NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-333

Design, Fabrication, and Testing of the Applications Technology Satellite Apogee Motor Nozzle

Richard A. Grippi, Jr.

JET PROPULSION LABORATORY

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Abstract

This Report documents the design, fabrication, and testing of the Applications Technology Satellite apogee motor nozzle. On firing, the apogee motor provides the necessary velocity increment, at the apogee of the elliptical transfer orbit, to place the satellite in a synchronous orbit. The nozzle construction consists of: (1) high-density, graphite throat insert, (2) tape-wrapped, carbon-cloth, phenolic-resin throat section, (3) tape-wrapped, silica-cloth, phenolic-resin exit cone, (4) aluminum attachment ring, and (5) an aluminum throat closure diaphragm. A length limitation was imposed on the propulsion system; therefore, the nozzle was submerged into the motor chamber to accommodate the 35:1 expansion ratio of the contoured nozzle. Verification of the nozzle design was accomplished through static motor firings and environmental tests, which included temperature cycle, booster acceleration, booster vibration, and space temperature vacuum exposure. On December 7, 1966, the first flight firing of the apogee unit placed the ATS-B satellite into a near-synchronous, equatorial orbit.

Design, Fabrication, and Testing of the Applications Technology Satellite Apogee Motor Nozzle

I. Introduction

In January 1963, the Jet Propulsion Laboratory (JPL) initiated a development program to provide a solid-propellant apogee rocket motor for a second-generation SYNCOM satellite. This program, under the management of the Goddard Space Flight Center (GSFC), was designated Advanced SYNCOM. The resultant design is a spin-stabilized, active repeater, communications satellite weighing about 750 lb, operating at a synchronous altitude (22,300 mi), with a capability of handling voice communications, teletype, and monochrome and color television signals.

In January 1964, the Advanced SYNCOM communication program was directed to include a number of experimental instruments, in addition to the original communication instruments. This expanded program, the Applications Technology Satellite (ATS) program, will result in a general purpose satellite capable of operation at medium or synchronous altitude, with experimental instruments of meteorology, communications, radiation, navigation, gravity-gradient stabilization, and various engineering experiments. The following five launches are planned:

(1) Two synchronous-altitude, spin-stabilized.

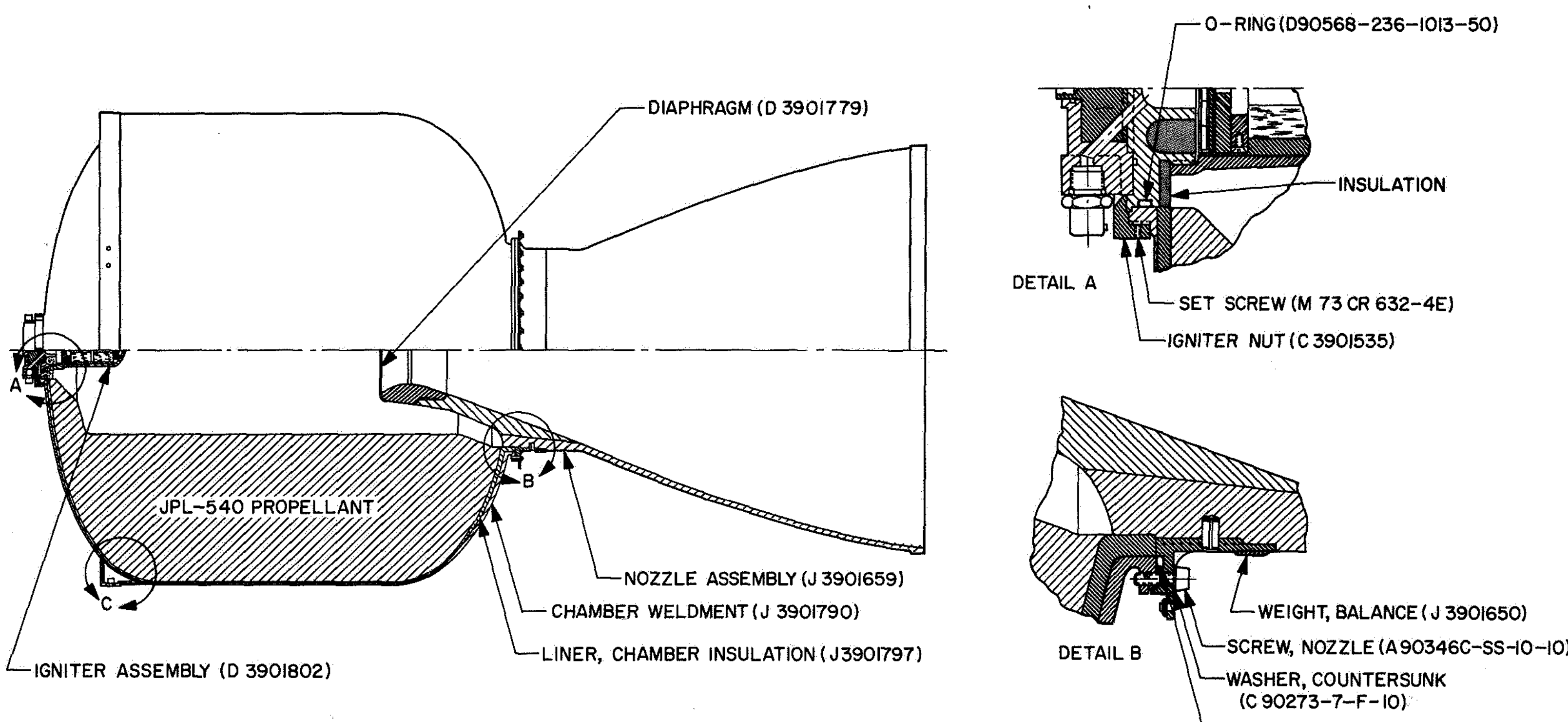
(2) Two synchronous-altitude, gravity-gradient, spin stabilized.

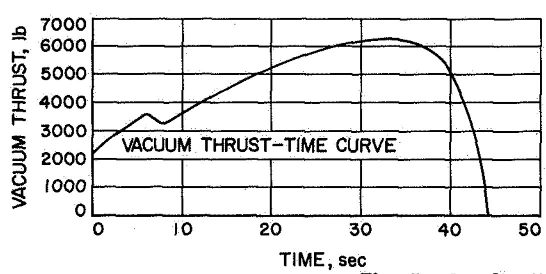
(3) One medium-altitude, gravity-gradient stabilized.

The medium altitude satellite does not require an apogee unit.

To place the satellites in synchronous orbit, JPL will furnish a solid-propellant rocket motor (JPL SR-28-3) to provide the final required velocity increment at the apogee of the elliptical transfer orbit. A total of five apogee units will be delivered to the Atlantic Missile Range (AMR) for flight support.

JPL has completed design, development, and formal qualification of the ATS apogee motor. This report describes the various phases of the design, fabrication, and testing of fifty nozzles used in the ATS apogee motor development, qualification, and flight phase (Fig. 1). Appendixes A and B present nozzle design drawings, and nozzle specifications, respectively.





NOMINAL DATA (AT 60 °F)

BURNING TIME	43.5	sec
MAXIMUM CHAMBER PRESSURE	260	psia
MAXIMUM VACUUM THRUST	6250	lb_f
TOTAL WEIGHT	840.7	lb_m
PROPELLANT WEIGHT	760	lb_m
PRE-FIRE INERT WEIGHT	80.7	lb_m
MAXIMUM DIAMETER	28.2	in.
OVER-ALL LENGTH	54.6	in.
THROAT DIAMETER	4.08	in.
NOZZLE EXPANSION RATIO	35:1	

Fig. 1. Applications Technology Satellite apogee motor assembly

II. Design

A. Background

At the beginning of the apogee motor development program, the basic nozzle design criteria was two-fold. The design approaches were to scale-up the JPL SYNCOM nozzle and to incorporate improvements in the state of the art of nozzle design and fabrication. Predicated on this concept, numerous changes were made to a basic scale-up of the SYNCOM nozzle.

Five major changes were incorporated into the design of the ATS nozzle. The method of attaching the nozzle to the chamber was changed from a threaded ring to a bolt circle flange attachment ring. This was innovated to alleviate possible difficulties with galling of large threaded joints, and to allow for precise positioning of the nozzle centerline with respect to the geometric center of the motor/spacecraft attachment ring.

To improve motor performance, i.e., specific impulse, the nozzle contour was changed from an 18-deg conical exit cone to a contoured or bell-shaped exit cone.

The nozzle body was tape-wrapped, rather than compression-molded. Considering the size of the ATS nozzle, compression molding is quite costly and impractical. Also, the tape-wrap construction is more uniform than compression molding, and decreases the erosion and char of ablative materials.

Silica was chosen as the exit cone material, as the char rate of silica is appreciably less than carbon. Also, as the erosion rate in the exit cone is negligible, silica will perform similarly to carbon even though its erosion resistance characteristics are less than carbon. Finally, a significant cost savings can be realized through the use of silica.

A fifth change incorporated an unsupported graphite insert, thereby minimizing fabrication procedures.

B. Configuration

The general configuration of the rocket motor nozzle was developed during the initial design phase of the propulsion system. To achieve an optimum propulsion system, numerous factors were considered in arriving at the nozzle's final form, resulting in compromises between chamber, propellant, and insulation configuration.

Specific design studies were conducted to evaluate numerous ablative materials, graphite throat insert materials, and fabrication methods. In addition, the stringent thrust vector alignment and motor balance requirements were considered in the nozzle design.

The nozzle construction consists of: (1) a high-density graphite throat insert, (2) tape-wrapped, carbon-cloth-phenolic resin throat section, (3) tape-wrapped, silica-cloth-phenolic resin exit cone, (4) aluminum attachment ring, and (5) an aluminum throat closure diaphragm (Fig. 2 and 3).

The physical geometry of the nozzle was based on a 2.3 scale-up of the SYNCOM nozzle. This results in a 4.083-in. throat diameter, 24.138-in. exit diameter, 31.835-in. sonic section to exit plane, and 33.685-in. overall length of the nozzle. Since the area expansion ratio is not a scale-up parameter, this remained identical at 35:1.

To obtain an increase in performance, the exit cone geometry was changed from an 18-deg half-angle cone to a contoured exit cone. The geometry of the contour was developed as a joint effort between JPL and TRW Systems, Inc. With JPL's experience in contoured nozzles and the contractor's experience in the same area on the *Minuteman* program, general ground rules and geometry parameters were established based on the nozzle geometry constraints. It was established that the geometry of the contour would be placed in the same space envelope as a direct scale-up of the SYNCOM nozzle, which has an 18-deg half-angle cone. Utilizing the contractor's two-phase (gaseous and solid particle) gas flow computer program, a run was conducted with an 18-deg half-angle cone contour to establish a performance (specific impulse) reference for comparison of various contours. After a series of computer runs with varying contours, the nozzle contour was chosen, based on the greatest improvement in theoretical motor performance. The contour consists of a 6-in. circular arc at the throat section, joined smoothly 3 in. downstream of the throat to a 108-in. circular arc (Fig. 4). The initial half-angle at the intersection of the arcs is 26 deg and the final exit cone angle is 10 deg.

The contractor's computer program predicted a motor performance (specific impulse) improvement of 2 sec, based on a comparison of specific impulses of an 18-deg half-angle cone and the contoured nozzle. Upon completion of the ATS apogee motor qualification program, a comparison of nominal performance data indicated a specific impulse improvement of approximately 5 sec.

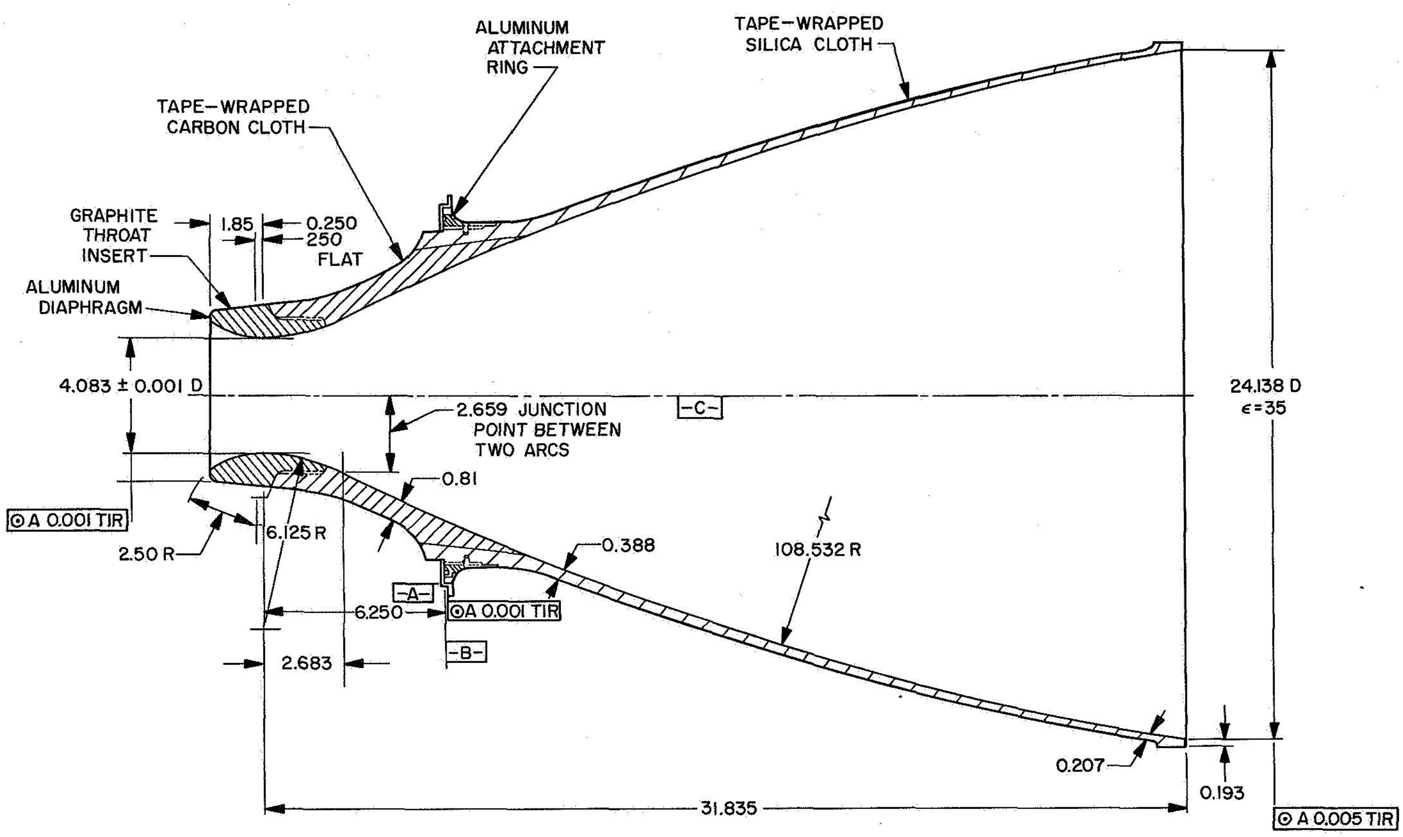


Fig. 2. Nozzle assembly drawing

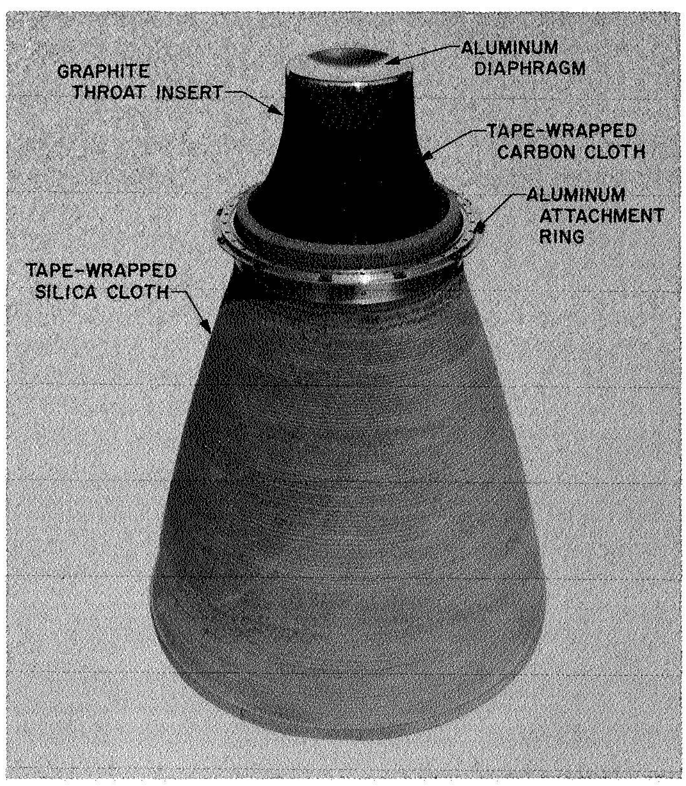


Fig. 3. Prefire nozzle assembly

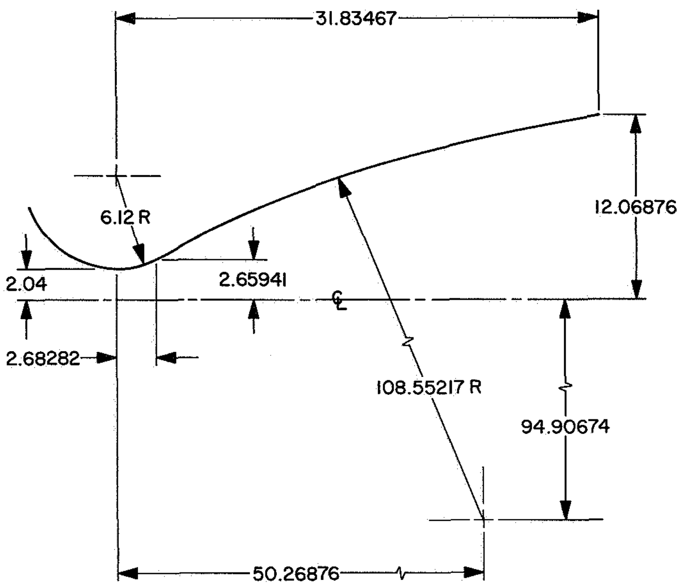


Fig. 4. Nozzle geometry contour

The greater increase in performance is a combined result of improved efficiencies of a larger scaled-up motor and the contoured nozzle.

The configuration of the nozzle attachment ring and its location on the nozzle body were chosen primarily to allow submerging the nozzle approximately 8½ in. into the chamber, to an area expansion ratio of 4.5:1. This was accomplished to accommodate a fully expanded ($\varepsilon = 35$) nozzle with a length restraint on the propulsion system as a result of minimizing the motor pitch to roll moment of inertia ratio. If the nozzle was not submerged, the moment of inertia of the spacecraft in the pitch direction would be increased, thereby placing a larger demand on its attitude control system. Submerging the nozzle into the chamber, places a distinct disadvantage on the system, since some energy in the combustion gases at the aft end of the propellant grain is lost through flow reversal.

The nozzle is attached to the chamber with 36 screws (size 10-32) to a flange turned outward from the center line of the chamber. On flight units, each high-strength screw has been drilled to accept lockwire for safety wiring the screws in sets of three.

Both structural and thermal considerations were analyzed during the nozzle design phase. As a result of the analysis, it was noted that the structural loads imposed on the nozzle body are relatively conservative, since both thermal and spacecraft requirements controlled the strength of the structural load-carrying members in the nozzle.

Since the structural loads on the nozzle body were relatively low as a result of the preceding considerations, the primary emphasis of structural analysis and experimentation was placed on the joint between the nozzle body and the attachment ring. The joint is composed of silica-cloth laminates, at an 8-deg angle, threaded to accept the aluminum attachment ring, which is subsequently bonded to the nozzle body. Since a joint of this design is seldom utilized (threaded ablative material), it was decided to experimentally evaluate the joint; therefore, several destruction tests were conducted and are discussed in a later section.

The thermal considerations involved determining and analyzing erosion and char rates of the selected ablative materials, on the basis of sub-scale firings with the SYNCOM motor. These data, together with a conservative approach, were used in the initial flight configuration design for altitude firing at the Arnold Engineering and Development Center (AEDC). The resultant design was a nozzle weighing approximately 53 lb.

Upon completion of the initial altitude static test at AEDC, the nozzle was dimensionally inspected, and then sectioned to determine the erosion and char depth. From the dimensional and visual inspection of the sectioned nozzle, it was concluded that the unit was conservatively designed, as intended, with respect to erosion and char depth. The final flight configuration design was based on the erosion and char depths of this unit and the stringent spacecraft requirements for thrust vector misalignment and post-fire dynamic balance.

Spacecraft requirements dictated that the misalignment of the nozzle thrust vector must be less than 0.001 in./in., and a thrust vector offset not greater than 0.030 in. at the motor/spacecraft interface. In addition, the spent motor should meet critical static and dynamic balance requirements. To assure successful demonstration of both spacecraft requirements, it was necessary to over-design the nozzle exit cone with respect to structural and thermal loads. The exit cone thicknesses were increased to maintain a thin membrane of virgin ablative material on the outside of the exit cone. This was accomplished to minimize distortion and eccentricity of the exit cone throughout motor burn, thereby maintaining precise thrust vector alignment. Also, the conservative design maintained lower nozzle temperatures and char depth, since the heat loads during and after motor burn were distributed through a larger mass. This resulted in a rigid and concentric exit cone after motor burn, and assured a minimum static and dynamic motor imbalance.

To control and minimize weight deviations, very tight dimensional tolerances were necessary. Since the weight of the nozzle is significantly affected by the thickness of the throat and exit cone sections, 100% in-process inspection and monitoring were maintained during fabrication and machining to assure precision tolerances and control. As a result of close quality assurance monitoring, the weight deviation was within a 2-lb range of the nominal 38-lb flight nozzle.

Close tolerances were also required to ensure a minimum misalignment of the thrust vector. Therefore, it was decided to precision-machine the inside of the nozzle exit cone rather than accept the larger tolerances normally associated with tape-wrapping an exit cone to net internal dimensions. Even though a precision tape-wrapping mandrel is practical to fabricate, the nozzle exit cone would distort beyond the desired tolerances during the ablative material cure cycle. Both the nozzle body and attachment ring, individually, required close dimensional control to assure minimum misalignment after the two parts were assembled.

A nozzle burst diaphragm covers the leading portion of the throat insert. Its primary purpose is to prevent foreign matter from entering the assembled apogee motor. The diaphragm is also utilized to block the throat section during a leak check test, to assure the efficient design of the nozzle O-ring sealing surface and adhesive-bonded interfaces. This diaphragm has been designed to burst at 30 psig.

C. Materials

JPL maintains a continuous nozzle materials evaluation program. Based primarily on the results of this program, numerous candidate materials were screened for the carbon throat section, silica exit cone, and graphite throat insert. The specific criteria considered important for screening of the carbon and silica ablative materials were the following:

(1) Erosion rate.

(2) Char rate.

(3) Char strength.

(4) Actual firing comparisons.

(5) Present industry uses.

(6) Physical properties.

(7) Impregnated properties; i.e., resin solids, volatiles, and flow characteristics.

(8) Tape-wrapping characteristics (ease in fabrication).

(9) Quality assurance.

(10) Availability.

(11) Costs.

(12) Material contractors.

(13) Resin systems.

The two materials chosen were FM 5024 carbon cloth and FM 5131 silica cloth, both manufactured by U. S. Polymeric, Inc. of Santa Ana, California. The raw carbon fabric is produced by the Carborundum Corporation, Sanborn, New York; the raw silica fabric is manufactured by H. I. Thompson Fiber Glass Company, Gardena, California and Haveg Industries, Inc., Wilmington, Delaware. U. S. Polymeric, Inc. impregnates the carbon fabric with a highly substituted ring structure phenyl-aldehyde condensation phenolic resin and the silica fabric with a modified phenolic resin.

Both resin systems contain proprietary additives to improve the ablative materials handling and fabrication characteristics along with end product ablative performance properties. Typical physical properties of the cured carbon cloth and silica cloth materials are shown in Table 1.

Several candidate materials were reviewed for the graphite throat insert based on the following criteria:

(1) Erosion rate with JPL 540 propellant.

(2) Physical properties.

(3) Availability.

(4) Cost.

Predicated on the negligible erosion rate and superior physical properties, compared with several other materials, Graph-i-tite "G", manufactured by the Carborundum Corporation, was chosen for the insert material. Typical physical properties are shown in Table 2.

Table 1. Ablative material physical properties

Typical laminated properties	FM 5024 Carbon fabric	FM 5131 Silica fabric
Tensile strength, psi	18,000	14,000
Tensile modulus, psi	2.8×10^6	1.9×10^6
Compressive strength, psi	26,000	17,000
Compressive modulus, psi	2.5×10^6	1.7×10^6
Flexural strength, psi	28,000	25,000
Flexural modulus, psi	2.7×10^6	2.6×10^{-6}
Thermal conductivity, Btu-in./hr ft^2	4.3	2.2
Thermal expansion, in./in./°F	7.1×10^{-6}	2.1×10^{-6}
Specific heat, Btu/lb/°F	0.23	0.23
Specific gravity	1.44	1.73
Hardness (Barcol)	66	71
Resin solids, %	34	32

Table 2. Graphite physical properties

Property	Room temperature	4200°F
Density, gm/cc	1.89	1.88
Tensile strength, psi	2,900	5,600
Compressive strength, psi	8,700	15,600
Transverse strength, psi	4,000	7,200
Modulus of elasticity, psi	12×10^5	23×10^5
Thermal expansion, in./in./°F	9×10^{-7}	27×10^{-7}
Thermal conductivity, Btu-ft/hr-°F-ft	98	11
Ash content, %	0.08	0.08

III. Special Requirements

A. Alignment

Because of spacecraft attitude control requirements, the thrust vector of the motor must be rigidly defined. To meet maximum requirements, the slope of the theoretical thrust vector (the line connecting the centroids of the nozzle throat and exit areas) may not deviate from, nor be misaligned with, the spin axis by more than 0.001 in./in. Further, when the measured thrust vector is projected to intersect the plane of the motor spacecraft attachment ring, the vector may not deviate from, nor be offset to, the plane center by more than 0.030 in.

The nozzle was designed to adequately meet both requirements before and after motor firing. To assure that each nozzle met all design requirements, the unit underwent a precision mechanical inspection for the following:

(1) Determination of drawing conformity.

(2) Comparison of data among parts for quality control purposes.

(3) Thrust misalignment and offset calculations.

The dimensional and misalignment data then became a factor in determining the assignment of each nozzle for development test, qualification test, or flight.

The dimensional inspections concerned the following: circumferential out-of-roundness, which is defined as the difference between maximum and minimum radii about the centroid of the measured profile; the centroidal offset, which is the horizontal deviation of the centroid of the profile in question from a vertical line originating from the centroid of a reference diameter; flatness, which is the vertical distance between the maximum peak and minimum valley of the surface (vertical is parallel to the axis of symmetry).

A total of 36 flight design nozzles were subjected to the precision alignment inspection prior to acceptance by JPL. The initial step in the inspection consists of placing the nozzle on a precision rotating table. Then the unit is centered with respect to the A-5 nozzle attachment ring surface. Since this surface is used to center the nozzle during motor assembly, it is used as the basic or reference surface during the alignment inspection (Fig. 5).

Subsequently, the centroidal offset and circumferential out-of-roundness of all A diameters were measured with respect to the A-5 reference. The B-3 surface is the mating plane with the chamber, the reference to which all the parallel measurements of the B surfaces were compared. The flatness of the B-3 surface was used to evaluate possible nozzle misalignment prior to installation on a chamber. To inspect all the aforementioned positions, the nozzle was placed on a rotating table and was supported by a precision inspection fixture.

B. Dynamic Balance

To maintain spin stability throughout the spacecraft mission, stringent balance requirements have been placed on the motor before and after propellant expulsion. The

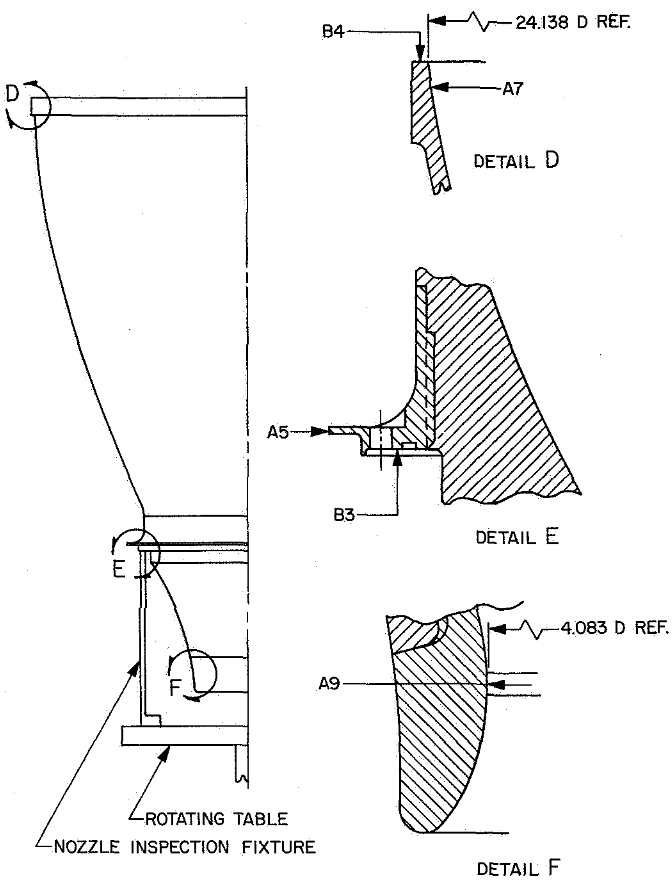


Fig. 5. Alignment inspection positions

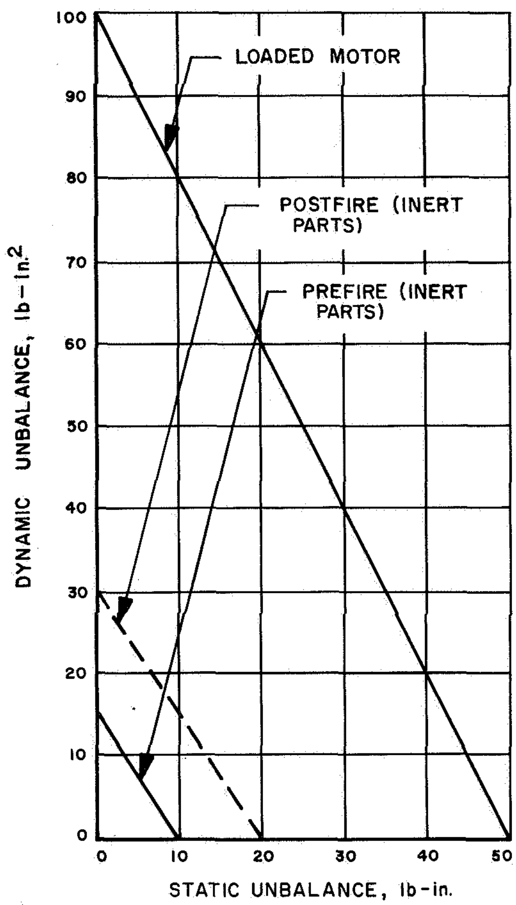


Fig. 6. Maximum allowable sum of static and dynamic unbalance

allowable dynamic and static imbalance prior to propellant loading, after loading, and at motor burnout is shown in Fig. 6.

Static imbalance, alone, shifts the principal axis parallel to, but not colinear with, the spin axis of the motor. Dynamic balance, alone, tilts the principal axis with respect to the spin axis. In a realistic case of imbalance, there will be a combination of static and dynamic imbalance. Therefore, the principal axis will be shifted with respect to the spin axis.

It is not possible to have the motor in static and dynamic balance before and after propellant expulsion. The more critical balance requirement is after motor burnout, since the unit stays with the spacecraft during its lifespan. Therefore, to minimize the motor imbalance at burnout, the empty assembly is balanced prior to loading.

To balance the motor assembly, lead ballast weights are affixed to the motor with an epoxy adhesive. The two selected balance planes are located on the motor attachment surface (inside of the mounting ring) and on the nozzle attachment ring. The balance weight on the nozzle ring is affixed by sandblasting the aluminum ring and balance weight, and then applying an epoxy adhesive to the balance weight. The weight and ring are carefully mated at the required angular location on the ring; then the epoxy is cured at elevated temperature. The balance weight's radial location and its distance from the motor center of gravity are recorded. It is then possible to calculate the amount of static and dynamic imbalance removed by the addition of the balance weight.

To assist in maintaining post-fire dynamic balance, two innovations were incorporated into the design of the nozzle. The exit cone thicknesses were designed to maintain a thin membrane of virgin material after motor operation and subsequent heat soak, thereby retaining rigidity and concentricity in the exit cone. Also, strict controls were maintained on the tape-wrap process to minimize post-fire irregular tape delaminations.

IV. Fabrication

Fifty nozzles were fabricated and used in the motor development, qualification, and flight phase. Of the 50 units, 14 were fabricated as test nozzles (Fig. 7) with an expansion ratio of 8.5:1 and used for ambient motor firings at the JPL-ETS facility. Five of the 14 units were heavy wall direct scale-ups of the SYNCOM nozzle, as shown in Fig. 8 and 9, and used exclusively for the initial boiler plate motor firings. The remaining test nozzles were used on the initial flight weight motor firings and closely resembled the flight design nozzles to the 8.5:1 expansion ratio.

The following discussion describes the fabrication of the flight design nozzles only.[1] Manufacturing the nozzle consists of two major operations, performed by two separate contractors. The first operation is tape-wrapping the composite carbon and silica nozzle body blank. The second operation consists of final machining the nozzle outside and inside surfaces, along with assembly of the

[1]Each unit was fabricated to JPL drawings J3901656B, J3901657D, J3901658D, J3901659D, J3901663 and JPL Specifications GMO-50111-GEN, GMO-50212-MTL, and COM-50321-TST.

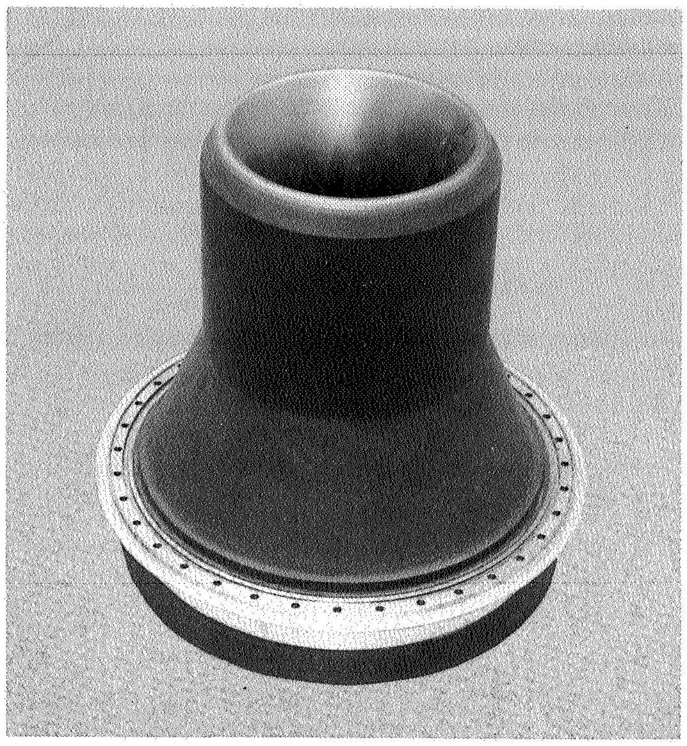


Fig. 8. Prefire SYNCOM scale-up nozzle assembly

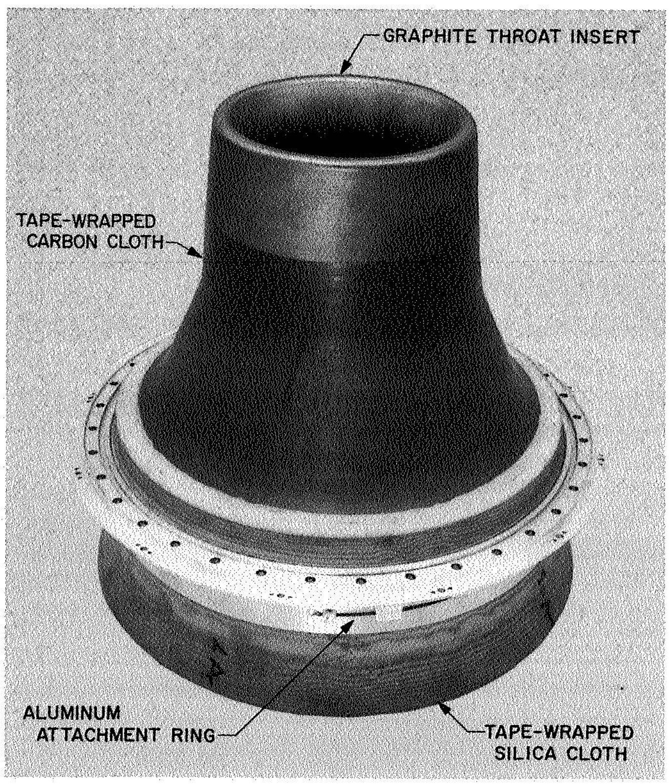


Fig. 7. Test nozzle assembly ($\varepsilon = 8.5$)

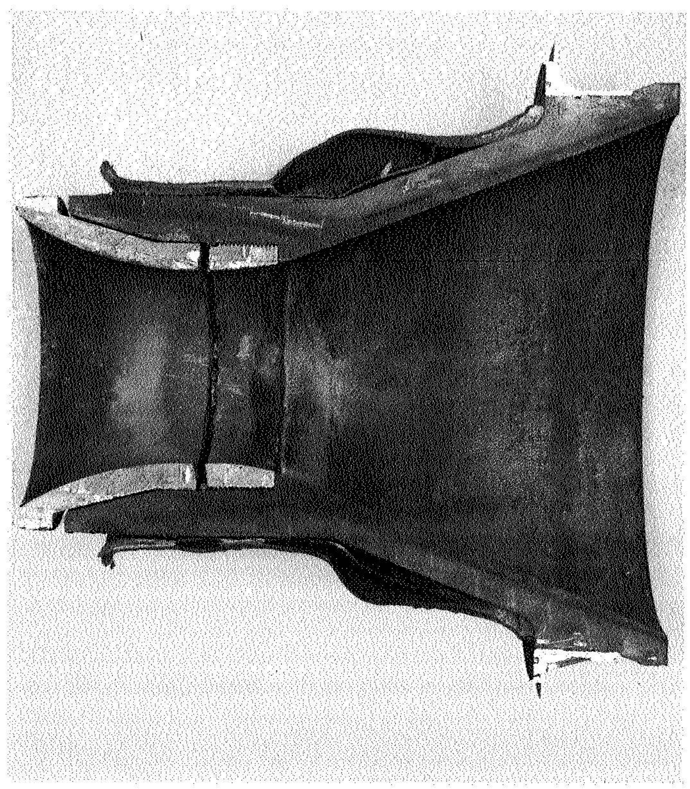


Fig. 9. Postfire SYNCOM scale-up nozzle assembly

graphite throat insert and aluminum attachment ring to the nozzle body.

Early in the program a decision was made to subcontract the nozzle manufacturing to two contractors, rather than one. This approach appeared more feasible, in order to obtain a precise and reliable nozzle assembly. This idea was based on the fact that the candidate contractors capable of tape-wrapping the nozzle blank were not highly qualified for precision-machining the nozzle to the required tolerances. Therefore, a contractor experienced in precision machining ablative materials was chosen to final-machine the nozzle assembly.

A typical sequence of fabrication operations is shown in Fig. 10.

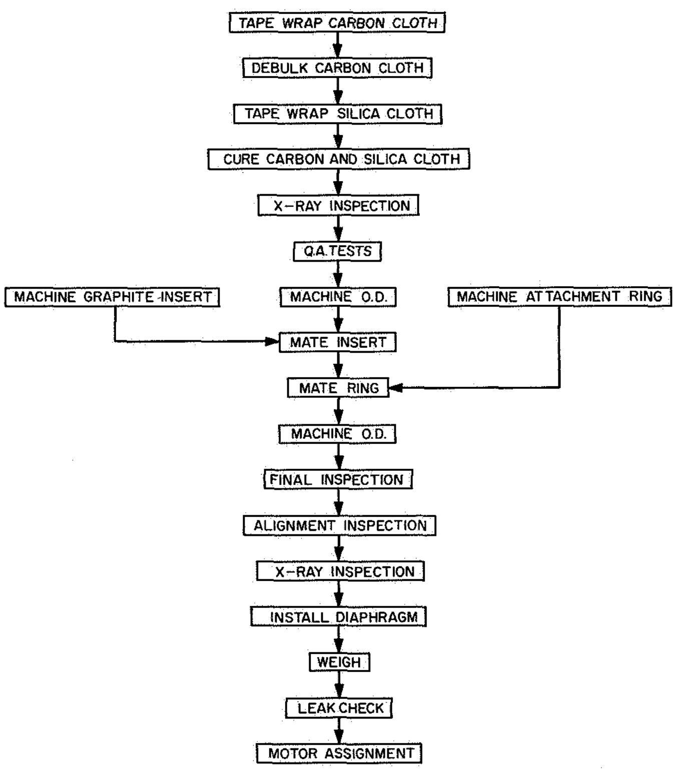


Fig. 10. General nozzle assembly fabrication flow chart

A. Materials

U. S. Polymeric, Inc. supplies both the carbon and silica, resin-impregnated cloth to the fabrication contractor. The raw cloth materials are inspected and tested prior to resin impregnation to assure compliance with specified chemical, physical, and workmanship requirements. Each accepted roll (42 in. wide, 150 yd long and 0.035 in. thick) is impregnated with the appropriate resin system under strict quality control. Throughout the impregnation process, strict control is maintained on the staging temperature, degree of resin polymerization, and resin content to assure uniform properties within the roll. Upon completion of the resin impregnation, quality assurance samples are randomly cut from the roll and tested for resin content, resin volatiles, and resin flow characteristics. These properties, if not within specified tolerances, affect both the tape-wrapping characteristics, or ability to fabricate the part, and the final physical properties of the cured ablative materials.

The final tape preparation operation consists of cutting or slitting the tape to the numerous contractor-specified widths, which vary from 4 to 8½ in. All carbon tape is cut parallel to the weave for straight wrapping while the silica tape is cut at an angle. The optimum silica tape form is a tape cut on a 45-deg bias, supplied in continuous rolls, and slit to the desired width. Splices every 4 ft or so are needed for continuous tape. These splices are made by a butt joint sewn with nylon thread. If necessary, the same joint is utilized in the carbon tape.

The bias tape is used when an angle orientation is required because the tape must deform as it is wrapped. The edge of the tape, in contact with the mandrel, is supplied at a slower rate than the outer edge of the tape because of the difference in circumference. This difference in speed (or actually difference in circumference from tape edge to tape edge) requires the tape to stretch across its width with the maximum stretch at the outer edge.

B. Tape Wrapping

The tape-wrap process is the application of narrow sheet material, which is woven and impregnated with resin, to a rotating mandrel that is circular in cross section. The tape application is made at a specific and controlled orientation relative to the mandrel centerline.

The quality of a tape-wrapped part is a direct function of the control of tape orientation during the wrapping operation and maintaining that orientation during subsequent high-pressure cure. This means that excessive wrinkling of the tape in the cured part cannot be tolerated (generally associated with poor erosion and char resistance and a weakening of the structural properties of the final laminate). The tape must be applied to the mandrel so that maximum density in the "as-wrapped" condition is realized.

A critical part of the tape-wrap process is control of material. Once the specific material is defined for the process, any major variations of resin content, degree of polymerization, and volatile content within the tape roll, or from roll to roll, will affect the final result.

The phenolic impregnated tape, i.e., carbon and silica, are susceptible to environment. Changes in temperature and humidity cause variations of moisture content. This in turn directly influences the tape-wrapping operation by affecting tack, drape, tape tensile strength, swelling, and shrinking of the wrapped material on the mandrel. Since these problem areas have been recognized, tape materials are utilized in a temperature (72°F) and humidity (45%) controlled environment.

Variations in the wrap process will also affect the final tape laminate. To assure a uniform product, the following variables are controlled: tape tension, roller pressure, tape temperature, rate of heating, cooling, and degree of resin advancement of the impregnated tape.

Tape temperature, cooling, and degree of advancement of impregnated material are directly and closely related. They could be summed up as tack temperature of the tape (230 to 260°F). For a specific degree of resin advancement, there is a minimum tack temperature required to assure positive tack or adhesion throughout the wrapping sequence.

Positive adhesion is of prime importance. Failure to achieve tack, even a part of one revolution, may mean that the wrapped part may separate or slide during the wrap operation, or during handling prior to application of final cure pressure and temperature. This can cause successive ply separation, loss of control of orientation, and delaminations which are causes for rejection of the nozzle body.

Adequate cooling is required to prevent a significant change in resin advancement during the wrap operation, where tape temperature may be high. Since resin advancement is a function of both temperature and time, it is possible to expose the tape to high temperatures (for tack) for a short time (by cooling rapidly) without noticeably affecting resin polymerization.

Compression roller pressure is of prime importance in bias tape since only minimum tape tension is applied to the tape to prevent *necking down* or *shrinking*; therefore, the roller pressure must compact the uncured laminates. An excessive roller pressure would crush the laminate fibers and degrade the cured physical properties.

The primary parameters of successful tape wrapping are: high-wrapped density, minimum wrinkles, absence of delaminations, minimum built-in stresses, maximum cured densities, control of tape orientation, and reproducibility.

C. Nozzle Body Blank

The nozzle body blank (Fig. 11), i.e., the composite tape-wrapped carbon and silica structure, was manufactured by Haveg Aerospace, Santa Fe Springs, California. Prior to initiating the fabrication of a nozzle body, the tape materials are removed from 40°F storage and subjected to various JPL specified physical tests to assure that the unpolymerized carbon and silica fabrics meet minimum requirements. These tests consist of confirming previously determined resin solids, volatiles, and flow. Also, the tape-wrapping characteristics of tack temperature and drape of the material are determined, which affect the ease and ability of the contractor to fabricate the unit. It is necessary to recheck these characteristics since, with age, even though stored at 40°F, they have a tendency to change.

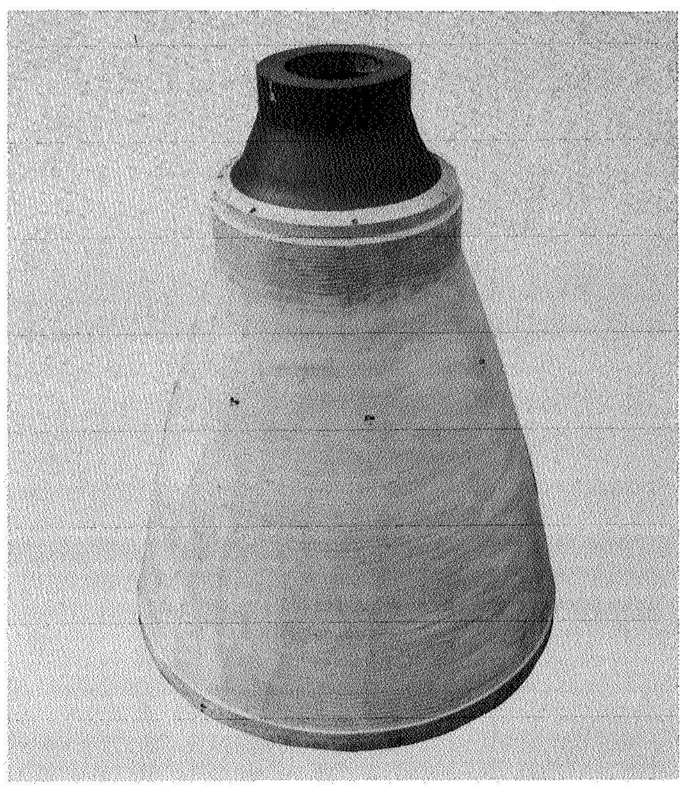


Fig. 11. Nozzle body blank

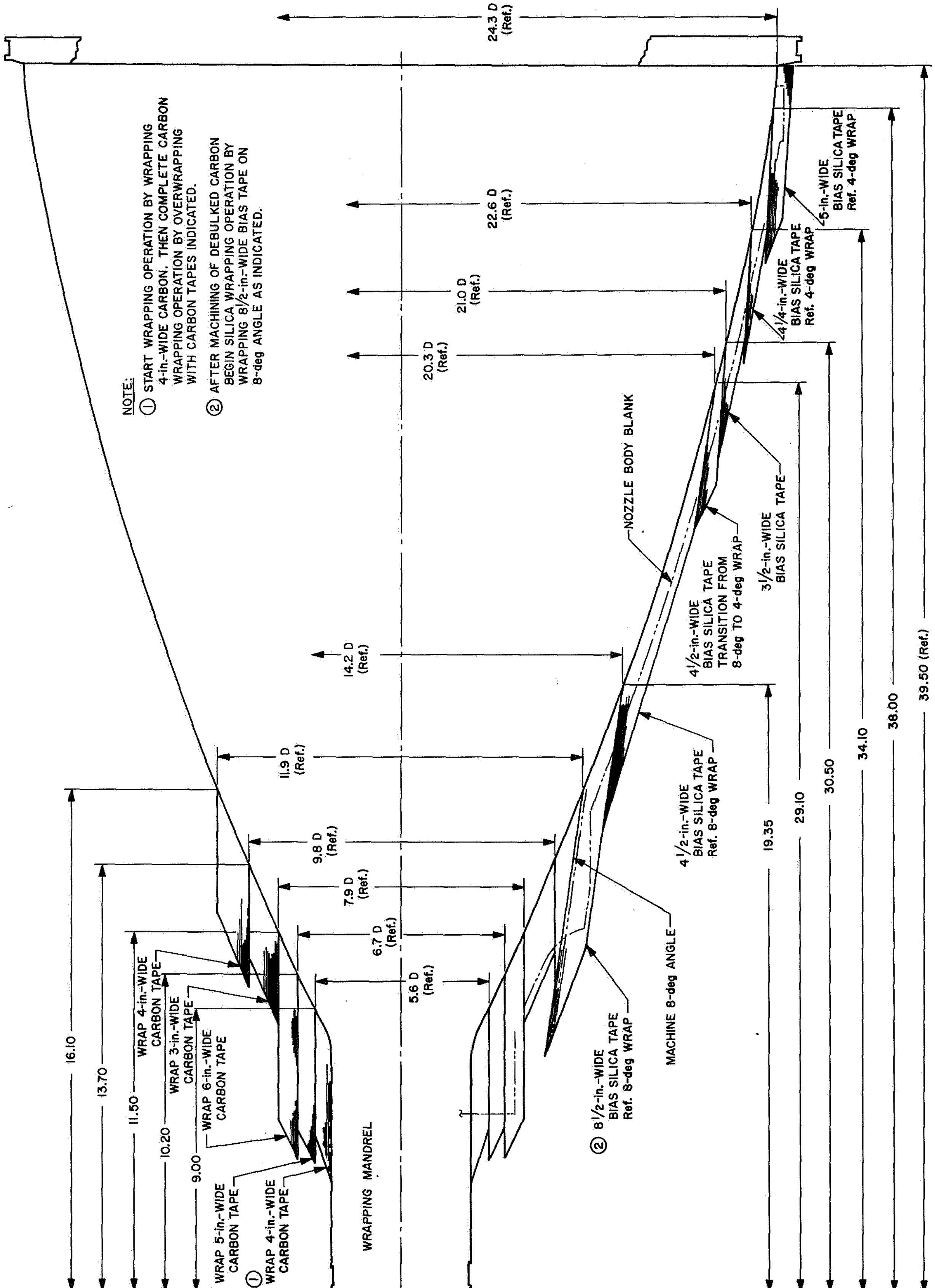


Fig. 12. Tape wrap layout

The initial wrapping operation consists of mounting a mandrel to the tape-wrapping machine. The mandrel matches the internal contour of the final nozzle except for 1/16 in. overstock. Figure 12 shows the mandrel and the tape-wrap layout of the carbon and silica tapes. Carnauba wax is then applied to the mandrel surface as a mold release for the ablative material. Next, parallel carbon tape is wrapped on the mandrel until the required configuration is achieved. The mandrel is then removed from the wrap machine, placed in a rubber bag, and debulked in an autoclave. Figure 13 shows the temperature and pressure vs time curves for the carbon-cloth debulk cycle. The primary reason for debulking the carbon cloth is to increase the density and further the polymerization of the resin; this facilitates machining an 8-deg angle on the carbon cloth for the silica cloth interface. Also, the debulk cycle improves the physical properties of the carbon throat section and avoids possible difficulties when initiating the silica wrap.

Upon completion of the debulk operation, the mandrel is returned to the wrap machine and the silica tape is applied at an 8-deg angle to the nozzle centerline. Approximately 8 in. from the exit end, the angle of wrap is changed to 4 deg to the nozzle centerline to assure a reasonable bond line between laminates.

If the angle was maintained at 8 deg, the bond line would approach the final exit cone angle, resulting in impractical and lengthy tape widths. If the silica exit cone was wrapped parallel to the nozzle centerline, as the carbon fabric, the bond line would approach a minimum marginal length in the final assembly. This would result in a possible loss of an exit cone during a motor static test at the tail off and diffuser blow back phase, since the narrow charred bond line would not be capable of withstanding the diffuser blow back load.

After the silica wrap is completed, the nozzle body is prepared for final cure in a hydroclave. The unit is encapsulated with a perforated cellophane material to aid in bleeding off excess resin during the cure cycle. Metal stripping is applied longitudinally to uniformly debulk the materials and thereby avoid the formation of wrinkles during the cure cycle. A cloth stocking-type material is then applied to absorb the excess resin. Again, a layer of cellophane cloth is applied as a release agent between the stocking and the rubber encapsulation bag. Subsequently, the rubber bag is checked for leaks, then evacuated and placed in a hydroclave. Figure 14 shows the temperature and pressure vs time for the final carbon and silica cloth-cure cycle. The unit is removed from the hydroclave and visually inspected for wrinkles, visible delaminations, and moisture damage during the cure cycle.

To assure successful fabrication of the nozzle body, the blank is rough machined on the outside surface, to remove surface defects, then radiographically inspected for cracks, tape delaminations, and resin rich areas. At each end of the unit, a tag sample is removed to conduct

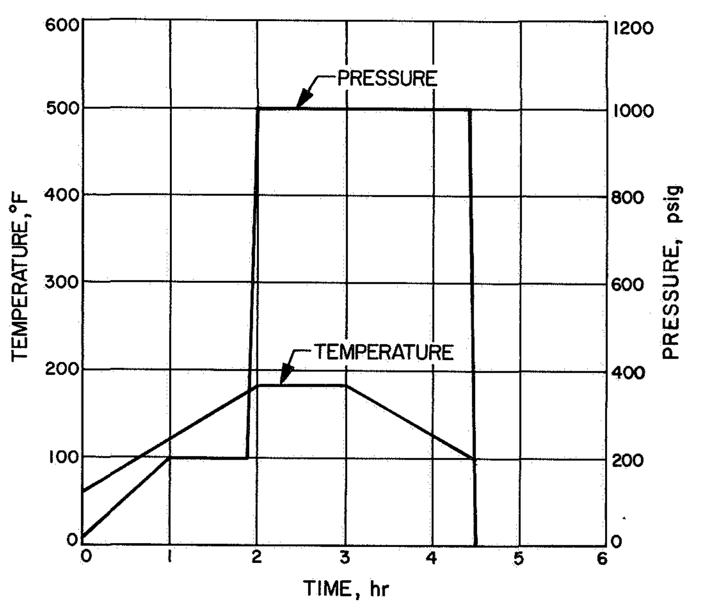


Fig. 13. Carbon cloth debulk cycle

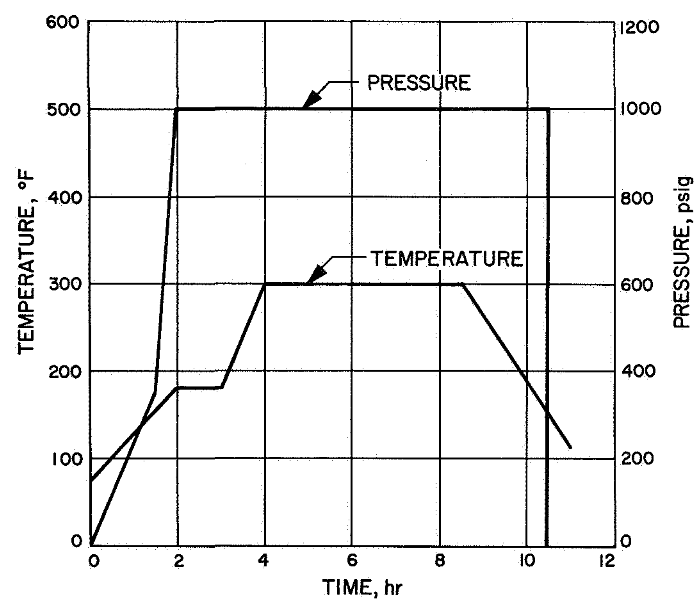


Fig. 14. Carbon and silica cloth-cure cycle

quality assurance tests, which include density and acetone extractables. If the X-ray inspection, quality assurance test, and tape material property requirements are achieved, the nozzle blank is accepted by JPL.

D. Final Machining and Inspection

Final machining and assembly of the nozzle was performed by R. W. Fricke Machine Company, San Gabriel, California. To assure a precision and reproducible nozzle, quality assurance in-process inspection was required on each unit.

The first machining operation includes machining internal threads on the forward carbon cloth section of the nozzle body to accept a previously machined graphite throat insert. The mating threads are closely inspected for laminate failures, then a coating of epoxy adhesive is applied to the carbon and graphite threads and allowed to cure at room temperature. The throat insert is threaded to provide a required mechanical interlock after motor firing.

After bonding the insert, the entire outside surface of the nozzle is finish-machined to final dimensions with a diamond cutting tool. A critical portion of this operation consists of turning a 12-in. diameter thread on the silica ablative material. Improper cutting speed, feed, tool pressure, or clearance will result in a failure of the laminate thread plies. Since the threads are a major load-carrying member in the nozzle attachment to chamber joint, any deviations in thread tolerances or configuration would be a cause for rejection. Therefore, each thread must be 100% inspected to avoid a possible motor failure mode.

A precision aluminum attachment ring is machined from 2014 T-6 aluminum forging. Then the aluminum ring threads and the silica nozzle body threads are coated with an epoxy adhesive, mated together, and the adhesive is allowed to cure at room temperature. The unit is now assembled in its final configuration.

Contour machining the inside surface is the final operation. Again this is accomplished through the use of a tracer valve assembly, diamond cutting tool, and a precision template. It is extremely critical that the template be properly positioned to achieve the correct throat diameter of 4.083 $\pm$ 0.001 in., and an exit diameter of 24.138 $\pm$ 0.010 in., along with the appropriate wall thicknesses.

During the machining and assembly operation, an inspection is made of each drawing dimension and the physical appearance of the threads, in addition to verification of proper assembly procedures are performed by quality assurance personnel.

A portion of the final inspection includes a precision alignment inspection. The primary purpose is to determine the relative locations, eccentricities, and roundness of the nozzle attachment ring surface, throat, and the exit plane. Therefore, a theoretical thrust vector misalignment may be determined to assist in choosing flight nozzles. Figure 5 shows the surfaces inspected, and Table 3 indicates the results of these inspections.

A final operation, which is performed at JPL, consists of weighing the completed nozzle assembly and installing the diaphragm. The diaphragm, which is installed over the leading edge of the throat insert, is fabricated from 0.004-in. thick No. 1100-0 aluminum, which is pressure formed from a precut disc. It is bonded to the graphite insert with an epoxy adhesive which cures at room temperature.

After final assembly, the nozzle is X-rayed to assure complete and precise fabrication of the unit. The nozzle is also leak checked to confirm the acceptability of the O-ring sealing surface on the attachment ring, and to assure that no gas passage exists at the two adhesive bonded interfaces.

V. Testing

A series of environmental and static tests were conducted to verify the design and structural adequacy of the nozzle assembly. Included in these tests were temperature cycling, static acceleration, vibration, nozzle joint interface destruct, and space temperature tests. The static motor firing tests included spinning and nonspinning, ambient, and altitude tests. At present, three motors with flight design nozzles are subjected to long-term storage environments.

A. Environmental

A total of 14 nozzles, which include eight units in the motor qualification phase, have been subjected to temperature cycle, booster accelerations, and booster vibration tests. Upon completion of the environmental phase, the nozzle was subjected to an alignment inspection, then removed from the motor chamber, X-rayed, and

Table 3. Nozzle alignment summary

Nozzle[a] serial No.	Code No.	Nozzle weight, lb	Surface inspection description						
			A-5 out of round, in.	A-7 out of round, in.	A-7 offset from A-5, in.	A-9 out of round, in.	A-9 offset from A-5, in.	B-3 Flatness, in.	B-4 Flatness, in.
F-8	D-1	52.28	0.0005	0.0050	0.0020	0.0007	0.0002	0.0017	0.0020
F-9	E-1	48.50	0.0004	0.0025	0.0008	0.0004	0.0005	0.0018	0.0017
F-15	E-2	37.12	0.0006	0.0060	0.0040	0.0006	0.0005	0.0018	0.0023
F-16	G-1	37.23	0.0006	0.0040	0.0020	0.0004	0.0004	0.0009	0.0018
F-17	G-2	37.61	0.0005	0.0070	0.0020	0.0003	0.0004	0.0011	0.0007
F-18	D-3	37.03	0.0021	0.0040	0.0050	0.0005	0.0002	0.0013	0.0018
F-19	G-7	37.94	0.0006	0.0035	0.0006	0.0003	0.0001	0.0010	0.0008
F-20	G-4	38.00	0.0012	0.0060	0.0007	0.0004	0.0007	0.0019	0.0026
F-21	G-6	38.22	0.0004	0.0030	0.0005	0.0004	0.0004	0.0006	0.0007
F-22	D-5T	39.55	0.0007	0.0020	0.0008	0.0001	0.0003	0.0008	0.0008
F-23	G-9T	39.44	0.0018	0.0040	0.0003	0.0003	0.0003	0.0010	0.0015
F-24	G-3	39.72	0.0004	0.0025	0.0013	0.0002	0.0003	0.0010	0.0015
F-25	D-4	39.36	0.0005	0.0025	0.0013	0.0002	0.0001	0.0008	0.0011
F-26	F-1	38.83	0.0018	0.0030	0.0018	0.0003	0.0002	0.0010	0.0017
F-27	F-2	39.15	0.0004	0.0055	0.0018	0.0004	0.0003	0.0019	0.0015
F-28	F-3	38.94	0.0007	0.0025	0.0070	0.0003	0.0003	0.0011	0.0008
F-31	Q-1T	38.27	0.0006	0.0035	0.0008	0.0003	0.0005	0.0015	0.0021
F-32	Q-5T	38.95	0.0005	0.0045	0.0013	0.0003	0.0003	0.0009	0.0013
F-33	Z-4	37.95	0.0005	0.0045	0.0018	0.0005	0.0003	0.0006	0.0010
F-34	Q-2T	38.23	0.0005	0.0060	0.0020	0.0002	0.0004	0.0012	0.0026
F-35	D-2T	39.25	0.0004	0.0060	0.0020	0.0002	0.0005	0.0020	0.0030
F-36	G-8T	37.88	0.0005	0.0038	0.0020	0.0002	0.0006	0.0013	0.0020
F-37	Q-9T	38.07	0.0007	0.0030	0.0015	0.0002	0.0005	0.0007	0.0022
F-38	Q-3T	38.57	0.0005	0.0065	0.0020	0.0004	0.0010	0.0015	0.0020
F-39	Q-8T	38.31	0.0002	0.0015	0.0010	0.0004	0.0004	0.0013	0.0012
F-40	Z-2	37.77	0.0004	0.0035	0.0020	0.0004	0.0007	0.0013	0.0017
F-41	Q-6T	37.13	0.0004	0.0045	0.0015	0.0006	0.0006	0.0017	0.0028
F-42	E-3T	38.29	0.0007	0.0060	0.0010	0.0003	0.0003	0.0016	0.0025
F-43	Q-7T	38.33	0.0006	0.0050	0.0025	0.0003	0.0006	0.0023	0.0025
F-44	Q-4T	38.13	0.0008	0.0090	0.0030	0.0003	0.0005	0.0036	0.0053
F-45	Z-1	37.86	0.0008	0.0090	0.0027	0.0003	0.0010	0.0035	0.0045
F-46	Z-3	37.94	0.0008	0.0030	0.0015	0.0002	0.0005	0.0016	0.0023
F-47	Z-6	37.50	0.0010	0.0065	0.0015	0.0004	0.0006	0.0023	0.0033
F-48	Z-5	37.24	0.0012	0.0055	0.0015	0.0003	0.0004	0.0021	0.0034
F-49	Z-7	37.70	0.0010	0.0120	0.0030	0.0006	0.0008	0.0033	0.0050
F-50	I-1	37.89	0.0006	0.0040	0.0025	0.0009	0.0008	0.0024	0.0033

[a]Nozzles F-22 through F-50 are flight design.

visually inspected. Each unit underwent the test environments without any changes in alignment, physical dimensions, or structural capability.

In all cases, the test environment levels, previously mentioned and described in the following, are more severe than the predicted actual environments.

1. Temperature Cycle. Exposure to this test environment verifies that the apogee unit is capable of withstanding temperature conditioning over a range of 10 to 110°F. Periods of temperature exposure are 72 hr at each extreme, as shown in Table 4. This time period allows the complete unit (including grain) to stabilize at the conditioning temperature.

2. Booster Acceleration. The purpose of the acceleration testing is to demonstrate that the apogee unit loaded with live propellant is adequate to withstand the static acceleration levels associated with the *Atlas–Agena*. Table 5 lists the schedule of static acceleration testing.

Table 4. Temperature cycle

Cycle A	Cycle B
hr °F	hr °F
72 at 110	72 at 10
72 at 10	72 at 110
72 at 110	72 at 10
48 at 60	48 at 60
(Alignment, X-ray and visual inspection)	(Alignment, X-ray and visual inspections)
72 at 10	72 at 110
(Static firing at 10)	(Static firing at 110)

Table 5. ATS apogee motor schedule of static acceleration testing

Test position	Acceleration				Centrifuge, rpm
	Level, g	Duration, min	Attachment point	Distance from centrifuge axis, in.	
Lateral (nozzle up)	2.3	10	Motor axis	216.0	19.3
Axial tension (nozzle out)	12.0	10	Chamber attachment skirt plane	205.2	45.4
Axial compression (nozzle in)	12.0	10	Chamber attachment skirt plane	226.9	43.2

3. Booster Vibration. This environment exceeds the predicted inputs of the *Atlas–Agena* booster system. The vibration specification which is presented in Table 6 gives the required input levels at the motor–spacecraft attachment plane.

Table 6. Vibration specification of the *Atlas–Agena* booster system[a]

Frequency range, cps	Random booster vibration	
	Condition	Magnitude (1.5 × expected)
20–80		0.04 g^2/cps
80–1280	6 min along each of 2 orthogonal axes in attachment plane	Increasing from 0.04 g^2/cps to 0.07 g^2/cps at 0.61 db/octave
20–1000	6 min along thrust axis	0.1 g^2/cps
	Sinusoidal booster vibration	
	Parallel to thrust axis, g peak	Perpendicular to thrust axis, g peak
5–15	0.25-in. double amplitude	0.25-in. double amplitude
15–250	3	3
250–400	5	5
400–2000	7.5	7.5

[a]Sinusoidal is 4.35 min logarithmic sweep at 2 octaves/min from 5 to 2000 cps along the thrust axis and two orthogonal axes.

Figure 15 depicts a typical nozzle acceleration response to a lateral sinusoidal sweep over the specified acceleration and frequency range. The accelerometer block, used to sense the peak g output, was located on the end of the nozzle exit cone with a response in the axial direction.

During the lateral sinusoidal sweep, the maximum nozzle response was recorded, at the exit end in the lateral direction, with resulting outputs of 150 g peak acceleration at 80 cps. Analysis of the power spectral density and spectra ratio plot indicates the nozzle resonance in the lateral axis to be 80 cps, which agrees with the sinusoidal test results.

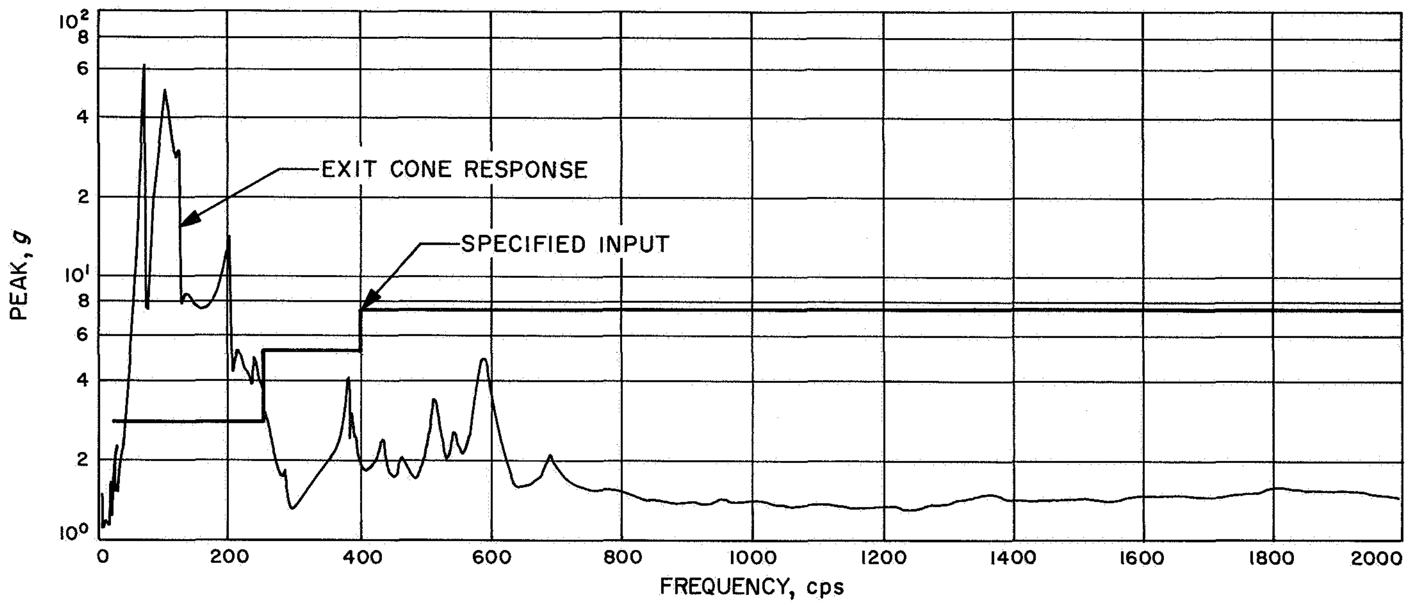


Fig. 15. Nozzle response during representative lateral axis sinusoidal test

4. Space Temperature. Prior to the ignition of the apogee motors, the spacecraft will complete three to five periods in an elliptical orbit with the apogee position being at synchronous altitude. In transversing these elliptical orbits, the nozzle exit cone, which extends out of the aft section of the spacecraft, is rapidly cooled, thus establishing a nozzle exit cone axial temperature gradient.

To evaluate the reliability of the nozzle exit cone under the above low-temperature conditions, a simulated temperature vacuum test was conducted at JPL. A thermocoupled nozzle was mated to a motor containing inert propellant so that heat transfer characteristics between nozzle and chamber could be maintained. The assembled unit was then positioned in an environmental test chamber, and the pressure was reduced to 3×10^{-4} torr.

To establish the temperature gradient, liquid nitrogen was circulated through a radiative shield until an average shield temperature of −300°F was established. Figures 16 and 17 show the nozzle environmental test setup with and without the radiative shield in place. Then a 4-hr low-temperature cycle was established which was significantly more severe than flight environments. The cooling period required 3 hr for the end of the exit cone to reach the desired −190°F and 1 hr for the exit cone to recover to ambient temperature of 70°F. Figures 18 and 19 show the established temperature gradients and their locations on the nozzle exit cone.

Upon completion of a 5-cycle test, the nozzle was removed from the chamber and subjected to visual, alignment, and radiographic inspection to assure that no detrimental effects had occurred during the cold-vacuum environment. Then the nozzle was assigned to a development motor and successfully static fired at simulated altitude conditions at Arnold Engineering Development Center.

B. Attachment Joint Destruct

The nozzle body attachment ring joint consists of a threaded silica (tape-wrapped) body and a matching threaded aluminum ring bonded to the silica body with an epoxy adhesive. A careful analysis of the structural strength of the joint required three critical assumptions as to the strength of load-carrying members. It was necessary to make an assumption as to the shear strength of the silica laminate, which is at an 8-deg angle to the pitch diameter of the silica thread. Also the clearance between the silica body and aluminum ring threads was held to maximum dimensions to retain sufficient space for the adhesive. Therefore, it was necessary to assume a thread efficiency. The strength which the adhesive added to the joint was also estimated.

To assure the reliability of the attachment joint, because of the numerous assumptions in the analytical design analysis, it was decided to test the joint and determine the actual margin of safety. Three nozzles were faced off forward of the attachment ring and sealed

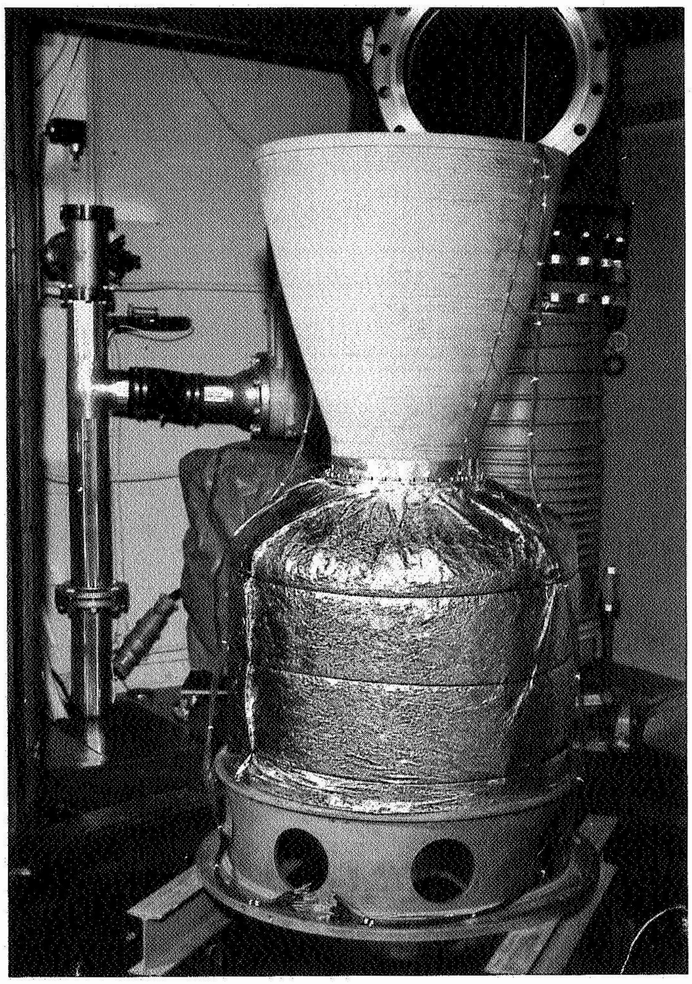


Fig. 16. Nozzle space vacuum environmental test setup

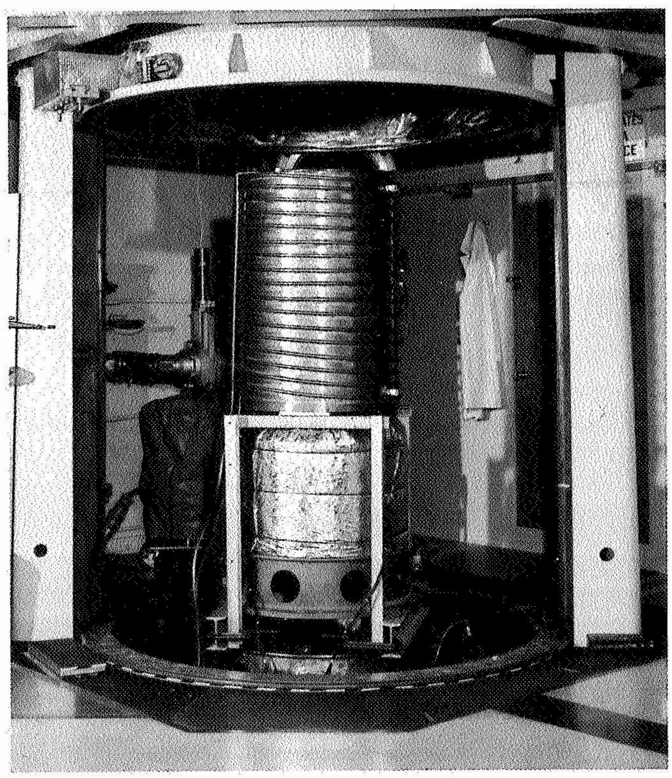


Fig. 17. Nozzle space vacuum environmental test—radiative shield in place

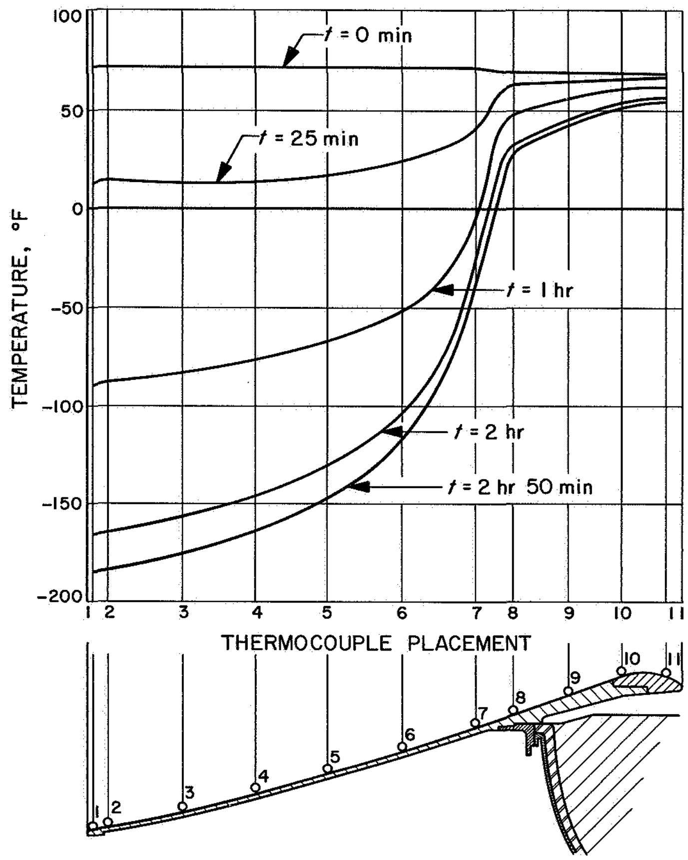


Fig. 18. Temperature profile of the nozzle space vacuum test

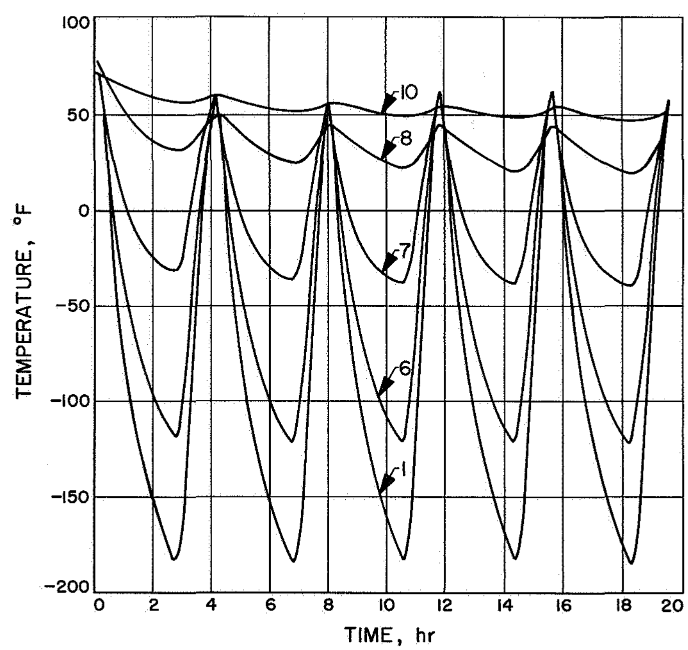


Fig. 19. Five-cycle test results of the nozzle space vacuum test

with a flat plate and O-ring. The units were placed in a test fixture, equipped with a pressure transducer, and subsequently pressurized to failure of the attachment joint. As expected, each unit failed in shear across the base of the silica thread. Two of the tested nozzles were assembled without adhesive while the third contained the adhesive. Consequently, the unit with the epoxy adhesive failed at a higher loading.

As a result of the tests, sufficient confidence was placed in the reliability of the joint since the margin of safety between the failure load of the joint and the actual flight loads is approximately 75%. The two units without the epoxy adhesive failed at loads which indicated a margin of safety of 25%.

C. Static Firings

A total of 34 motors have been fired in the motor development and qualification phases at ambient and altitude conditions to confirm the design, structural adequacy, and reliability of the nozzle (Tables 7 and 8). Under altitude conditions, the nozzle exit cone is subjected to the maximum thermal loads since the exhaust gases undergo complete expansion in the exit. This results in realistic heat flux loads, char, and erosion to the ablative exit cone. A total of 12 motors have been fired under simulated altitude conditions. Table 9 summarizes the nozzle prefire and postfire parameters of motors fired in the development and qualification phases under simulated altitude conditions at AEDC. Table 10

Table 7. ATS apogee motor development phase

Item	Development code No.[a]	Test conditions					Test environment				
		Temperature, °F			Location	Test stand type	Temperature cycle	Shipping temperature	Booster acceleration	Booster vibration	Vacuum start
		10	60	110							
A Heavy weight (J3901512)	A-1	Dummy loading to check motor casting fixtures, casting procedures and charge preparation									
	A-2		√		ETS	Single component					√
	A-3		√								√
	A-4		√								√
	A-5		√								√
B Hydrotest (J3901513) 410 Steel	B-1	Ambient			JPL	None required	Hydrotest to destruction				
	B-2										
	B-3F										
(J3901790) Titanium	B-4T										
	B-5T										
	B-6TF										
C Basic	C-1		√		ETS	Single component					√
	C-2		√								√
	C-3		√			Diffuser					√
	C-3A		√								√
	C-4	√				Single component					√
	C-5			√							√
	C-6		√								
	C-7			√							
D Dynamic model JPL	D-1	Ambient			ETS/JPL/Vendor	None required			√	√	
JPL	D-2T									√	
Hughes	D-3				Hughes						
Hughes	D-4										
Hughes	D-5T										
Thermal model Hughes	D-6F										
Hughes	D-7F										
Hughes	D-8TF										

Table 7 (contd)

Item	Development code No.[a]	Test conditions: Temperature, °F: 10	60	110	Location	Test stand type	Test environment: Temperature cycle	Shipping temperature	Booster acceleration	Booster vibration	Vacuum start
E Altitude	E-1		✓		AEDC	Single component					✓
	E-2		✓								✓
	E-3T		✓			Soft-HAC payload					✓
	E-4T		✓								✓
F Storage	F-1	✓			ETS	Spin—150 rpm	✓		✓	✓	
	F-2	✓					✓		✓	✓	
	F-3	✓					✓		✓	✓	
G Environment	G-1			✓	ETS	Single component	✓	✓			
	G-2	✓					✓	✓			
	G-3		✓		AEDC	Spin—100 rpm					✓
	G-4		✓							✓	✓
	G-5		✓		ETS	Spin—150 rpm					
	G-6			✓			✓		✓	✓	
	G-7	✓					✓		✓	✓	
	G-8T			✓		Single component					
	G-9T	✓				Spin—150 rpm	✓		✓	✓	
H Minimum propellant load	H-1	✓			ETS	Single component					
I Safe and arm	I-1		✓		ETS	Single component					

[a] T = Titanium chamber; F = Fired chamber; A = Repeat test.

Table 8. ATS apogee motor qualification phase

Item	Qualification code No.[a]	Test conditions: Temperature, °F: 40	110	Location	Test stand type	Test environment
Qualification	Q-1T	✓		AEDC test cell T-3	Spin 100 rpm	1. Temperature cycle 2. Booster acceleration 3. Booster vibration 4. Vacuum start
	Q-2T		✓			
	Q-3T	✓				
	Q-4T		✓			
	Q-5T	✓				
	Q-6T		✓			
	Q-7T	✓				
	Q-8T		✓			

[a] T = Titanium chamber

Table 9. Nozzle static firing summary of altitude tests

Code No.	Nozzle serial No.	Expansion ratio (ε)	Weight, lb			Throat diameter, in.			Average thrust coefficient
			Before	After	Lost	Before	After	Erosion, %	
E-1	F-9	35.0	48.78	44.89	3.89	4.085	4.124	1.92	1.808
E-2	F-15	35.0	37.12	32.84	4.28	4.090	4.124	1.67	1.814
E-3	F-42	35.0	38.31	33.65	4.66	4.083	4.116	1.68	—
G-3	F-24	35.0	39.75	35.40	4.35	4.083	4.110	1.33	1.82
G-4	F-20	35.0	38.14	33.80	4.34	4.082	4.112	1.48	1.81
Q-1T	F-31	35.0	38.29	33.63	4.66	4.083	4.112	1.43	1.821
Q-2T	F-34	35.0	38.36	33.82	4.54	4.082	4.116	1.67	1.815
Q-3T	F-38	35.0	38.63	34.16	4.47	4.083	4.112	1.43	1.822
Q-4T	F-44	35.0	38.00	33.60	4.40	4.085	4.117	1.58	1.815
Q-5T	F-32	35.0	38.92	34.96	3.96	4.083	4.112	1.43	1.817
Q-6T	F-41	35.0	37.01	32.21	4.80	4.084	4.125	2.02	1.818
Q-7T	F-43	35.0	38.28	33.35	4.93	4.083	4.112	1.43	1.819
Q-8T	F-39	35.0	38.32	33.85	4.47	4.083	4.117	1.67	1.819

Table 10. Nozzle static firing summary of ambient tests

Code No.	Nozzle serial No.	Expansion ratio (ε)	Weight, lb			Throat diameter, in.		
			Before	After	Lost	Before	After	Erosion, %
C-1	F-13	8.5	18.40	16.75	1.65	4.083	4.123	1.97
C-2	F-7	8.5	18.59	16.92	1.67	4.083	4.125	2.07
C-3	F-6	8.5	18.64	N.A.	N.A.	N.A.	N.A.	N.A.
C-3A	F-5	8.5	18.56	N.A.	N.A.	4.083	4.127	2.17
C-4	F-11	8.5	18.50	16.55	1.95	4.084	4.114	1.47
C-5	F-12	8.5	18.24	16.52	1.72	4.083	4.113	1.48
C-6	F-30	8.5	18.43	16.79	1.64	4.084	4.114	1.47
C-7	F-29	8.5	18.49	16.66	1.83	4.083	4.120	1.82
G-1	F-16	35.0	37.22	32.38	4.84	4.083	4.114	1.52
G-2	F-17	35.0	37.60	32.83	4.77	4.083	4.115	1.57
G-5	F-14	8.5	18.29	16.46	1.83	4.083	4.113	1.48
G-6	F-21	35.0	38.52	33.28	5.24	4.082	4.108	1.28
G-7	F-19	35.0	38.28	33.15	5.13	4.082	4.105	1.13
G-8T	F-36	35.0	37.92	33.40	4.52	4.084	4.114	1.47
G-9T	F-23	35.0	39.39	34.56	4.83	4.083	4.106	1.13

summarizes these parameters on units fired at ambient conditions at the JPL-Edwards Test Station (ETS) facility.

A postfire visual inspection of the nozzles fired at altitude conditions indicates that the units adequately survived the test environments. The units were relatively clean on the inside surface and submerged throat section, except for aluminum oxide deposits at the end of the exit cone. The attachment rings showed no indication of overheating as indicated by both visual inspection and thermocouple instrumentation on four of twelve nozzles. All dynamic balance weights were intact on the nozzle ring. There were no indications of rutting or severe erosion at the graphite throat inlet or spalling of the ablative throat and exit section. Ablative tape delaminations on the inside surface were very minor; most units had none, or a single delamination extending 90 to 270 deg around the circumference and less than 0.1 in. into the tape lamination. Figures 20, 21, and 22 show the postfire condition of the nozzle.

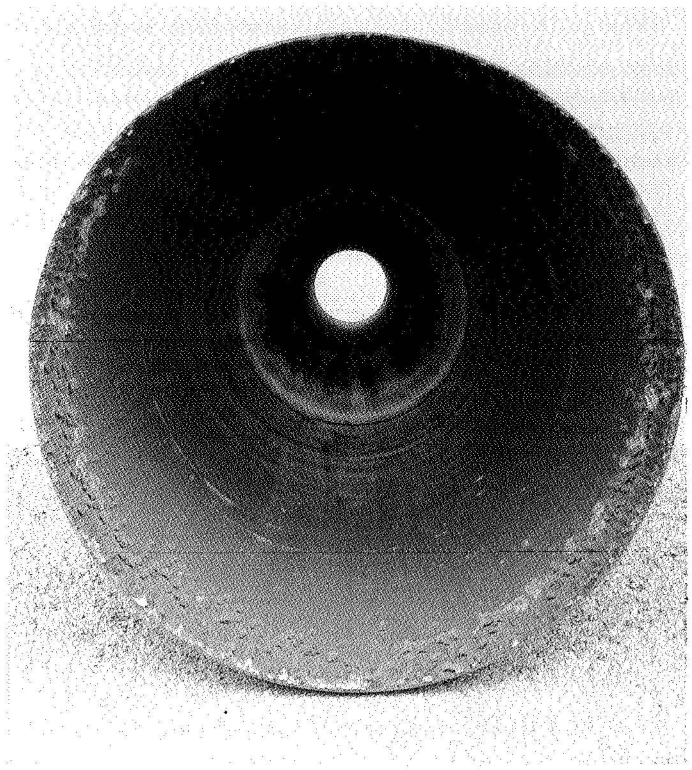


Fig. 21. Postfire condition of internal nozzle surface

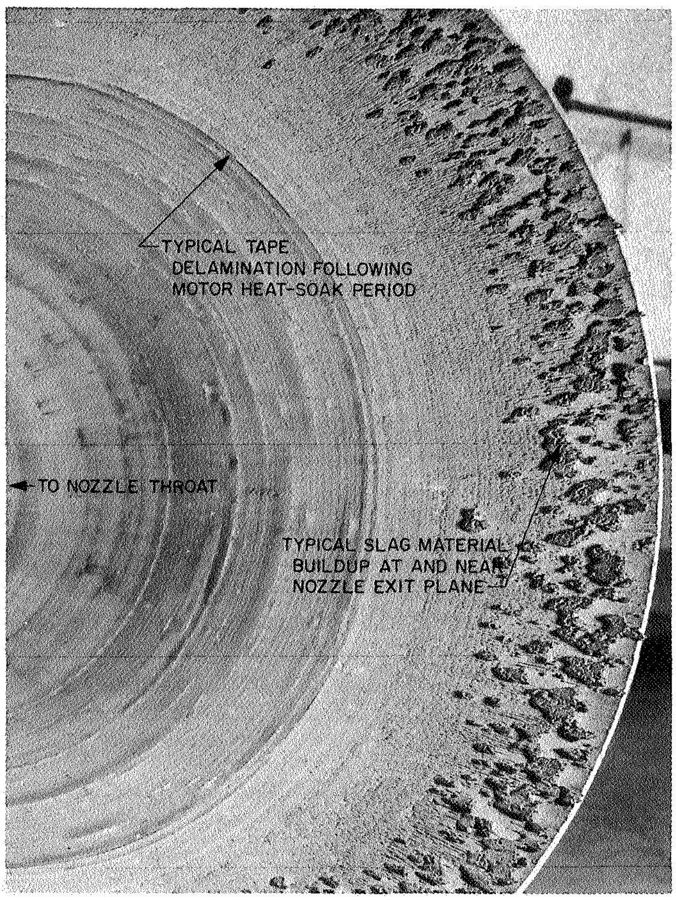


Fig. 20. Postfire condition of nozzle exit cone

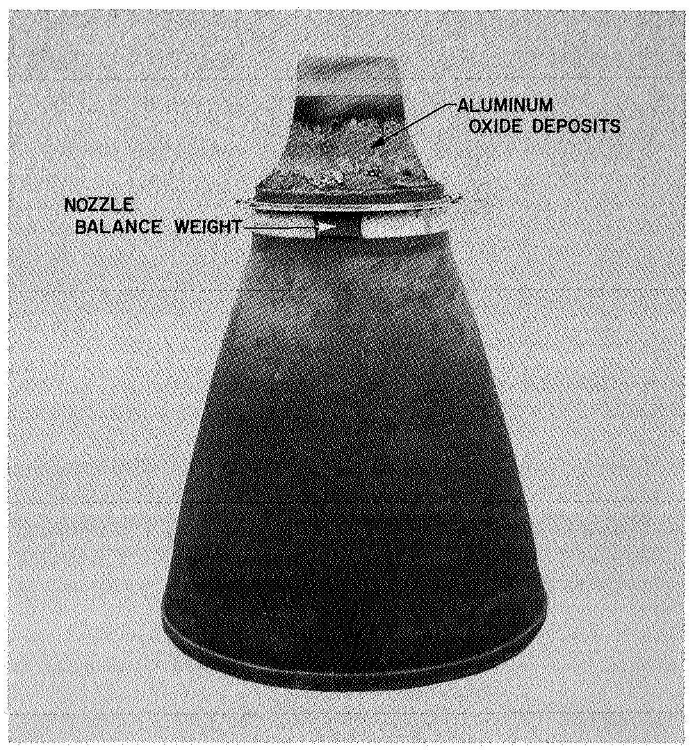


Fig. 22. Postfire condition of external nozzle surface

Prior to disassembly of a spent motor fired under simulated altitude conditions, a dimensional alignment inspection was performed to determine the postfire thrust vector alignment and offset. The inspection consists of determining the circumferential out-of-roundness and offset of the nozzle exit and throat with respect to the motor attachment surface. The geometric thrust vector misalignment and offset are tabulated for motors fired at AEDC under altitude conditions. Refer to Table 11. The postfire alignment results may be considered greater than actual misalignment and offset that occur during actual motor firing, since the nozzle exit cone distorts during post-fire heat soak and subsequent cool down. Each unit adequately met alignment requirements.

Table 11. Prefire and postfire motor alignment for simulated altitude firings

Development code	Misalignment in./in.		Offset at attachment plane, in.	
	Prefire	Postfire	Prefire	Postfire
Specification GSFC/SZ-0153	0.001	0.001	0.030	0.030
E-1	0.0003	0.0006	0.008	0.014
G-3	0.0001	0.0006	0.004	0.016
G-4	0.0001	0.0002	0.0005	0.005
Q-1	0.00001	0.0005	0.0006	0.013
Q-2	0.00005	0.0002	0.0017	0.003
Q-3	0.00009	0.0002	0.0022	0.004
Q-4	0.00005	0.0006	0.0001	0.014
Q-5	0.00002	—	0.0004	—
Q-6	0.00004	0.0003	0.0008	0.007
Q-7	0.0001	0.0004	0.0003	0.008
Q-8	0.00005	—	0.0009	—

Several nozzles, which were on motors fired under simulated altitude conditions at AEDC, were sectioned to determine both erosion and char depth of the ablative materials. Char depth in the submerged carbon throat section is 100% of the thickness, primarily due to post-fire heat soak from the graphite throat. In the nozzle exit cone, char depth is nominally 50% of the thickness. Figures 23 and 24 show the nozzle char depth.

Since the motor operates at a relatively low chamber pressure, the erosion of ablative material is negligible in most areas. However, there are two areas in the exit cone which are subjected to minor erosion. Both eroded areas are a result of minor deviations from an optimum contour for two-phase gas flow. The most severe area is located on the last three inches of the exit cone. At this point the aluminum oxide in the gas stream impinges, and adheres to the silica exit cone, thereby increasing the erosion. In the area just downstream of the nozzle attachment ring, particles do not deposit on the surface, but impinge, which results in minor erosion.

To determine and confirm the reproducibility of the temperatures on the outside surface of the nozzle exit cone, thermocouples were installed on four flight design nozzles assigned to motors fired at AEDC. Figures 25 and 26 graphically show typical nozzle temperature versus time plots, and Fig. 27 shows the locations of the thermocouples. Thermocouple R_1 attached to the aluminum nozzle ring achieves a maximum temperature of 420°F at approximately 1100 sec after motor ignition. As shown by the temperature plot, thermocouple R_5 positioned at the end of the exit cone achieves a temperature of 1100°F which is beyond the decomposition temperature of the phenolic resin binder in the silica material. Also, this temperature is sufficient to char the parent ablative material, which can be confirmed from a visual inspection of the nozzle.

Since the ATS spacecraft is spin-stabilized, the apogee motor fires while spinning at 100 rpm. Therefore, 14 of 28 motors were fired while spinning at 100 rpm at ambient and simulated altitude conditions to confirm the motor design and determine performance under this condition. It is interesting to note the effect that spinning at 100 rpm had on the post-fire condition of the nozzle. Three noticeable changes occurred: throat erosion was slightly reduced, a minimum amount of aluminum oxide deposit remained on the submerged throat section, and rutting of the leading edge of the graphite throat was significantly reduced. Figures 28 and 29 show a comparison between throat inserts on motors fired under spinning and non-spinning conditions.

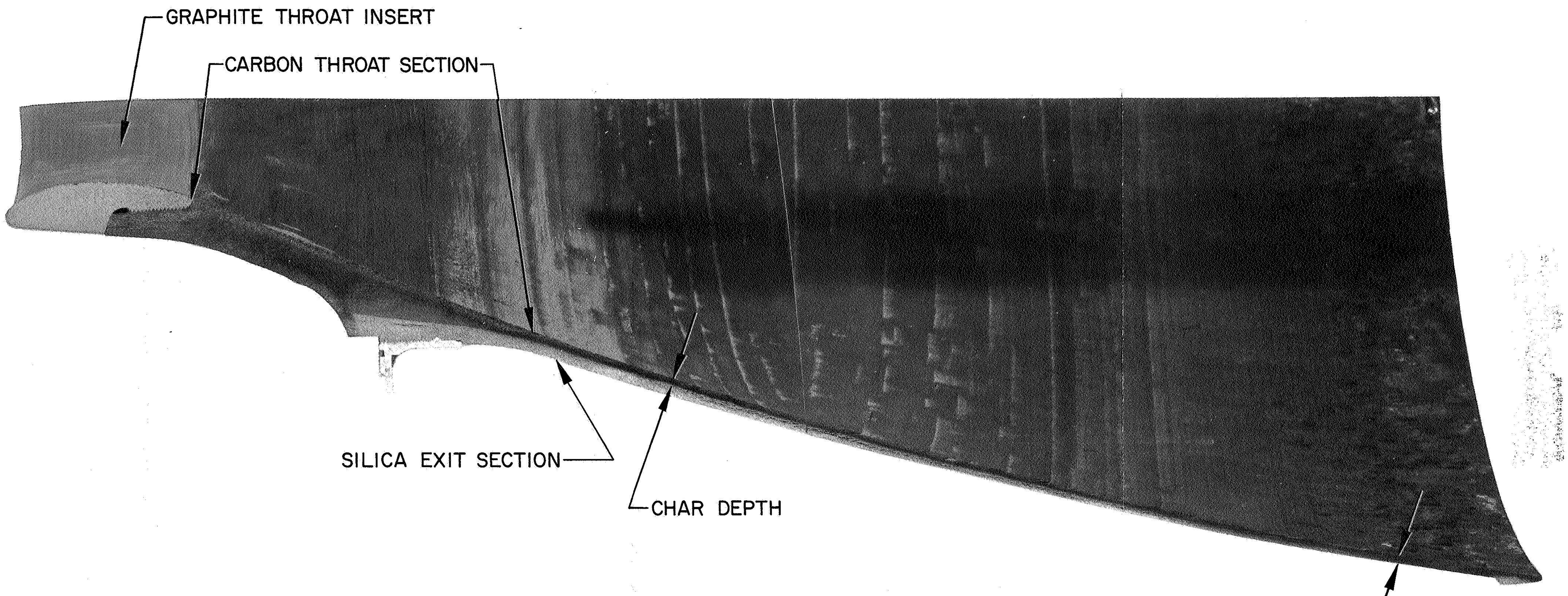
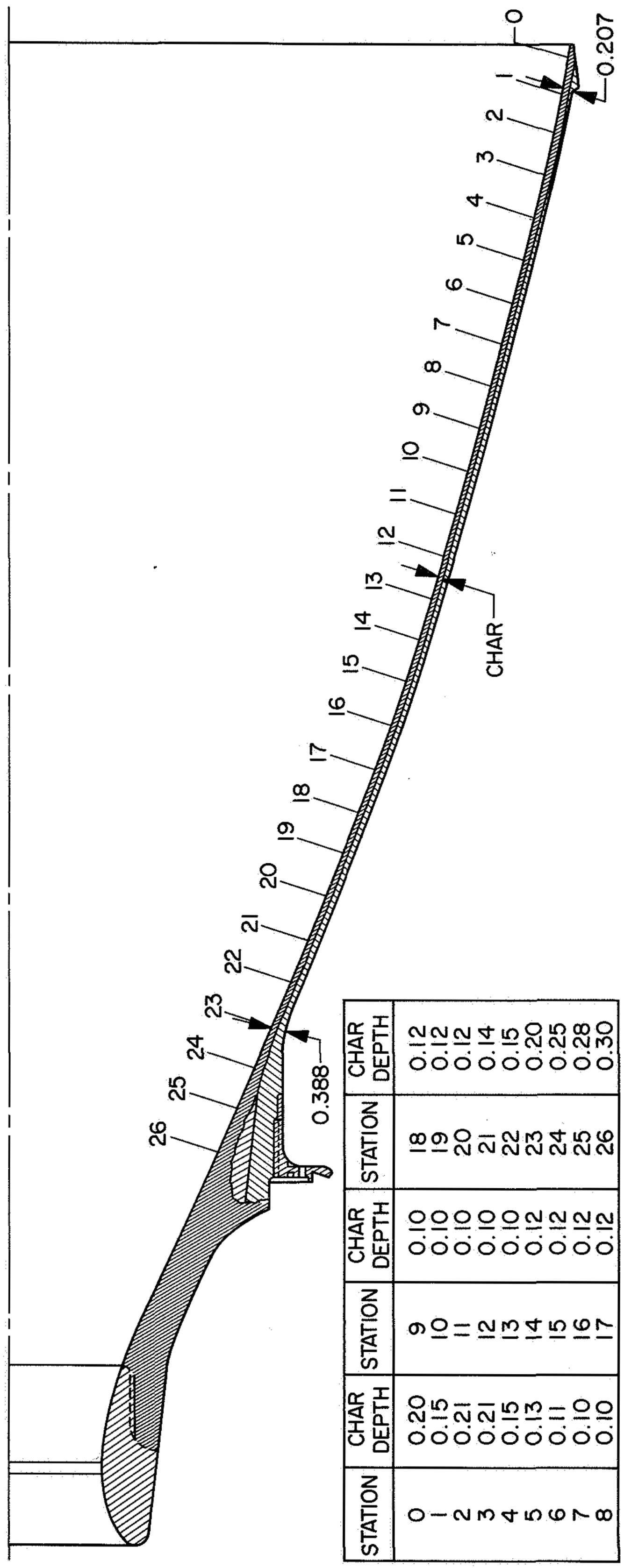


Fig. 23. Postfire nozzle assembly char depth



STATION	CHAR DEPTH	STATION	CHAR DEPTH	STATION	CHAR DEPTH
0	0.20	9	0.10	18	0.12
1	0.15	10	0.10	19	0.12
2	0.21	11	0.10	20	0.12
3	0.21	12	0.10	21	0.14
4	0.15	13	0.10	22	0.15
5	0.13	14	0.12	23	0.20
6	0.11	15	0.12	24	0.25
7	0.10	16	0.12	25	0.28
8	0.10	17	0.12	26	0.30

Fig. 24. Postfire nozzle assembly char depth dimensions

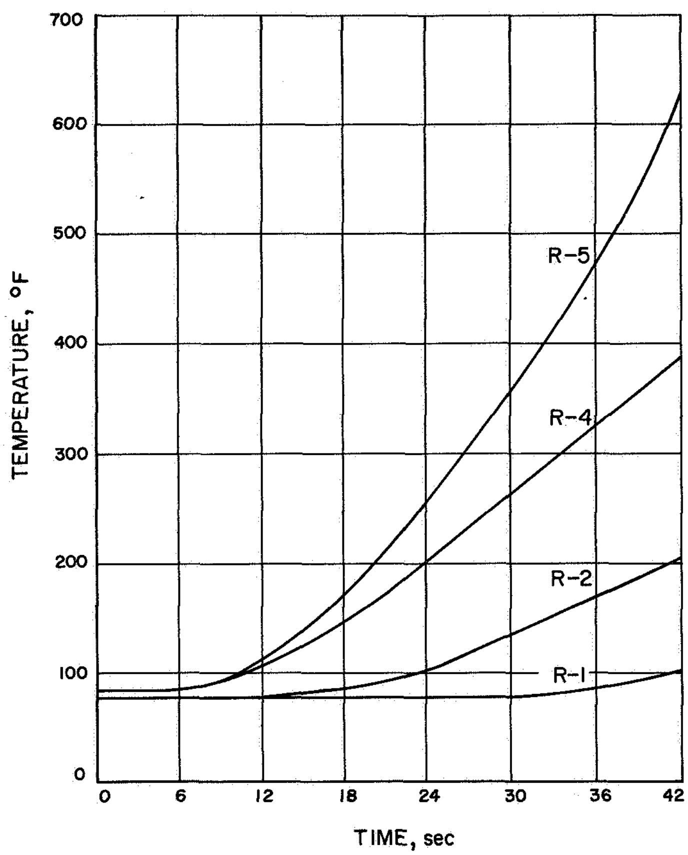


Fig. 25. Nozzle exit cone temperatures (0–42 sec)

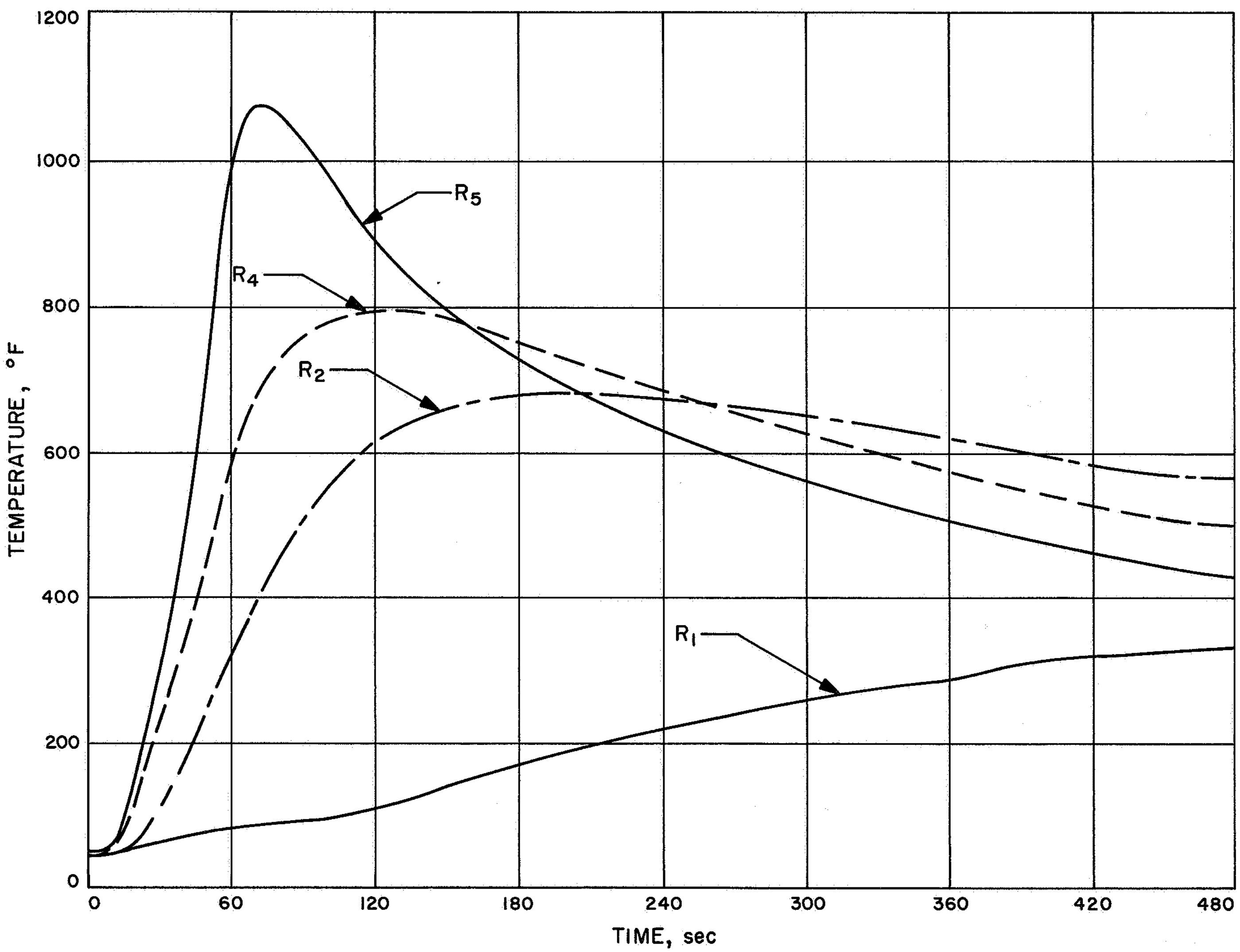


Fig. 26. Nozzle exit cone temperatures (0–480 sec)

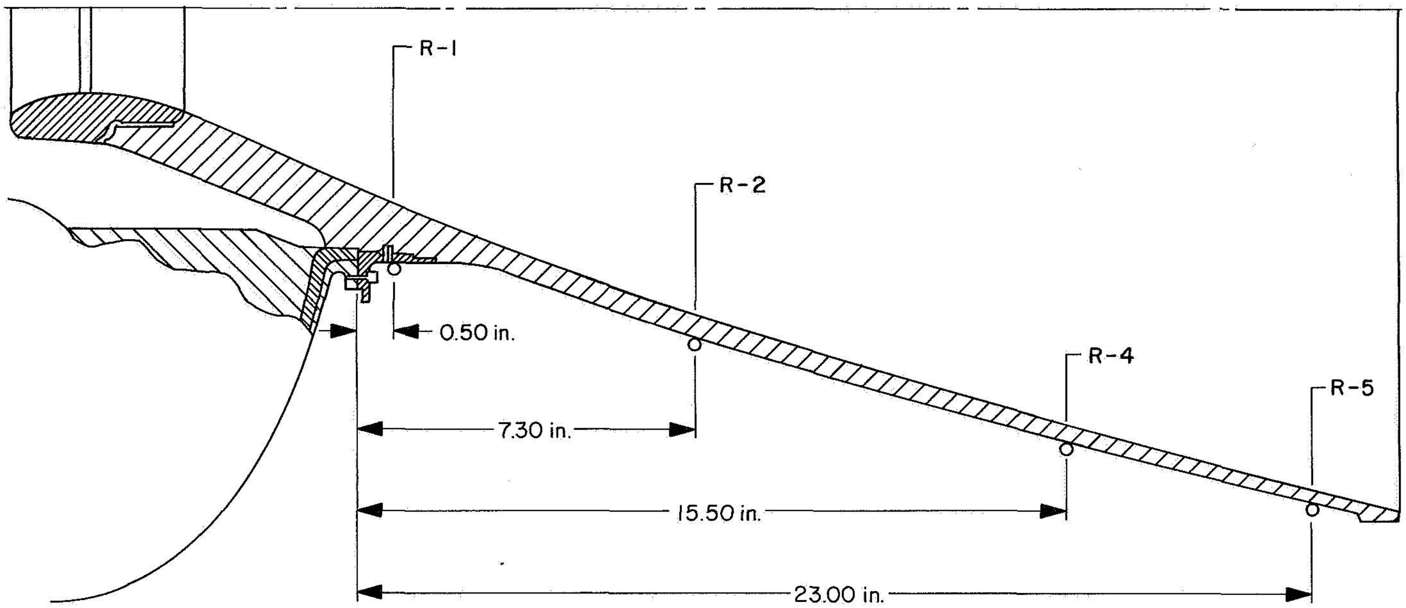


Fig. 27. Nozzle exit cone thermocouple placement

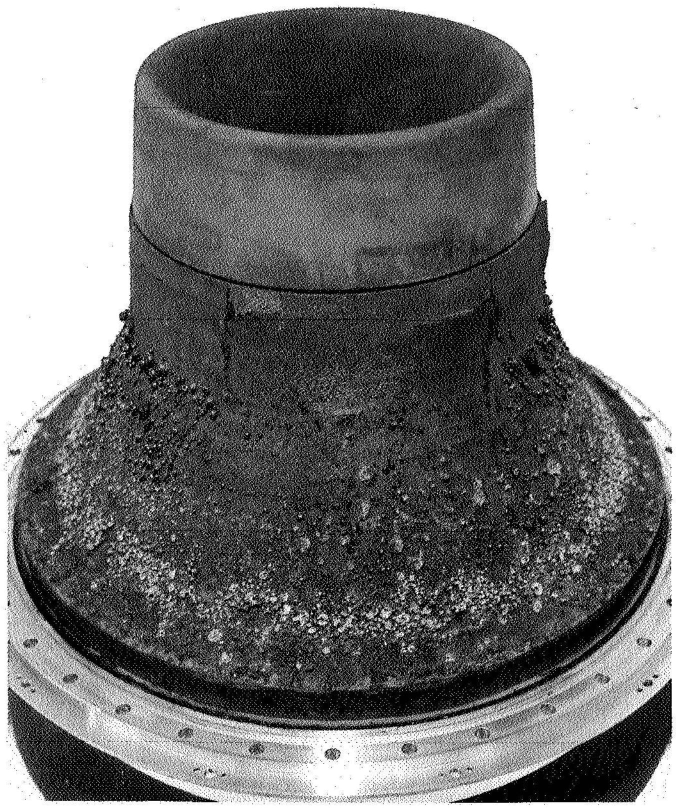


Fig. 28. Postfire nozzle insert (static tested at 150 rpm)

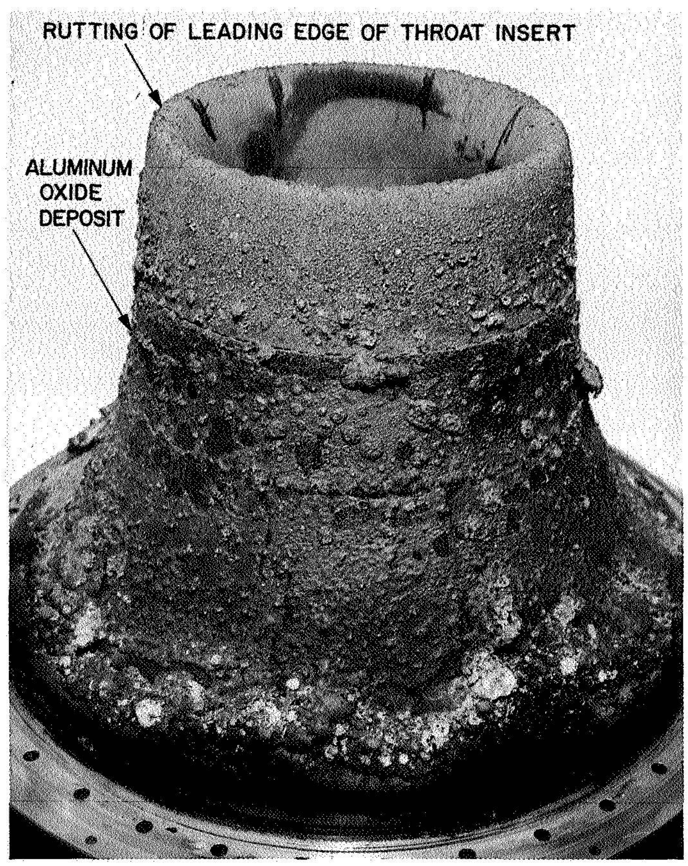


Fig. 29. Postfire nozzle insert (static tested, non-spinning)

Appendix A

Rocket Motor Nozzle Design Drawings

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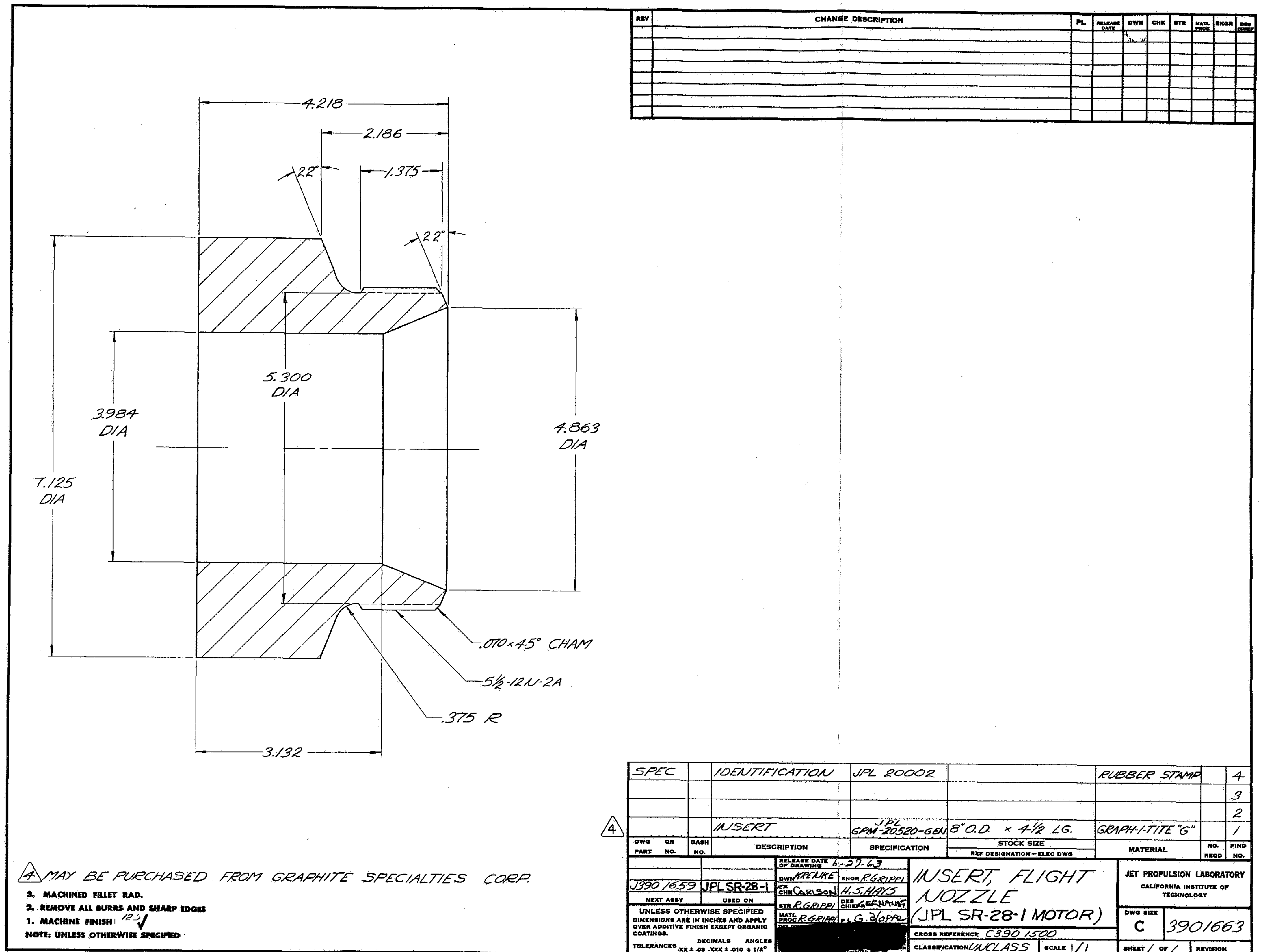
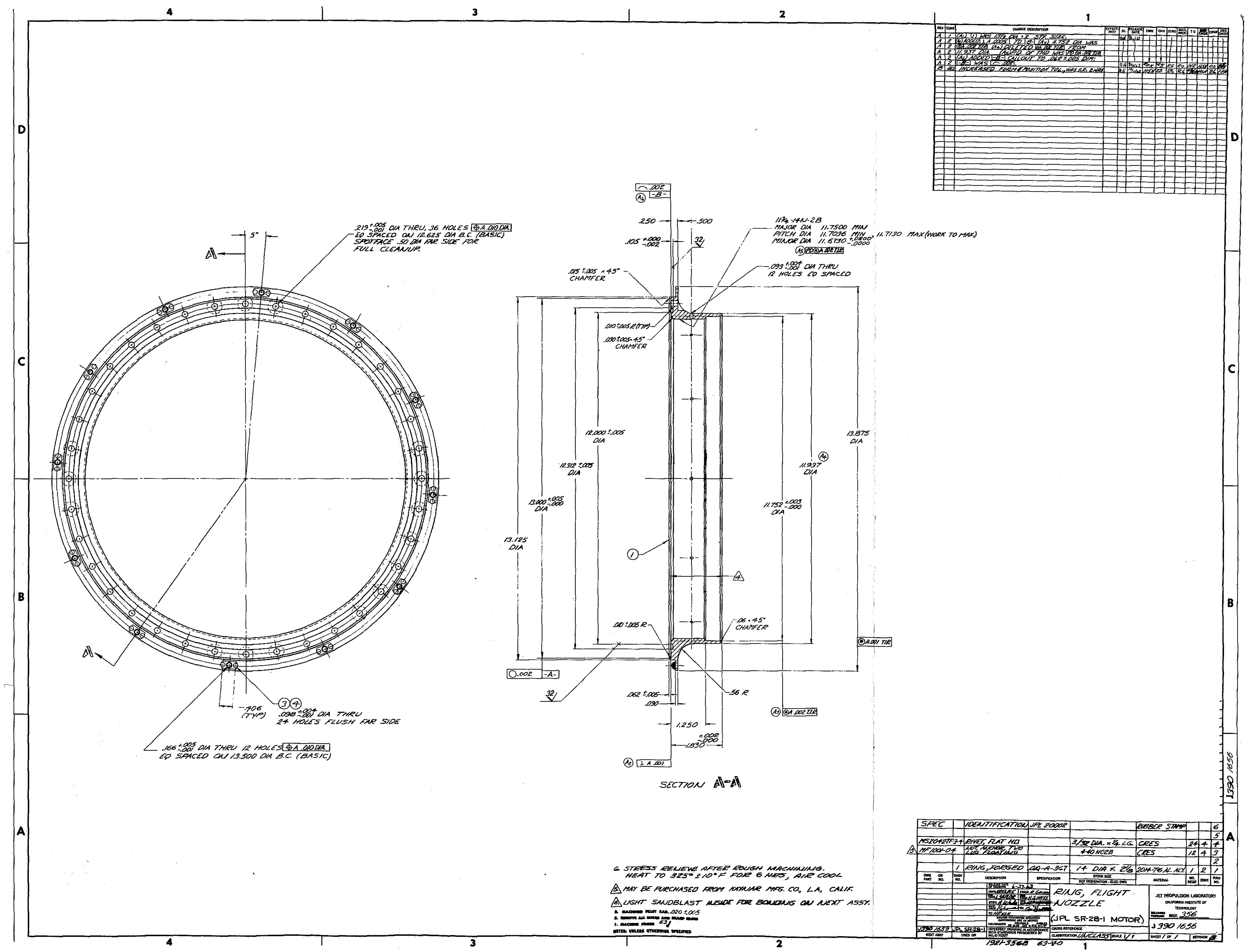



SECTION A-A
RING, FLIGHT NOZZLE
(JPL SR-28-1 MOTOR)
J 390 1656
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
6. STRESS RELIEVE AFTER ROUGH MACHINING. HEAT TO 325° ±10° F FOR 6 HRS, AIR COOL
MAY BE PURCHASED FROM KAYNAR MFG. CO., L.A., CALIF.
LIGHT SANDBLAST INSIDE FOR BONDING ON NEXT ASSY.
.219 +.005 -.001 DIA THRU, 36 HOLES EQ SPACED ON 12.625 DIA B.C. (BASIC) SPOTFACE .50 DIA FAR SIDE FOR FULL CLEANUP.
.166 +.005 -.001 DIA THRU 12 HOLES EQ SPACED ON 13.500 DIA B.C. (BASIC)
.098 +.004 -.001 DIA THRU 24 HOLES FLUSH FAR SIDE
11 3/4 -14N-2B
MAJOR DIA 11.7500 MIN
PITCH DIA 11.7036 MIN
MINOR DIA 11.6730 +.0800 -.0000
11.7130 MAX (WORK TO MAX)
.093 +.004 -.001 DIA THRU 12 HOLES EQ SPACED
13.875 DIA
13.125 DIA
12.000 ±.005 DIA
11.937 DIA
11.752 +.003 -.000 DIA
SPEC
IDENTIFICATION
RUBBER STAMP
RIVET, FLAT HD
RING, FORGED
14 DIA X 2 1/8
2014-T6 AL ALY
1921-3568 63-40

D

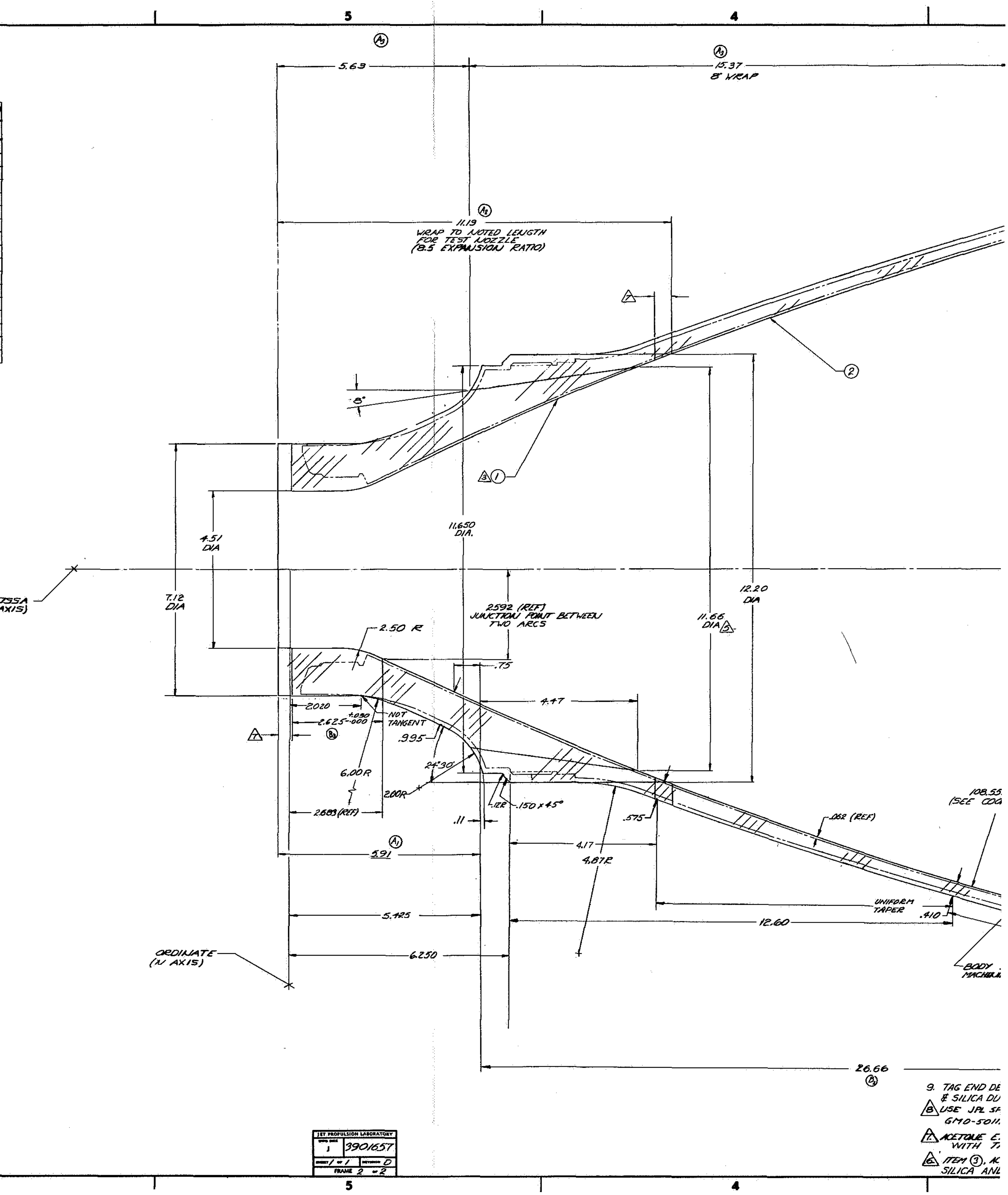
INSIDE
M AXIS
2.683
2.753
2.859
2.968
3.083
3.202
3.324
3.982
4.552
5.296
6.280
6.996
7.642
8.682
9.731
10.856
11.994

C

B

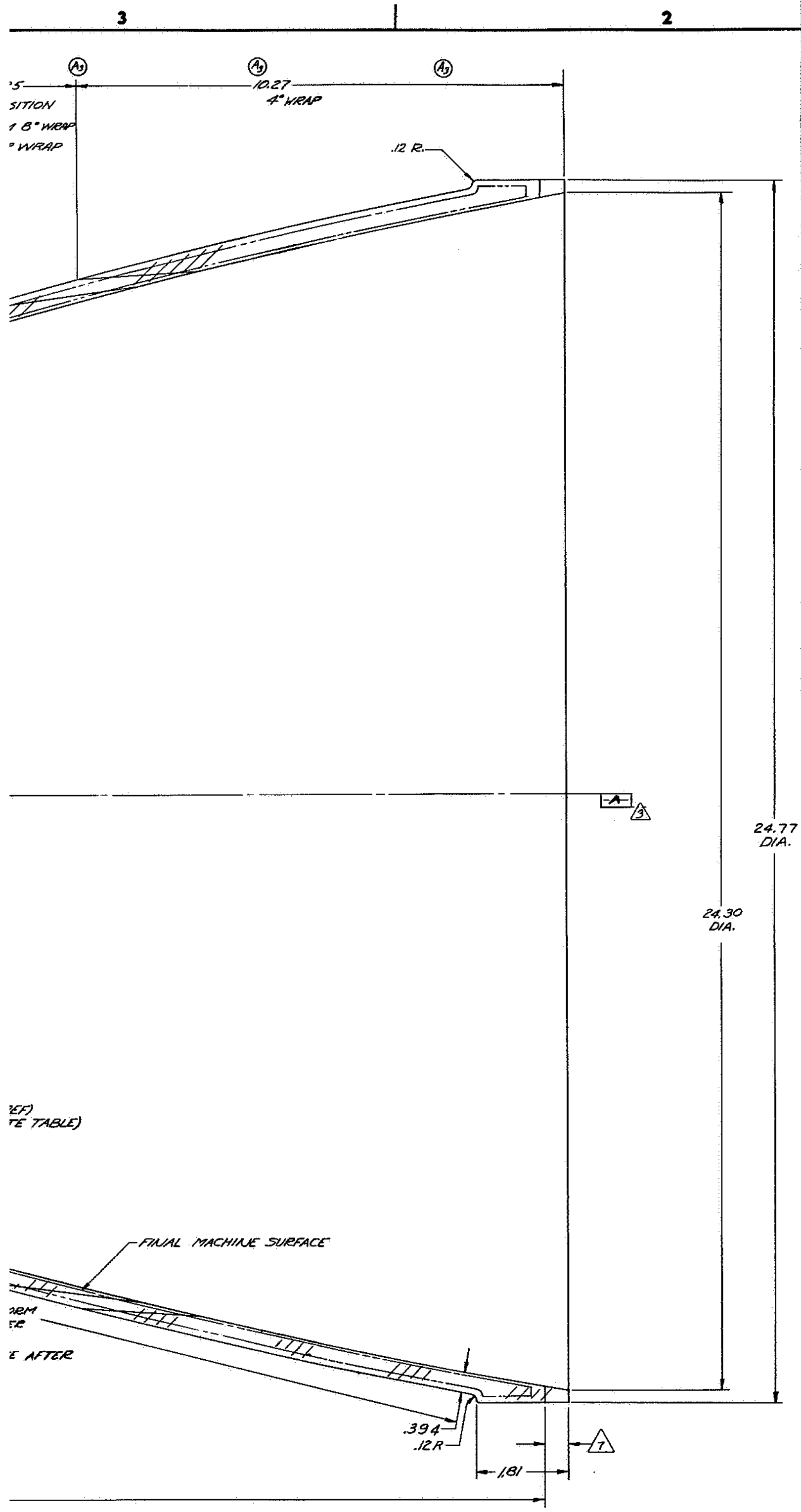
A

UTOUR COORDINATES (INCHES)		
S	M AXIS	N AXIS
97	13.232	7.070
/	14.888	7.655
2	15.912	8.002
5	16.994	8.358
1	18.244	8.751
49	19.594	9.159
07	21.351	9.661
20	22.970	10.094
37	24.165	10.398
29	25.410	10.698
71	26.593	10.970
35	27.815	11.235
64	29.021	11.483
01	30.273	11.726
30	31.407	11.931
75	31.835	12.007
11	32.335	12.105



35A

35B



REV	ZONE	CHANGE DESCRIPTION	EFFECTIVITY	DL	RELEASE DATE	DWN	CHK	STRU	MATL PROC	T C	ENGR	ENGR	DES CHKR
A	5	A, 5.91 WAS 5.85; A2: 11.19 WAS 10.85;		GH									
A	3&4	A3 ADDED 4.68, 17.59 & 3.75 DIMS.;		GH									
A	2	A4 NOTE 3 WAS (8" TO -A-);		GH		RDC	GS	RG	RG	NR	HSH	RG	
B	2,1	ADDED 6, ADDED "MIN" TO NOTE 4, JPL SR-28-1		GH		HSH		RG	RG			RG	
B	4	WAS ADV SYNCOM; B2 WAS 27.41 TO END; B3 ADDED						RG	RG			RG	
B	5	2.625, B4) 2 WAS FM5027A		GH		HSH	CCD	RG	RG	NR	HSH	RG	
C	ALL	GENERAL REVISIONS		GH		HSH		RG	RG	NR	HSH	RG	
D	ALL	GEN'L REV. & INCL. E.C.I. 4511, 4512 & 11412		GH		HSH	RB	RG	RG	NR	HSH	RG	

SAMPLES & MIN OF 15 GRAMS OF CARBON
ACCOMPANY NOZZLE BLANK ON DELIVERY.
-50212-MTL FOR 1 AND JPL SPEC
B FOR 1 & 2
ION & DENSITY TESTS CONDUCTED
D SAMPLES. USE 3 SAMPLES PER TEST.
EXTRACTION, NOT TO EXCEED 0.5%
ARBON.

5. ITEM 1 TO BE WRAPPED TO NOTED DIA. REMAINING NOZZLE TO CONSIST OF ITEM 2.

4. HYDROCLAVE FOR MAX SP. GR.; ITEM 1 1.44 MIN & 2 1.70 MIN.

3. MATERIAL TO BE WRAPPED 0° TO -A- (MANDREL CENTERLINE)

~~2. CALCOM INDUSTRIAL LAB OR EQUAL~~

1. PURCHASE FROM U.S. POLYMERIC CORP. (SILICA OR CARBON CLOTH & PHENOLIC RESIN)

NOTES: UNLESS OTHERWISE SPECIFIED

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	ZONE	FIND NO.
JPL SPEC		IDENTIFICATION	ZPO 20002 PRS		RUBBER STAMP			5
JPL SPEC		RADIOGRAPHIC INSPEC	COM 50321 TST					4
		ACETONE EXTRACTION	ASTM D494-46					3
FM5131	2	BODY		TAPE WRAP	BIAS SILICA CLOTH	AS REQD	4	2
X 5024	1	BODY		TAPE WRAP	CARBON CLOTH	AS REQD	5	1

NEXT ASSY	USED ON
	JPL SR-28-3
J390 1658	JPL SR-28-1

RELEASE DATE OF DRAWING 6-27-63

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: DECIMALS .XX ±.03 .XXX ±.010 ANGLES ±1/2°

INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-D-70327

BLANK, FLIGHT NOZZLE BODY (JPL SR-28-1 MOTOR)

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
RELEASED THROUGH SECT. 356

J390 1657

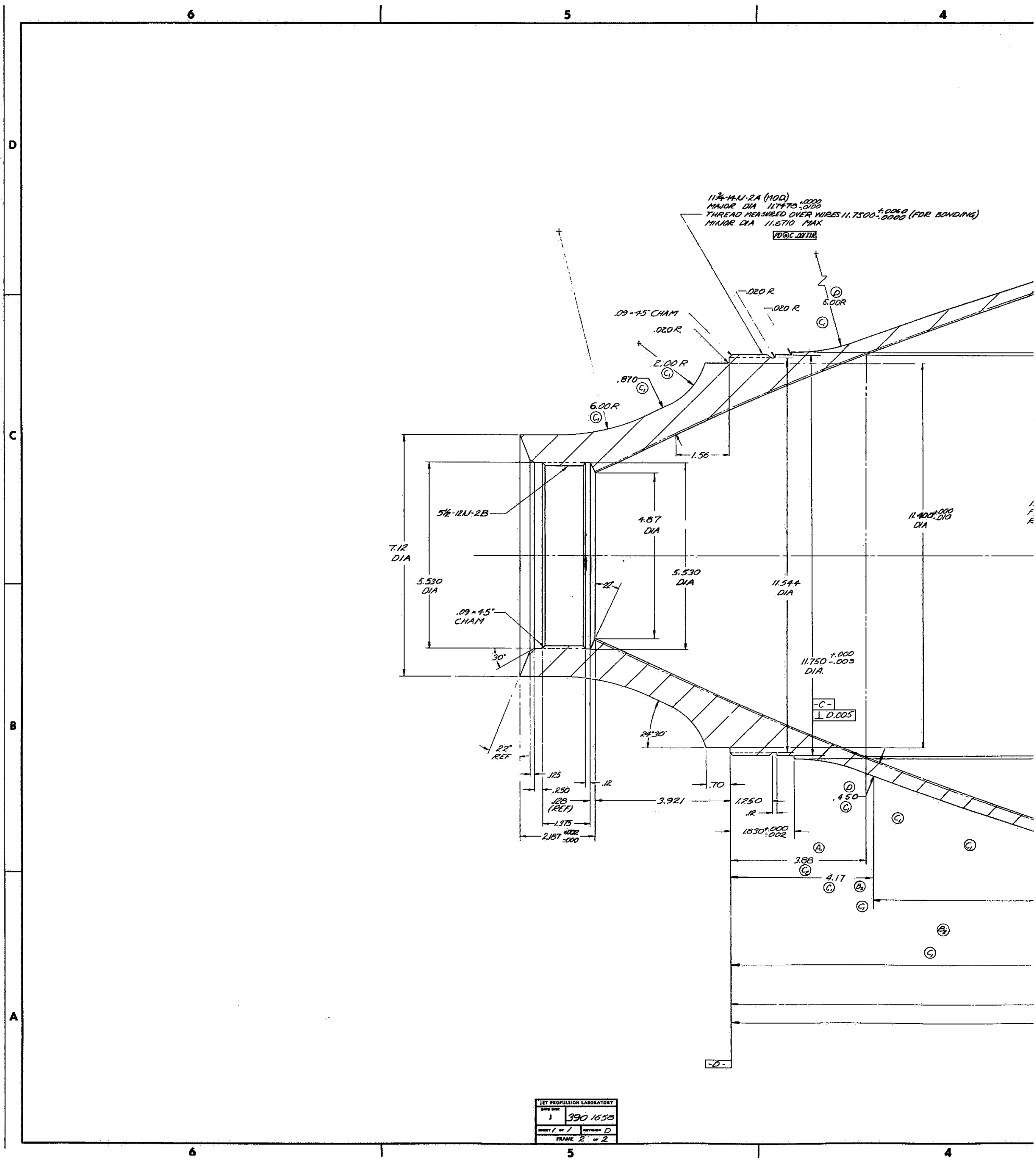
CROSS REFERENCE

CLASSIFICATION UNCLASS | SCALE 1/1 | SHEET 1 OF 1 | REVISION D

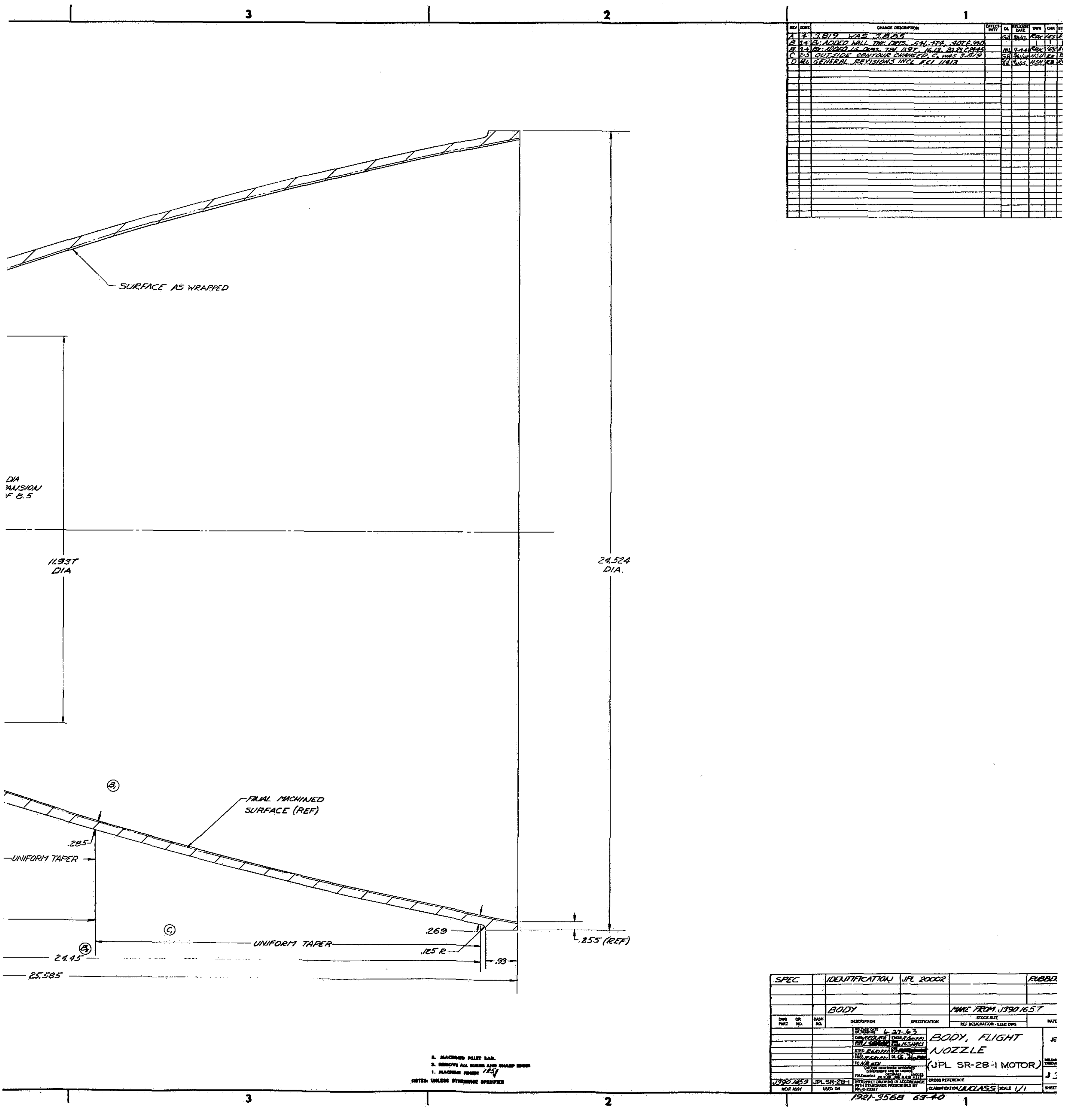
1921-3568 63-40

J390 1657

ECTS



6
5
4
D
C
B
A
11¾-14N-2A (MOD)
MAJOR DIA 11.7470 +.0000 -.0100
THREAD MEASURED OVER WIRES 11.7500 +.0060 -.0000 (FOR BONDING)
MINOR DIA 11.6710 MAX
.020 R
.020 R
5.00R
.09 × 45° CHAM
.020 R
2.00 R
.870
6.00 R
1.56
5½-12N-2B
4.87 DIA
7.12 DIA
5.530 DIA
5.530 DIA
11.544 DIA
11.400 +.000 -.010 DIA
.09 × 45° CHAM
30°
22°
11.750 +.000 -.005 DIA.
-C-
⊥ D.005
24°30'
22° REF
.125
.250
.128 (REF)
.12
3.921
.70
1.250
.12
1.830 +.000 -.002
.450
1.375
2.187 +.002 -.000
3.88
4.17
-D-
JET PROPULSION LABORATORY
J
390 1658
SHEET 1 OF 1
REVISION D
FRAME 2 OF 2



REV | ZONE | CHANGE DESCRIPTION | EFFECTIVITY | DL | RELEASE DATE | DWN | CHK
A 4 3.819 WAS 3.885
B 3-4 B: ADDED WALL THK DIMS .541, .474, .407 & .340
B 3-4 B: ADDED I.S. DIMS. 7.81, 11.97, 16.13, 20.29 & 24.45
C 2-5 OUTSIDE CONTOUR CHANGED, C WAS 3.819
D ALL GENERAL REVISIONS INCL ECI 11413
SURFACE AS WRAPPED
DIA
PANSION
F 8.5
11.937
DIA
24.524
DIA.
FINAL MACHINED
SURFACE (REF)
.285
UNIFORM TAPER
.269
UNIFORM TAPER
.125 R.
.93
.255 (REF)
24.45
25.585
3. MACHINED FILLET RAD.
2. REMOVE ALL BURRS AND SHARP EDGES
1. MACHINE FINISH 125
NOTES: UNLESS OTHERWISE SPECIFIED
SPEC
IDENTIFICATION
JPL 20002
BODY
MAKE FROM J390 1657
STOCK SIZE
REF DESIGNATION - ELEC DWG
DWG OR PART NO.
DASH NO.
DESCRIPTION
SPECIFICATION
RELEASE DATE OF DRAWING 6-27-63
BODY, FLIGHT
NOZZLE
(JPL SR-28-1 MOTOR)
J390 1659
JPL SR-28-1
NEXT ASSY
USED ON
INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-D-70327
CROSS REFERENCE
CLASSIFICATION UNCLASS
SCALE 1/1
1921-3568 63-40

D

C

B

J390 1658

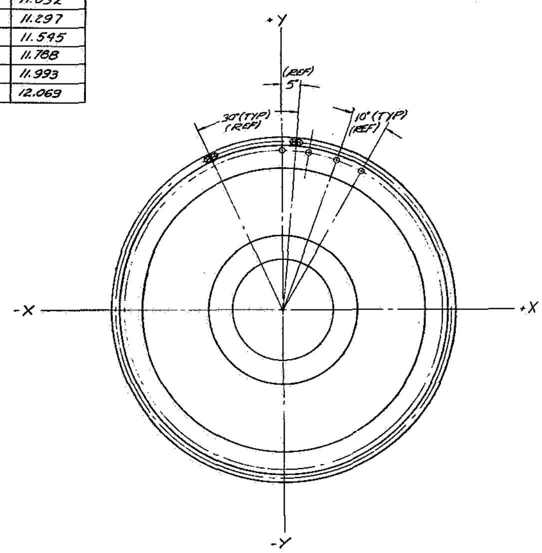
A

	NO. REQD	ZONE	FIND NO.
			4
			3
			2
			1

ION LABORATORY
A INSTITUTE OF
NOLOGY
356
558
REVISION D

8 | 7

WALL COORDINATES (INCHES)			
M	N	M	N
0	2.0415	4.552	3.549
1.272	2.174	5.296	3.891
1.359	2.193	6.280	4.333
1.425	2.208	6.996	4.647
1.525	2.233	7.642	4.926
1.601	2.253	8.682	5.363
1.693	2.279	9.731	5.792
1.834	2.321	10.856	6.237
1.906	2.344	11.994	6.673
1.993	2.374	13.232	7.132
2.082	2.405	14.888	7.717
2.172	2.438	15.912	8.064
2.263	2.474	16.994	8.42
2.357	2.512	18.244	8.813
2.452	2.553	19.594	9.221
2.549	2.596	21.351	9.723
2.65	2.644	22.97	10.156
2.683	2.659	24.165	10.46
2.753	2.693	25.41	10.76
2.859	2.744	26.593	11.032
2.968	2.797	27.815	11.297
3.083	2.853	29.021	11.545
3.202	2.911	30.273	11.788
3.324	2.969	31.407	11.993
3.982	3.282	31.835	12.069



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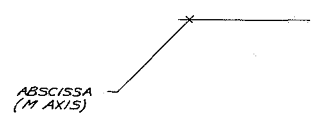
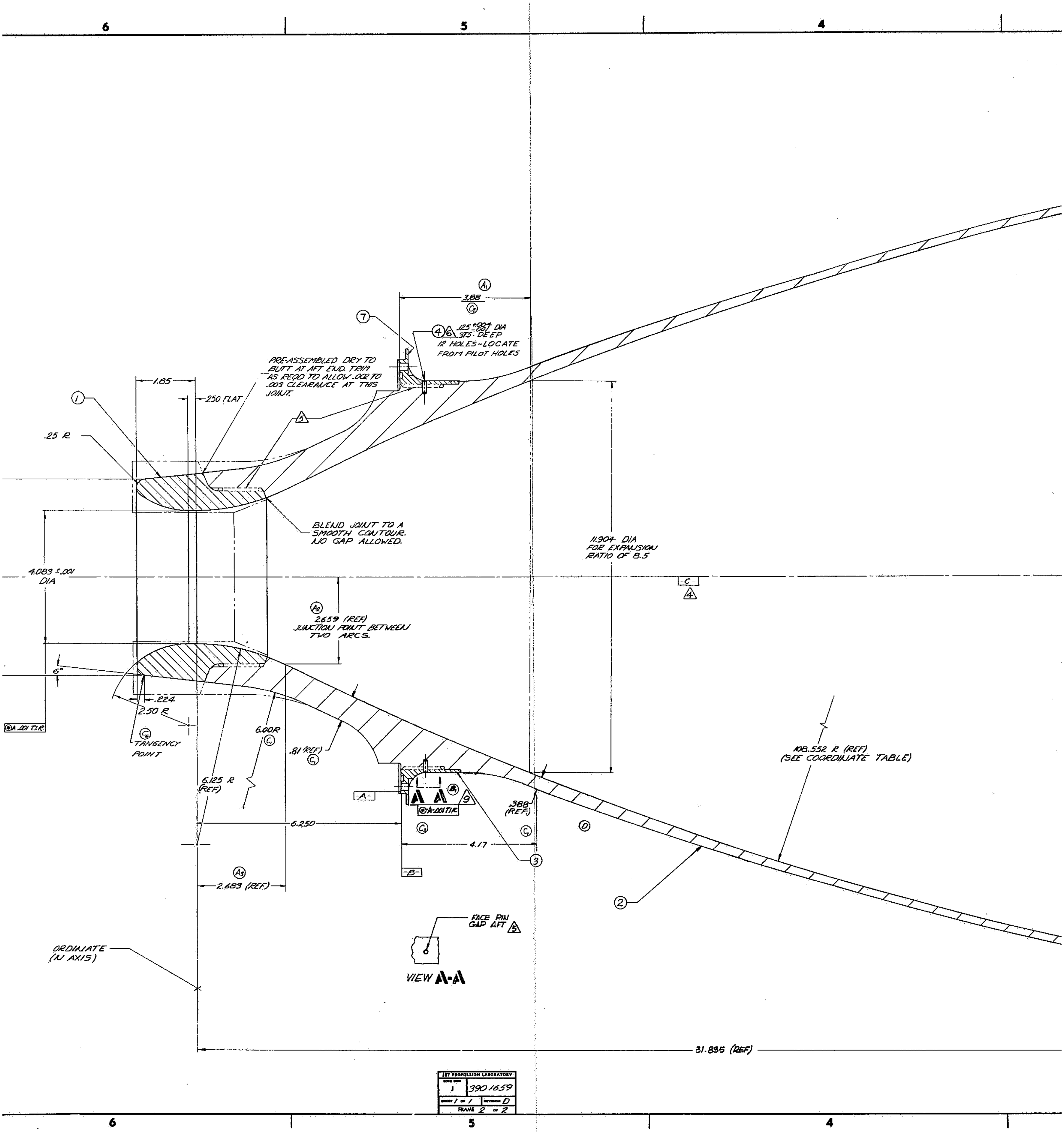


D C B A

8 | 7



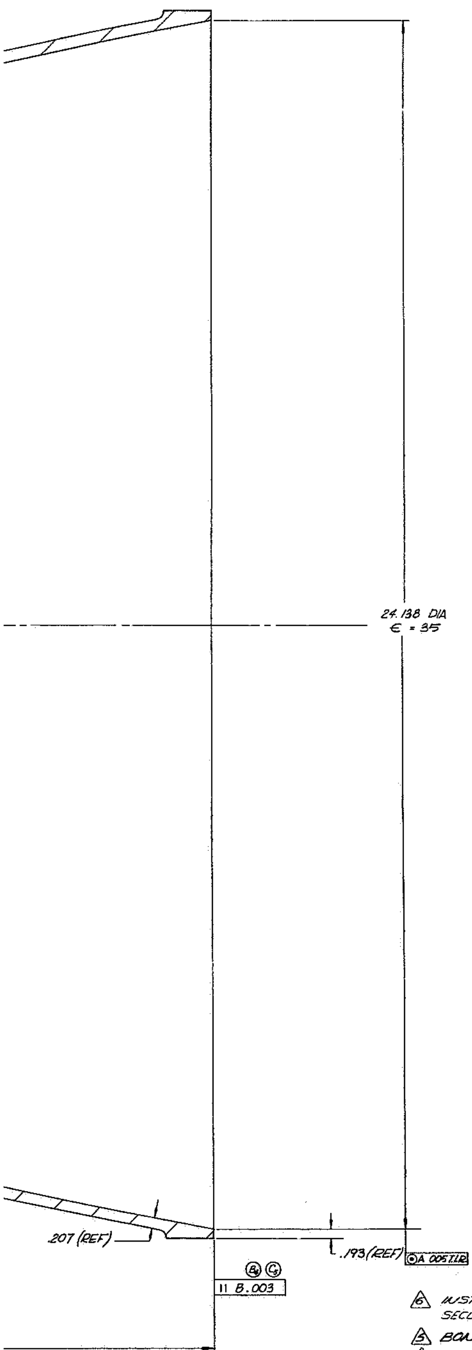
JET PROPULSION LABORATORY	
J	390/659
SHEET 1 OF 1	REVISION D
FRAME 2 OF 2	

37B

3	2	1

REV	ZONE	CHANGE DESCRIPTION	EFFECTIVITY	DL	RELEASE DATE	DWN	CHK	STRU	MATL PROC	T C	ENGR	ENGP	DES CHIEF
A	5	A1 3.819 WAS 3.827; A2) 2.659 WAS 2.683;											
A	6	A3 2.683 WAS 2.659				ROK							
B	5	(B1) ADDED ⊙ & // DIMS. (B2) DELETED EXPANSION											
B	5	RATIO (ε0 TO 1) DIM. OF 19.490 MEASURED											
B	5	FROM N AXIS TOWARDS AFT END OF ②											
B	3	(B3) ADDED 7. (B4) ADDED PARALLEL NOTE											
C	3-6	C1 OUTSIDE CONTOUR CHANGED PER ② C2 WAS 3.819											
C	2,5	C3 [illegible] & ALIGNMENT REQMTS, C4 ADDED											
C	3,6	C5 WAS .010, C6 ADDED .224 & TANGENCY [illegible]					RB						
D	3-5	OUTSIDE CONTOUR CHANGE & ADDED A-A ⊙				WSH	FD			NE	WSH		

D



C

B

A

THIS DIA MAY BE USED INSTEAD OF [A], AFTER RING IS BONDED, FOR FABRICATION & ASSEMBLY.

USE ROOM TEMPERATURE CURE FORMULATION AND CURE AT 70°F FOR 24 HOURS.

MEASURE PARALLELISM AT EDGE TO .125 FROM EDGE OF ③.

6. INSTALL ITEM ④ AFTER INSTALLATION & SECURING OF ITEM ③.

5. BOND PER ITEM ⑧.

4. CENTERLINE [-C-] IS DEFINED AS PASSING THRU THE CENTERS OF THE 4.083 & 24.138 DIAS.

3. MACHINED FILLET RAD.

2. REMOVE ALL BURRS AND SHARP EDGES

1. MACHINE FINISH 125

NOTES: UNLESS OTHERWISE SPECIFIED

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	ZONE	FIND NO.
SPEC (8)		BONDING	JPL 20519					8
JPL SPEC		IDENTIFICATION	ZPO 20002 PRS		RUBBER STAMP			7
								6
ECCOBOND 55 (5)		EMERSON & CUMING ADHESIVE				AS REQD	5	5
MS9048-098		PIN, SPRING		1/8 DIA × 3/8 LG.		12	5	4
J390 1656		RING, NOZZLE				1	5	3
J390 1658		BODY, NOZZLE				1	5	2
C390 1663		INSERT, NOZZLE				1	6	1

NEXT ASSY	USED ON
J390 1520	JPL SR-28-1

RELEASE DATE OF DRAWING 6-27-63
DWN [illegible] ENGR R. GRIPPI
CHK [illegible] ENGR N. SHAYS
STRU R. GRIPPI
MATL PROC R. GRIPPI
TC N. E. [illegible]

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES DECIMALS .XX ±.03 .XXX ±.010 ANGLES ±1/2°
INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-D-70327

NOZZLE ASSEMBLY, FLIGHT

(JPL SR-28-1 MOTOR)

CROSS REFERENCE

CLASSIFICATION UNCLASS SCALE 1/1

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

RELEASED THROUGH SECT. 356

J390 1659

SHEET 1 OF 1 REVISION D

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Appendix B

Rocket Motor Nozzle Specifications

SPECIFICATION AMENDMENT

JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY • PASADENA, CALIFORNIA

GENERAL SPECIFICATION
CARBON AND SILICA FABRIC TAPES
WITH
PHENOLIC RESIN FOR SOLID ROCKET
MOTOR NOZZLES

JPL SPEC GMO-50111-GEN-B

AMENDMENT 1

DATE: 1 September 1964

PAGE 1 OF 1 PAGES

1) Change page 4, paragraph 3.5.2 to read as follows:

3.5.2 Tape length. When possible, no more than one roll, on any width per contractor order, shall be less than 50 yards. Splices within the rolls shall be overlapped and bonded with a compatible phenolic adhesive. The method of splicing and the adhesive shall be approved by the contractor prior to delivery of the tapes.

REMARKS:

RELEASE:	APPROVED:	APPROVED:	PREPARED BY:
R. E. Melton			R. Grippi

SPECIFICATION AMENDMENT

JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY • PASADENA, CALIFORNIA

GENERAL SPECIFICATION
CARBON AND SILICA FABRIC TAPES
WITH
PHENOLIC RESIN FOR SOLID ROCKET
MOTOR NOZZLES

JPL SPEC GMO-50111-GEN-B

AMENDMENT 2

DATE: 26 February 1965

PAGE 1 OF 1 PAGES

1) Delete Item No. 1 of Amendment No. 1 in its entirety.

2) Change page 4, paragraph 3.5.2 to read as follows:

3.5.2 Tape length. When possible, no more than one roll, on any width per contractor order, shall be less than 50 yards. Splices within the rolls shall be evenly butted and shall be sewed and not taped or bonded. The method of sewing shall be approved by the contractor prior to delivery of the tapes.

REMARKS:

RELEASE: R. E. Melton

APPROVED:

APPROVED:

PREPARED BY: R. Grippi

JPL SPEC. GMO-50111-GEN-B

DATE: 4 May 1964

ENGINEER: R. A. Grippi

RELEASE: R. E. Melton

SUPERSEDES:

JPL SPEC. NO. GMO-50111-GEN-A

DATED: 9 December 1963

GENERAL SPECIFICATION CARBON AND SILICA FABRIC TAPES WITH PHENOLIC RESIN FOR SOLID ROCKET MOTOR NOZZLES

Revised and Rewritten

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

1. SCOPE

1.1 Scope. This specification covers the general requirements for carbon and silica fabric tapes impregnated with a phenolic resin binder system that will be used for fabrication of solid rocket motor nozzles.

2. APPLICABLE DOCUMENTS

2.1 Except as otherwise specified herein, the following documents of the issues in effect on the date of the invitation for bids shall form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

MIL-R-9299 A	Resin, Phenolic, Low Pressure Laminating

OTHER PUBLICATIONS

U.S. Polymeric Chemicals, Incorporated

CTM-6A	Dry and Wet Resin Solids Content by Soxhlet Extraction (Carbon Fabric)
PTM-11A	Resin Solids by Burn-Off (Silica Fabrics)
PTM-17	Volatile Content of Prepreg Materials
PTM-19A	Flow by Flash Removal

3. REQUIREMENTS

3.1 Conflicting requirements. In case of conflict between the requirements of this specification and any document referenced herein, the requirements of this specification shall govern.

3.2 Rejection. Carbon or silica fabric that is not processed, inspected and tested in accordance with the requirements of this specification shall constitute cause for rejection of the fabricated rocket nozzle by the Jet Propulsion Laboratory.

3.3 Samples. To assure conformity of material specified in this document, random samples of each master roll of material shall be inspected and tested in accordance with the specifications or procedures as indicated in the following paragraphs.

3.4 Material. The material shall be a straight, or plain weave, coated with a phenolic resin and in a "B" stage condition prior to fabrication into a component. The material shall meet the requirements listed below.

3.4.1 Carbon fabric. The carbon fabric shall be coated with a modified, filled, phenolic resin system compatible with MIL-R-9299A.

3.4.1.1 Resin solid content. The resin solid content of the carbon fabric after resin impregnation shall be 34 ±3 percent. The resin solids content shall be determined by test method CTM-6A.

3.4.1.2 Flow content. The flow content, in percent, shall be specified by the fabricator. The flow content shall be determined by test method PTM-19A.

3.4.1.3 Volatile content. The volatile content, in percent, shall be specified by the fabricator. The volatile content shall be determined by test method PTM-17.

3.4.2 Silica fabric. The silica fabric shall be coated with a modified, filled, phenolic resin system, compatible with MIL-R-9299A.

3.4.2.1 Resin solid content. The resin solid content of the silica fabric, after resin impregnation, shall be 32 ±3 percent. The resin solids content shall be determined by PTM-11A.

3.4.2.2 Flow content. The flow content, in percent, shall be specified by the fabricator. The flow content shall be determined by test method PTM-19A.

3.4.2.3 Volatile content. The volatile content, in percent, shall be specified by the fabricator. The volatile content shall be determined by test method PTM-17.

3.5 Tape requirements. The tape shall be supplied to the following requirements and shall be delivered, packaged on rolls, with polyethylene backing on one side and placed in sealed polyethylene bags.

3.5.1 Tape width. The width shall be as specified by the fabricator with an allowable variation of ±1/8 inch from the specified nominal dimension.

3.5.2 Tape length. When possible, no more than one roll, on any width per contractor order, shall be less than 50 yards. Splices within the rolls shall be evenly butted, and must be sewn and not taped or bonded. In situations where sewing is impractical, the splices may be overlapped and heat sealed. The method must be approved by the fabricator prior to delivery.

3.6 Identification. Each roll of material shall be identified with a suitable numbering system by the manufacturer. This shall include batch/lot number, purchase order number, date, resin solids, flow, volatiles and weight.

3.7 Material storage. Material may be stored at room temperature (70°F) for a period not to exceed 30 days from date of manufacture. Material retained for a longer period must be held in cold storage at a maximum temperature of 40°F. Material stored over 90 days from date of manufacture shall be retested in accordance with the requirements stated herein prior to use. The material shall always be stored in sealed polyethylene bags.

3.8 Workmanship. The material shall be uniform in color, texture and shall generally reflect high quality workmanship and process control. The edges of the tape shall be straight and even with no ragged areas. There shall be no selvage remaining on the slit fabric. There shall be no resin pockets, or blowing effect, on the surface of the impregnated fabric.

4. QUALITY ASSURANCE PROVISIONS

4.1 Contractor inspection. The contractor shall be responsible for performance of all inspection and test requirements as specified herein. Except as otherwise specified, the contractor may utilize his own or any other inspection test facility acceptable to JPL. Inspection records of the examinations and tests shall be kept complete and available to JPL. JPL reserves the right to perform any of the inspections and tests set forth in this specification, where such inspections are deemed necessary to assure services conform to the requirements stated herein.

4.2 Test equipment. Test equipment used shall be of sufficient accuracy and quality to permit performance of required testing. The contractor shall establish adequate calibration of test equipment to the satisfaction of JPL.

4.3 Rejection and resubmittal. Delivered material that fails to meet all the requirements of this specification shall be rejected and returned to the materials supplier. Prior to any resubmittal, the contractor shall furnish the JPL cognizant engineer full particulars, in writing, regarding the cause of failure, and action taken to correct the defects. All rejected material shall be identified by a serialized rejection tag. This rejection tag shall not be removed until the requirements specified herein have been complied with, and then the tag shall be removed by the JPL inspector.

4.4 Reports. A report certifying that the requirements of this specification have been complied with, shall accompany each tape wrapped part when shipped to the Jet Propulsion Laboratory. This report shall also contain, on each roll of material in the wrapped part:

a. Carbon and silica cloth batch numbers.
b. Resin, flow and volatile content of carbon and silica cloth.
c. Raw materials manufacturers.
d. Tape materials supplier.

5. PREPARATION FOR DELIVERY

5.1 Packaging. The fabricated part shall be packed in a suitable container for delivery on a truck, such as a pickup. There shall be only one nozzle packed per container. The nozzle shall be packed in the container in a manner so that it can not move in any direction.

6. NOTES

Not applicable.

JPL SPEC. GMO-50212-MTL

DATE: 20 December 1963

ENGINEER: R. Bailey
R. Bailey

RELEASE: G. Inouye
G. Inouye

MATERIAL SPECIFICATION
WOVEN HIGH CARBON CONTENT CLOTH
FOR RESIN IMPREGNATION FOR
SOLID ROCKET MOTOR NOZZLES

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

1. SCOPE

1.1 This specification covers the requirements for a fabric with a high carbon content, which was prepared from commercial quality synthetic woven fabric prior to impregnation by any resin system.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of release of this specification, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

CCC-T-191	Textile Test Methods

Military

MIL-Q-9858	Quality Control System Requirements

STANDARD

Military

MIL-STD-129	Marking for Shipment and Storage

2.2 Other publications. The following documents shall also form a part of this specification.

National Aeronautics Space Administration (NASA)

NPC 200-3	Inspection System Provisions for Suppliers of Space Materials, Parts, Components and Services

American Society for Testing Materials (ASTM)

C 135-61	Method of Test for True Specific Gravity of Refractory Materials
D 39-61 (Sec. 5, 10 psi)	Method of Test for Fabric Thickness

D 271	Methods of Sampling and Analysis of Coal and Coke
D 461-61	
(Sec. 22)	Method of Test for Ash Content
(Sec. 24)	Method of pH Determination of Carbon Fabric
D 578-61	Method of Testing Glass Yarn
D 629-59T	Method for Quantitative Analysis of Textiles

U.S. Polymeric Chemical Co. Test Methods

PTM-2	Fabric Width
PTM-3	Fabric Weight
PTM-5	Fabric Thread Count
PTM-6	Fabric Weave Distortion
PTM-28	Areal Shrinkage

3. REQUIREMENTS

3.1 Qualification. The material furnished under this specification shall be a product which has been tested and has passed the qualification tests specified herein, and has been listed on or approved for listing on the applicable qualified products list.

3.2 Chemical requirements. The chemical requirements of carbon fabric shall be as follows:

	Characteristic	Acceptance Limits
a.	Carbon assay	94.0% minimum
b.	Ash content, wt.%	0.75% maximum
c.	pH	6.5 to 9.0

3.3 Physical requirements. The physical requirements of carbon fabric shall be as follows:

	Characteristic	Acceptance Limits
a.	Specific gravity @ 25°C	1.8 to 1.9
b.	Electrical resistivity ohms/sq. in. @ 70°F	0.5 to 1.25
c.	Breaking strength, lbs./in.	
	Warp	20.0 minimum
	Fill	20.0 minimum
d.	Weight, oz./sq. yd.	7.0 to 9.0
e.	Thread count, yarns/in.	
	Warp	25 to 30
	Fill	22 to 25
f.	Thickness, in.	0.014 to 0.020
g.	Width, inches	40 to 44 (to nearest 1/4 inch)
h.	Areal shrinkage, %	2.0 maximum
i.	Moisture content, %	3.0 maximum
j.	Salt impurities, %	To be established
k.	Weaving distortion	Test and report

3.3.1 Carbon structure. The carbon structure shall be verified using X-ray diffraction with copper radiation.

3.4 Weave. Synthetic cloth construction shall be plain weave of continuous yarns. The number of filaments per yarn shall be 1440 nominally.

3.5 Workmanship. The material shall be free of binders, additives, or added finishes. There shall be no contamination, discoloration, holes or tears greater than 1/4 inch or in any case of greater frequency than two per ten yards. Color of the fabric shall be typically black and uniform. Bagginess, when measured in the fill direction using 4-inch diameter cores placed parallel to each other and spanned 30 inches, shall not exceed 2.0 inches when the fabric is taut. The bagginess measurement also shall be conducted on a 15-foot span. The acceptance value is to be determined when sufficient data is available.

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection. The JPL inspector will make such inspections as are necessary to determine that the material is in accordance with the requirements of the contract, pertinent drawings, and specifications. Unless otherwise specified, these inspections will be conducted in accordance with the requirements of NASA Document NPC 200-3.

4.2 Supplier inspection. Unless otherwise specified, the contractor is responsible for the performance of all inspections prior to submission for JPL inspection and acceptance. Except as otherwise specified, the contractor may utilize his own facilities or any commercial facility acceptable to JPL. Inspection records of the examinations and tests shall be kept complete and available to JPL as specified in the contract or order. The requirements of Military Specification MIL-Q-9858 and NASA Document NPC 200-3 shall apply in particulars relevant to the contractor.

4.3 Lot definition. A lot of fabric shall consist of material that was produced in one continuous processing run, from a single lot of raw materials, and offered for inspection at one time. The cloth supplied is subject to inspection and testing to any or all parts of this specification. Nonconforming material is subject to rejection and return to the contractor.

4.4 Sampling plan. Sufficient material shall be taken from each roll of carbon fabric to perform the tests specified herein.

4.5 Classification of tests. The inspection and testing of this material shall be classified as follows:

a. Qualification tests
b. Acceptance tests

4.6 Qualification tests. The qualification tests for this material shall consist of all the tests listed in Table I. At the discretion of the procuring activity, these tests may be repeated subsequent to the initial qualification.

Any change in processing techniques, materials, test methods, or other factors affecting the quality of the product shall be immediately brought to the attention of the procuring activity for determination of the necessity for requalification.

4.7 Acceptance tests. The acceptance tests for this material shall be as specified in Table II.

4.8 Test procedures. The test procedures shall be in accordance with the applicable procedures listed in Tables I and II, and outlined as follows.

4.8.1 Carbon assay. The carbon assay determination of the fabric shall be as follows:

a. The sample shall be dried to a constant weight at 225 ±5°F before combustion, and the percent carbon shall be based on weight of dried sample.
b. The determination shall be conducted in accordance with ASTM D271, Section 38, Ultimate Analysis.

4.8.2 Ash content. The ash content for carbon fabric shall be determined on each roll with triplicate determinations. The ash content shall be conducted in accordance with ASTM D461-61 Sec. 22 and as follows. Take approximately five grams of carbon fabric, which has been ground in a Wiley Mill (or equivalent), or cut into approximately 1/16-inch squares, and dry in an air circulating oven at 225 ±5°F for a minimum of one hour. Remove the sample and place it into a desiccator to cool. Two grams of this cooled sample shall be weighed in a tared crucible and placed into a muffle furnace at 1400 ±25°F, for a minimum of three hours in an oxidizing atmosphere. At the end of three hours, the furnace temperature shall be raised to 1600 ±25°F, for a minimum of one hour in an oxidizing atmosphere. Allow a thirty-minute burning time or until a constant weight is obtained should ashing be incomplete. The sample shall be removed and placed into a desiccator to cool. The

Table I

Qualification Test Schedule	
Characteristic	**Test Procedure**
(a) Carbon Assay	ASTM D271
(b) Ash Content	ASTM D461-61 Sec. 22
(c) pH	ASTM D461-61 Sec. 24 (250 ml. of water)
(d) Specific Gravity	ASTM C135-47
(e) Surface Electrical Resistivity	
(f) Breaking Strength	CCC-T-191
(g) Weight	PTM-3
(h) Thread Count	PTM-5
(i) Thickness	ASTM D39-61
(j) Width	PTM-2 (to nearest 0.25 inch)
(k) Moisture Content	ASTM D629-59T

Table II

Acceptance Test Schedule	
Characteristic	**Test Procedure**
(a) Ash Content	ASTM D461-61 Sec. 22
(b) pH	ASTM D461-61 Sec. 24 (250 ml. of water)
(c) Breaking Strength	CCC-T-191
(d) Weight	PTM-3
(e) Thread Count	PTM-5
(f) Thickness	ASTM D39-61
(g) Width	PTM-2 (to nearest 0.25 inch)
(h) Moisture Content	ASTM D629-59T
(i) Weave Distortion	PTM-6
(j) Areal Shrinkage	PTM-28

postheat weight shall be obtained and the percent ash calculated as shown in the following equation:

$$\text{Percent Ash} = \frac{\text{Postheat ash weight}}{\text{Preheat sample weight}} \times 100$$

4.8.3 Determination, pH. The pH determination of carbon fabric shall be conducted on each roll with triplicate determinations in accordance with ASTM D461-61, Section 24. The solution shall be prepared as follows:

a. Take approximately ten grams of carbon fabric and pour into a 500 milliliter flask.
b. Add 250 milliliters of freshly boiled distilled water, and boil for approximately 20 minutes under a reflux condenser.
c. Remove and stopper the flask, and allow the extract to cool to room temperature.

4.8.4 Breaking strength. The breaking strength determination of carbon fabric shall be conducted, on each roll with triplicate determinations in each of the warp and fill directions, as specified in Federal Specification CCC-T-191.

4.8.5 Weight. The weight of carbon fabric shall be determined in accordance with PTM-3 on each roll as follows:

a. Weigh the roll of material on a calibrated scale.
b. Measure the length and width of the material.
c. Calculate the weight in ounces per square yard (oz./sq. yd.).

4.8.6 Thread count. The method for determining thread count shall be as outlined below, and in accordance with PTM-5.

4.8.6.1 Test specimen. The specimen shall be a piece of carbon fabric of sufficient size to permit the counting of the yarns in 1.0 ±0.032 inch. No special preparation of the specimen is required, however, the raveling of yarns from a cut edge may facilitate the counting. One test per roll shall be performed.

4.8.6.2 Apparatus. Pick glass or suitable magnifying glass and scale.

4.8.6.3 Procedure. The carbon fabric shall be laid smoothly and without tension on a horizontal surface. The actual number of warp and fill yarns in one inch shall be counted at three places across the width in each roll of carbon fabric and the average number of yarns per inch calculated. No two determinations shall include the same yarns. No count shall be made nearer the selvage than one-tenth the width of the carbon fabric.

4.8.7 Thickness. The thickness of carbon fabric shall be determined on each roll in accordance with ASTM D 39-61. The thickness shall be the average of five measurements at five different places on the sample. No readings shall be taken on the selvage edge.

4.8.8 Width. The method for determining the width of carbon fabric shall be in accordance with PTM-2 and as outlined below.

4.8.8.1 Test specimen. The test specimen shall be a full width portion of carbon fabric. Whenever practical repeat the measurement in at least five places evenly separated along the length of the roll, and not more than fifty yards apart.

4.8.8.2 Apparatus. The measuring device shall be in 0.125 inch gradations.

4.8.8.3 Procedure. The carbon fabric shall be laid smooth, without tension, on a horizontal surface. The distance from edge to edge, in a line perpendicular to the lengthwise direction of the carbon fabric, shall be measured to the nearest scale graduation. The roll shall be measured in at least five equidistant locations.

4.8.9 Moisture content. The moisture content for carbon fabric shall be determined on each roll with triplicate determinations in accordance with ASTM D 629-59T.

4.8.10 Surface electrical resistivity. The electrical resistance of carbon fabric shall be determined with a Wheatstone Bridge. A strip of fabric one inch wide and five inches long shall be cut and mounted on a good nonconductive surface with two electrical grade (copper) one inch wide clamps spaced three inches apart. The clamps are to make good contact with the carbon fabric so that a direct contact with the fabric and the Wheatstone Bridge exists. The resistance shall be measured to plus or minus 0.01 ohm. The surface area between the clamps shall be measured to plus or minus 0.20 square inch, and surface resistivity calculated by:

$$\text{SER, ohms/in.}^2 = \frac{\text{Resistance}}{\text{Surface Area}}$$

4.9 Sampling. Sampling for acceptance shall be random by lot and ten percent or greater with a minimum of three package units included if three or more are supplied. Each unit shall be sampled if less than three are supplied. All of the preceding acceptance tests will be conducted on each sampled roll.

4.9.1 Package unit. A package unit shall contain 60 yards minimum, unless otherwise specified, and shall contain a maximum of two pieces. No piece shall be shorter than 10 yards.

4.10 Accept/reject basis. If all rolls sampled per 4.9 meet the requirements of the specification for the tests conducted, the lot will be accepted. Any property whose test value falls outside specification will be retested in duplicate. Each of the duplicate values must fall in specification limits for acceptance. If any rolls sampled per 4.9 are out of specification for any property tested, the lot may be tested on a 100 percent sampling basis and rejections placed on a roll basis. If 25 percent of the rolls fail any one characteristic, the lot and/or shipment is subject to rejection.

5. PREPARATION FOR DELIVERY

5.1 Packaging. The carbon fabric shall be rolled on a heavy duty cardboard core, approximately three inches in diameter, and supported by the ends in the box. Each roll will be encased in a three millimeters thick polyethylene bag and heat sealed. Unless otherwise specified, the carbon fabric shall be packed in a clean, dry container of the size and type to insure acceptance by common or other carrier for safe transportation at the lowest rate, to the point of delivery specified by the purchase order or contract.

5.2 Marking. Marking of each package shall be as indicated in MIL-STD-129 and shall include but not be limited to the following:

a. Manufacturer's name
b. Material name and number
c. Net weight
d. Lot and roll number
e. Date of manufacture
f. Ounces per square yard
g. Average width
h. Purchase order number

6. NOTES

Not applicable

SPECIFICATION AMENDMENT

JET PROPULSION LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY • PASADENA, CALIFORNIA

TEST SPECIFICATION
JPL-SR-28-1 FLIGHT EQUIPMENT
RADIOGRAPHIC INSPECTION AND RADIOGRAPHIC INSPECTION STANDARDS, CARBON AND SILICA CLOTH REINFORCED ROCKET MOTOR NOZZLE

JPL SPEC COM-50321-TST

AMENDMENT 1

DATE: 3 February 1965

PAGE 1 OF 1 PAGES

1) Change the call out in Figure 1b, page 8, that reads:

"SILICA PENE ON INSIDE SURFACE" to read:
"CARBON PENE ON INSIDE SURFACE."

REMARKS:

RELEASE:	APPROVED:	APPROVED:	PREPARED BY:
R. E. Melton			R. Grippi

JPL SPEC COM-50321-TST

DATE: 16 June 1964

ENGINEER: R. Grippi

RELEASE: J. Ryciak

TEST SPECIFICATION
JPL-SR-28-1 FLIGHT EQUIPMENT
RADIOGRAPHIC INSPECTION
AND
RADIOGRAPHIC INSPECTION STANDARDS
CARBON AND SILICA CLOTH REINFORCED ROCKET MOTOR NOZZLE

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

1. SCOPE

1.1 This specification sets forth the requirements for radiographic inspection and radiographic inspection standards for the JPL-SR-28-1 carbon and silica cloth reinforced rocket motor nozzle.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATION

Jet Propulsion Laboratory

ZPO-20002-PRS	Process Specification, Identification Requirements, Parts and Assemblies

STANDARD

Military

MIL STD 453	Inspection, Radiographic

3. REQUIREMENTS

3.1 General. The radiographic equipment and materials used by the contractor shall be subjected to the approval of the Jet Propulsion Laboratory.

3.2 Materials. The radiographs shall be processed utilizing extra fine grain film.

3.3 Equipment. The radiographic equipment utilized shall meet the following requirments.

3.3.1 Penetrameters. Penetrameters shall be fabricated from the same base material and of the same approximate density of the carbon and silica nozzle to be radiographed. Penetrameters will be fabricated in accordance with Military Standard MIL STD 453 with respect to the dimensions and method. The penetrameters should be fabricated from blocks of material that have been laminated under 1000 psi minimum pressure. Resin solids content of material as laminated should be 32 ±5 percent by weight. A specific gravity reading is to be taken of the blocks before penetrameters are fabricated and is to have a minimum value of 1.44 and 1.68 for carbon and silica cloth respectively.

3.3.1.1 Dimensions. The dimensional fabrication of the penetrameter shall be in accordance with this specification, and shall incorporate a minimum of one each of one T and 2 T diameter holes. The penetrameter thickness shall not be greater than two (2) percent of the thickness of the section to be radiographed.

3.3.2 Identification. The penetrameters shall be identified with a number made of lead alloy and attached to the penetrameter. This number shall reflect the thickness in inches of material to which the penetrameter is normally applicable, and shall have a value equal to 50 times the thickness of the penetrameter. Fractions of an inch in identifying number shall be expressed as decimals. Penetrameters shall have suitable permanent identification marks as to be distinguishable with respect to material.

3.3.3 Film holders. Ready pack type film holders shall be used.

3.4 Inspection.

3.4.1 General. All radiographic examinations shall be performed with techniques which will be capable of indicating the presence of any defects having any dimension equal to at least 2 percent of the thickness of the section being radiographed.

3.4.2 Method. Particular attention shall be given to highly stressed areas, and a sufficient number of views shall be taken, as shown in Figure 1 (a. through e.), to establish the nature and extent of any defects in these areas.

3.4.2.1 Stage of radiography. Radiographic inspection shall be performed at a stage in the process of manufacture or assembly at which harmful subsurface and internal discontinuities in the part or material can be detected. Radiographic inspection will be performed upon completion of hydroclaving, and post curing, but prior to any final machining operation that might be performed.

3.4.2.2 Non-film techniques. Use of non-film radiographic techniques shall not be considered acceptable for the purposes of this specification.

3.4.3 Processing. Radiographs shall be free from blemishes and shall be properly processed in accordance with Military Standard MIL STD 453. Normal development of film is to be 5 minutes at 68°F.

3.4.4 Placement of penetrameters. A penetrameter shall be placed on each part radiographed, for the duration of the exposure.

3.4.5 Film size and location. The film size for all views shall be as shown in Figure 1 (a. through e.). The film during exposure shall be as close to the surface of the material as practicable.

3.4.6 Focal distance. For any type of x-ray exposure, the ratio of the distance of the source of radiation from the near surface of the material to the distance of the photographic film from the same surface, shall be such that sharply defined images result.

3.4.7 Marking. Each part inspected shall be marked with a serial number or letters of test which will identify the part with the corresponding radiograph and/or report of the test. All such marking shall be in accordance with JPL Specification ZPO-20002-PRS.

3.4.7.1 Acceptable parts. Parts which have satisfactorily met the applicable radiographic inspection requirements shall be marked in one of the following methods, in a manner and location harmless to the part and which will preclude remoal, smearing or obliteration by subsequent handling.

3.4.7.1.1 Rubber stamping. Rubber stamping shall be used where permitted by the applicable specifications or drawings. Markings shall be located in areas adjacent to the part number or inspector's stamp.

3.4.8 Locating test area. Location markers whose images will appear on the film shall be placed on the material surface, and their locations accurately and permanently marked on the surface of the material in order that the orientation of the film may be established, and any defects appearing on the film precisely located (see Figure 1).

4. QUALITY ASSURANCE

4.1 General. Radiographic inspection will be conducted by the contractor under the periodic surveillance of the Jet Propulsion Laboratory inspector or cognizant engineer. All reports required herein shall be available to the inspector at any time.

4.2 Reports of inspection. Unless otherwise specified, the contractor shall furnish the Jet Propulsion Laboratory with inspection reports, giving the results of the radiographic inspection required, and signed by an authorized representative of the contractor or x-ray laboratory, as applicable. The report shall list the purchase order, number or equivalent identification, the number of parts on order, and the date of the test. For each part there shall be listed the part number, the serial number of the test and the rated condition of the part.

4.2.1 Record of details. The contractor shall keep a complete record of the details of inspection on a form acceptable to the Jet Propulsion Laboratory, which shall list the potentials and currents used in the radiographic process, the time exposure, the distance of these sources of radiation from the surface of the material, the distance of the film from the same surface, the approximate angle between the central beam of radiation and the film, the size of the focal spot, the time of development of the film, and the serial number(s) of the test or the part(s) to which they apply. Where an identical technique is utilized for a number of parts, a single record tabulating all identical features of the technique will suffice for all parts. Copies shall be made available to the Jet Propulsion Laboratory.

4.2.2 Radiographs submittance. Unless otherwise specified by contract, radiographs shall be submitted to the Jet Propulsion Laboratory with the delivery of each component part.

4.2.3 Negatives. Each negative shall carry a radiographic inspection serial number or code letters of test of the part(s) to which it pertains.

4.3 Rejection. Component parts not radiographed in accordance with the requirements of this specification and radiographic inspection processing deviating from this specification shall be cause for rejection of the part(s) by the Jet Propulsion Laboratory. Also the part(s) shall show no evidence of the following defects as determined visually and radiographically. The following defects shall be cause for rejection (b. through g. shall be subject to engineering review):

a. Cracks across plies of tape regardless of size or location.
b. Metallic inclusions.
c. Foreign material.
d. Resin rich areas.
e. Voids or porous areas.
f. Wrinkles.
g. Delaminations.

4.4 Reradiographic inspection. Whenever the Jet Propulsion Laboratory is in doubt as to the interpretation or clarity of a radiograph, reradiography may be required.

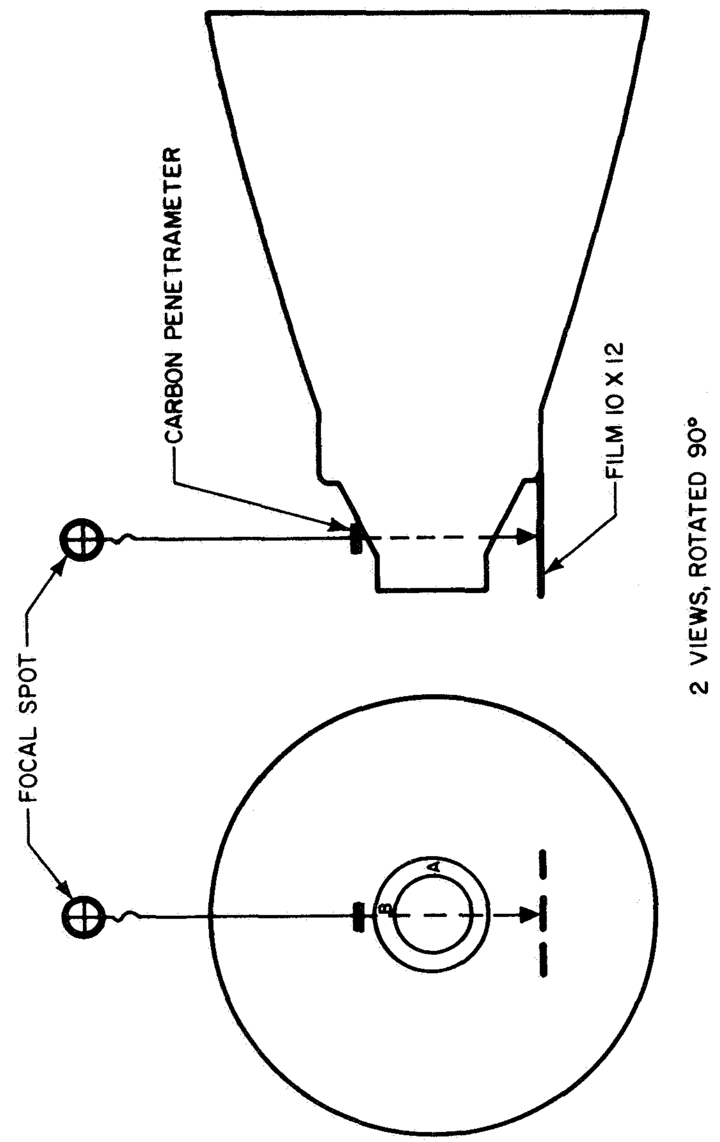

CARBON PENETRAMETER
FOCAL SPOT
FILM 10 X 12
2 VIEWS, ROTATED 90°
A
B

Figure 1a

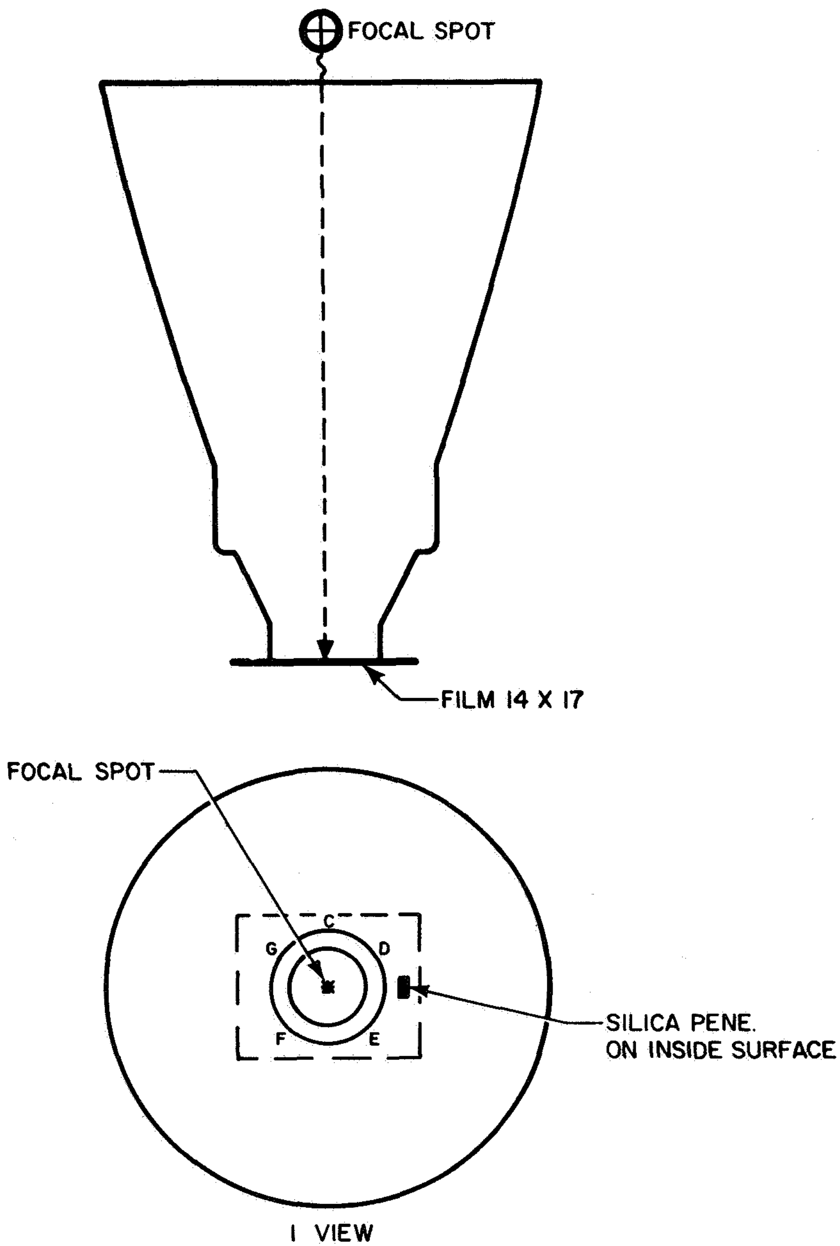
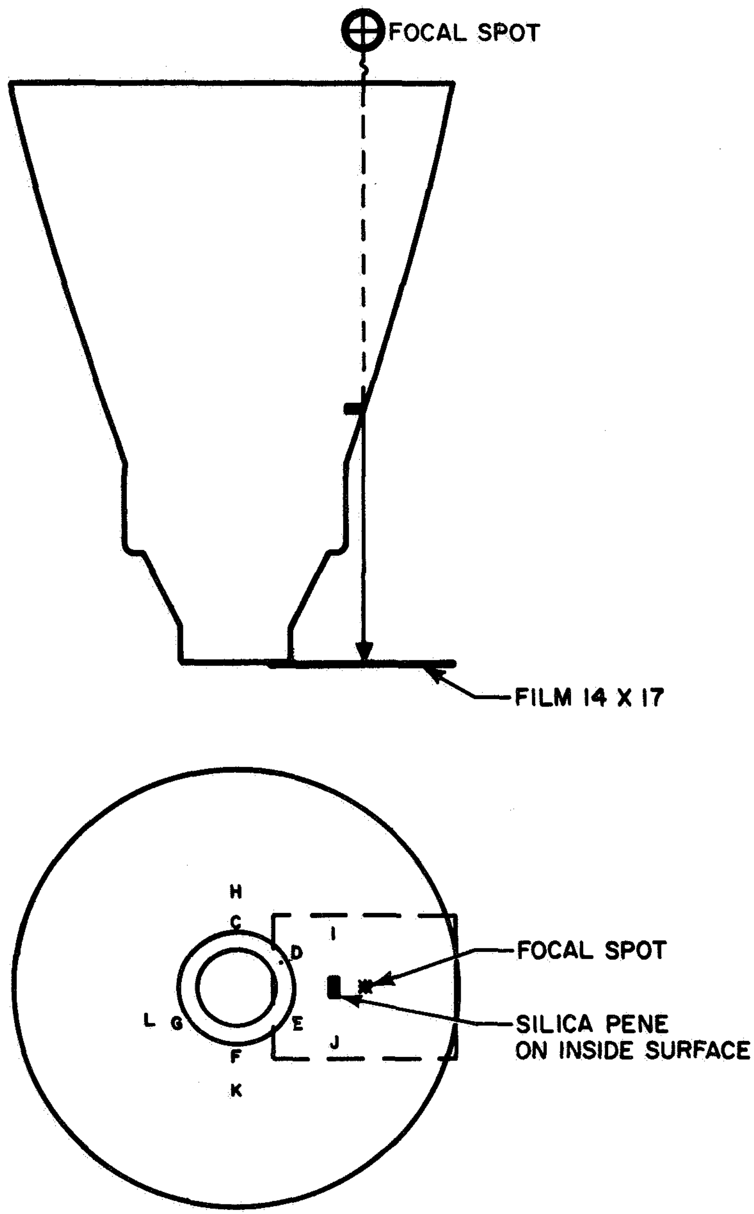


Figure 1b

01108



5 VIEWS ROTATED 72°

Figure 1c

01109

9

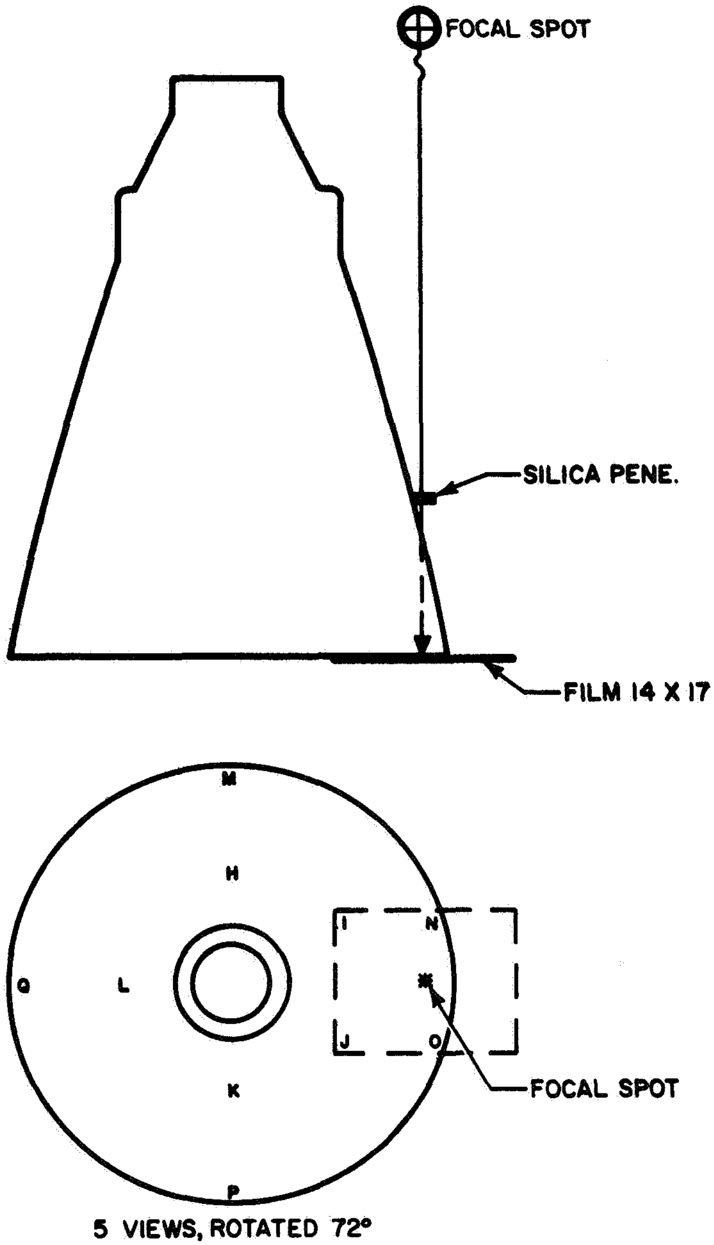
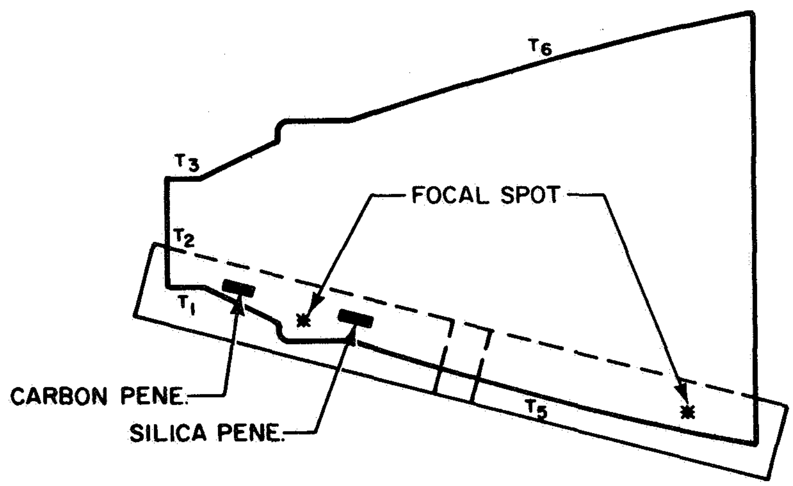
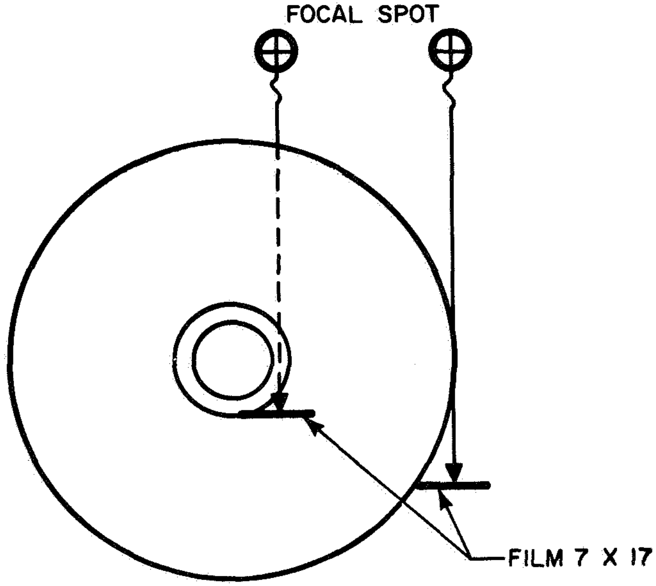


Figure 1d

01110



4 VIEWS THROAT TANGENT ROTATED 90°



2 VIEWS EXIT CONE TANGENT ROTATED 180°

Figure 1e