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FINAL REPORT

PHASE II STUDY OF IMPROVED MATERIALS FOR USE ON SCOUT ROCKET MOTOR NOZZLES

By R. D. Stutzman

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Prepared under Contract No. NAS1-10500, T. O. 2 by
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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

A program to obtain nozzle material performance data and to determine the feasibility of using new materials on the Scout rocket motor nozzles was conducted by the Vought Systems Division. The program included the following tasks.

Conducting stress and heat transfer analyses to aid in the selection of optimum materials for nozzle tests.

Fabricating a reimpregnated and graphitized throat insert.

Fabricating two nozzles with ablative throats.

Dissection and determining char and erosion of two nozzles fired on X-259 loaded cases. One of these nozzles used a graphite phenolic ablative throat insert and was fabricated under this contract and the other unit was a standard X-259 nozzle with a reduced area ATJ graphite throat insert.

As a result of this program, a nozzle materials change from a monolithic graphite throat insert to a graphite phenolic ablative throat insert was made in the third stage Scout rocket motor.

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FINAL REPORT

PHASE II STUDY OF IMPROVED MATERIALS FOR USE ON SCOUT ROCKET MOTOR NOZZLES

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SUMMARY

This report summarizes the work accomplished under Contract NAS1-10500 Task Order 2, by Vought Systems Division on a program entitled "Phase II Study of Improved Materials for Use on Scout Rocket Motor Nozzles". This effort was performed during the period November 1971 to March 1973.

A Hercules Incorporated X-259 loaded motor case was used as the test vehicle to obtain material performance data on two nozzles. The nozzle throats were designed to obtain average pressures above 4.134×10^6 N/m^2 (600 psi). The erosion and char depths for one nozzle using a graphite phenolic ablative throat insert and another standard X-259 nozzle with a reduced area ATJ graphite throat insert were obtained. Post-fire examination indicated material performance for the exit cone liners of the two nozzles were equivalent, however a carbon phenolic throat back-up performed superior to the molded asbestos phenolic being used in the present X-259 nozzle.

In addition to obtaining performance data on the two test nozzles, stress and heat transfer analyses were conducted to predict the performance of materials in the X-259 nozzle and several nozzle components were fabricated. The results of these efforts are discussed.

DISCUSSION

Introduction

Vought Systems Division (VSD) had previously conducted a study (Reference 1) to investigate available new materials with the potential for improving performance and/or reliability of Scout rocket motor nozzles. This effort was conducted under Contract NAS1-6935 T.O. 20. During this study several materials were reported with promising potential; however, additional analyses and testing were required to determine the feasibility of using these materials in solid propellant motors of the Scout vehicle. For this reason, a Phase II effort was initiated to investigate nozzle design, fabrication methods and obtain firing data on selected materials identified during the Phase I study (Reference 2).

The materials considered for test under this effort included the following:

Component	Vendor designation	Material type
Throat insert	Carbitex 700	Fibrous graphite
	RPP-4	Reinforced carbon carbon
	MXG-175	Graphite phenolic
	FM-5014	Graphite phenolic
Throat backup insulation	FM-5272	Kraft paper phenolic
	MX-2600	Silica phenolic
	MX-4926	Carbon phenolic
Throat extension	FM-5072LD	Carbon phenolic
	MX-4926	Carbon phenolic
Exit cone	FM-5272	Kraft paper phenolic
	FM-5525	Asbestos phenolic

The effort under this program included the design of test nozzles using the above materials. Carbitex 700 and RPP-4 were eliminated from full scale motor testing as throat inserts because of high cost and the fact that those materials could not be bought to a controlled manufacturing specification (i.e. manufacturing would be proprietary). FM-5272 was also eliminated for the throat backup since predicted erosion was greater than desired. After the elimination of these materials, the program was redirected to include the fabrication of one complete test nozzle, the fabrication of components for another test nozzle and the post test analysis of two nozzles, one with a graphite phenolic ablative throat and a modified X-259 nozzle.

The material performance data from two high pressure X-259 motor firings, results of thermal and stress analyses, and fabrication of nozzles and components are discussed below.

Nozzle Dissection and Performance

Two nozzle tests were conducted by Hercules Incorporated/Allegany Ballistic Laboratory on X-259 loaded motor cases. The nozzles were removed and dissected to determine char and erosion depth. Char measurements were taken by making strip photographs of the cross section at 3X magnification and taking measurements from the photograph using a calibrated scale. The results of these investigations are shown in Reference 2.

One of the nozzles was fabricated by Haveg Industries, Incorporated under this program. The materials used, nozzle design and material performance are shown in Figure 1. The nozzle incorporated an MXG-175 graphite phenolic throat insert with a MX-4926 carbon phenolic insert backup. The exit cone was fabricated from MX-4926 carbon phenolic and FM-5525 asbestos phenolic. Initial throat diameter was .141 m (5.568 in.) in diameter. The transition point from the throat insert to the throat extension was at a diameter of .179 m (7.030 in.) The exit cone carbon phenolic was extended from this point to a diameter of .304 m (11.974 in.). Measurement of char and erosion at .013 m (1/2 in.) intervals along the exit cone are shown in Table I. Erosion and char measurements taken on the throat insert and backup are shown in Table II.

An average erosion rate of .232 x 10^{-3} m/sec (9.15 mils/seconds) for the throat was calculated for this firing based on a post fire area of .0185 m^2 (28.64 in^2) and a pre-fire area of .0151 m^2 (23.341 in^2). Nozzle throat area increase during the firing was 17.8%. Material loss varied from .0049 m (.191 in.) on the forward radius of the insert to .0067 m (0.266 in.) maximum at the throat plane.

The second nozzle evaluated was a modified X-259 design. The nozzle had previously been fabricated through throat bonding operations and hydrotested, but the throat contour had not been final machined. The nozzle throat diameter was machined to .1443 m (5.68 in.) vs .1694 m (6.670 in.) used in a normal X-259 motor to achieve higher pressure. The exit cone was cut off for sea level operation. The nozzle throat insert was ATJ graphite backed up with a molded RPD-150 insulator. The exit cone was fabricated from MX-2630 graphite phenolic and MX-2600 silica phenolic. The entire exit cone is overwrapped with Tayloron PA6 asbestos phenolic. The nozzle performance is shown in Figure 2. Measurements of char and erosion taken at .013 m (1/2 in.) intervals along the exit cone are shown in Table III. Erosion and char measurements taken from the throat insert and backup are shown in Table IV. Nozzle throat erosion averaged .1034 x 10^{-3} m/sec (4.07 mils/sec) with a throat area increase of 7.4%.

The results of the test nozzle examination indicate that the char and erosion depths for the nozzle exit cone of the two nozzles were not significantly different. The insert backup fabricated from tape wrapped MX-4926 carbon phenolic was superior to the backup fabricated from molded RPD-150. Material loss for the RPD-150 throat backup was .0145 m (0.57 in.) as compared to .0064 m (0.25 in.) for the carbon phenolic. Post fire photographs of the throat and backup insulation are shown in Figures 3 and 4.

Motor Test Data

Motor S/N HIB 222 cast June 1967 was used for testing of the modified X-259 nozzle. Motor S/N HPC 209 cast July 1966 was used to test the ablative throat nozzle fabricated under this program. The motors were tested under NASA Contract NAS1-10481. These motors were tested on November 15, 1972 and December 5, 1972. Prior to firing the motors had been conditioned to 297 ± 3°K (75 ± 5°F) and the grain cavity evacuated to simulate vacuum firings. Both motors were water quenched at T + 69 seconds. Average motor burn times and pressures are given below.

Nozzle design	Modified X-259	New materials
Motor S/N	HIB 222	HPC 209
Throat insert material	ATJ (graphite)	MXG 175 (graphite phenolic)
Burn time, sec	24.86	26.41
Avg. burn pressure, N/m^2	4.42 x 10^6 (641 psi)	3.97 x 10^6 (576 psi)
Web time, sec	22.8	24.08
Avg. web pressure, N/m^2	4.63 x 10^6 (672 psi)	4.21 x 10^6 (611 psi)
Peak pressure, N/m^2	5.11 x 10^6 (742 psi)	4.86 x 10^6 (706 psi)

Strain gauges attached to the nozzle .0254 m (1 in.) aft of the nozzle flange showed strains less than .1% for both motor firings. Temperature increase at T + 69 seconds from thermocouples mounted on the nozzles are given below.

Thermocouple location	Modified X-259 nozzle on motor S/N HIB 222	New materials nozzle on motor S/N HPC-209
.0254 m (1 in.) aft of nozzle attachment flange	293°K (35°F)	283°K (18°F)
.0763 m (3 in.) aft of nozzle attachment flange	317°K (80°F)	287°K (25°F)
.0254 m (1 in.) forward of nozzle exit plane	366°K (168°F)	298°K (45°F)

Motor pressure-time for both motors is shown in Figure 5.

Analyses

Thermal analysis. — Several thermal analyses were conducted to aid in material selection, sizing of nozzle components, and to predict material erosion and char depth. The results of the first analysis, Reference 3, were used to determine required exit cone insulator thickness and bond line temperatures. The analysis assumed a 30 second burn time and 4.134×10^6 N/m^2 (600 psi) pressure. Past X-259 analyses calculated for a 2.412×10^6 N/m^2 (350 psi) chamber pressure were used as the starting point to calculate heat transfer coefficients and predict erosion results. A convective heat transfer coefficient of 10.15×10^6 cal/m^2-°K-hr (2075 BTU/ft^2-°F-hr) was calculated for the high pressure X-259 motor design. This compares to 6.8×10^6 cal/m^2-°K-hr (1390 BTU/ft^2-°F-hr) for a motor with an average pressure of 2.5×10^6 N/m^2 (363 psi). Radiation heat flux of 0.51×10^6 cal/m^2-sec (187 BTU/ft^2-sec) was used for the throat. Significant results of this analysis for the two nozzle configurations analyzed were as follows:

> The maximum temperature for the bond line between the throat insert and the throat backup insulation was calculated to be 2089°K (3300°F) for the Carbitex 700 and 922°K (1200°F) for RPP-4. The reason for the large difference in the predicted temperatures is the much greater thermal conductivity for the Carbitex 700.
>
> The erosion of asbestos phenolic (FM-5525) was more than the cellulose phenolic (FM-5272) when used in the exit cone. For equal asbestos and cellulose thickness, bond line temperatures using the cellulose phenolic were approximately 45% of those using asbestos as an exit cone insulator.
>
> Carbon phenolic material erosion was predicted to be approximately $.51 \times 10^{-3}$ m (0.02 in.). 0.762×10^{-2} m (0.3 in.) of insulator was determined to be sufficient to protect the aluminum flange from excessive heating.

More detail analysis was conducted to predict erosion of the throat insulator and exit cone materials and to predict the temperature profile occurring in RPP-4 and Carbitex 700 throat inserts. This analysis showed that the FM-5272, which had been selected for the throat backup insulator, would erode excessively in the X-259 nozzle. For this reason, the FM-5272 was replaced with MX-4926. The erosion rate of Carbitex 700 and RPP-4 was calculated to be .272 x 10^{-3} m/sec (10.7 mil/sec).

An erosion analysis of the FM-5014 graphite phenolic throat insert using MX-2600 silica phenolic as a throat insulation backup material gave the following results. The locations represent different axial distances along the nozzle centerline with 0.0 being the leading edge.

Distance from leading edge — m			Erosion rate — m/sec		Surface erosion — meters	
Leading edge	0	(0.0 in.)	.2253 x 10^{-3}	(8.87 mils/sec)	.0059	(.231 in.)
Throat insert	.0152	(0.6)	.3137	(12.35)	.0082	(.321)
Throat backup	.0254	(1.0)	1.4656	(57.70)	.0381	(1.5)
Throat insert	.0318	(A/A* = 1)	.3302	(13.00)	.0086	(.338)
Throat insert	.0559	(2.2)	.2492	(9.81)	.0065	(.255)
Throat insert	.1016	(4.0)	.1849	(7.28)	.0048	(.189)

The results of the thermal analysis conducted showed that the test nozzle configurations would survive the nozzle tests. Erosion of the graphite phenolic insert was predicted to be .328 x 10^{-3} m/sec (13.0 mils/sec) vs .272 x 10^{-3} m/sec (10.7 mils/sec) for a RPF-4 or Carbitex 700 insert.

Stress analysis. — Finite element analyses of nozzle configurations assuming a graphite phenolic throat insert with both carbon phenolic (MX-4926) and silica phenolic (MX-2600) throat backup insulators were conducted.

The results of this analysis showed that exit cone stresses were not critical. Axial, radial and hoop stress distributions were determined for the throat assembly as well as shear stresses along the bondline.

Maximum tensile and compressive stresses are listed in Table V for the insert, overwrap and carbon phenolic insulation located along the inner surface and aft of the insert. Comparison of the stress levels of the two configurations shown in Table V show the superiority of the configuration with the carbon phenolic throat backup insulation. It was predicted that bond line integrity beween the silica phenolic and the insert would be lost and delamination in the silica overwrap would occur due to high radial tensile stresses. A further evaluation of maximum strains that would occur in the axial and hoop directions was made to determine if the components would survive for the throat assembly with the silica phenolic backup insulation. The calculated strains were compared with a maximum allowable of 4%. Figure 6 shows calculated strains in the hoop and axial directions in the nozzle for the nozzle with the silica backup. Failure of fibers in the overwrap due to strains in the hoop direction was predicted due to the high strain values shown (shaded) in Figure 6. The type of failure was predicted to be delamination between the plies due to the fibrous nature of the material. After the thermoelastic stresses had been dissipated due to degradation of the overwrap, the backup material aft of station 4 (Figure 6) would support the insert against chamber pressure loads. To determine if the material aft of station 4 could resist the nozzle pressure loads in shear, pressures were integrated around the insert and along the exit cone to determine the aft shear load on this area. At 26 seconds, motor pressure produces a shear load of $.0533 \times 10^6$ N (12,000 lbs.). Since this corresponds to an average shear stress of 1.46×10^6 N/m^2 (212 psi), it was concluded that the insert with the silica phenolic backup would be retained in the nozzle despite damage to the overwrap material due to heating and thermal stresses.

Comparision of Predicted and Motor Firing Results

Predicted and actual erosion results from the motor firing are shown below. "Z" is defined as the distance from the leading edge of the throat insert.

Z (m)	Material	Actual erosion rate, meters/sec		Predicted total erosion, m		Actual total erosion, m	
.112 (4.4 in.)	MX-4926	$.170 \times 10^{-3}$	(6.7 mils/sec)	4.420×10^{-3}	(.174 in.)	2.540×10^{-3}	(.10 in.)
.201 (7.9)	MX-4926	.102	(4.0)	2.642	(.104)	.762	(.03)
.291 (11.4)	MX-4926	.067	(2.65)	1.727	(.068)	1.016	(.04)
.341 (13.4)	FM-5525	.076	(3.01)	1.956	(.077)	3.810	(.15)
.468 (18.4)	FM-5525	.033	(1.28)	.864	(.034)	3.302	(.13)
.596 (23.4)	FM-5525	.023	(0.9)	.610	(.024)	1.270	(.05)

The asbestos phenolic (FM-5525) erosion was predicted to range from .00061 m (.024 in.) to .00196 m (.077 in.) along the exit cone. Actual results showed the erosion was twice this value. The carbon phenolic cloth erosion was predicted to be .00173 m (.068 in.) to .0044 m (.174 in.) with actual values one half of that predicted. Erosion for the graphite phenolic throat insert was $.233 \times 10^{-3}$ m/sec (9.15 mil/sec) as compared to $.33 \times 10^{-3}$ m/sec (13.0 mil/sec) predicted.

A comparision of the char and erosion at selected locations of the two nozzles is given below:

Distance from aft end of exit cone (meters)		Ablative throat			ATJ throat		
		Material	Erosion/char, m		Material	Erosion/char, m	
Insert interface							
.5461	(21.5 in.)	MX-4926	2.50×10^{-3}	(.10* in.)	MX-2630A		
.5080	(20)	MX-4926	1.270	(.05/)	MX-2630A	1.270×10^{-3}	(.05/* in.)
.4572	(18)	MX-4926	1.016	(.04/)	MX-2630A	1.54	(.10/)
.4064	(16)	MX-4926	.508	(.02/)	MX-2630A	2.032	(.08/)
.3556	(14)	MX-4926	.762	(.03/)	MX-2630A	1.270	(.05/)
.3048	(12)	MX-4926	.762	(.03/)	MX-2630A	1.016	(.04/)
.2667	(10.5)	FM-5525	3.048/3.302	(.12/.13)	MX-2630A	1.270	(.05/)
.2032	(8.0)	FM-5525	4.318/2.794	(.17/.11)	MX-2630A	1.270	(.05/)
.1016	(4.0)	FM-5525	2.540/2.540	(.10/.10)	MX-2600	4.572/3.302	(.18/.13)
.0254	(1.0)	FM-5525	2.032/2.540	(.08/.10)	MX-2600	2.794/3.810	(.11/.15)
.0127	(0.5)	FM-5525	2.032/2.540	(.08/.10)	MX-2600	2.540/4.572	(.10/.18)
Exit plane							

*Char depth cannot be determined.

The results show that MX-4926 carbon phenolic performance is equivalent and at some locations better than the MX-2630A graphite phenolic. Differences in performance could be due to the minor differences in throat diameters for the two firings and the fact that ATJ graphite is the upstream material in one nozzle and graphite phenolic in the other nozzle. While the FM-5525 asbestos phenolic performed better that the MX-2600 silica phenolic, the different locations in transitioning from the more erosion resistant graphite and carbon phenolic in the two nozzles to the more erosive silica or asbestos phenolic could bias direct comparisions. Erosion depth immediately downstream of this transition point could be twice that obtained if the more erosion resistant material were not upstream. However, it appears that a lighter weight nozzle could be made from materials investigated in this nozzle firing than using the materials of the present design.

A Carbitex 700 throat insert and a Vought Systems Division RPP-4 throat insert were fabricated for use on this program; however, due to a program redirection, these inserts were not tested as a part of this program. The Carbitex insert was subsequently purchased by Thiokol Chemical Corporation and fired as an entrance insulator. The erosion of Carbitex 700 was approximately 50% of the graphite phenolic tested in the same region. Thiokol has also tested Carbitex 700 as throat inserts and has determined that their erosion rate is significantly lower than that of graphite phenolic. The RPP-4 insert has not been tested but is available for this purpose. Based on the results of the MXG-175 graphite phenolic throat insert fired in the X-259 motor, a predicted erosion rate for the RPP-4 billet would be in the range of $.102 \times 10^{-3}$ m/sec (4 mils/sec), or less than half of a typical graphite phenolic throat insert.

Fabrication

One complete nozzle assembly, the components for another nozzle assembly and an RPP-4 and Carbitex 700 throat billet were fabricated under this program. A discussion of the fabrication methods used, fabricated parts physical properties, and problems encountered follows.

The nozzle assembly fabricated consisted of an MXG-175 graphite phenolic throat insert and an MX-4926 carbon phenolic throat insulator. The exit cone assembly was fabricated from MX-4926 carbon phenolic to a diameter of approximately .305 m (12 in.) and overwrapped with FM-5525 asbestos phenolic.

A second nozzle was fabricated but was not final assembled. This nozzle consisted of a FM-5014 graphite phenolic throat, an MX-2600 throat insulator and an exit cone fabricated from FM-5072 LD with a FM-5272 light weight Kraft Paper backup. Fabrication and assembly methods were similar for both nozzles and are detailed below. Properties of the materials taken from "tag end" specimens are shown in Table VI.

Exit cone: The exit cone was fabricated in the following manner:

The desired material of FM-5072 LD (nozzle 2) or MX-4926 (nozzle 1) was wrapped parallel to centerline on a mandrel. Roller pressure was 26270 to 61300 N/m (150 to 350 lbs/in.) of tape width and the temperature of the tape was 380°K (225°F) maximum at point of application.

The part was debulked in an autoclave per the following cycle:

Debulk cycle			
Description	Temp °K	Pressure, N/m^2	Time (minutes)
Raise temp & pressure	355 ± 6 (180 ± 10°F)	$1.72 \times 10^6 \pm 1.72 \times 10^5$ (250 ± 25 psi)	
Hold at	355 ± 6 (180 ± 10)	$1.72 \times 10^6 \pm 1.72 \times 10^5$ (250 ± 25)	60
Decrease temp	300 ± 6 ((80 ± 10)	$1.72 \times 10^6 \pm 1.72 \times 10^5$ (250 ± 25)	
Decrease pressure	300 ± 6 (80 ± 10)	0	

After debulking the part was machined to desired drawing dimensions in preparation for the next wrapping operation.

After applying a thin coat of SC-1008 resin to the OD of the previously wrapped material, the FM-5272 (nozzle 2) and FM-5525 (nozzle 1) were wrapped parallel to centerline while maintaining roller pressure at 26270 to 61300 N/m (150 to 350 lbs/in.) of tape width. The parts were cured per the following schedule.

Cure cycle			
Description	Temp, °K	Pressure, N/m^2	Time (minutes)
Raise temp & pressure	339 ± 6 (150 ± 10°F)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25 psi)	–
Hold at	339 ± 6 (150 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	120
Raise temp	366 ± 6 (200 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	–
Hold at	366 ± 6 (200 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	120
Raise temp	380 ± 6 (225 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	–
Hold at	380 ± 6 (225 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	120
Raise temp	394 ± 6 (250 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	–
Hold at	394 ± 6 (250 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	60
Raise temp	408 ± 6 (275 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	–
Hold at	408 ± 6 (275 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	60
Raise temp	436 ± 6 (325 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	–
Hold at	436 ± 6 (325 ± 10)	1.72×10^6 $\pm 1.72 \times 10^5$ (250 ± 25)	180
Decrease pressure	339 ± 6 (150 ± 10)	0	

After the OD of the exit cone had been machined to the desired contour, fiberglass rovings were applied and cured.

Throat backup insulation: The throat backup insulation was fabricated in the following manner:

The desired material, MX-4926 (nozzle 1) or MX-2600 (nozzle 2), was wrapped over a mandrel parallel to centerline while maintaining roller pressure between 26270 to 61300 N/m (150 to 350 lbs/in.) of tape width. The temperature of the tape at this point of application was 380°K (225°F) maximum.

The assembly was bagged and autoclave cured as identified above. After cure the part was machined to desired drawing dimensions.

Throat insert: The throat insert was fabricated in the following manner:

The desired material, MXG-175 (nozzle 1) or FM-5014 (nozzle 2), was wrapped over a mandrel 45° to centerline while maintaining roller pressure between 26270 to 61300 N/m (150 to 350 lbs/in.) of tape width. The temperature of the tape at the point of application was 380°K (225°F) maximum.

The assembly was bagged and hydroclave cured at 6.89×10^6 N/m^2 (1000 psi) and 428°K (310°F) for four hours. The throat insert fabricated from MXG-175 was post cured at 422°K (300°F) for 24 hours.

After the part had been machined to the desired dimensions the throat insert and throat backup insulation were bonded together with Epon 934 adhesive.

Final assembly: Final assembly was conducted by bonding the aluminum attachment ring to the throat assembly with Epon 934. After this assembly had cured, the exit cone assembly was bonded to the throat assembly with Epon 934 and cured.

Fabrication problems: The problems encountered during fabrication of the nozzles included limited production of selected materials, cracking in FM-5272 material and wrapping the throat billets at 90° to centerline.

The limited production of some of the materials used for component fabrication resulted in long lead time for delivery and additional cost on the per pound use basis. It was determined that many materials, for example FM-5072 LD, identified in material suppliers catalogs are manufactured on request with quantities around 227 Kg (500 lbs) required for a production run. The user either has to purchase the entire lot or pay a premium price for the materials.

Another problem was encountered in machining the FM-5272 Kraft Paper phenolic material. When the final exit cone outside diameter was being machined a crack was initiated which propagated to the carbon phenolic liner. Further review indicated that the crack was caused by high internal stresses built into the part by the wrapping and curing processes. When a groove was machined in the material during final machining operations, the groove caused a stress riser which caused the material to crack. The part was repaired by machining a Vee groove in the center of the delaminated area down to the carbon phenolic approximately .00636 m (0.250 in.) wide and wrapping FM-5272 in the Vee groove area. After machining flush, MXB-6001 glass cloth and E-801 glass roving were applied over the repaired area. It is believed that cracking could be eliminated by proper machining methods.

VSD had planned to have the ablative throat billets wrapped at 90° to centerline. However, because of the small ratio between the OD and the ID of the part, this could not be done without excessive wrinkling. After several attempts, the wrap angle was revised to 45° and the parts were fabricated without difficulty.

RPP-4 fabrication: RPP-4 is a reinforced carbon carbon material which is manufactured by Vought Systems Division. This material is manufactured by first fabricating a reinforced graphite phenolic billet. Four alternate cycles of pyrolyzing and impregnating are then performed and the part graphitized to obtain the desired material.

Two reinforced graphite phenolic billets were fabricated for nozzle throat application under this program. One billet was prepared with ply orientation 90° to the centerline and the other with ply orientation 45° to the centerline.

The reinforced graphite phenolic billet 90° to centerline was fabricated from WCA graphite fabric impregnated with phenolic resin to LTV specification 307-7-7. This material was purchased from Hexcel and has a resin content of 55.3% and a volatile content of 8.2%. Initially it was planned to tape wrap the part 90° to centerline; however, the high OD to ID wrapping ratio, high resin content and high resin flow caused excessive wrinkling and the following hand layup method was used.

WCA graphite fabric phenolic broad goods were cut using a "donut" cutting tool. Three hundred and sixty-six of these donut shaped plies were layed up on a billet molding tool to produce a billet height of approximately 0.127 m (5 in.) The tooling and layup are shown in Figures 7 and 8.

The layup assembly was preheated to 355°K (180°F) in an air circulating oven. This preheated layup was then placed in a platen press preheated to 355°K (180°F) and compressed to mechanical stops to yield the desired billet thickness. When the temperature of the billet reached 372°K (210°F), the stops were removed and a constant pressure of 3.445×10^6 N/m^2 (500 psi) was applied. The part was then cured under pressure for 16 hours at 422°K (300°F). Small areas of edge delamination were observed after cure which appeared to be due to resin shrinkage. The billet was then post cured to 533°K (500°F) for 48 hours under 1.378×10^6 N/m^2 (200 psi) pressure and placed in a stainless steel retort packed in petroleum coke and pyrolyzed to its initial carbon carbon state. After the first impregnation with furfuryl alcohol and pyrolysis, further processing was discontinued and the part scrapped because of excessive delaminations.

A second graphite phenolic billet was fabricated by wrapping 45° to centerline with FM-5014 bias tape. The FM-5014 tape has a resin content of 34% and a volatile content of 4%. During wrapping, roller pressure was adjusted to attain a debulked or wrapped condition of 90% minimum theoretical density. After the part had been wrapped, it was autoclave cured by heating it to 422°K (300°F) in 7 hours and then holding the part at 422°K (300°F) for 2 hours while at a minimum of .663 m (26 in.) of Hg vacuum. The cured billet was then post cured, pyrolyzed and strengthened to the RPP-4 condition by the processing method depicted in Figure 9.

The RPP billet fabricated from FM-5014 wrapped 45° to centerline was radiographic inspected and alcohol wiped. No delaminations or voids were observed and the x-ray showed the part to be of uniform density and free from defects. The final density of the graphitized RPP-4 billet was 1.52 grams/cc. The dimensions of this billet are approximately .234 m (9.2 in.) OD by .127 m (5.0 in.) long. Wall thickness is .046 m (1.8 in.).

CONCLUSIONS

Throat Insert

Reimpregnated reinforced carbon carbon materials can successfully be fabricated into throat insert billets. Predicted performance of these materials is superior to the graphite phenolic material tested. For example, erosion rate is predicted to be approximately 0.1×10^{-3} m/sec (4 mils/sec) which is less than half of that experienced in the graphite phenolic throat insert tested.

MXG-175 represents a reliable nozzle throat material that is adequate for an X-259 or larger SCOUT motor. Only a small performance gain (~0.2%) in delivered Specific impulse is obtained by using the lower erosion rate graphite material. Based on the results of the Phase II program, an MXG-175 nozzle throat insert has been incorporated into the SCOUT X-259 third stage motor design.

Throat Backup Insulation

The MX-4926 carbon phenolic backup insulation performed superior to the RPD-150 asbestos phenolic insulator presently being used in the X-259 nozzle. A review of thermocouple data shows that the carbon phenolic insulation properties are sufficient to protect the aluminum attachment flange from excessive heating.

Throat Extension

MX-4926 carbon phenolic performed well as the throat extension liner in the exit cone.

Exit Cone Liner

Low cost material such as paper and asbestos phenolic can be successfully fabricated. The asbestos phenolic performed equal to the MX-2600 silica phenolic presently being used in the exit cone of the X-259 nozzle. However, further investigation is warranted before the optimum material for this region can be identified.

RECOMMENDATIONS

It is recommended that the investigation of improved materials for SCOUT nozzles be continued. To maximize data from one test, the nozzle throat and exit cone should be segmented to obtain data on several materials. In addition, the program should include a study to determine the feasibility of standardizing nozzle materials, including adhesives, for all SCOUT nozzles. Preliminary design and fabrication cost data would be investigated to determine optimum selection. Based on information in the Phase I study which shows the use of carbon phenolic as a throat insert material, it is predicted that this material may also be used as a throat insert with equivalent performance as obtained from the MXG-175 tested under this program. In addition, because of the erosion resistance properties of MXG-175 demonstrated during this program, this material may also be satisfactory for the throat backup insulation and throat extension areas of the nozzle.

Since one of the objectives of this program was to identify a material which may be used in several locations in the nozzle, further investigation of incorporating either MXG-175, MX-4926 or a similar material in the high erosive regions of the nozzle is recommended. The objective of this investigation would be to determine the feasibility from a fabrication, cost, design and performance standpoint of using a two-material nozzle design in the SCOUT rocket motors. Candidate materials for further investigation during the next phase of the nozzle material program include:

Throat Insert

The recommended throat insert materials are RPP-4 which was fabricated but not tested, MXG-175 and other materials selected based on an up-to-date review from literature and material suppliers.

Throat Backup Insulation

Since additional investigation shows that there are high reject rates in the fabrication of the molded RPD backup insulation, it is recommended that the RPD-150 in the SCOUT X-259 nozzle be replaced with MX-4926 or an equivalent material.

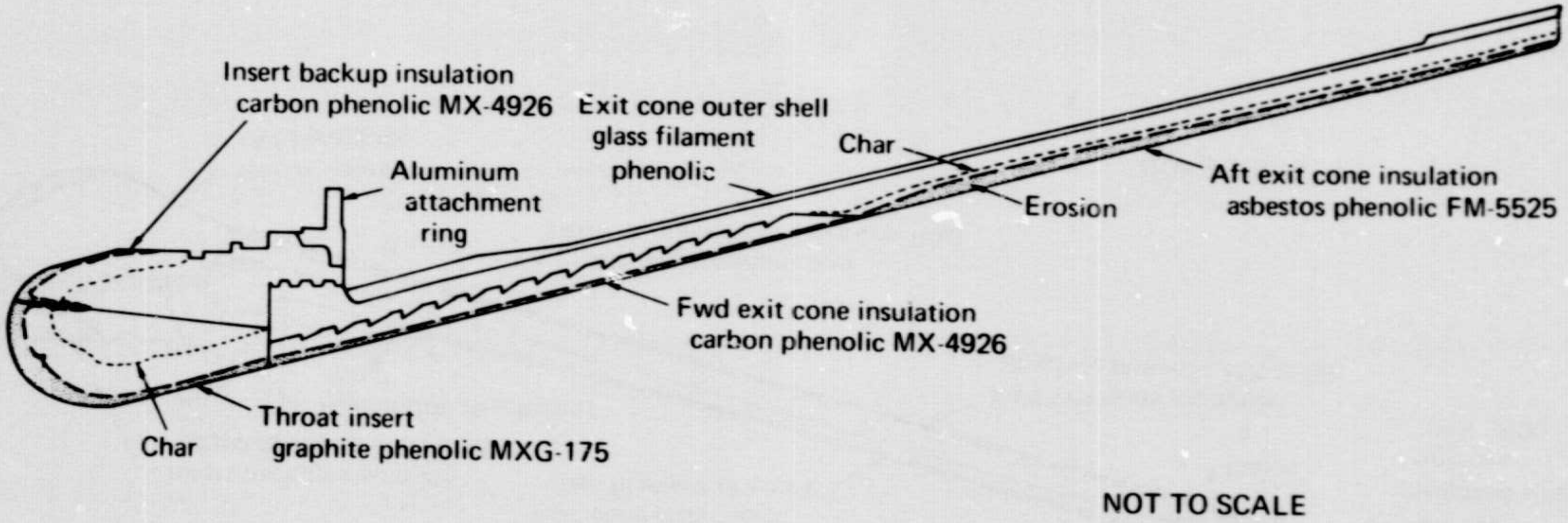


FIGURE 1. – X-259 ABLATIVE THROAT POST FIRE RESULTS

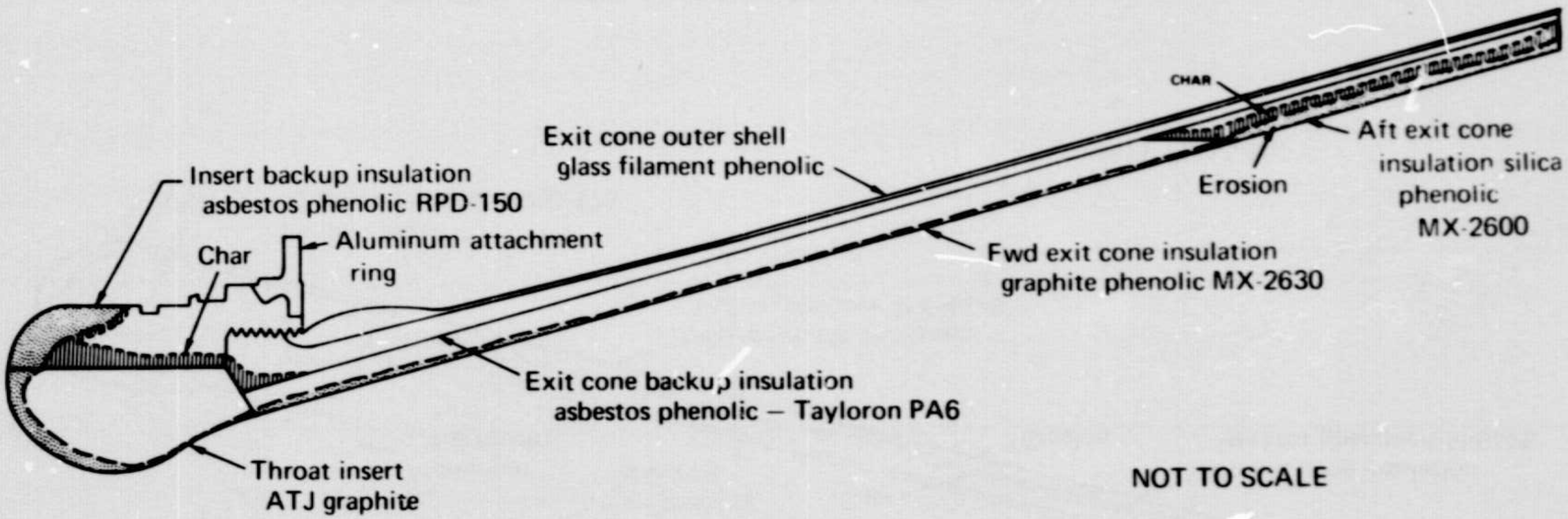
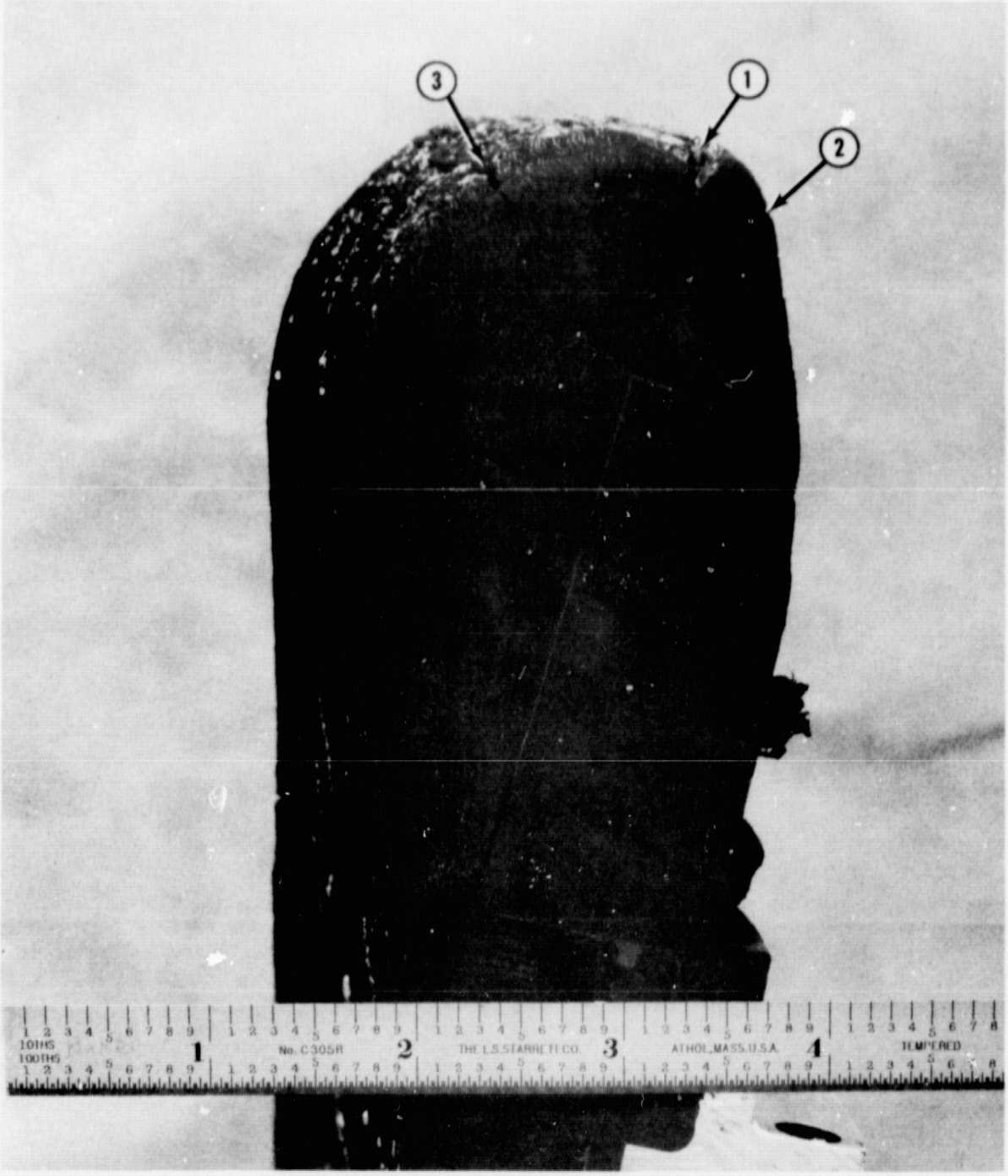
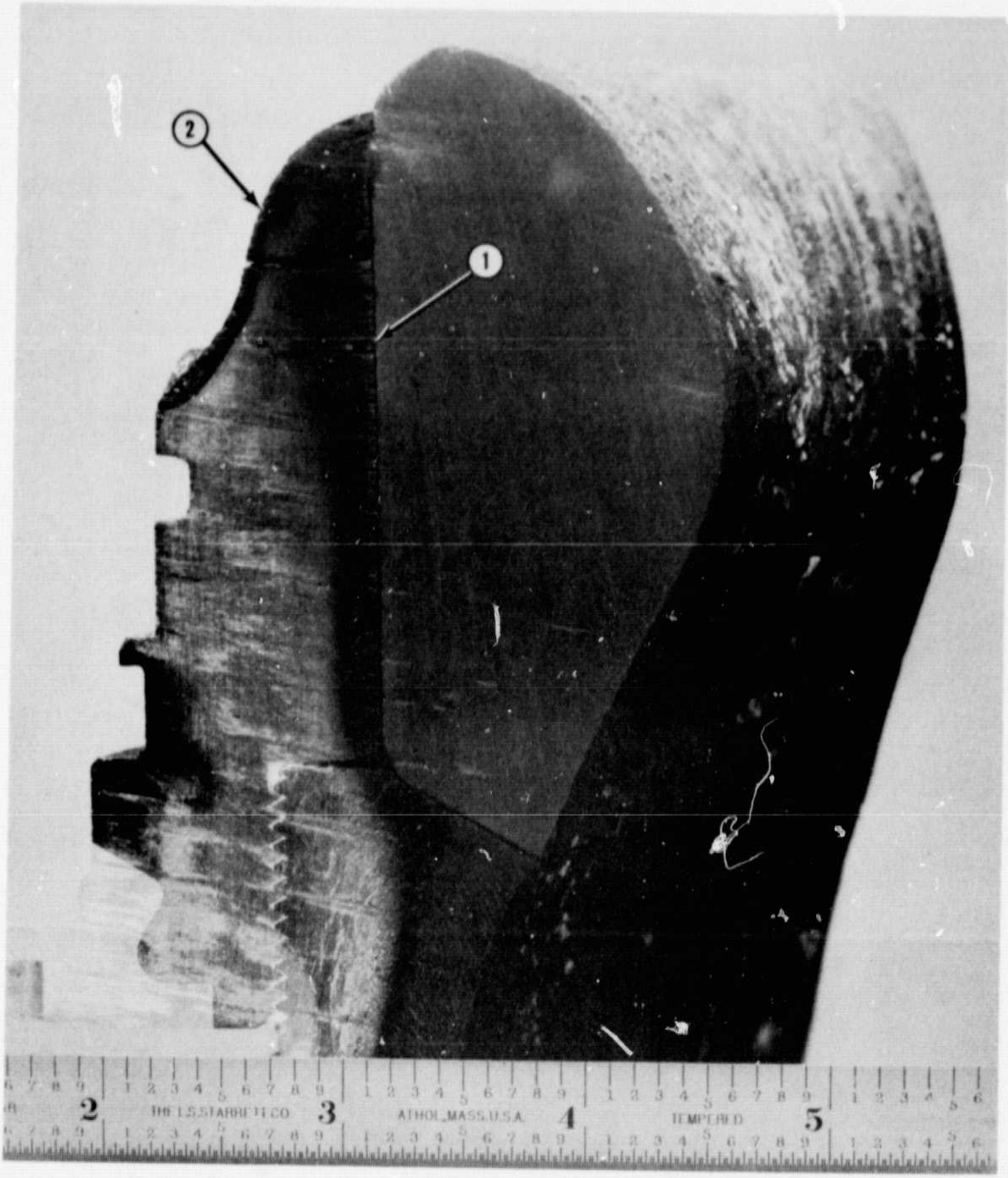


FIGURE 2. – X-259 ATJ THROAT POST FIRE RESULTS



1. Bond line separation
2. Delaminations on outer surface of backup insulation
3. Crack in outer surface of throat insert

FIGURE 3. – CROSS SECTION OF GRAPHITE PHENOLIC THROAT INSERT AND CARBON PHENOLIC BACKUP INSULATION



1. Extensive char along bond line
2. Cracks in backup insulation

FIGURE 4. – CROSS SECTION OF ATJ GRAPHITE THROAT INSERT AND ASBESTOS PHENOLIC BACKUP

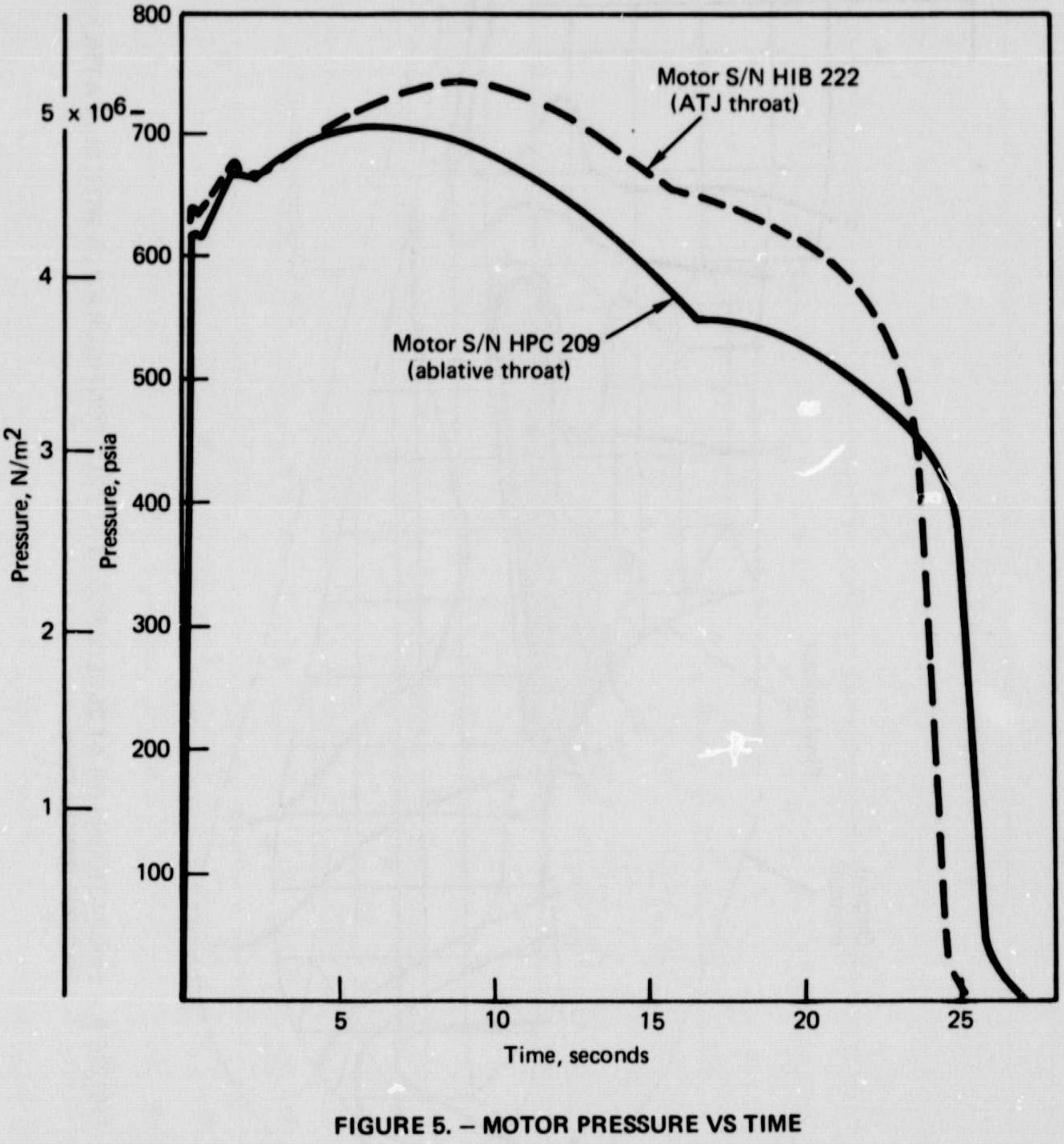
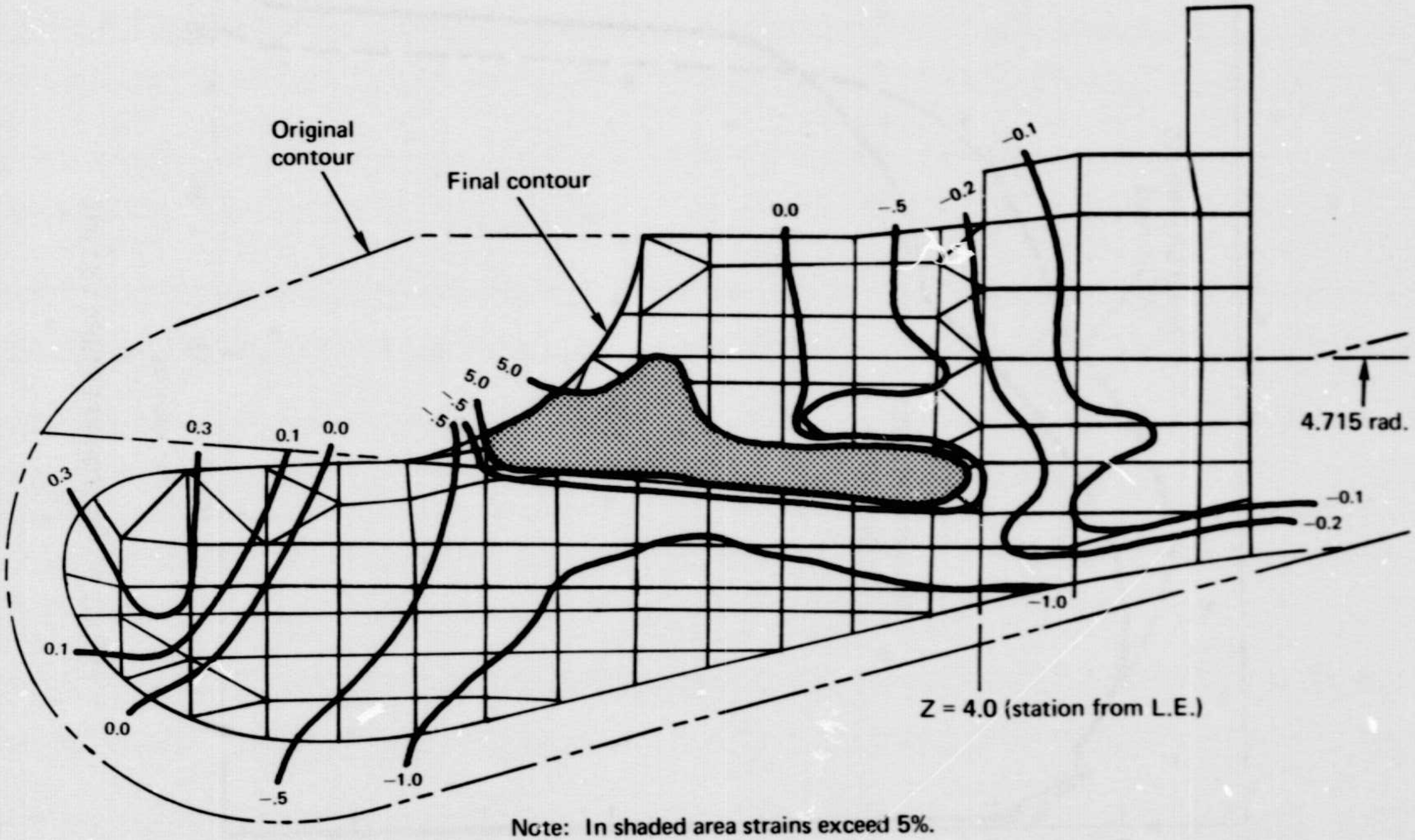


FIGURE 5. – MOTOR PRESSURE VS TIME



Note: In shaded area strains exceed 5%.

FIGURE 6. – HOOP STRAINS (%) AT 26 SECONDS IN NOZZLE CONFIGURATION WITH SILICA PHENOLIC BACKUP INSULATION

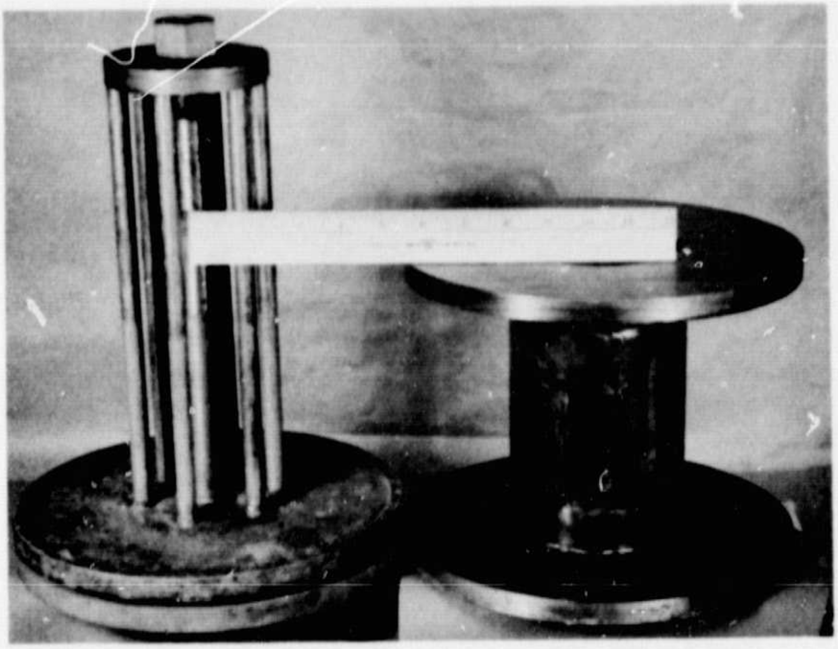


FIGURE 7. – BILLET MOLDING TOOL

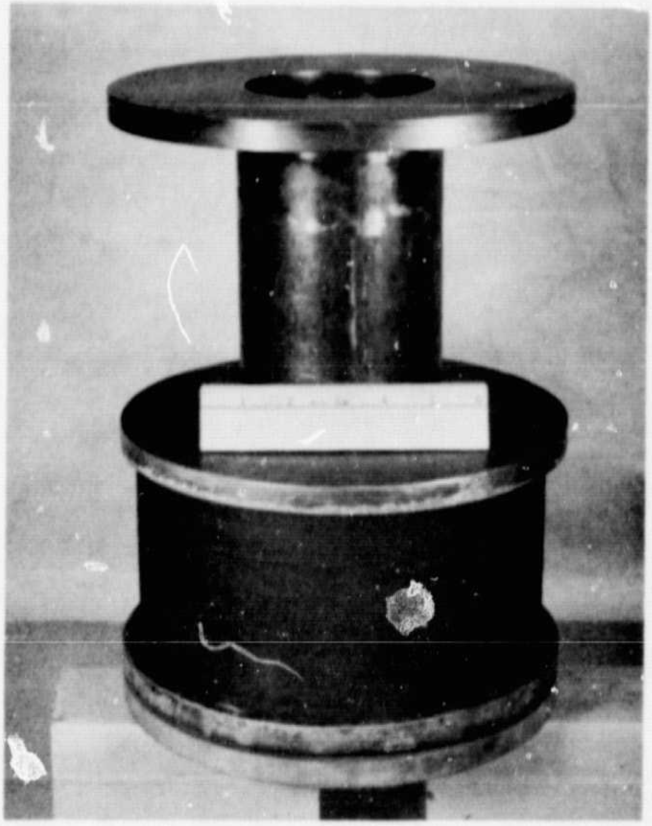
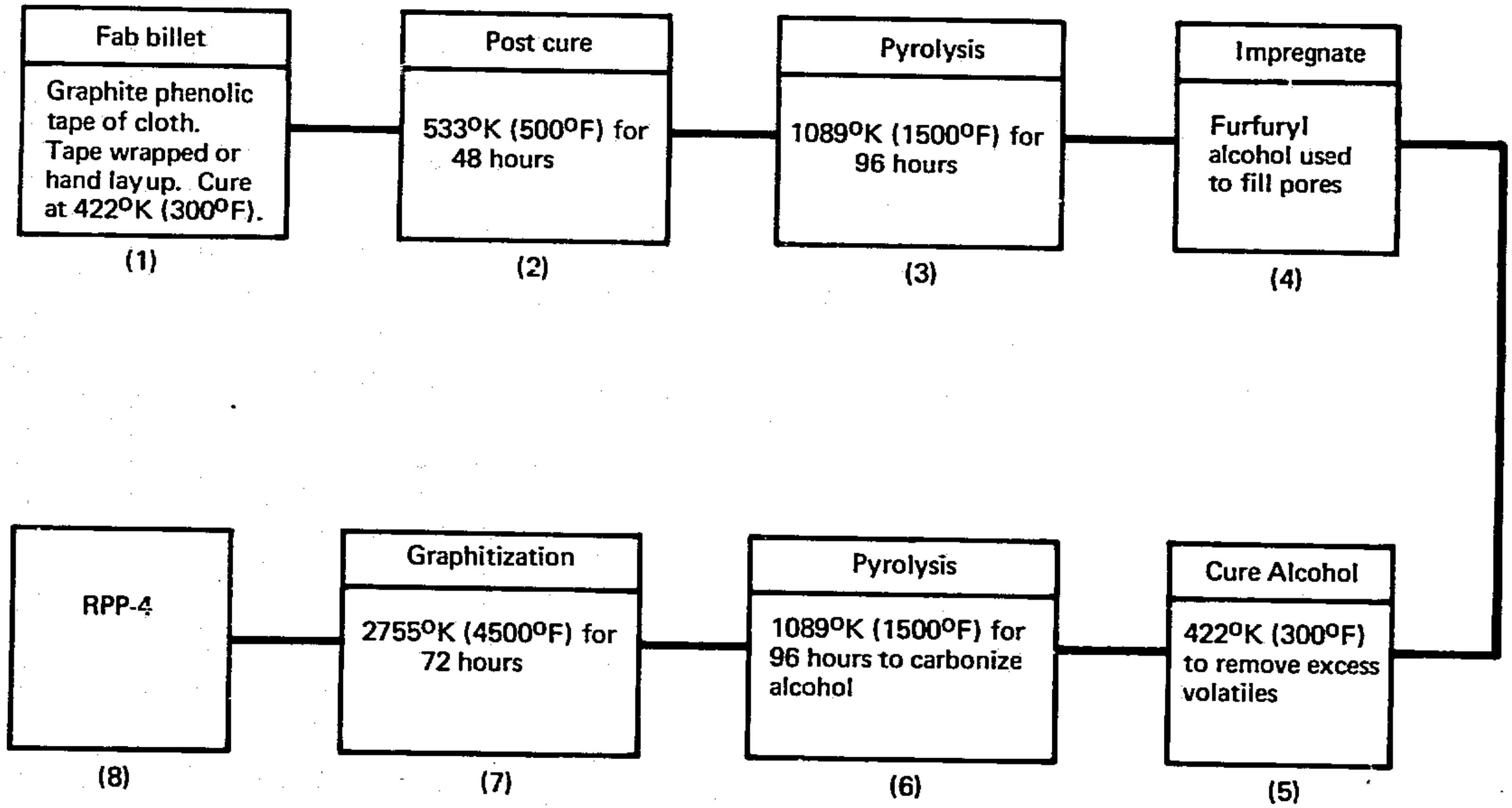


FIGURE 8. — ASSEMBLED BILLET MOLDING TOOL WITH BILLET IN PLACE



Steps 4, 5, and 6 performed 4 times to achieve desired density and strength

FIGURE 9. — PROCESS STEPS FOR RPP-4 CARBON CARBON MATERIAL

TABLE I. – X-259 EXIT CONE LINER EROSION AND CHAR MEASUREMENTS (ABLATIVE THROAT)

Distance from aft end of exit cone (meters)		Erosion depth (meters)		Char depth (meters)	
0	(0 in.)	1.27×10^{-3}	(.05 in.)	2.794×10^{-3}	(.11 in.)
.0127	(0.5)	2.032	(.08)	2.540	(.10)
.0254	(1.0)	2.032	(.08)	2.540	(.10)
.0381	(1.5)	2.540	(.10)	2.794	(.11)
.0508	(2.0)	2.794	(.11)	2.286	(.09)
.0635	(2.5)	2.540	(.10)	2.286	(.09)
.0762	(3.0)	2.540	(.10)	2.286	(.09)
.0889	(3.5)	2.286	(.09)	2.540	(.10)
.1016	(4.0)	2.540	(.10)	2.540	(.10)
.1143	(4.5)	2.794	(.11)	2.540	(.10)
.1270	(5.0)	3.302	(.13)	2.794	(.11)
.1397	(5.5)	3.302	(.13)	2.032	(.08)
.1524	(6.0)	3.302	(.13)	2.286	(.09)
.1651	(6.5)	3.810	(.15)	2.032	(.08)
.1778	(7.0)	4.064	(.16)	2.032	(.08)
.1905	(7.5)	4.318	(.17)	2.286	(.09)
.2032	(8.0)	4.318	(.17)	2.794	(.11)
.2159	(8.5)	4.318	(.17)	3.048	(.12)
.2286	(9.0)	4.318	(.17)	2.794	(.11)
.2413	(.95)	4.572	(.18)	2.286	(.09)
.2540	(10.0)	3.810	(.15)	2.794	(.11)
.2667	(10.5)	3.048	(.12)	3.302	(.13)
.2794	(11.0)	.508	(.02)	Char on carbon phenolic wrap could not be measured	
.2921	(11.5)	.762	(.03)		
.3048	(12.0)	.762	(.03)		
.3175	(12.5)	.762	(.03)		
.3302	(13.0)	1.016	(.04)		
.3429	(13.5)	.762	(.03)		
.3556	(14.0)	.762	(.03)		
.3683	(14.5)	.762	(.03)		
.3810	(15.0)	.762	(.03)		
.3937	(15.5)	.762	(.03)		
.4064	(16.0)	.508	(.02)		
.4191	(16.5)	.762	(.03)		
.4318	(17.0)	1.016	(.04)		
.4445	(17.5)	1.016	(.04)		
.4572	(18.0)	1.016	(.04)		
.4699	(18.5)	1.016	(.04)		
.4826	(19.0)	1.270	(.05)		
.4953	(19.5)	1.016	(.04)		
.5080	(20.0)	1.270	(.05)		
.5207	(20.5)	1.778	(.07)		
.5334	(21.0)	2.286	(.09)		
Throat insert interface		2.540	(.10)		

TABLE II. — X-259 THROAT INSERT EROSION AND CHAR MEASUREMENTS (ABLATIVE THROAT)

Distance measured from aft end of exit cone (meters)	Erosion (meters)		Char (meters)	
	Throat insert	Insert backup	Throat insert	Insert backup
.5461 (21.5 in.)	2.794×10^{-3} (.11 in.)		10.922×10^{-3} (.43 in.)	
.5525 (21.75)	3.048 (.12)		11.938 (.47)	
.5588 (22.0)	3.048 (.12)		11.684 (.46)	
.5652 (22.25)	3.048 (.12)		11.430 (.45)	
.5715 (22.5)	2.794 (.11)		11.430 (.45)	
.5779 (22.75)	2.540 (.10)		11.938 (.47)	
.5842 (23.0)	1.778 (.07)		12.954 (.51)	5.08×10^{-3} (.20 in.)
.5906 (23.25)	2.032 (.08)	$.508 \times 10^{-3}$ (.02 in.)	13.208 (.52)	6.096 (.24)
.5969 (23.5)	2.540 (.10)	.762 (.03)	11.684 (.46)	6.096 (.24)
.6033 (23.75)	3.810 (.15)	1.270 (.05)	12.446 (.49)	6.350 (.25)
.6096 (24.0)	4.318 (.17)	1.778 (.07)	13.208 (.52)	7.874 (.31)
.6160 (24.25)	5.588 (.22)	2.286 (.09)	15.240 (.60)	8.128 (.32)
.6223 (24.5)	7.620 (.30)	1.778 (.07)	14.986 (.59)	8.890 (.35)
.6287 (24.75)	8.890 (.35)	2.286 (.09)	14.478 (.57)	12.700 (.50)
To end	8.89–6.35 (.35–2.5)	2.286–6.35 (.09–.25)	9.906 (.39)	12.700 (.50)

TABLE III. – X-259 EXIT CONE LINER EROSION AND CHAR MEASUREMENTS (ATJ THROAT)

Distance measured from aft end of exit cone (meters)		Erosion depth (meters)		Char depth (meters)	
.0025	(0.1 in.)	3.81×10^{-3}	(.15 in.)	6.096×10^{-3}	(.24 in.)
.0127	(0.5)	2.54	(.10)	4.572	(.18)
.0254	(1.0)	2.794	(.11)	3.810	(.15)
.0381	(1.5)	3.048	(.12)	3.556	(.14)
.0508	(2.0)	4.064	(.16)	2.794	(.11)
.0635	(2.5)	4.318	(.17)	2.540	(.10)
.0762	(3.0)	4.064	(.16)	3.048	(.12)
.0889	(3.5)	4.318	(.17)	2.794	(.11)
.1016	(4.0)	4.572	(.18)	3.302	(.13)
.1143	(4.5)	4.064	(.16)	3.302	(.13)
.1270	(5.0)	2.794	(.11)	4.064	(.16)
.1397	(5.5)	1.270	(.05)	Char on graphite phenolic wrap could not be measured ↓	
.1524	(6.0)	1.270	(.05)		
.1651	(6.5)	1.016	(.04)		
.1778	(7.0)	1.270	(.05)		
.1905	(7.5)	1.270	(.05)		
.2032	(8.0)	1.270	(.05)		
.2159	(8.5)	1.524	(.06)		
.2286	(9.0)	1.524	(.06)		
.2413	(9.5)	1.016	(.04)		
.2540	(10.0)	1.270	(.05)		
.2667	(10.5)	1.270	(.05)		
.2794	(11.0)	1.016	(.04)		
.2921	(11.5)	1.016	(.04)		
.3048	(12.0)	1.016	(.04)		
.3175	(12.5)	1.016	(.04)		
.3302	(13.0)	1.270	(.05)		
.3429	(13.5)	1.270	(.05)		
.3556	(14.0)	1.270	(.05)		
.3683	(14.5)	1.016	(.04)		
.3810	(15.0)	1.270	(.05)		
.3937	(15.5)	1.270	(.05)		
.4064	(16.0)	2.032	(.08)		
.4191	(16.5)	1.270	(.05)		
.4318	(17.0)	2.032	(.08)		
.4445	(17.5)	2.286	(.09)		
.4572	(18.0)	2.540	(.10)		
.4699	(18.5)	2.794	(.11)		
.4826	(19.0)	3.302	(.13)		
.4953	(19.5)	3.302	(.13)		
.5080	(20.0)	1.270	(.05)		

TABLE IV. – X-259 THROAT INSERT EROSION AND CHAR MEASUREMENTS
(ATJ THROAT)

Distance measured from aft end of exit cone (meters)	Erosion (meters)		Char (meters)	
	Throat insert	Insert backup	Throat insert	Insert backup
.5461 (21.5 in.)	1.016×10^{-3} (.04 in.)			4.064×10^{-3} (.16 in.)
.5525 (21.75)	.508 (.02)			4.826 (.19)
.5588 (22.0)	— —			4.826 (.19)
.5652 (22.25)	— —			4.318 (.17)
.5715 (22.5)	.508 (.02)			4.318 (.17)
.5779 (22.75)	1.778 (.07)			4.826 (.19)
.6096 (24.0)	2.794 (.11)	1.27×10^{-3} (.05 in.)	3.81×10^{-3} (.15 in.)	6.096 (.24)
.6160 (24.25)	4.318 (.17)	7.366 (.29)	2.032 (.08)	7.366 (.29)
.5969 (23.5)	5.588 (.22)	9.652 (.38)	1.524 (.06)	8.382 (.33)
.6033 (23.75)	6.096 (.24)	11.684 (.46)	11.684 (.46)	9.652 (.38)
.6096 (24.0)	7.112 (.28)	14.478 (.57)	7.874 (.31)	— —
To end	7.112–12.7 (.28–.5)	14.478–12.7 (.57–.5)	3.810 (.15)	— —

TABLE V. – MAXIMUM NOZZLE STRESSES AT 26 SECONDS

Nozzle with carbon phenolic overwrap

Direction	Insert		Overwrap		Carbon phenolic aft of throat insert	
	Max stress – N/m^2		Max stress – N/m^2		Max stress – N/m^2	
Radial	-8.67×10^6	(–1259 psi)	-29.06×10^6	(–4218 psi)	-23.98×10^6	(–3480 psi)
	.32	(+46)	32.76	(+4755)	32.23	(+4678)
Axial	–13.25	(–1923)	–15.71	(–2280)	–26.29	(–3816)
	3.54	(+514)	19.88	(+2886)	38.04	(+5521)
Hoop	–15.49	(–2248)	–19.51	(–2832)	–14.39	(–2088)
	5.35	(+776)	18.38	(+2668)		
Bondline shear	3.86	(560)	NA		NA	

Nozzle with silica phenolic overwrap

Direction	Insert		Overwrap		Carbon phenolic aft of throat insert	
Radial	-11.12×10^6	(–1614 psi)	-41.63×10^6	(–6042 psi)	-8.14×10^6	(–1182 psi)
	8.22	(+1193)	75.97	(+11026)		
Axial	–47.11	(–6837)	–78.13	(–11339)	–25.98	(–3771)
	10.69	(+1552)	88.88	(+12900)		
Hoop	–26.81	(–3891)	–95.03	(–13792)	–20.08	(–2915)
	7.30	(+1060)	106.48	(+15454)		
Bondline shear	33.07	(+4800)				

TABLE VI. – TAG END SPECIMEN TEST RESULTS

Component	Property			
	Specific gravity	Interlaminer shear, N/m^2	Acetone extraction %	Volatile content %
Throat insert				
MXG-175	1.4	14.89×10^6 (2191 psi)	0.32	NA
FM-5014	1.41	15.6×10^6 (2297 psi)	0.19	NA
Throat backup				
MX-4926	NA	NA	0.05	NA
MX-2600	NA	NA	0.09	NA
Throat extension				
MX-4926	1.47	NA	0.27	2.8
FM-5072LD	1.31	NA	0.48	1.41
Exit cone insulation				
FM-5525	1.83	NA	0.31	2.0
FM-5272	1.33	NA	0.43	1.47

REFERENCES

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2. VSD Report 23.546, X-259 Test Nozzle Examination, 20 February 1973.

3. Design Information Release 23-DIR-1325, Preliminary Thermal Analysis for Scout Improved Nozzle Materials, 14 January 1972.