designs (Moog, Whittaker, and TMC) were evaluated in detail with respect to all significant parameters. It was concluded from this comparison that the valves be made by TMC were most suitable particularly because of best overall design features and also because of logistic advantages.

The conclusions of this tradeoff study, in conjunction with the specification requirements for flow versus Δ P, response, sealing and power consumption; and with previous experience gained on boilerplate valves of this concept were used to arrive at the development valve. Development valve test experience was combined with specification requirements for envelope, nitrogen purge ability, all welded valve assembly, and with target weight to produce the prototype valve design. The DET valve design resulted from prototype valve experience modified by minor specification requirements such as continuous energization for three hours with no flow, etc.

4.4 Experience

Accumulated experience gained on DET valves, and valves leading directly to the DET valves, is presented in Table III, "Valve Summary of Experience". It can be noted here that many of the engine requirements and specification requirements have been satisfied and some requirements have been far surpassed, i.e., more than 10,000 cycles operation, burst pressure safety at approximately 4,000 psi, more than 80 minutes of engine run time, 160 hours of accumulated propellant soak time, energization for one hour during non-operation, propellant temperatures ranging from 18 to 176°F, and valve operation at temperatures above 200°F.

4.5 Structural Status

No vibration tests have been conducted on the DET valves but a vibration analysis has been made on the valve assembly with special emphasis on the PFRT valve configuration. In order to raise the natural frequency above the maximum induced frequency of 2,000 cycles, extreme rigidity is necessary. PFRT valves incorporate a conoseal configuration rather than a welded flange type sealing inner face between first and second stages. Thus, the joints between the upstream and downstream valve, and between the downstream valve and injector have been strengthened as required which slightly increases the weight of the PFRT valves. Also, extensive stress analysis was performed on the PFRT valves, bolts, tapped holes, flanges, body casting, and material. PFRT valve bodies were pressure tested up to 6700 psi with no indications of structural problems.

4.6 Fabricability Status

Manufacture of the Saturn propellant valves requires no special fabrication processes. Most detail parts require only routine machining operations with an extreme close tolerance of 0.0003 inch. Tooling is complete for machining the body casting and tool proofing has successfully been completed. Machining methods for the valve seat configuration have long been established at TMC. Coil winding techniques along with vacuum impregnating and potting methods have also been well established at TMC. Although some difficulties were experienced in the fabrication of DET seat assemblies, corrective action has been taken to prevent reocurrence. Action taken was to make the seat material callout more limiting, to prevent use of inferior grade teflon.

4.7 Quality Status

Quality of the valve assembly has improved continuously since the initiation of the program, and quality standards are now at a level satisfactory for the production of end item hardware.

A casting is now used in place of a weldment for the valve body. Not only is it less expensive than a weldment but it is more desirable from a structural viewpoint. Dimensional samples of the casting have been checked for deformation under load, have been sectioned and examined for porosity, and threads of tapped holes have been tested to the point of failure of attaching bolts.

It has been known that certain types of teflon do a better job than others for this valve seat seal configuration. Only recently it became possible to ensure the use of the most desirable type of teflon. Some fluorocarbon companies now specify different grades of teflon material depending upon what particle size was used to fabricate the teflon rod or "bar stock", etc. A callout for "Virgin grade 7-TFE teflon" is being used to ensure the quality of teflon that will perform satisfactorily for this seat seal.

TABLE I

Engine Status Summary

Parameter	DAC Requirement	TMC Status
Life	Spec. Life = 92.2 sec. Mission Duty Cycle = 28.6 sec.	MTTF = 260 to 300 sec. (approx. 9 mission duty cycles)
Specific Impulse	Minimum = 290 sec. for any valve failure which does not stop propellant flow.	Minimum = 286 sec. (for ox. valve failure, (including effect of instrumentation tolerance, repeatability, & (setting tolerances) Nominal = 302 sec. (at $A_e/A_t = 20$)
Thrust	1750 lbs ± 53 lbs	1750 lbs ± 28 lbs at t = 28.6 sec. 1796 lbs ± 37 lbs at t = 92.2 sec. 1960 lbs ± 56 lbs at t = 260 sec.
Weight	Goal = 65 lbs Max. = 80 lbs	DET Engine = 68.2 lbs PFRT Engine = 71.1 lbs (est.)
Response	0-90% in 150 ms 100-10% in 150 ms	0-90% in 150 ms) 100-10% in 150 ms) DET Engine 0-90% in 120 ms) 100-10% in 220 ms) PFRT Engine (est.)
Engine Exterior Temperature	Max. = 250°F. (See Note)	Max. = 250°F w/ 1/4" insulation blanket, max. during soak after 28.6 sec. mission duty cycle. NOTE: At the design freeze, DAC stated that this requirement would be deleted. Thus, no insulation blanket would be used on DET engine. Exterior temperature of 400°F is expected during soak after 28.6 sec. mission duty cycle.
Start Capability at Propellant Temperature Extremes	T_{min} = 20°F. T_{max} = 160°F.	Demonstrated successfully during development phase (Run 31).
Operational Vibration	5-20 cps at 0.35" d.a. 20-96 cps at 7 g's 96-180 cps at 0.015" d.a. 180-2000 cps at 25 g's	Demonstrated successfully during development phase for thrust chambers #6A, 7A.
Operational shock, operation under extreme environmental temp., off-design operation.	See DAC Specification SCD 1A39598	To be demonstrated during DET phase.

TABLE II

Saturn S-IVB Hardware Status

		Percent Completion				
		Development		PFRT	RDT	End Item
		Dev.	DET			
Valves	Des.	100	100	95	95	90
	AMR	100	100	100	100	0
	Fab.	100	100	70	0	0
	Acc. Test	100	100	0	0	0
Injectors	Des.	100	100	95	95	95
	AMR	100	100	30	0	0
	Fab.	100	100	0	0	0
	Acc. Test	100	30	0	0	0
Chambers	Des.	100	100	100	100	100
	AMR	100	100	100	0	0
	Fab.	100	100	24	0	0
	Acc. Test	100	100	0	0	0
Engine	Des.	100	100	95	95	95
	Assem.	100	100	0	0	0
	Acc. Test	100	25	0	0	0
	Test	100	25	0	0	0
S.T.E.	Des.	100	100	-	-	-
	Fab.	100	100	-	-	-
	Install.	100	96	-	-	-
Tooling	Des.	100	100	85	-	-
	Fab.	100	100	69	-	-

TABLE III VALVE SUMMARY OF EXPERIENCE

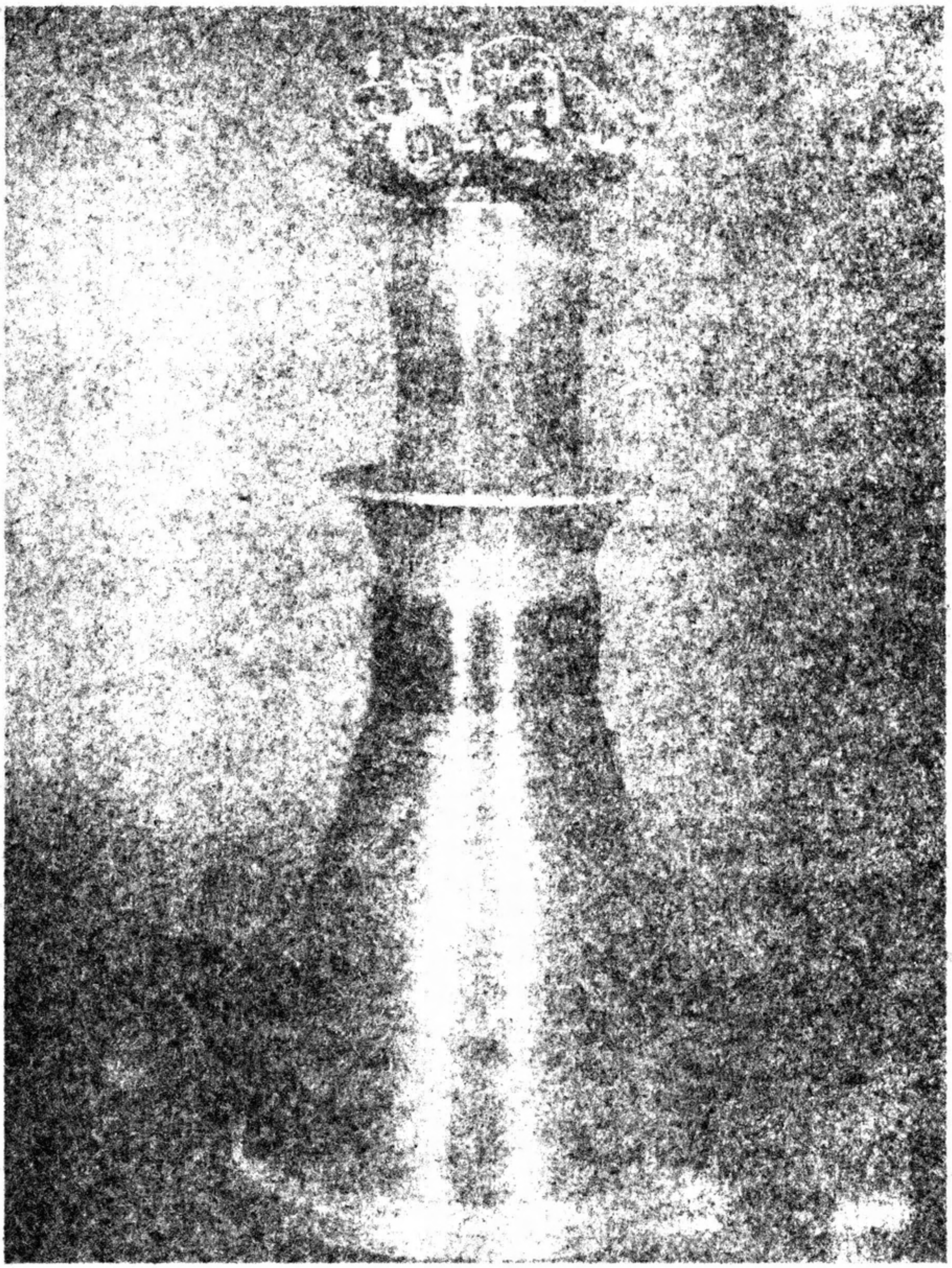
	No. Cycles on Air (approx.)	No. Cycles on H_2O (approx.)	No. Cycles on Propellants	Total No. of Cycles	Engine Run Time (accumulated) (sec.)	Max. Prop. Temp (°F)	Min. Prop. Temp. (°F)	(accumulated) Propellant Soak Time (hours & minutes)	Time that 24 VDC Power was left applied during non-operation	Maximum Valve Temp at any time (°F)	Maximum Pressure seen by valve (PSI)	Total Accumulated On Time (air, prop, H_2O) hours	Total Time in Propellant Use (days)	Total Time in Use (days	Accumulated Run Time with Propellant Temp <40°F (sec.)	Accumulated Run Time with Propellant Temp > 150°F (sec.)
DET VALVES																
227330 (fuel) S/N001	100	110	-0-	210	-0-	-0-	-0-	-0-	-0-	80	510	Negligible When Compared With X19080 Hardware				
227330 (fuel) S/N002	100	110	-0-	210	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
227330 (fuel) S/N005	50	60	-0-	110	-0-	-0-	-0-	-0-	-0-	80	275	"	" "	"	"	"
227330 (fuel) S/N006	100	170	35	305	300	65	52	15:42①	1 hr.	~800	510	"	" "	"	"	"
227330 (fuel) S/N009	50	60	-0-	110	-0-	-0	-0	0-	-0-	80	510	"	" "	"	"	"
227330 (fuel) S/N011	30	40	-0-	70	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
227330 (fuel) S/N012	50	60	-0-	110	-0-	-0-	-0-	-0-	-0-	80	275	"	" "	"	"	"
227330 (fuel) S/N013	100	170	35	305	300	65	52	15:42①	1 hr.	~800	510	"	" "	"	"	"
277340 (ox) S/N003	100	110	35	245	300	65	52	15:42①	1 hr.	~800	510	"	" "	"	"	"
277340 (ox) S/N004	100	110	-0-	210	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
277340 (ox) S/N007	100	110	-0-	210	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
227340 (ox) S/N008	100	210	35	345	300	65	52	15:42①	1 hr.	~800	510	"	" "	"	"	"
227340 (ox) S/N010	50	60	-0-	110	-0	-0	-0	-0-	-0-	80	275	"	" "	"	"	"
227340 (ox) S/N014	50	60	-0-	110	-0-	-0-	-0-	-0-	-0-	80	275	"	" "	"	"	"
227340 (ox) S/N015	50	60	-0-	110	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
227340 (ox) S/N016	50	60	-0-	110	-0-	-0-	-0-	-0-	-0-	80	510	"	" "	"	"	"
PROTOTYPE VALVES (very similar to Det.)																
X19080 (ox) S/N001	2,800	2,920	130	5,850	1,148.3	176	18	160②	?	200	?	6.15	114	204	28	33
X19080 (ox) S/N002	2,900	3,110	130	6,140	1,148.3	176	18	160②	?	200	?	6.15	114	204	28	33
X19080 (fuel) S/N003③	2,800	8,920	130	11,850	1,148.3	176	18	160②	?	200	~4,000	6.15	114	204	28	33
X19080 (fuel) S/N004③	2,780	2,810	130	5,640	1,148.3	176	18	160②	?	200	~4,000	6.15	114	204	28	33
DEVELOP. VALVES (heavy weight, basis for Prototype Design)																
X19031 S/N001	>1,000	>1,000	274	>2,000	4,885.6	?	?	334④	?	?	?	>1.5	156	~200	-0-	-0-
X19031 S/N002	>1,000	>1,000	274	>2,000	4,885.6	?	?	334④	?	?	?	>1.5	156	~200	-0-	-0-
X19031 S/N003	>1,000	>1,000	274	>2,000	4,885.6	?	?	334④	?	?	?	>1.5	156	~200	-0-	-0-
X19031 S/N004	>1,000	>1,000	274	>2,000	4,885.6	?	?	334④	?	?	?	>1.5	156	~200	-0-	-0-
X19031 S/N005	Valves were used for component development and not for support of engine testing.															
X19031 S/N006	Valves were used for component development and not for support of engine testing.															

① 7:35 +0:33 + 7:34 = 15 hours 42 minutes

② 22.5 + 45 + 72 + [illegible] = 160 hours

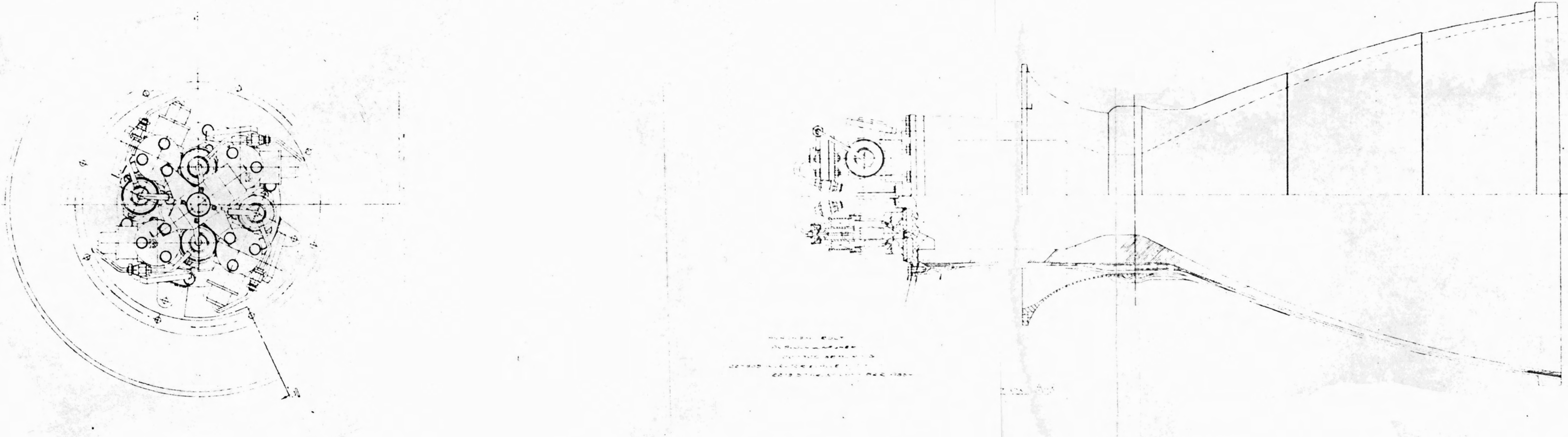
③ Retired from operational duty on 1-2-64 due to body warpage resulting from facility over-pressurization

④ [illegible] + 98 + [illegible] = 334 hours



1750 POUND THRUST DESIGN EVALUATION TEST ROCKET ENGINE

FIGURE 1



DESIGN EVALUATION TEST
ENGINE CONFIGURATION

FIGURE 2

EVOLUTION OF VALVE DESIGN

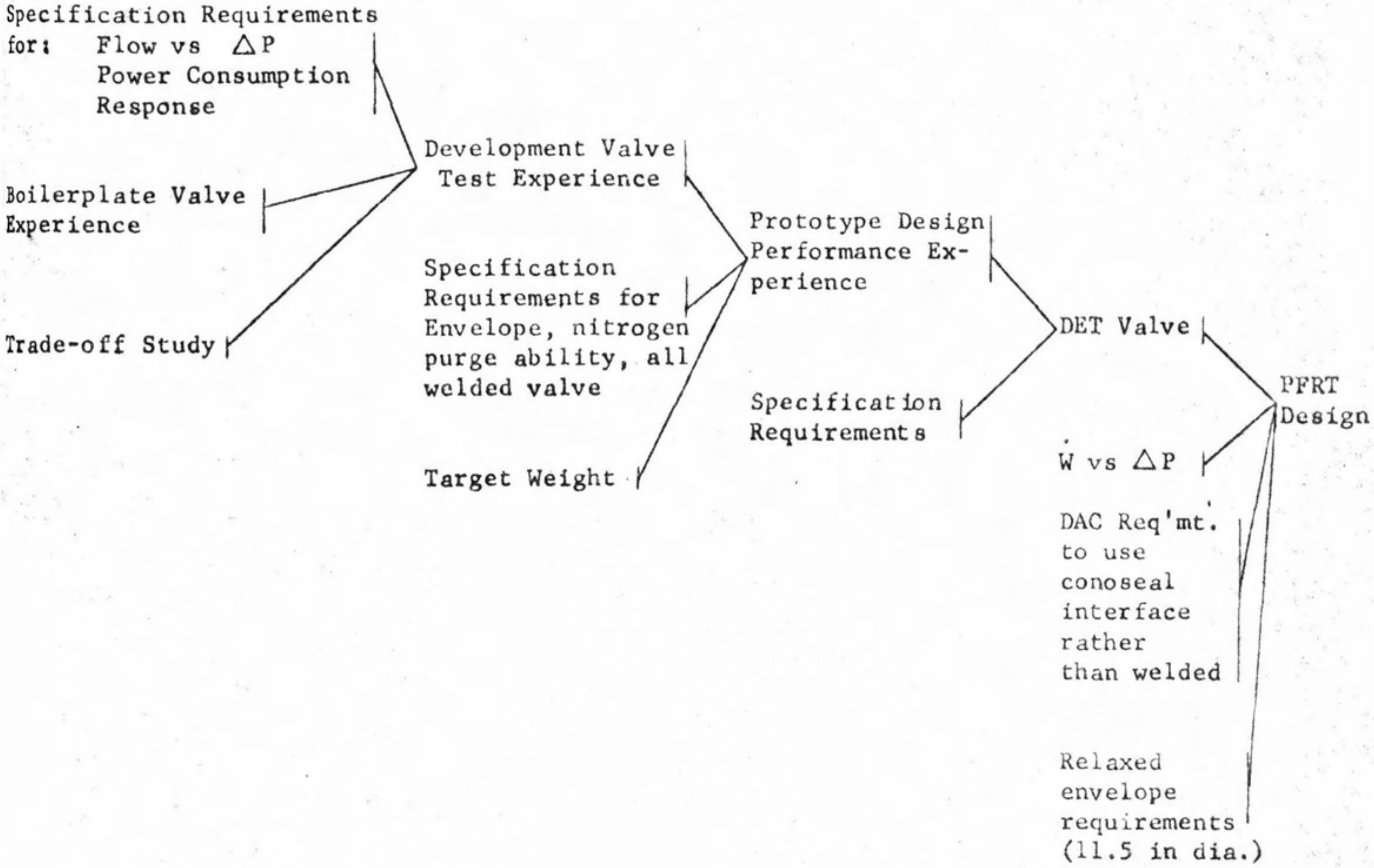


Figure 3