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TECHNICAL REPORT RK-CR-80-2

METHODOLOGY FOR PRODUCING LOW COST/ DISPOSABLE MANDRELS

FINAL REPORT

Thiokol Corporation
Huntsville Division
Huntsville, Alabama

FOR

Propulsion Directorate
US Army Missile Laboratory

December 1979

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

Approved for Public Release; Distribution Unlimited.

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This report describes work accomplished during a program to develop manufacturing methods and technology required to reduce the cost of batch processing of small, high production motors such as SEAS, Viper, and FFR by using disposable (low cost throw-away) casting fixtures using quick cure HTPB propellant.

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FOREWORD

This program was conducted by Thiokol Corporation under Contract DAAK40-77-C-0009 for the U. S. Army Missile Command, Propulsion Directorate, Redstone Arsenal, Alabama.

Thiokol Control No. U-79-03 has been assigned to this report. The report contains no classified information.

Mr. G. F. Mangum served as Project Director, and Mr. G. E. Webb as Program Manager.

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FINAL REPORT

INTRODUCTION

Objective

The overall program objective was to develop the manufacturing methods and technology (MM&T) which is required to reduce the cost of batch processing of small high production motors such as SEAS, 2.75", Viper and Free Flight Rockets by the use of disposable (low cost throw-away) casting fixtures using quick cure HTPB propellant.

Background

The program was implemented in November 1976 in the following two major phases of technical effort:

Phase I - Basic Effort (Estimated Cost Savings using Disposable Casting Fixtures)

Phase II - Option I. (Simulated Production Feasibility Production Run)

By the end of 1977, comprehensive process engineering studies had been made to determine the recurring and nonrecurring costs associated with manufacturing 2.75-inch SEAS and Viper type rocket motors using both conventional reusable metal mandrels and disposable (throw-away) plastic mandrels. In addition, extensive evaluations of candidate mandrel plastic materials as to cost, fabrication techniques, structural characteristics, compatibility with propellant, and dimensional control had been conducted. The results of these studies and evaluations led to the following conclusions:

1. The cost of using the conventional reusable metal mandrel concept in SEAS and Viper motor applications is lower than the cost of using a throw-away disposable mandrel.

2. Based on the wealth of material technical data and cost information generated, there were indications of cost benefits of using "foamed" leave-in-place disposable mandrels in other motors.

These conclusions prompted Thiokol to recommend that the subject program be redirected to the development of foamed mandrels for FFR-type motor applications. The program was redirected by the Army (Mod P0002 to Contract DAAK40-77-C-0009); this final report covers accomplishments under both the original contract scope of work and under the revised program.

ACCOMPLISHMENTS

Original Scope of Work (Nov. 76 thru Apr. 78)

Basic Effort

The basic program involved the following major tasks:

(1) Evaluation and selection of candidate disposable mandrel materials (including coatings and release agents) for use in SEAS and Viper motors,

(2) Validation of physical properties and formability of prime candidate materials,

(3) Laboratory compatibility testing of selected candidate materials (compatibility of mandrel materials/release agents/coatings/propellant),

(4) Pull tests of candidate mandrels (with various materials/release agents and coatings),

(5) Selection of a cost saving disposable mandrel casting fixture approach and establishment of recurring/nonrecurring costs of disposable versus reusable casting techniques,

(6) Loading of prototype motors (SEAS or Viper to be selected) using disposable mandrel concept, and

(7) Delivery of prototype motors to MIRADCOM for testing.

As pointed out in the Background section of this report, the conventional reusable metal mandrel concept for SEAS and Viper size motors proved to be the lower cost casting approach than the disposable mandrel concept. The program was then redirected to evaluate the foamed leave-in-place disposable mandrel concept for larger motors, such as free flight rockets, and Tasks 6 and 7 above were not conducted. The results of the original program effort are discussed in the following sections.

Materials Selection

Two categories of materials were investigated for evaluation during the program; one, mold release agents for a disposable mandrel; and the other, materials for the mandrel itself. Each category of materials is discussed separately.

Release Agents

The following mold release agents were purchased for testing to determine compatibility with propellant and mandrel materials as well as releasing qualities.

Material/Description	Manufacturer
MS-122 fluorocarbon, dry lubricant in aerosol spray can	Miller Stephenson Chemical Co. Chicago, Ill.
Durafilm CTF, compound TFE finish in aerosol spray can	American Durafilm Co. Newton Lower Falls, Mass.
Poly-Lease 77 mold release, in aerosol spray can	Allied Chemical Corp., Plastics Div., Morristown, N.J.
Floro-Glide, air dried Teflon in aerosol spray can	Aetna Plastics Corp. Cleveland, Ohio
6075 Dry Fluorocarbon, lubricant and release agent in aerosol spray can	Crown Industrial Plastics Co.

A number of the spray-on mold release agents were subjected to exploratory evaluation tests using already available ambient cure HTPB propellant and polyurethane foam which were residual from another program. The tests were conducted by coating flat polyurethane foam samples with the release agents (using recommended manufacturer's procedures), casting cylinders of propellant against the coated samples, and, after propellant cure, conducting bond tests. Rather than acting as parting agents, the materials gave bond strengths in the order of 30 to 80 psi, as can be seen from data given in Table 1.

Application of the release agents using manufacturer's recommended procedures resulted in coatings which were too thin and ineffective. Four materials (those listed first in Table 1) did appear to offer the most promise as mold release agents. Although high adhesion values were obtained with these four materials, failure did occur at the propellant-to-plastic bond line. Use of thicker coatings of the agents was explored during evaluation of the candidate mandrel materials. Further discussion of the release agent evaluation is included in the writings on mandrel material evaluation which follow.

Mandrel Materials

One of the most important initial program tasks was to select candidate materials for use in mandrels (cores) for the SEAS and Viper motors.

General

Engineering data collection and compilation, begun during the precontract phase, was expanded to provide a comprehensive base of preliminary materials selection. The broad array of material candidates has been subsequently narrowed to 9 polymeric and 2 metallic primary candidates shown in Table 2. The criteria for this preliminary screening, in order of importance, were:

1. Expected chemical resistance
   a. General compatibility with propellant ingredients and processing parameters.
   b. General compatibility with most (candidate) barrier coatings and/or release agents.

2. Processability cost

3. Material cost

The materials with the best design critical mechanical properties, physical-chemical properties, and costs are reported by rank in Tables 3 through 13. Two modifications of the basic thermoplastic polymers are state-of-the-art technology and can improve performance and/or economy:

1. Addition of glass fibers

2. Structural foam molding

Examples of both types of modified material and one glass-filled, structural foamed specie are characterized in the Tables. Properties and cost effectivity of each polymer modified with glass fiber content or foamed can be reliably predicted, and were considered as indicated.

Cost Considerations

Material Costs - Basic material cost was a prime consideration for selection of a cost effective, disposable unit design. If several materials possess similar performance properties required by the application and have similar processing/manufacturing costs, then the one(s) with lowest material cost per unit volume ($/in.^{3}) rather than cost per unit weight ($/lb.) is clearly the choice.

However, the material with the advantage in cost per unit volume may lose this advantage when traded against a more costly, but higher performing (e.g. stronger) material which requires a proportionately smaller section size. This in turn can reduce the overall material amount and cost. The recent advent of thin wall zinc alloy die casting illustrates such a case.[1] Not only has material amount decreased with a corresponding increase in mechanical properties, implying also better achievable tolerance control, but casting time in terms of solidification rate has also decreased. The payoff involves manufacturing capability and cost trades. Need and costs of any indicated coatings must be added as required to determine overall cost effectivity. Prices (1976 dollars) per unit weight ($/lb.) and per unit volume ($/in.^{3}) are shown in Table 13.

Fabrication Costs - It can be expected that the best opportunity for utilization of cost competitive material(s) will be realized in the prudent selection of the manufacturing process(es). Zinc and magnesium are primarily die casting technique studies. The polymeric materials are economically fabricated in the following ways:

Method	Abbreviation
Injection Mold	I
Compression/Transfer Mold	C/T
Extrusion/Injection Blow Mold	E/IB
Structural Foam Mold	SF
Pour Cast/Reaction Injection Mold	PC/RIF
Extrusion Mold	E
Case	C

Materials Properties Validation

A candidate material must be relatively "low cost" in order to be a viable competitor for a throw-away design application. It follows then that those materials with best potential will be those widely used in many industries, over a substantial time frame, and therefore possess well characterized properties. This was true of the eleven classes of candidates evaluated.

1. Reference "Materials Engineering", March, 1977, Page 3.

Verification of the mechanical and physical properties of these materials by testing was not necessary for the following reasons:

1. A voluminous body of data exists in handbooks, government and industry specifications, technical reports, and supplier literature which sufficiently characterizes all candidates. The data from these numerous sources is in good agreement. These sources of materials are:

   Handbook Data

   A. 76-77 Modern Plastics Encyclopedia and Engineering Data Bank, McGraw-Hill.
   B. User's Practical Selection Handbook for Optimum Plastics, Rubbers and Adhesives, International Technical Institute, 1976.
   C. Materials Selector 77, November, 1976, Penton/PC Reinhold Publishing Co., Inc.
   D. Corporate Design Standards Manuals, D-5000, The Boeing Company, 1970.

   Product Specifications

   General Electric, E. I. DuPont de Nemours, Celanese, Borg-Warner, Stepan Chemical, Fiberite, CPR Div. of Upjohn, Union Carbide, American Cyanamid, Fiberfil Div. of Dart Industries, Morrison Molded Fiberglass, Haveg Industries, Hercules, Owens Corning Fiberglass, AKSO Plastics Div. B. F., Mobay Chemical, Eastman Chemical, Shell, GAF, and Thiokol.

2. Some small differences were expected in the as-fabricated components versus test specimen values due to inherent effects of the selected processing method(s), and influence of processing parameters.

3. There are small differences between various products of the same generic material.

Laboratory Testing of Candidate Materials

Samples of seven of the eleven candidate mandrel materials listed in Table 2 were ordered, in sheet form, for easy use for laboratory determinations of: (1) propellant bond compatibility, (2) absorption of plasticizer/NHC (as contained in Viper propellant), (3) release agent coating compatibility, and (4) barrier requirements and compatibility. The seven materials were:

Polyethylene - High Density

Polypropylene

Polycarbonate (Lexan - Merlon)

Polyphenylene Oxide (Noryl)

Acetal (Celcon or Delrin)

Phenolic (G - 10)

Nylon

Figure 2 is a block diagram of tests conducted to evaluate the candidate materials (mandrel/release agents/barriers). Preliminary screening of these materials was conducted to determine their compatibility with various materials such as DOA plasticizer, NHC and IPDI was also evaluated with various mandrel coating materials and mold releases. The results of these tests are shown in Table 14. In addition to the absorption test, tensile test specimens were made to verify the physical properties of the mandrel materials. Table 15 summarizes the results of these tests. Tensile stress ranged from 3,301 psi at ambient temperature for polyethylene to over 10,000 psi for acetal and ambient strain from 4.2% for polycarbonate to 31.4% for nylon.

The results of all preliminary screening tests of candidate materials are given in Tables 16 and 17 for 2.75 inch SEAS and Viper motors, respectively. From this evaluation, the mandrel materials and mold releases selected for additional evaluation for the 2.75-inch motor propellant and the Viper propellant. Conclusions drawn from the data were:

1. The MS-122 silicone release agent provided the lowest adhesion values.

2. The absorption of NHC (or DOA) for all the polymeric candidate core materials was lower than the maximum 0.5% limit set in a prior study. The tests showed that high density polyethylene, the container material used to ship the NHC burning rate catalyst, was the highest (0.3%) of the seven materials evaluated.

3. Uncoated nylon, polyethylene, polypropylene, and release coated phenolic showed the lowest adhesion to the two propellants.

The mandrel materials selected for the 2.75-inch program propellant were polypropylene, nylon, and a material not tested in this plan, PTMTN/

PBT polyester. The mold releases selected were MS-122 with all mandrel materials and Crown 6075 with the nylon mandrel. These selections were based upon mandrel materials physical properties, cost and absorption properties. The mold release was selected for its low bond strength to propellant and absorption properties.

The mandrel materials selected for the Viper propellant were G-10 phenolic and melamine. The melamine was not evaluated in this series of tests. The mold release selected was MS-122. The reasons for selecting these materials were the same as above.

Mandrel Pull Tests

The next step in evaluating candidate materials for disposable mandrels was to fabricate mandrels and use them in actual SEAS and Viper motor loadings. The force (lbs/in^2 of propellant surface) required to extract the mandrels would be a good indication of their suitability. Considerable problems were encountered in finding a plastics vendor interested in manufacturing the needed 1.5-inch diameter cores for use in the mandrel pull tests. However, a vendor was located and given an order for the following injection molded cores shown in Figure 3 (Drawing R55222):

Quantity	Material	Drawing
50	Nylon	R-55222-basic
50	Polyester	R-55222-1
50	Phenolic	R-55222-2
50	Polyisoprene	R-55222-3

Figure 4 (R55232) is a drawing of the core assembled to a 2-inch x 4-inch ballistic test motor (TX-395) which will be used as the test vehicle for determining the pull loads required to remove the cores of various materials coated with release agents and without release agents. A plan for the mandrel pull tests is shown in Table 18.

A series of measurements of the TX-395 prototype core mandrels was taken. Sixteen specimens of each of the four different materials (nylon, polyester, phenolic, and polypropylene) were measured in triplicate for length, outside diameter at three locations, and inside diameter at one location, 1.6 inches from the aft end. A second short series of referee measurements was taken as an independent check using different techniques and personnel. Differences between the two series were relatively small. The results are summarized in Table 19.

As an evaluation of the co-dependent effects of core mandrel versus propellant physical properties and dimensional variability, another series of measurements is scheduled following determination of the core extraction forces. The cast and cured TX-395 motors, both HTPB-carborane (Viper) and the unmodified HTPB (SEAS) propellants, were measured for propellant bore and diameter at three locations, 0^{o} and 90^{o} apart. The corresponding core mandrel was likewise measured, and compared to determine variability in bore dimensions, and correlated with the extraction pull forces. Teflon-coated steel cores were used as standard comparison mandrels.

A corresponding set of dimensions was taken of the part injection molding die. These numbers were compared with the averages and extremes to determine the typical mold shrinkage values and part-to-part variability for cores of each material. A photograph of the die is shown in Figure 5.

A comparison of the die dimensions and the corresponding average part dimension is shown in Table 20. The results show that part variability from the die dimensions was relatively consistent and generally about - 1.5% for all materials which is similar to published values.* The phenolic parts exhibited the lowest shrinkage, as expected, and the most isotropic behavior of that property while the other three materials exhibited higher shrinkage through the part thickness.

The ultimate usability of these parts/materials as injection molded was determined from (1) the data acquired from the comparison of propellant bore dimensions with corresponding individual cores, and (2) the SEAS ballistic/derived propellant geometry requirements.

Three one-gallon propellant mixes were made to load TX-395 motors using both plastic cores and, for comparison standards, Teflon-coated steel cores. A total of twelve motors was cast with TP-H8248 (Viper) propellant; four each with Teflon-coated steel cores, four each with Teflon-coated steel cores sprayed with IMS silicone release agent, and four each with phenolic cores sprayed with MS-122 release agent. Twenty-four motors were cast with DTS-8338 (SEAS-type) propellant from two mixes: four each with Teflon-coated steel cores, three each with polypropylene cores, four each with polypropylene cores sprayed with MS-122, three each with nylon cores, four each with nylon cores sprayed with MS-122, three each with PTMT cores, and three each with PTMT cores sprayed with MS-122. Figure 6 shows a number of the cores for the SEAS propellant mixes prior to insertion. Figures 7 and 8 show a typical plastic core (PTMT) ready for insertion into a cast motor assembly. Figure 9 shows the same assembly with the core inserted into it.

After the motors were cured, arrangements were made to pull the cores using a strain gage load cell and recorder to record the force-time profile required to pull them. It had been intended to do the core pulling in a remotely-operable Instron testing machine, using a constant cross-head speed. Further evaluation of this operation indicated that it would be extremely difficult and expensive to provide a means of sufficiently restraining the motor assembly to meet safety requirements.

*"User's Practical Selection Handbook for Optimum Plastics, Rubbers, and Adhesives," ITI, 1976.

Core pulling was therefore done in the standard small motor core pulling machine. This unit uses a long-stroke hydraulic cylinder to apply force to the core. The force is controlled in magnitude by controlling the hydraulic pressure. The velocity of core removal is virtually uncontrolled. The motor assembly is clamped in a restraining chock, and the piston rod assembly lowered to the level of the core cap. An engagement wrench mounted on the end of the rod connects to the pins on the core cap. When the rod is retracted, the wrench pulls on the core cap to pull the core out of the motor assembly.

A strain-gage load cell was provided with approximate fittings to allow its insertion between the rod and the extraction wrench. The cell was excited by a remotely located bridge supply/amplifier connected to a linear strip chart recorder. Initially, a 500 pound cell, calibrated to give one inch displacement for 50 pounds of load, was used. Subsequently, a 1000 pound cell, calibrated for 100 pounds per inch of chart displacement, had to be used. Figure 10 shows a motor clamped in the securement chocks, and the core pulling equipment attached to the core cap. The strain gage load cell is shown in the upper center, with its signal cable running off to the left. Figure 11 shows a core (PTMT with MS-122 release agent) suspended above the motor immediately after core removal.

Table 21 gives the conditions and results for the core pulling operations in detail, including visual inspection of the cores and propellant surfaces after disassembly. Table 22 summarizes the data, along with comments on the suitability of the motors for static test.

Several items in the tables warrant further comment. The use of IMS release agent spray over Teflon-coated metal mandrels for the Viper propellant had been recommended by MICOM. A significant reduction in pulling forces had been expected, but not quite as dramatic a reduction as actually experienced. It leads to the question of how effective the IMS spray would be on plastic cores. The MS-122 silicone release agent spray significantly reduced the pulling forces involved for all three of the plastic cores used with the SEAS-type propellant. However, it did not prevent adhesion of the propellant to the nylon cores, and the subsequent damage to the propellant grains. The fact that both the cores and the grains had sticky surfaces leads to the conclusion that the nylon itself interfered with the cure of the propellant binder system. The PTMT cores are marginally satisfactory <u>if</u> coated with a suitable mold release agent; the relatively high pulling forces with MS-122 are not that different from those for polypropylene, with or without the MS-122 release agent. One of the PTMT cores split open during propellant cure, indicating possibly less than satisfactory physical characteristics.

TX395 motors from the three propellant mixes (16Q-607, 16Q-609, and 16Q-610) were static tested to determine if there are differences in ignition or motor ballistic performance due to differences in mandrel materials and release agents used in casting the motors. Data from the tests are tabulated in Table 22 and pressure versus time traces for the 25 tests are given in Figures 12 through 17. All motors were fired on the same day at conditions as identical as possible.

Examination of the data in Table 22 for motors containing SEAS-type propellant shows no significant differences in operation caused by the use of different mandrel materials. The small differences observed in ballistic parameters are within expected normal variations. However, data from motors containing Viper propellant tell quite another story. These motors cast using phenolic mandrels coated with MS-122 release agent (the only combination which appeared to be usable in earlier screening tests) had twice the delay times as those motors cast with either coated or uncoated metal mandrels. Also, ignition rise rates were lower. Thus, there must have been some interaction between the release agent/mandrel material and the Viper propellant that affected ignition of the motor. Such an interaction is unacceptable and would preclude the use of plastic mandrels/release agents for motors containing Viper propellant.

Photographs were taken of the TX395 propellant grain surfaces and corresponding plastic mandrels before the above discussed ballistic tests were made. Figures 18 through 34 are these photographs. Those motors for which the mandrel pull load was low had the highest quality surface whereas those motors requiring high pull loads had scratched and torn surfaces. Comparison of the photographs with pull load data given in Table 21 will confirm this statement.

Summary of Materials Selection Effort

The econometrics and engineering parameters for seven primary mandrel manufacturing methods were evaluated in order to determine the cost of a single-use disposable mandrel for SEAS and Viper motors. An overview of the mandrel manufacturing methods survey is given in Figure 35.

In conducting the study, which led to the mandrel cost estimate, full advantage was taken of the prototype mandrel/motor experimental work described previously. Briefly, four candidate disposable materials were fabricated into 1.5 x 5 inch motor core mandrels, and 40 motors cast of 2 varieties and 4 lots of propellant compositions. By taking an array of measurements of TFE coated steel baseline cores and the four types of plastic cores, comparisons were first made with the mold and part shrinkage determined. From measurements of the cores, 16 units of each material and of the motor base (I. D.), the part variability was established. An overview of the measurement survey is depicted in Figure 36. The results are summarized in Table 23.

The cost information from suppliers of seven various fabrication methods was compiled for a comprehensive unit production cost estimate.

Where vendor (jobber/supplier) quotes were not attainable or not solicited, engineering estimates of production unit costs were made.

From the detailed investigation of materials, manufacturing feasibility, and costs, it is concluded that a satisfactory single-use disposable mandrel could be fabricated from a polypropylene material by a melt processable structural foam process for the SEAS motor. The full acceptability of the unit is still contingent upon a complete assessment of the motor ballistic envelope as influenced by part dimensional variability. This core mandrel would cost between $0.80 and $0.90* per unit in minimum lots of 600,000.

The VIPER core was not found to be producible by any of the high volume production methods investigated. The primary reasons being the requirement for close dimensional control, and inherent problem of removal of a cast or molded part from a die/mold which allows no draft. Only extensive redesign of the core or investment of point development has any prospects for fabrication of a high production core in the $1.00 copy range; and this is not competitive with a conventional reusable approach.

The above mandrel cost estimates are based on extensive evaluation of the seven mandrel manufacturing methods (see Figure 35). Detailed discussions of the methods and associated materials are given below. The methods are numbered 1 through 7 for convenience - the numbering does not indicate preference.

1. Melt Processable Structural Foam

Jobber Response

Written replies were received from two (2) of the ten (10) jobbers who were furnished a copy of drawing R55237 for the 2.75 SEAS core (Figure 37). Research on the capability of the process indicated that the VIPER core could not be manufactured by this method for reasons of dimensional producibility and part strippability. This conclusion was confirmed in discussions with the various jobbers. The VIPER core was dropped from further consideration.

Part Tolerances

The tolerances obtainable by structural foaming of a thermoplastic were acquired during conversations with four (4) of the jobbers solicited. In general, ± 0.010 inch/inch of length is standard in the industry.[1]

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* These and other costs given in the report are vendor prices unless otherwise stated. Cost of quality control, overhead, or other normal material burdens would have to be added to the vendor price to get the total unit cost.

1 American Plastics, Inc. and S. F. Plastics, Inc. claim 0.010 in/in on production part tolerance.

However, one of the two (2) companies submitting a final reply claimed parts would be fabricated at ± 0.001 inch/inch of length, but at a much higher cost. The other company furnished the table of information requested in the solicitation. That data is shown in Table 24.

TABLE 24

PRODUCTION TOLERANCES OBTAINABLE ON DRAWING R55237

Material	Tolerance (In or In/Length)		
	2.036 Dia.	Straightness	0.842 Dia.
Nylon	± 0.010	± 0.10	± 0.005
Polyester	± 0.010	± 0.15	± 0.005
Poly Propylene, filled	± 0.015	± 0.20	± 0.010
Poly Propylene, unfilled	± 0.020	± 0.25	± 0.015

Production Cost Estimates

The two responders to the cost and technical inquiry are identified in Table 25. Shown in the table are also the quotes and lot sizes for production unit cost and tooling for four different materials.

The difference in cost between the two quotes has reasonable explanation. First, the STRUCTO-PLAST approach put a premium on the past dimensional variability. Second, STRUCTO-PLAST did not invest in as much tooling as AMOS Molded Plastics ($24K vs $98.5K) and this difference is reflected in the number of mold cavities which drives molding costs. Third, STRUCTO-PLAST proposed to mold the component from two halves, joined; AMOS proposed to mold the part in a single shot. They also recommended the unfilled polypropylene from a moldability standpoint. Glass fillers normally induce part warping or imperfect distribution of the fill material during flow or solidification.

Conclusions on the Study of Melt Processable Structural Foam (MPFS) Processing Method

Although written replies were received from two of the ten jobbers solicited, four others discussed at length our requirements and their approaches to production of the 2.75 motor core: Jamison Plastics Corp., The Valspar Corp. S. F. Plastics, Inc., and American Plastics, Inc. These three seemed knowledgeable, and interested in providing information, however, it is presumed that the heavy work load experienced across the plastics industry inhibited a response, especially from the smaller jobber. AMOS appears to have the most knowledge and capability in the processes and the materials. AMOS also showed special consideration by paying a visit with a sales representative and manufacturing engineer to discuss the program.

A MPSF polypropylene core appears to be the best competitor for the reusable approach to 2.75 motor core fabrication. In our judgment, the 0.80 to 0.90 $/unit production cost is creditable. The only uncertainty remaining is whether the part dimensional variability is acceptable for the motor ballistic requirements.

2. Zinc Die Casting

General

The low cost per pound of a zinc die casting alloy ($0.38)[1] made it an obvious candidate for single-use cores, especially with the advent of the thin-wall (<0.040 inch) casting techniques. The cost and performance benefits of this automated process over conventional die casting are:

a. Material strength is higher due to higher "skin"-to-wall thickness ratio, see Figure 38. (The "skin" has a finer grain, higher density in die casting fabrication).

b. Less material is required (wall thickness of 0.012 inch is feasible).

c. Production rates are higher with thinner part wall, see Table 26.

d. Improved fracture resistance.

e. On an energy requirement consideration, either by weight or volume, zinc alloys are less reliant on energy availability than most materials, see Figures 39 and 40.

The basic dimensional tolerances achievable with zinc die casting are closer than for aluminum or copper alloys, and possibly suitable in the as-cast condition for even the requirements of the Viper core[2].

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(1) "American Metal Market/Metalworking News Edition", August 8, 1977.
(2) Metals Handbook, Volume 5, Forging and Casting, page 446-7.

Jobber Response

Replies were received from six (6) of the eight (8) jobbers who were furnished a copy of drawing R54509 for 2.75 core (Figure 41) and R54886 (Figure 42) for the VIPER core. All eight (8) had expressed interest in supplying information upon the initial telephone contact. No attempt was made to follow up and clarify reasons for no response from the two (2) who did not reply.

Part Tolerances

The critical tolerances obtainable by S.O.A. zinc die casting were computed as follows:

for R54509 (2.75)

L = 29.65	D = 2.036	D = 0.842
± 0.025 inch	± 0.003	± 0.001

plus allowance
for 1° DRAFT = 0.51 inch

The tolerances appear acceptable for a 2.75 class motor, excepting the 1° draft requirement. However, it may be feasible to design a ballistically acceptable grain with a 1° taper to permit a one-piece core approach.

The other alternative is to die cast the mandrel in two longitudinal halves, and accept an additional (undetermined at this time) cost for joining.

ROM Cost Analysis

Cost/unit ($) = material + casting and finishing + miscellaneous

Materials = weight x cost/pound

Weight_A = density x volume_A

= 0.24 [(2.0)(0.5)(29.65)] - [(1.8)(0.3)(29.55)]

= 3.29 lb.

Weight_B = 0.24 [(2.0)(0.5)(29.65)] - [(1.9)(0.4)(29.60)]

= 1.72 lb

Materials_A = weight x cost (1)/pound

= (3.29)(0.35)

(1) American Metals Market, 78 Jan. 23

$= 1.15$

$\text{Materials}_B = (1.72)(\$0.35)$

$= \$0.60$

Casting and finishing = Total Mfg. cost x inflation factor

$= (\$0.175)^{1} (2.0)$

Miscellaneous = Amortized tooling

$= \$0.10$

$\text{Cost/unit}_A = \$1.15 + \$0.35 + \$0.10$

$= \$1.50$

$B = \$0.60 + \$0.35 + \$0.10$

$= \$1.05$

$\text{Cost/unit}_B = \$0.60 + \frac{\$0.35}{2}^{2\ 3} + \$0.10$

$= \$0.88$

An updated summary of replies from the die casting jobbers who were solicited is contained in Table 27.

Conclusions on the Study of Zinc Die Casting Processing Method

Although two jobbers expressed an interest in pursuit of a two-part core for the 2.75 motor meeting the dimensional requirements, the potential cost benefit does not appear competitive with the reusable baseline costs. Therefore, no further investigation was undertaken.

3. Compression, Transfer, or Injection Molded Thermosets

Jobber Response

No jobbers were solicited for cost estimates, design advice, or manufacturing information on this method of production of cores for the 2.75 motor. However, the engineering concept drawing was prepared, R55284, and is shown in Figure 43. The VIPER core was precluded from consideration because of problems of removal from a mold, dimensional tolerances, or the complexity of molding and joining multi-segments.

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1 Metals Handbook, 8th Edition, Vol. 5, Page 312, Example No. 372, 1 cavity die, 80 shots/hour.

2 Assuming equipment size available to cast in a 2 cavity die.

3 Does not include cost for joining of a two-piece design.

A list of 11 commercial and military/government thermoset plastic hardware producers was prepared and is shown in Table 28. Kurz-Kasch, Inc. and Tri-Cities Manufacturing and Engineering were contacted by phone concerning the project. Both companies furnished advice for the concept drawing and expressed willingness to supply production cost estimates.

Reasons for not continuing investigation of cost quotes were based on a brief engineering cost study of the process for six generic classes of candidate materials. The results are discussed and summarized in the following material.

Part Tolerances

Material mold shrinkage largely controls the part dimensional variability. Data for this characteristic are available in various sources of open literature, and is shown to be between 0.003 in/in for polyester and 0.010 in/in for melamines and ureas.

From the comparison of extensive measurements of the R55222 (TX395 Prototype) cores and the bore I.D.'s of the part die (Table 20), the actual shrinkage achieved in the part was calculated. Values are in close agreement with published numbers except for the G. P. phenolic which was higher by a factor of about 2.0 (0.6% in the literature, 1.2% actual).

The part-to-part variability within a material class proved to be about ± 0.17% for the G. P. phenolic to about 0.57% for the polypropylene and polyester. Nylon and steel cores varied about ± 0.3% on the O.D.

Based on the measured variability of the R55222 prototype cores, the predicted critical as-molded tolerances in inches for an injection molded 2.75 core (R55284) in G. P. phenolic would be as follows: 2.036 ± 0.003, 29.65 ± 0.050, and 0.842 ± 0.001. Prototype core straightness could not be adequately determined without costly procedures, so no values were predicted for the 2.75 core. However, our experience with molded phenolics indicates that warpage can be worked out acceptably in development and controlled during production.

ROM Cost Analysis

Table 29 shows the costs of materials as \$/lb, \$/in^3, and \$/part based on a computed 2.54 core (R55284) part volume of 15 in^3, assuming an average part wall thickness of 0.10 inch. Polypropylene is shown for reference purposes since it showed well in the prototype motor casting and extraction experimental work. The phenolics show the best material cost advantage and are known to process economically. Data should be examined for the unsaturated polyester since process economy indicates it can be better than phenolic. However, the data are scarce and must be acquired by speciality jobbers.

Finished part cost is most dependent on processing. Material costs of thermosets most often are less than those for the thermoplastic they are competing with. However, thermoplastics end up being cheaper because their molding, secondary finishing and scrap costs are less. In addition, thermoplastics usually have a lower specific gravity, narrowing the material cost on a volume basis.

Next to material costs, molding is the next highest part of the total cost. This is the reason that injection molding of thermosets can swing the balance in their favor. Not only can thermosets be injection molded, but they can be processed by this method at a speed comparable to thermoplastics. To determine the exact speed with which each process, cure time of thermosets needs to be compared with cooling time for thermoplastics. Whereas a thermoplastic such as nylon 6/6 requires 30 sec per 0.125-in. (3.22-mm) thickness, a thermoset polyester part 0.25 in. (6.4 mm) will cure in about 40 sec.[1]

For a comparison with compression molding procedures, Figure 44 shows a typical molding cycle.

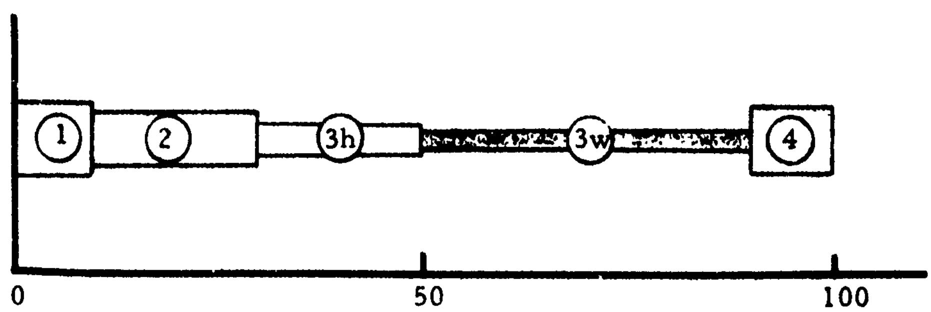

Figure 44. Typical Thermoset Molding Cycles (1) Press Closing; (2) flow period (including degassing when used); (3w) Cure Time Without Preheat; and (4) Press Opening.

1 Materials Engineering, 2-76, Page 72, "Thermosets and Thermoplastics Vie on Performance, Moldability, and Cost."

2 Milby, Robert V., "Plastics Technology," Page 131, McGraw-Hill, 1973.

For a comparison with injection molding procedures of thermoplastics, Table 30 shows typical molding cycles for a thick wall (0.125 - 0.150 inch) part (Example #1) and a thin wall (< 0.125 inch) part (Example #2).

TABLE 30

TYPICAL THERMOPLASTIC INJECTION MOLDING CYCLE TIMES

	Example #1	Example #2
Condition	Time, Sec.	Time, Sec.
Plunger forward (total time)	15	7
Delayed-unload time (booster)	12	4
Mold fill (actual time)	5	5
Dwell time	10	2
TOTAL	42 sec.	19 sec.

Conversation with the supplier of the prototype cores revealed that the injection mold cycle time for the G. P. phenolic (thermoset) was about twice as long as for the polypropylene (thermoplastic). This agrees in trend with the literature.

4. Multicomponent Liquid Foam Molding (Expanding Foam)

Jobber Response

A request for technical and cost information was made to ten knowledgeable shops concerning the 2.75 core in a 5 to 12 lb/ft^3 polyurethane foam density range with a $\pm$ 1.5 lb/ft^3 variation allowable in accordance with engineering concept drawing R54509. Foamed urethane was rejected as a viable approach for the VIPER mandrel because of processing complexities and dimensional control. No replies, written, or telephoned were received from solicited jobbers. All had been contacted by phone previous to sending out the letter and drawing and each had expressed interest in providing the information.

The chief reason no replies were received is because most, or all, received four other inquiries, simultaneously from Thiokol about other components, from other programs. Some of the companies are too small to handle all requests, especially on an "information only" basis, i.e., where there is no immediately visible market.

Part Tolerance

Perry Chemical and Manufacturing Co. of 2335 S. 305h St., Lafayette, Ind. 47902 conducted a study for development of a urethane foam mandrel as a result of solicitations for a Thiokol research program, Free Flight Rocket Technology (FFRT). About 30 mandrels were produced of three different densities for evaluation. Motors were cast and fired using these prototype components with acceptable ballistic parameters. That core mandrel R54975, shown in Figure 45, was produced with tolerances acceptable as standard rocket motor design practice. It is not realistic to predict a straightness for the 2.75 core since the FFRT core contains a 0.25 inch diameter steel rod.

Cost Estimates

As part of the FFRT inquiry, Perry Chemical furnished production unit cost estimates of $7.50 - 8.00 based on a lot size of 125,000.

Assuming the same foam material and density, 15 lb/ft^3 urethane, and reaction injection molding techniques with a mold cycle time of 4 minutes, an ROM unit production cost of $3.80 appeared reasonable. This was based upon a calculated material volume of 15% of the FFRT mandrel and application of a 90% learning curve, typical for detail parts, over the lot size increase from 125,000 to 600,000.

Conclusions

The processing mechanics probably preclude a dimensional control multicomponent liquid foam molding from consideration for a VIPER core.

For the 2.75 motor core, based on scaling from one other cost data point, it appears not to be cost competitive with either a reusable approach or some of the other manufacturing methods. A technical concern for the 2.75 core straightness and long-term stability for the 2.75 must still be addressed by further experimental work.

5. Thermoplastic Injection Molding

Jobber Response

No additional solicitations were made beyond those in the proposal phase of the methodology study. The process was generally characterized as to manufacturing capability (dimensional variability, sizes/geometry, materials) and economy during our meetings with various plastics processors. During the courses of study, several shops with injection mold capability were engaged in discussions of production of both type cores.

As more data were accrued and analyzed on the unit cost of the reusable mandrels, and information from the other manufacturing processes for a competitive disposable concept, specifically melt processable structural form molding and thermoplastic blow molding, it became evident that the cost of a single-use core mandrel by thermoplastic injection molding was too high.

Part Tolerance

The experimental work conducted on the prototype (TX395) motor core mandrels demonstrated excellent part dimensional control for all four materials; polypropylene, thermoplastic polyester, nylon, and G. P. phenolic. Most likely, all materials would be acceptable for the 2.75 motor. However, opinion from jobbers indicate the VIPER cores most likely would not, and if proven under development, would require an expensive engineering plastic, ex-polycarbonate ($1.05/lb or $0.045/in^3) for control and stability. If an acceptable dimensional envelope is calculated, the significant problem must be solved of removing the complex, mechanically captured part cylinder from the mold.

Cost Estimates

The industry concensus was that neither the VIPER nor the 2.75 core could be molded in one piece (VIPER) or single shot (2.75). This adds the costs of a joining operation to the part molding costs.

Our ROM unit production cost estimates for VIPER ranged from $2.50 to $9.00, and for 2.75 from $1.35 to $7.00. Much of the cost difference is due to the jobber's preference in material.

Conclusions

Thermoplastic injection molding does not appear to be a cost competitive method of manufacture of a single-use motor core mandrel when compared with a reusable mandrel or with certain other manufacturing methods, e.g., melt processable structural foam molding and thermoplastic blow molding for either VIPER or 2.75.

Two companies did offer to conduct technical development for the VIPER core: Neutron Plastics, 3645 N. W. 67th St., Miami, Florida 33147 and Value Engineered Components, 1770 Jensen Blvd., Hanover Park, Illinois 60103. Neutron Plastics, specialists in mold design and fabrication, reviewed the VIPER core concept drawing. In their judgement, the part has potential of being injection molded to the tolerance requirements (zero draft mandated) in a special high density or ultra high molecular weight polyethylene or preferably, ABS; possibly one part, more likely two or four parts joined. R.O.M. unit production cost would approach a $0.90 to $1.00 minimum. Development costs were not discussed.

6. Thermoplastic Profile Extrusion

Jobber Response

Of the 13 jobbers solicited for technical comments and production cost estimates, seven submitted written technical information; six of these included tooling and unit cost data for the 2.75 motor core. One of the seven responders, Plexco, Franklin Park, Illinois, indicated interest in research and development of the VIPER core.

Part Tolerances

The concept engineering drawing of the thermoplastic profile extruded 2.75 motor core is shown in Figure 46. A description of the tolerances expected for each of six materials on four dimensions is provided in Table 31. Although information was requested for thermoplastic polyester materials, none was received. Modified PPO and rigid P V C were added to the four baseline materials because of the strong preference for these materials by the majority of the jobbers. Three sets of values are shown for the rigid PVC and represent three different extruders.

Tolerance on the profile of an extruded shape tend, admittedly by the respondees, to be conservative, or in keeping with "standard industry practice." It is reasonable to expect this process to provide acceptable profile tolerances after a modicum of development.

It is questionable if the best part straightness attainable, especially in the 0.842 diameter plane, would be acceptable. The requirement again, needs to be established from a motor ballistics investigation. The technical concern of long term (storage conditions) dimensional stability and warpage would also require experimental evaluation.

Cost Estimates

The tooling and unit production cost estimates for the 2.75 motor core from six jobbers are detailed in Table 32.

All the costs shown must have an additional cost for an end closure. This can be an inexpensive injection molded part which is joined to the extrusion by a simple solvent welding or ultrasonic bonding operation. The additional cost should run in the \$0.10 to \$0.30 range per unit.

Conclusions

It appears feasible to obtain an extruded 2.75 motor core from a polypropylene or modified PPO, or rigid PVC material with the added end closure for a production unit cost of from \$0.40 to \$0.70.

The unanswered questions are whether the part can be extruded to an acceptable straightness, and if that acceptable straightness is stable over the expected storage periods and conditions.

7. Thermoplastic Extrusion Blow Molding

Jobber Response

The summary of the solicitations for cost data and technical information from 11 custom thermoplastic extrusion blow molders is summarized in Table 33. Each was then contacted by phone and sent a copy of the 2.75 motor engineering concept drawing, R55264, with the baseline procurement requirements. During the telephone contacts, no one would consider the VIPER design due to the dimensional requirements, and the problems of part removal from the mold. A written response was received from only two of the eleven so contacted. Four of these eleven, and three others contacted by phone, stated that formation of the extruded parison (preform) was either impossible, or would require extensive development. The problem occurs in the vertical extrusion operation because the high length-to-diameter ratio causes the parison to stretch, neck, and thin as it emerges hot from the extrusion die. This would have to be solved with a secondary cooling/sizing die.

Captive Plastics, Bekum Plastics Machinery, and Boise Plastics Products, in addition to the two prime respondees, Advanced Plastics and Geauga Plastics, expressed interest in a product development program. Advanced Plastics quoted on a development plan at $600.00 per day, plus a typical single cavity mold cast for 2.75 core of $4,200.00.

Part Tolerances

The tolerances quoted from Geauga Plastics are shown in the table in Figure 47. The numbers appear conservative from the conservations with others in the industry, for example, several manufacture containers to $\pm$ 0.005 or better on a 2 inch diameter. In general, the outside diameters and length could be made acceptable. Although a requirement on straightness from motor ballistics was not defined, a 0.25 inch/length would not be acceptable. It is questionable if the 2.75 motor core could be precision extrusion blow molded to $\leq \pm$ 0.010 over the length in the plane of the 0.842 inch part diameter.

Cost Estimates

Both jobbers who worked up the cost package came in with the identical production unit cost, $0.48 for the same material, high density polyethylene. Tooling and piece costs are identified in Table 33.

Conclusions

The unit costs and tolerances on diameter for an extruded blow molded 2.75 motor core appear attractive. Acceptable part straightness is questionable. A molding development program also appears economical. However, if an acceptable as-molded straightness is developed, the long-term dimensional stability and straightness is another question which needs to be resolved.

It is the opinion that the thermoplastic extrusion blow mold process for a 2.75 motor core would probably not produce a part with acceptable control of dimensions.

This method should be considered ɪor other motors of high production lot and rate where: the length-to-diameter ratio are lower and straightness of the part is less critical.

Estimate of Cost Savings

General Considerations

Selection of Casting Process and Design of Casting Tooling

The casting process and the design of the fixtures used to load solid propellant rocket motors are interrelated and must be based on many considerations. Factors that must be considered include: ballistic performance requirements, motor case and hardware design, physical properties and handling characteristics of the propellant composition, production rate requirements and production quantity, propellant ingredient and processing costs, propellant and ingredient sensitivity/toxicity characteristics, motor manufacturing cost constraints (if known), etc. With so many factors that have to be considered, there is no simple, straightforward procedure for selection of either a casting process or a casting fixture design; each job is a separate, new entity. The following discussion covers a number of the alternative motor processing procedures open to the Process Engineer or Designer. It is applicable only to composite solid propellant motor loading, and is not intended to be a complete, definitive document covering all possibilities. The nomenclature used is arbitrary, and does not necessarily conform to current usage at any plant or facility.

On examination, there were at least four categories into which a specific casting process may be divided, with at least two alternate groups in each category, and possibly many subgroups, as listed in Table 34. Theoretically, any combination of the eight major alternatives is possible although some of the subgroups are very unlikely to occur together. For example, a case bonded motor (1.1) may be cast (case design permitting) either with the core in-place (2.1) or with the core inserted after casting (2.2); the casting operation can be either at atmospheric pressure (3.1) or carried out inside a vacuum bell (3.2), regardless of how the core is handled; and, the propellant can be cast into the motor cavity either through the aft end (4.1) or bottom cast through the forward end (4.2), regardless of the way in which the core is handled or whether done under vacuum or at atmospheric pressure. It is unlikely that a continuously-extruded grain (1.2.2) would involve either a movable core of perforation former (2.1.2) or a sequentially assembled core (2.1.3), much less be cast with either bayonets (4.1.1) or fixed dispensing nozzle (4.1.2).

Not every combination is possible for a given motor, and by common practice, some are limited to relatively large motors (or, conversely, to small motors), or to relatively low viscosity and/or long potlife propellants (or, conversely, viscous or short potlife compositions), etc.

Selection of a casting process, therefore, involves eliminating from consideration those possibilities that are obviously not applicable, then choosing the one, from those remaining, with the best chance of success. Once the process is selected, the casting tooling can be designed.

The casting tooling performs several functions: it contains the propellant within the motor case during casting and subsequent cure, it forms the internal cavity surfaces, and it locates the cavity both radially and axially within the case. In addition it may provide reservoir capacity to allow for overfilling, it may "form" the aft surface so as to eliminate cutback or trimming, and it may perform special functions not related to the casting process (e.g., provide a reference surface for finishing operations). The tooling design must be based not only on the motor case design and on the motor ballistic performance requirements, but also on the selected casting process, on a knowledge of the propellant physical properties and handling characteristics, on subsequent operations that must be performed after cure, and on cost considerations. The dimensional and manufacturing tolerances to be specified on the tooling drawings should be based on ballistic considerations, but often are based only on accepted design practice.

The tooling design generally consists of a "casting fixture assembly drawing", depicting the motor case and tooling components fully assembled together as though for propellant cure, but without any propellant in it. It may or may not be in the assembly state in which propellant is cast into the case (e.g., a motor cast without the core in place, followed by core insertion). The specific components are detailed on the associated fabrication drawings. The casting tooling basically consists of the following items (or functions):

1. Mandrel, or cavity former ("core")
2. Base, or forward-end closure/attachment
3. Sleeve, or aft-end attachment
4. Hold-down mechanism for mandrel
5. Grain surface former
6. Securement devices for holding the sleeve and base to the case

For some motors, each of the above components is a separate entity, while for others, two or more functions may be provided by a single part or may not even be required.

Tooling Costs and Cost Comparisons

The cost of casting tooling must be considered under two classifications, recurring and non-recurring. The non-recurring cost covers the initial fabrication or procurement, while the recurring cost involves those efforts and materials associated with use and reuse of the items in casting operations.

Non-recurring cost of tooling is a function of such factors as the complexity of the shapes involved and of the dimensional tolerances required, of the number of components involved in the assembly, of the materials of construction, of the critical inspection areas that must be verified for quality control, and of the overall number of parts to be procured or fabricated at one time. There are probably many more factors or cost elements that could be listed, but they are relatively unimportant to the current discussion.

Recurring costs of casting tooling include refurbishment of damaged items, cleaning or decontamination of used components prior to reuse, protection of the components against damage between uses, storage of the items when not in use, and periodic reinspection of the items for quality control.

A comparison of the costs of competitive tooling designs or concepts must be based on a detailed breakdown to the ultimate cost per use (or per motor).

SEAS Motor

Process Selection and Tooling Design

The concept design of the disposable casting fixtures for the 2.75-inch rocket motor is presented in Figures 48, 49, and 50. The comparable designs of the reusable tooling are presented in Figures 51 through 57. The basic operational concepts are the same for both designs, as dictated by the motor performance requirements and case design. The alternatives considered are discussed below.

The closed forward end of the 2.75-inch motor case obviously eliminated bottom casting. The small diameter of the motor, as well as the space occupied by the core virtually eliminated any casting technique with the core in place. Even with the core removed, the motor cross-section is too small for either vacuum casting (slit deaeration directly into the motor case) or "pour casting" (dropping propellant from a fixed dispensing nozzle down through the case) to produce void-free propellant grains, particularly under production conditions. Thus, bayonet casting of the propellant, followed by insertion of the core, appeared to be the only reasonable casting process open for consideration. It should be noted that a type of extrusion casting could possibly have been used by providing a vent hole at the forward end of the core. Such a process would probably require that a vacuum be applied to the motor cavity, through the core and vent hole, to insure a void-free grain. The complexity of such an approach was felt to be undesirable for a production operation; therefore, bayonet-casting followed by core-insertion was selected.

The lack of an opening in the forward motor bulkhead, coupled with the necessity for full insulation in this region on the inside of the case eliminated the use of a forward core centering device. Centering long, narrow cores at both ends is very desirable where ballistic requirements call for precise cavity location. Although the cavity location tolerances, as currently established, for the Thiokol design of the 2.75-inch motor are not very stringent, the relatively large L/D ratio of the motor necessitates either a very long, precision core insertion guide (or sleeve) or a precision insertion machine. A core insertion machine with built-in precision was a better technical choice and the lower cost approach than individual motor tooling components with the precision requirements built in. This approach, however, does require that the forward insulation provide locational support to the forward end of the core during post-insertion handling and cure. The core must be pressed into the liner/insulation at the forward end, to prevent it from backing out or away from this position. The spring in the Hold-Down Fixture, Figure 53, provides this restraint for the reusable tooling design, while the Core Retainer (Figure 50) performs the function for the disposable tooling. It can be deduced from the casting fixture assembly drawings that the disposable tooling concept requires very tight control over the thickness of the forward insulation and liner to function properly, while the reusable tooling concept is more forgiving in this respect.

Projection of the motor nozzle into the aft end of the case requires the use of a grain former, or sleeve insert, to precisely locate the aft end of both the liner/insulation and the propellant grain (after cut-back). This function is provided by the Teflon sleeve, Figure 54, for the reusable tooling, and the plastic sleeve (Figure 49). In both instances, the liner/insulation will probably be applied up to, and against, a lining sleeve that projects into the case slightly less than the casting sleeve. When the lining sleeve is removed after liner/insulation precure, there will be a slight interference fit with the casting sleeve on insertion to effect a good seal at the joint between the case and sleeve. This seal will prevent propellant from seeping into the region of the nozzle and spline fit. Careful control of the casting depth should prevent propellant contamination in the region of the aft end of the casting sleeve.

Removal of the casting sleeves for the two designs will be by similar methods after core extraction and removal of the core hold-down device. On the disposable tooling, it is anticipated that the hold-down device, or retainer

(Figure 50) will be extracted with the core in one operation. An as-yet-undesigned tool will then engage the overhanging lip of the sleeve and extract it. For the reusable tooling, the hold-down device, Figure 53, will be lifted off, after retracting the plunger that engages the spline opening. The core will then be extracted by conventional means. The casting sleeve can then be removed manually by engaging the sleeve puller and puller rings, Figures 56 and 57, in the groove of the casting sleeve, Figure 54, and lifting upward.

The internal spline joint for attachment of the nozzle, and the lack of any external features suitable for attachment, presented a problem in determining how to fasten the casting sleeves and core restraints to the case. Several alternatives were open, including tie rods from an external base, and split clamps on the outside of the case. Both of these were felt to be both undesirable and costly for high rate production, as well as more susceptible to contamination, than the method selected. The disposable tooling design uses shearable tips, molded in the outside surface of the plastic sleeve (Figure 49) to snap into the spline groove inside the case. The success of this concept is predicated on the ability of the molder to provide the tips, and on the ability of the sleeve to be inserted into the case and the tips to withstand all forces but intentional extraction, all of which are unknown at this time. Such a concept was unsuitable for the reusable tooling, as extraction of the sleeve is expected to shear off the retention tips.

Figure 53 depicts the method selected for fastening the sleeve to the case for the reusable tooling. The close fit between the case and hold-down fixture is expected to allow the single fastening device to perform adequately by engaging the spline insertion opening. Some cocking of the sleeve may occur as the surface inside the hold-down fixture wears, but this should not present a problem if excessively worn parts are removed from the operation by routine tooling reinspection.

The casting fixture assembly drawing, Figure 51, for the reusable tooling, depicts an alignment stand for precisely locating the motor assembly on an existing core insertion machine for small and intermediate sized motors at the Huntsville Plant. Detailed in Figure 55, is a concept only, but usable for either disposable or reusable tooling motors for the demonstration program. A different set-up would be designed for actual production use, to allow faster cycling of the motor assemblies through the system without compromising either safety or quality. For the reusable tooling, the core stud would engage in a precision checking mechanism on the insertion machine shaft. For the disposable tooling process, the shaft of the insertion machine would terminate in a rigid steel mandrel (or rod) which would fit snugly inside the plastic core. The core and core retainer would be installed on the insertion mandrel, and the cast motor case positioned in the alignment base. The insertion machine would push the core into the motor to the precise depth required for the core retainer to engage the casting sleeve lip. After the retainer and sleeve are locked together, the insertion mandrel will be extracted and the motor assembly removed for cure.

Cost Estimate (SEAS)

The methodology used in developing the recurring and non-recurring costs for the SEAS (or Viper) reusable tooling is defined below. A similar approach applies to determining the costs associated with the disposable tooling for comparison.

1. Define the propellant processing characteristics (e.g. potlife, cure time) to be used in developing the motor production plan.

2. Define the casting parameters that determine the number of motors per mix, the mix size, and the mix frequency.

3. Examine the process of core refurbishment and define viable product-rate schemes for expected levels of core refurbishment.

4. Define the nominal core refurbishment conditions, and compare to the established production process capabilities.

5. Establish allowances for irrepairable damage.

6. Determine the overall quantity of cores required (initial procurement quantity).

7. Establish the non-recurring cost per core by obtaining vendor quotations for manufacture and adding the costs for initial preparation for use.

8. Establish the overall production quantity to be used to amortize the core procurement cost over, then compute the non-recurring cost per use.

9. Establish the time rate of refurbishment of cores and the quantity of cores actually out of service at any one time.

10. Compute the cost of refurbishing a core and extend it to the estimated cost per use to establish the recurring cost per use.

11. Add the non-recurring cost per use to the recurring cost per use to establish the net cost per use.

The engineering design concept for the 2.75-inch motor used in developing the tooling designs was documented as Thiokol drawing R53939 (Figure 58). Based on this drawing and on the tooling design described in the previous section, a set of assumptions was developed for defining the production process. These assumptions, along with those obtained from the Propellant Development Chemists concerning a suitably formulated delayed quick-cure propellant composition, are given below with discussions where applicable.

1. Production rates to be considered are 100,000 and 500,000 rounds per year.

   For simplification, these rates are the total motors produced, and include rounds for static test and reject allowances. Actual delivery quantities would be 3 to 5% less, depending on Quality Assurance and net production allowance requirements.

2. The finished propellant grain weight is 6.32 lbs.

3. Motors will be bayonet cast in a semi-automated batch casting machine to a controlled volume. The core will be inserted immediately afterward. Casting waste will be limited to that which comes halfway up inside the sleeve (of the disposable tooling design).

4. The propellant viscosity and the casting processes will be such that one motor can be cast every minute at a given casting station.

5. A 420 gal. propellant mix size of 6120 lbs. will be used, with a 94% utilization factor.

   The current similar propellants are made in mix size of 6120 lbs. Propellant utilization factors of 93 to 94% are common.

6. The propellant composition will be a delayed quick-cure material having from 8 to 12 hours useful potlife after cure agent addition.

   Propellant development efforts to date have demonstrated at least 8 hours potlife, and, on occasion, 12 hours or more, using mixing and casting temperatures of 135°F. Calculations will be made for both 8 and 12 hours.

7. Approximately 2 hours will elapse between cure agent addition and start of casting.

   This time delay is highly dependent on the mix cycle, the deareation time, the design and operation of the casting machine, and on the transportation time between the mixer building and the casting station. Two hours is a best-guess estimate.

8. Motors will be sufficiently cured, at 145°F, to allow core removal in either 2, 3 or 4 days cure time.

Propellant development efforts have demonstrated cures in as little as 3 days, as determined by physical properties. It may be possible to reduce the time to 2 days, although the final composition, as tailored, may actually require 4 days. All three times will be considered, to show the effect on the cost.

9. Motors leaving the core insertion station will be grouped as required and put into the cure oven within 30 minutes of the casting time.

   The actual time delay between casting and entrance into the cure oven is more a function of the production facility layout than any other factor. The half-hour is strictly a best-guess estimate.

10. After completion of cure, motors will require about 16 hours cool-down prior to core removal.

    This is based on actual experience with test motors of the same general size as the 2.75-inch motor.

11. If required, cores will be extracted from motors immediately after cool-down, and at a rate comparable to the casting rate.

12. A minimum surge time of two hours is required between core extraction until it can be reinserted into a newly cast motor.

    This allows for clean up, drying, inspection for defects, and forwarding to the casting station.

13. Reusable cores will be refurbished (re-Teflоned) after average uses of 20, 60, and 100 times.

    Current practice for a similar motor is to re-Teflon cores after about 20 uses. The limiting number of uses seems to be related more to incomplete cleaning of the Teflon surface after each use than to damage from handling. Careful work on a cleaning process, therefore, should allow a greater number of uses between refurbishment. The 60 and 100 use levels are strictly best-guesses, for illustration.

14. Regardless of the crew and facility setup for core refurbishment, the initial application of Teflon to the metal core bodies will be done at the lowest cost, highest rate condition.

15. Time allocations for production jobs will be based on a maximum useful work period of 400 minutes per shift.

Time and motion studies have indicated that coffee breaks, lunch, transportation to and from work stations, etc., leave about 400 minutes of effective work time per man per shift.

16. Nonrecurring costs for cores will be allocated over periods of one to six years.

The non-recurring costs per motor are highly dependent on the total number of motors to be produced, whether with reusable or with disposable tooling. Time periods of from one to six years were selected as being representative of typical production programs. Any other range of value could easily be specified, but no such specification was made in the Technical Requirements.

17. For a first assessment, only the costs associated with the core will be considered.

Other items of casting tooling certainly are involved in either the disposable or reusable tooling concept. These other items, however, have been excluded from the cost analysis simply to apply reasonable limitations on the scope of the cost analysis effort. It is felt that the core will be representative of the tooling as a whole.

18. Labor costs will be based only on the non-exempt (hourly paid) employees effort required to perform the specific task.

Supervision allowances (salaried employees) will not be included, primarily because our experiences with the Production Plant and with product plan studies indicate the degree of supervision required to be very small in a fully operational system, and the actual cost to be almost indeterminant. The concept taken, therefore, is that supervision will be available, as required, from the overall motor production process, to ensure proper work continuity and quality, but it will not be included in the cost comparisons.

19. For the reusable cores, allowances will be provided both for irrepairable damage (0.1%) during handling, and for spares during refurbishment (based on refurbishment capabilities).

Maverick production experiences have been that there has been negligible damage to the tooling in over 25,000 motors produced. This is a minuscule percentage, so a best-guess value of 0.1% of the operating quantity was selected, for illustration.

20. <u>Spares for refurbishment will be based loosely on the average uses between refurbishment, but will be specified on the basis of actual refurbishment process capabilities.</u>

Spares based on 20, 60, or 100 uses between rework may or may not be compatible with the refurbishment process schemes to be developed. Therefore, the actual spares requirement will be based on the average daily refurbishment rates achievable, the estimated rates required, and the assumption that requirements of up to 30% more than those achievable are acceptable.

Calculations were made based on the above noted assumptions for sizing the propellant mix, number of motors to be cast, number of parallel casting stations that must function to operate within the propellant potlife, the time intervals between successive mixes, and the operating quantity of cores required. Table 35 summarizes the net operating quantities of cores required for each condition. These quantities do not contain allowances for spares for either irrepairable damage or for refurbishment.

Viable process schedules for refurbishment of the Teflon mold release finish on the cores were established. The process is based on applying one coat of primer and two coats of finish to the bare metal surface, using FEP Teflon. A number of assumptions were made, based on the size and similarity between the 2.75-inch motor core and a core for which time and motion studies have been made for Teflon refurbishment. Several variations on the utilization of the operating personnel were considered, in order to arrive at realistic average refurbishment rates, man-hours of labor per core refurbished, core recycling times, and actual quantities that must be provided as spares, based on the number of cores involved in the refurbishment process. An assessment of the materials required and their cost per core refurbished was also made and documented. Since the initial application of Teflon to the newly procured cores would not require walnut-hull blasting to strip off any old finish, a separate assessment of the man-hour requirements per core procured was also made.

Calculations were made for establishing the allowances for irrepairable damage during handling, and the selection of allowances for refurbishment for each of the many conditions that were considered. Table 36 gives the summation or projected procurement quantity for each of the process conditions considered. The non-recurring cost for each process condition will be based on these procurement quantities according to the following general equation:

$$C = \frac{(a + b + d)q}{r \cdot y}$$

where C = nonrecurring cost, per use
a = procurement cost per core
b = labor cost per core to apply initial Teflon finish
d = materials cost per core to apply initial Teflon finish
q = procurement quantity, from Table 36
r = actual yearly production rate
y = years of production at rate "r"

As the procurement cost for each core metal body has not yet been established from vendor quotes, complete calculation of the non-recurring cost per use can not be made at this time. The labor requirement per core was calculated to be 0.3000 man-hours per core, while the materials cost is $0.03311 per core. Using an adjusted labor rate of $10.517 per man-hour (estimated current production operator wage rate brought to the same burden scale as the materials purchase price), gives a labor cost of $3.1551 per core, or a combined Teflon finish application cost of $3.1882 per core, representing "b+d" in the above equation.

The recurring cost, on a per use basis, includes both the labor and materials to refurbish the cores (spread over the actual uses between refurbishment), plus the cost of any labor and materials identifiable as being specific only to the reusable tooling process. In developing the process concept, it has been assumed that the cores will be handled on a continuous, suspension conveyor system from the time the core is removed from one motor until it is inserted into the next one. The labor and materials costs for refurbishment were developed. The only other cost involved is cleanup of the cores prior to reuse. For the purpose of this cost study, it was assumed that cores would pass through an automated cleanup machine, using solvents or detergent solution, rotating soft bristle brushes, and suitable drying conditions. Labor will be involved, however, as each core comes out of the cleanup operation, in the form of a 100% visual inspection for scratches, dents, or other damage requiring either refurbishment or replacement. During this inspection, cores will be identified and set aside for refurbishment, and newly refurbished cores installed in their place, as required or as they become available. One minute of operator time was estimated as the identifiable labor cost, per motor loaded, for this operation, or 0.0167 man-hours. This must be added to the refurbishment labor and materials costs adjusted to a per use basis to determine the recurring cost of reusable cores. The per-core-refinished labor required for each of the refurbishment conditions was calculated. Only two rates were used based on whether a nine man crew or a single man crew was selected. Using the same labor cost of $10.517 per man-hour, the labor cost per core refinished becomes $4.8073 for the single man crew, and $4.7326 for the nine man crew. Adding the materials cost, the net refurbishment costs per core refinished become $5.8873 and $5.8126 respectively.

To convert the above refurbishment costs to a per use basis, they must be allocated over the number of uses that a core will see before it is refurbished. Because the refurbishment schedules are tied to specific refurbishment crew capabilities, the nominal 20, 60, and 100 use figures cannot be used. Actual use rates were estimated in the form of percentages based on the required operating quantity of cores and the refurbishment spares allowance, for each condition that was considered. The only problem is that the rates for the 100,000 rounds per year production rate are excessively high because of the excess of refinishing capacity above and beyond the refinishing rates required. This was a direct result of the assumption that the time interval between mixes would be used to compute the average daily refurbishment rate. A more realistic approach would be to assume that the refurbishment operation would be cranked up and operated every other week or once a month. Once a month would reduce the Actual Rate Values (for the 100,000 rounds per year only) to one-tenth those shown, or 3.539%, 2.360%, and 1.770% in the various positions. This adjustment was carried through in evolving Table 37.

Table 37 gives the net adjusted refurbishment cost for each process condition considered, on a per use (or per month loaded) basis. Table 38 combines the per use costs from Table 37 with the labor cost for inspecting cores that have been cleaned and are ready for reinsertion. Table 38, therefore, gives the net recurring cost for the reusable core production process. It should be stressed that these are incremental costs, for comparison purposes only, and do not necessarily represent the full cost of reusable cores in a production plant. It should also be strongly noted that the left hand column, labeled "Nominal Average Uses Before Refurbishment", is for labeling purposes only, as actual uses before refurbishment, as computed, vary widely from the nominal.

The overall cost per use of a reusable core is the sum of the non-recurring and the recurring costs. With the large number of process variables considered, and the range of production periods covered, presenting such data in tabular form would be extremely cumbersome and confusing. Therefore, Figure 59 presents selected data for illustration purposes. The non-recurring cost data used is that given in Figure 60, while the recurring costs are direct from Table 38. A total use cost for any other condition can be determined by adding the appropriate recurring cost, from Table 38, to the appropriately-adjusted (for amortization period) non-recurring cost. From Figure 59, it can be seen that the per use cost varies from a high of $1.21 (100,000 rds/year, 20 uses, 8 hr potlife, 4-day, 1 year) down to a low of $0.51 (500,000 rds/year, 100 uses, 12 hr potlife, 2 day cure, 6 years). Table 39 recaps net cost per core use for a five-year production quantity.

Viper Motor

Process Selection and Tooling Design

Tooling for both the disposable and the reusable core Viper was designed. Figure 61 is the casting assembly (DR-54894) for the reusable (aluminum) core design. The core itself (DR-54892) is shown in Figure 62, while Figures 63, 64 and 65 show the auxiliary parts. Motor cases, with the core support (Figure 63) and casting sleeve (Figure 64) installed, will be installed in precision-aligned cups on an indexing table. Retaining rings (Figure 65) will already be in position on top of the cups. The cases will be positioned by the table under volumetric-dispensing casting heads, where each case will be charged with the proper amount of propellant. The table will then index to the core insertion position, where the cores (Figure 62) will have already been fixed in place in the insertion fixtures, and precisely positioned above the motor positions. The cores will be inserted and released, and the insertion fixture retracted. The attendant operator will raise the retaining rings and snap the O-ring retainers over the milled grooves in the end of the cores. The motors are ready at that point for placement in the handling boxes, for transport into the cure oven.

The disposable tooling casting assembly (DR-54889) is shown in Figure 66, while the core itself (DR-54886) is shown as Figure 67. The auxiliary parts are the same as for the reusable core concept, as shown in Figures 63, 64 and 65. Use of the tooling would be essentially the same as for the reusable core concept except for handling of the core itself. The insertion fixture must be designed to accommodate the hollow, studless plastic core, and the tie-down O-ring will go over the top of the core and down to the other side of the retaining ring.

Cost Estimate (Viper)

The engineering design concept for the Viper motor used in developing the tooling designs is shown in Figure 68. Based on this concept and on the tooling design described in the previous section, a set of assumptions was developed for defining the production process for the Viper motor.

1. Nominal production rates of 100,000 and 500,000 rounds per year are to be considered.

   For simplification, these rates are considered to contain rounds for static test and reject allowances. Actual delivery quantities would be 3 to 5% less, depending on quality assurance and net product allowance requirements. In addition, the ultimate production quantities used in the cost analyses will be based on realistic motor casting and processing consideration, and therefore may deviate somewhat from the nominal values.

2. The finished propellant grain weight is 0.473 lbs.

3. Motors will be cast, four at a time, using a volumetric-dispensing loading machine. The core will be inserted immediately afterward, again 4 at a time. Casting waste will be limited to that which comes halfway up inside the sleeve of the tooling.

4. Casting and core insertion will be accomplished on an indexing table, and the propellant viscosity and processing characteristics will be such that one casting sequence (of 4 motors) can be completed every minute.

5. A 50 gal. propellant mix size of 700 lbs. will be used, with an approximate 94% utilization.

6. The propellant composition will be a delayed quick-cure material having a potlife of at least 8 hours.

7. Approximately 2 hours will elapse between cure agent addition and the start of casting.

8. Motors will be sufficiently cure, at 145°F, to allow core removal in either 2, 3, or 4 days cure time.

9. Motors leaving the core insertion station will be boxed, 20 per box, and placed on a cure dolly holding 32 boxes. The cart will be in the cure oven within 30 minutes of placement of the last box on the cart.

10. After completion of cure, motors will require about 16 hours cool-down before the cores can be removed.

11. The required, core extraction will start immediately after completion of cool-down, and will proceed at a rate comparable to the casting rate, using a multistation extraction machine.

12. A minimum surge time of 2 hours is required between core extraction and reinsertion in a newly cast motor.

    This allows for cleanup, drying, visual inspection for defects, and forwarding to the casting station.

13. Reusable metal cores will be refurbished (re-Tefloned) after average uses of 20, 60, and 100 times.

14. Initial application of teflon finish will be done at the lowest cost, highest rate processing condition, regardless of the scheme actually selected for refurbishment.

15. Time allocations for production jobs will be based on a maximum useful work period of 400 minutes per shift.

16. Non-recurring costs for cores will be allocated over production periods of one to six years.

17. Cost comparisons will be based only on the differences in the reusable and the disposable cores themselves, as the rest of the tooling is identical for both cores.

18. Labor costs will include only the non-exempt (hourly paid employees) effort required to perform the specific task.

19. For the reusable cores, allowances will be provided for irrepairable damage during handling at 0.1% of the nominal operating quantities.

20. Spares allowances for refurbishment will be based loosely on the average uses between refurbishment, but will be specified on the basis of actual refurbishment process capabilities.

The above assumptions are nearly the same as those developed for the 2.75-inch rocket motor.

Calculations were made based on the above assumptions and on the earlier devised Viper production plan. The mix size, motor casting requirements and time schedules, mix manufacture schedules, and basic tooling quantity requirements were established.

The process schedules and crew developments for refurbishing the Teflon finish on the reusable Viper core were assumed. Crew size and shift schedules, labor costs per core refurbished, materials requirements, basic refurbishment spares requirements, and labor costs for initial Teflon finish application were among the parameters established.

An estimation of spares allowances and refurbishment crew and shift selections for each of the motor production conditions was also made.

Table 40 summarizes the quantities of cores that must be procured initially for each condition. Each value is the summation of the basic operating quantity, the spares allowance for irrepairable damage, and the spares allowance for refurbishment. These initial procurement quantities were used in the development of the non-recurring costs or the cores. The labor and materials costs for initial application of Teflon finish to the newly-received core bodies were calculated based on the information generated for process schedules and crew sizes. The labor required of 0.6452 nonexempt man-hours per core, factored at \$10.517 per man-hour, gives \$6.7856 per core for labor. Adding \$1.35, for materials, gives a total cost for initial Teflon application of $8.1356 per core.

The recurring cost, on a per use basis, includes both the labor and materials to refurbish the cores (spread over the actual uses between refurbishment), plus the cost of any labor and materials identifiable as being specific to the reusable tooling process. The labor and materials costs for refurbishment of the cores was developed. The only other cost involved is cleanup after use, and prior to reinsertion in a newly-cast motor. As for the 2.75-inch motor cost analysis, it was assumed that an automatic or semiautomatic core cleaning process will be in use, using solvents, soap and water, rotating soft bristle brushes, etc., to clean the cores without labor costs. However, as the clean, dry cores emerge from the cleaning process, each must be scrutinized to insure no damage has occurred. Due to the complexity of the core shape, two minutes of operator time, or 0.0333 nonexempt man-hours, were allocated for this inspection. At $10.517 per man-hour, the inspection costs $0.3502 per core use.

For the refurbishment cost, each core processed by a single man crew requires 0.9412 nonexempt man-hours, or $9.8986 labor cost, per refurbishment, at a rate of $10.517 per man-hour. Adding in the $1.35 materials cost gives a total refurbishment cost of $11.2486 per core refurbished. The 7 man crew requires 0.9032 nonexempt man-hours, or $9.4990 labor cost. Adding the materials gives $10.8490 total refurbishment cost per core refurbishment. Table 41 summarizes the costs as applied to each production condition, and the actual refurbishment rate, as a percentage, as well as the extended refurbishment cost per use.

The recurring cost for each production condition is given in Table 42, and is the value of refurbishment per core use added to the inspection cost noted above. It should be stressed that these are incremental costs, for comparison purposes only, and do not in any way represent the full cost of processing a motor using reusable cores in a production plant.

Procurement cost quotations were obtained for the metal body for the reusable Viper core, in increments of 1000 units. These quotations, in combination with labor and materials cost estimates and process quantity estimates described above, were used to compute the non-recurring costs for the reusable core concept. Net costs per use were then derived by adding the appropriate recurring cost to the allocated non-recurring cost. This is discussed below.

As for the 2.75-inch motor non-recurring cost calculations, the costs are based on the core alone and include only those costs and operations that are different from what the disposable tooling would involve, This is particularly justifiable for the Viper, since the other components of the tooling (e.g., casting sleeve, core support, etc.) are identical for the "reusable" and the "disposable" concept assemblies. The costs are incremental, and for comparison purposes only; they do not represent the true cost of making rocket motors with the components.

Because of the range of variables studied (i. e., cure time, uses between refurbishment, and production time periods), the resulting non-recurring costs become too cumbersome for tabular presentation in their entirety. Table 43 summarizes the results in a convenient form for comparison, using a one-year production period as the basis for comparison. It is highly unlikely that such a short production contract would ever be let in reality. The non-recurring cost for any other production period, such as 2.5 years, can be obtained by dividing 2.5 with the appropriate cost from the Table. For example, at a nominal 500,000 rounds/year production rate, and 20 uses between refurbishment, and a 3-day propellant cure time, the non-recurring cost per motor loaded is $0.3416 for a one-year operation, but reduces to one-third, or $0.1139, for a three-year contract. This is illustrated, for selected process conditions, in Figure 69. Only four of the conditions are shown, for reasons of clarity, because the others would lie very close to those illustrated and cause excessive clutter. The upper and lower curves represent the extremes of the non-recurring costs for all of the conditions studied.

Adding the allocated non-recurring cost, from Figure 69 properly extended to the appropriate recurring cost (Table 42), gives the overall cost per use of a reusable Viper core (on an incremental cost basis). Figure 70 presents the overall (or net per-use) costs for selected process conditions. As the curves are more spread out than those in Figure 69, a great number of the curves are presented. Tabular data for all of the process conditions, for a 5-year production period, are given in Table 44. An unexpected result, that can be seen both in Figure 70 and Table 44, is that the 4-day cure condition gives lower per-use costs than the 3-day cure (and, in places, the 2-day). This is contrary to what logic would predict, and is probably a result of the relationships between the estimated core-refurbishment rate requirements and the rates at which realistic operating crews could refurbish the cores.

The primary conclusion that can be drawn from the net per-use cost data is that, regardless of the actual initial investment for metal cores, the cost per motor loading is in the region of $1.20 or less for production periods of two or three years or more. High production rates and long Teflon finish life (i.e., up to 100 uses between refurbishments) can bring the cost down to around $0.50 per motor.

Conclusions for Original Basic Effort

The previously discussed process engineering studies and cost estimates for SEAS and Viper rocket motors led to the following conclusions:

1. There is evidence that the cost of using the conventional reusable metal mandrel concept in SEAS and Viper motor applications is lower than the cost of using a throw-away

disposable mandrel. The recurring and non-recurring costs of using a metal mandrel is estimated to be $0.65* (see Figures 59 and 70). This is less than half the cost of a $1.39* hard disposable mandrel.

2. Based on the wealth of material technical data and cost information generated on the program, there are indications of cost benefits of using "foamed" leave-in-place disposable mandrels in other motors.

Based on the above conclusions, the program scope of work was redirected by contract change, to the development of foamed mandrels for free flight rocket type motor applications. Thus, the remainder of this final report covers work accomplished from the date of the revised contract, April 1978, through December 1979 on development of the foamed leave-in-place mandrel concept.

Revised Scope of Work (Apr 78 - Dec 79)

Motor and Mandrel Design Concepts

The first step in pursuing the redirected program objective of evaluating foamed, leave-in-place mandrels for FFR-type motor applications was to formulate a design concept of an FFR motor. Using this concept, a foamed mandrel design was generated. Figure 71 shows a sketch of both a preliminary motor design and a foamed mandrel. The following features were incorporated in the mandrel/motor design:

1) The preliminary configuration of the GFE case to be fabricated by McDonnell Douglas/Titusville was used.

2) A stress relief bulb is incorporated at the propellant-nozzle interface.

3) The stress relief bulb also serves to control the expansion of propellant gases at the grain aft end to obtain more uniform and lower nozzle erosion.

4) The mandrel forms the nozzle environmental closure.

5) A steel rod, used to center the core and prevent warpage during cure, leaves a hole through the mandrel igniter leadwire for support.

The predicted performance (thrust and pressure) of the motor is shown in Figures 72 and 73. At 70°F, maximum thrust is 7543 lbf, maximum pressure is 2067 psia, and the motor loads 54.5 lbm of propellant. Total impulse is 13,200 lb. sec.

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* These costs are vendor prices plus quality control and normal burdens. Thus, they are total unit costs (see Summary of Materials Selection Effort section of this report).

The preliminary motor grain design shown in Figure 71 was then refined to provide more taper to the initial propellant bore (see Figure 74). This change accomplished two objectives. First, the additional taper will improve fabricability of the mandrel and permit it to be easily ejected from the mold without incorporating a longitudinal split-line. Secondly, the taper will improve ballistics by reducing the initial surface area thus lowering PMEOP and will reduce the effects of erosive burning at ignition. Maximum pressure was reduced from 2067 psia to 1553 psia at 70°F exclusive of igniter contribution. Reducing erosive burning has produced a more level pressure time trace. In the process, propellant loaded weight was reduced from 54.5 lbm to 53.17 lbm.

Table 45 shows a summary of motor ballistic data for the refined motor (designated TX707) at -50°F, 70°F, and +145°F. Figures 75 through 80 show motor pressure and thrust plots.

Mandrel Requirements Document/Experimental Plan

Having established a motor design concept along with the leave-in-place foamed mandrel concept, the next step was to establish basic requirements for the mandrel. These requirements are set forth in detail in Appendix A.

Next, plans for procuring, inspecting, and evaluating the foamed mandrels were prepared and are given in Tables 46, 47, and 48. Briefly, the plans include the following:

1. Work Statement - Describes, to the vendor, what work is required in the evaluation of blowing agents, in the delivery of test samples to Thiokol, in the manufacture of a permanent mold, and in the delivery of mandrels.

2. Mandrel Inspection Plan - Gives the dimensional and other physical measurements to be made by Thiokol on the foamed mandrels.

3. Laboratory Mandrel Material Evaluation - Outlines tests to be conducted by Thiokol to evaluate vendor-supplied foam mandrel material specimens.

Foamed Mandrel Procurement/Evaluation

Procurement

Five vendors were requested to provide quotes on the Work Statement presented in Table 46. Four of the five vendors submitted "no bids" but the fifth vendor (Perry Chemical & Mfg. Co.) did quote on providing the foamed mandrels. This is the same problem encountered previously in procuring parts for the mandrel pull tests; plastic shops do not want to be bothered with small research and development efforts. They are looking for high rate production items.

Mandrels were procured in two groups. The first group of twenty mandrels was made for the purpose of checking out the manufacturing process and foam materials. The second group of mandrels consisted of fifty "production run" items to evaluate the selected process/materials under simulated production conditions. Figure 81 is a drawing of the foamed core with a polyethylene grain former sleeve in place. The grain former sleeve forms the cavity into which the igniter is inserted. One hundred of these sleeves were made for use on the program. The mandrels were fabricated by casting into a split epoxy mold. The epoxy mold was also formed by casting epoxy around a metal core mold of the same configuration as the finished foam mandrel (see Figure 82). Polyurethane, foamed with a fluorocarbon (F-11) and water, was the selected mandrel material. Figure 83 is a photograph of a finished mandrel.

Material Evaluation

Three different density polyurethane sets of samples were received for evaluation for foam mandrels. One of the sets (7 lbs. /cu. ft.) was acceptable for test samples. Any foamed mandrel would have a molded skin which would form the propellant cavity to provide a smooth non-porous mold release surface. Since the other two sets (3 lbs. /cu. ft. and 5 lbs. /cu. ft.) did not have a molded skin on any surface, they were unacceptable for use. These two sets were evidently sawed from thick molded blocks. However, a few pieces of 5 lbs. /cu. ft. material were obtained from the vendor (Perry Chemical and Mfg. Inc., Lafayette, Indiana) with a skin on at least one of the surfaces. Tests were conducted with the 5 lbs. and 7 lbs./cu. ft. materials. Due to a shortage of the 5 lbs. /cu. ft. material the propellant bond samples could not be made.

Samples of the 5 and 7 lbs. /cu. ft. polyurethane foam mandrel materials were soaked in NHC and DOA. These tests were conducted to see if the mandrel material would absorb NHC or DOA when used with propellants containing these materials. The data shown on Tables 49 and 50 show that the 5 lbs. /cu. ft. material will absorb more NHC and DOA than the 7 lbs. /cu. ft. material. The 5 lbs. /cu. ft. material was saturated within one day, whereas, it took three days for the 7 lbs. /cu. ft. material to become saturated.

Dimensional stability and weight loss tests were conducted with the two different density foam materials. Both materials showed a slight increase in weight at $0^{o}F$ and a weight loss at $170^{o}F$. The 5 lbs. /cu. ft. material lost approximately twice as much weight as the 7 lbs. /cu. ft. material after 28 days. The weight increase at $0^{o}F$ was approximately the same for both materials (See Table 51 and 52).

The dimensional stability was measured for the length, and width for samples of the 5 and 7 lbs./cu. ft. density materials. Change in the thickness of the samples appears to be greater than for the width of the samples. There is no appreciable difference in the measurements after 28 days than at 7 days (See Table 51 and 52). A visual inspection of the samples after storage at +170°F showed blistering and warpage (bow) of the rectangular samples.

A limited amount of data was obtained for the 5 and 7 lbs./cu. ft. density polyurethane foam material. Tensile stress and strain were measured at three temperatures and compressive strength at 77°F (See Table 53). The tensile strength of the 7 lbs./cu. ft. material is three times that of the 5 lbs./cu. ft. material.

Due to the limited amount of polyurethane material available for testing, propellant to foam mandrel material test could be made only with the 7 lbs./cu. ft. density material. Three adhesion samples were prepared for each of three spray on mold releases for testing. One set of samples were made as a control which did not use any mold release. The polyurethane materials were sprayed with the mold releases approximately one hour before being cast with TP-H8266 propellant after propellant cure samples were tested at 77°F (See Table 54). The data shows that the propellant stuck to the foam mandrel material in all cases. It appears that the samples coated with IMS and MS-122 mold releases failed at a slightly lower load than the control and the set coated with Crown 6075.

<u>Conclusions (Material Evaluation)</u>

The conclusions reached from the data obtained from this evaluation are as follows:

1) Polyurethane foam mandrel material will absorb NHC and DOA.

2) Polyurethane foam will expand ≈5-10% when heated from room temperature to 170°F depending upon density and direction of the material.

3) The foam mandrel materials will increase in weight (absorption of moisture) at 0°F and lose weight at +170°F.

4) The foam mandrel material will blister and warp at 170°F.

5) Tensile stress for the 7 lbs./cu.ft. density material is 222 psi and 70 psi for the 5 lbs./cu. ft. material. Strain is approximately the same for both materials 1.8 and 1.4%, respectively.

6) TP-H8266 propellant bonds well to the foam mandrel material (polyurethane with no mold release).

7) The mold release evaluated appears to be relatively ineffective as a propellant release agent to polyurethane. The adhesion failures were in the propellant (32 psi) or bond and propellant at 50 - 60 psi.

8) Based on conclusions 1 (absorption tests) and 6 (propellant bond tests) above, polyurethane used against propellant as a mandrel material should be coated with a release agent and/or barrier material.

Dimensional Inspection

Results of dimensionally inspecting the first two polyurethane foamed mandrels were compared with those from the metal mandrel used as a mold former. Table 55 lists the inspection station results for all three pieces. The slight changes in dimensions of the foamed parts from the metal part are not considered to be of any consequence.

All of the first twenty prototype mandrels had varying degrees of subsurface voids or bubbles; some with voids which opened to the surface. Also, the four head end extensions on some of the mandrels were twisted or warped out of shape. However, six mandrels with especially good workmanship/appearance/quality were selected for use in the 50-gallon mix loading of TX707 motors. The remaining mandrels were acceptable for evaluation of storage life, bakeout tests, etc.

Information concerning the generally poor quality of the mandrels was passed on to the fabricator - Perry Chemical. Quality of the fifty "production run" mandrels was considerably better than the initial prototype group. The bubble or blister problem was eliminated and the protrusions on the grain former end of the mandrel were straight and untwisted.

Process Engineering Cost Comparison

Process engineering studies to compare costs of loading motors with foamed, leave-in-place disposable mandrels versus removable, reusable mandrels were conducted. Figure 84 is an assembly drawing of a removable metal mandrel concept for loading TX707 motors. Figure 85 shows the finished loaded case. The design uses a conventional Teflon coated steel mandrel approach with a rope and rubber "bulb" for casting the aft propellant configuration. The cost difference between manufacturing motors using foamed, leave-in-place disposable mandrels versus removable, reusable mandrels was determined as discussed below.

A methodology for developing the recurring and non-recurring costs for comparing the use of reusable hard tooling with the use of disposable plastic tooling was established during the original program effort. It was used to compare the costs for both the 2.75-inch and the Viper rocket motor concepts. A similar approach was used to evaluate the cost of using "hard" or reusable, tooling for the FFR motor concept.

First, a set of assumptions was developed for defining the motor production process, at least to the extent that the casting tooling was affected. These assumptions are given below, with discussions where applicable.

1. Production rates to be considered are 50,000 and 100,000 rounds per year. For simplification, these rates are approximations of the total motors produced, and include rounds for static test and reject allowances. Actual delivery quantities would be 3 to 5% less, depending on Quality Assurance and net production allowance requirements. The rates may also be adjusted slightly up or down to conform to normal or projected mix quantities.

2. The finished propellant grain weight is approximately 55 lbs.

3. Motors will be vacuum cast six at a time in a special vacuum casting bell. The cores will be in place during casting. Casting waste will be minimized by controlling the excess material cast into the casting sleeve, but will be about 4 lbs. per motor.

4. The propellant viscosity and the casting process will be such that the bell can be cycled every 35 minutes.

5. A 420-gallon propellant mix, of TP-H8266 propellant, of 6120 lbs. will be used, with a 94% utilization factor.

6. TP-H8266 is a delayed quick-cure composition having a usable potlife of 7 to 8 hours after cure agent addition.

7. Approximately 2 1/2 hours will elapse between cure agent addition and the start of casting of the first bell full of motors.

8. Multiple casting bells will be used as needed, to make maximum use of the propellant mix size within the potlife limitations.

9. Motors will be sufficiently cured, after two days at 170°F, to allow cores to be removed.

10. After completion of cure, motors will require about 16 hours of cool-down prior to core removal.

11. If required, cores will be extracted from motors immediately after cool-down, and at a rate comparable to, or faster than, the casting rate.

12. A minimum surge time of two hours is required between core extraction and reinstallation in a new motor casting assembly. This allows for clean-up, drying, inspection for defects, and forwarding to the motor assembly area.

13. Assembly of a core into a motor assembly, plus metal parts preheat prior to casting, requires a minimum of 5 hours.

14. Cores will be refurbished (re-Tefloned) after average uses of 20 or 60 times.

15. Time allocations for production jobs will be based on a maximum useful work period of 400 minutes per shift.

16. Non-recurring costs for cores will be allocated over periods of one to six years.

17. For the cost comparison, only the costs associated with the core itself and with the rope/rubber core bulb will be considered. All other tooling and processing costs will be assumed to be the same.

18. Labor costs will be based only on the non-exempt (hourly paid employees) effort required to perform the specific task.

19. For the reusable cores, allowances will be provided both for irreparable damage (0.1%) during handling, and for spares during refurbishment (based on refurbishment capabilities).

20. Spares for refurbishment will be based loosely on the average uses before refurbishment, but will be specified on the basis of actual refurbishment process capabilities.

21. Casting tooling, except for the core assemblies, will be the same for both the foam core and the reusable hard cores.

22. The core bulb for the reusable core may be made either of rope and RTV rubber, for removal after tooling disassembly, or of foam plastic for leave-in-place.

Based on these assumptions, calculations were then made to estimate the propellant mix size, casting time and turn-around cycle, and, from these, the number of mixes required per year. It was estimated that 96 motors could be cast per mix, using the 420-gallon vertical mixer, and roughly 10 mixes per week would be required to approximate a production rate of 50,000 rounds per year. Likewise, some 20 mixes per week would be required to approach the production rate of 100,000 rounds per year. Even at a full 52 weeks per year, these conditions do not quite reach the nominal values of 50,000 and 100,000 rounds, however, the difference is less than 0.2%. Massaging all the assumptions to squeeze one extra motor out per mix was felt to be unnecessary and unjustified. The actual yearly production numbers used were therefore 49,920 motors per year at the lower rate and 99,840 at the higher rate.

Tooling turn-around cycles were estimated from the assumed casting and cure schedules, motor finishing operations, and tooling cleaning requirements. It was determined that a reusable core could be returned to service in slightly over 3 calendar days if all materials, components, and operations moved with "clockwork precision." Assuming the nominal 50,000 round/year operations to be done primarily on a 2/8/5 (shifts per day/hours per shift/days per week) schedule basis, some seven sets of tooling, or 672 cores, plus spares, are required. The higher production rate operations, necessitating a 3/8/7 schedule basis, requires ten complete sets, or 960 cores, plus spares to meet the production needs.

The operations required to refurbish the Teflon surface of the cores were then studied to estimate the labor and materials costs, and to establish realistic refurbishment processing rates. The time and motion information used to cost the 2.75 inch and Viper motor concepts were used, and the processing rate established for the Viper core, based on the relative sizes and complexities, was felt to be directly applicable to the FFR mandrel. Crew labor requirements of either 0.9412 manhours per core refurbished were developed, depending on the refurbishment crew concept used. The high labor requirement is associated with using one man per shift to process at the nominal rate of 8 1/2 cores per shift. On a one shift per day basis, some 51 cores are in process at any one time. Changing to three shifts per day increases the nominal rate to 25 1/2 cores per day, but the number in process at any one time increases only to 68. The lower labor requirement is associated with seven-man crews with the capability of processing at the nominal rate of 62 cores per shift. On a one shift per day basis, some 372 cores are in process at any given time. Increasing the work schedule to 3 shifts per day increases the nominal production rate to 162 cores per day, while the number in process at any time goes to 434. It was assumed that initial application of Teflon finish to the cores would involve only 0.6452 manhours per core.

The quality of cores that must be procured, and, therefore, amortized over the production period being considered, is the sum of the numbers of cores in motor manufacture, in refurbishment operations, and held in stores against possible irreparable damage. As the irreparable damage allowance rate is only 0.1% of the basic operating quantities, only one extra core is needed for either nominal production rate. Allowances for refurbishment involve comparing the actual refurbishment rate capabilities of specific crew concepts with the assumed nominal values of 20 to 60 motor casting uses between refurbishment. The spares allowances are then determined by selecting the actual rate that is closest to the nominal. The information given in Table 56 was selected by this method for the four nominal production conditions being studied.

Procurement quantities were determined to be as follows:

Nominal Yearly Production Rate	Nominal Uses Before Refurbishment	Initial Procurement Quantity
50,000	20	1045
50,000	60	741
100,000	20	1395
100,000	60	1333

As noted in a later discussion, the above-noted quantities were used in nearly all the subsequent cost calculations, even though, in some cases, larger numbers of metal parts were actually assumed to have been purchased.

Refurbishment costs, as well as the cost of initially applying Teflon finish, involve both labor and materials. The primer and finish coat (2 coats) materials required were estimated from the surface area of the core design itself, and from FEP Teflon application standards. Materials costs were obtained from the February 23, 1979, issue of the Thiokol Supply Catalog, which lists the following procurement costs:

FEP Primer Cat. No. 28-5388-060	$18.24 per quart
FEP Green Finish Cat. No. 26-5388-100	$85.66 per gallon

From these values, a materials cost of $4.2974 per application of Teflon finish per core was calculated. Labor costs were subsequently adjusted to the same overhead burden basis before being added to the materials costs.

The final data required to compute the non-recurring cost of the core for the reusable tooling concept is the initial procurement cost of the metal core body itself. A preliminary cost estimate was obtained from Brindlee Mountain Machine Shop as follows:

$300 each in quantities of 750
$275 each in quantities of 1100
$260 each in quantities of 1400

The quotation quantities were specified before the spares allowance calculations were completed, with the result that they are all slightly larger than the final procurement quantities that evolved. Consideration was given to simply using the nearest quoted price without any adjustment, but the decision was ultimately made to either adjust the prices by assuming the actual quoted quantity would be procured, or to use the next higher quote for the computed procurement quantity, whichever was smaller. Thus, for the 741 core calculated procurement quantity, 750 would actually be procured at $300 each, for a total of $225,000. This results in an adjusted procurement cost of $303.64 each for the 741 cores actually put into use. In a similar manner, the adjusted procurement costs for the remaining three quantities were determined to be:

$289.47 each for 1045 cores
$273.07 each for 1333 cores
$260.93 each for 1395 cores

Non-recurring costs could then be calculated for each of the four production conditions according to the following general equation:

$$C = \frac{(a + b + d)\,q}{r \cdot y}$$

where C = non-recurring cost, per use
a = procurement cost per core
b = labor cost per core to apply initial Teflon finish
d = materials cost per core to apply initial Teflon finish
q = procurement quantity
r = actual yearly production rate
y = years of production at rate "r"

However, other items of tooling for the motor manufacturing operation involve potential non-recurring cost elements, so detailed cost calculations were delayed until the overall process was analyzed further.

The leave-in-place foam core concept provides several benefits that come from the design of the foam core itself. They include a self-contained nozzle closure/environmental seal, a built-in stress-relief/core centering bulb, and a support for the lead wires to the igniter assembly. The reusable tooling concept motor design includes the stress-relief/core centering bulb, as either a destructible rope/rubber part or a leave-in-place foam plastic part, but does not include either a nozzle closure or a support for the igniter leads. An effort was therefore made to estimate the costs involved in providing all three items or features. These items potentially involve both recurring and non-recurring costs, depending on whether they are produced in-house or purchased from a supplier.

First, an estimate was made of the cost of core bulbs made from RTV silicone rubber and rope. This technique, though expensive, has been used extensively in the fabrication of slot formers and other "captive" cavity-forming components that must ultimately be removed from the rocket motor prior to final assembly. The shape and size of the required bulb is very similar to one being made for another motor, so accurate cost data was readily available. Unfortunately, the labor involved is intensive, and the materials quite high. The recurring cost was estimated to be $50.10 per bulb, while the non-recurring cost allocatable to each bulb on a one year production period at 50,000 rounds per year nominal would be on the order of $4.74. The rope/rubber manufacturing technique was therefore abandoned in favor of a leave-in-place foam plastic part. This approach had the added advantage of also providing the nozzle closure/environmental seal for the rocket motor.

A foam plastic manufacturing operation was considered, using single-cavity waxed molds, and an automated mix/pour dispensing machine. Procurement costs were developed for the molds, but costs for the dispensing machine were not included. For the nominal 50,000 round/year production plan, the non-recurring cost was estimated to be $31,627 overall, or $0.6336 per motor for a one year production period at 49,920 rounds/year actual production rate. For the 100,000 rounds/year nominal production rate, the overall non-recurring cost is doubled, but the allocated cost per motor is the same. The recurring costs of labor and materials were estimated to be $2.6137 per bulb manufactured. These were felt to be reasonable costs for use in the cost analysis.

The support for the igniter lead wires was assumed to be a hollow cylinder fitting in the central cavity of the motor, and extending from the core bulb back to the igniter cavity. The support would be molded from foam plastic material in the same manner as the core bulbs, using single cavity molds. The non-recurring costs, for the molds were estimated to be $18,507 overall for the nominal 50,000 rounds/year condition, and twice that for the 100,000 rounds/year rate. The allocatable cost for either is therefore $0.3707 per support for a one year production period. The recurring costs of labor and materials were estimated to be $2.6982 per support manufactured.

Non-recurring costs were then calculated, assuming a one year production period, for the four motor manufacturing conditions under study. Included were the costs of the cores themselves, as previously discussed, and the molds for the core bulbs and wire supports. The results were:

Nominal Yearly Production Rate	Nominal Uses Before Refurbishment	Non-recurring cost per Motor Produced
50,000	20	$7.3276
50,000	60	$5.6982
100,000	20	$4.8259
100,000	60	$4.8181

Conversion of the above costs to any other production period simply involves dividing the cost by the production period, in years.

A motor manufacturing operations sequence was established to identify the differences between the leave-in-place foam core concept and the reusable hard tooling concept, particularly those differences that affect the manufacturing costs. The basic assumption is that all components and tooling items were either procured to specification, or the costs of inspection and acceptance are included in the procurement costs. The two operations sequences are as follows:

Reusable Hard Tooling	Leave-in-Place Foam Cores
1. Obtain usable core	1. Obtain usable core
2. Obtain usable core bulb, & install on core	N/A
3. Obtain case and rest of tooling	2. Obtain case and rest of tooling
4. Assemble tooling	3. Assemble tooling
5. Cast and cure motor	4. Cast and cure motor
6. Cool assembly to ambient	5. Cool assembly to ambient
7. Pull core	6. Pull core support rod
8. Inspect and clean core	N/A
9. Refurbish core or return to line for reuse	N/A
10. Disassemble casting tooling	7. Disassemble casting tooling
11. Pull out core bulb (if rope/RTV)	N/A
12. Finish forward end of grain	8. Finish forward end of grain
13. Obtain and install support for igniter wires	N/A
14. Install igniter, with wires run through support	9. Install igniter with wires run through foam core
15. Install forward closure	10. Install forward closure
16. Install nozzle closure (if rope/ RTV bulb is used)	N/A

As discussed earlier, the rope/rubber concept of core bulb manufacture was eliminated as being too expensive, so steps 11 and 16 of the Reusable Hard Tooling process sequence can be eliminated. This leaves only four specific operations that are required only by the reusable hard tooling concept. All the other operations are similar enough for the two manufacturing concepts that the costs should be essentially the same. As the intent of this cost study is to establish only incremental costs for comparison of the concept costs, rather than by developing the complete motor manufacturing costs, only those four particular operations were studied further.

The first operation required only by the reusable tooling concept is to obtain a usable core bulb and install it on the core. Recurring and non-recurring costs for manufacturing foam plastic bulbs were developed earlier, so only the costs related to installation of the bulb on the core need be considered here. It was assumed that this involves sliding the bulb down over the core stud, then painting a thin ring of adhesive around the region where the bulb will contact the nozzle entrance cone. It was estimated that one minute of labor should be allowed for each motor assembled. The next specific operation is to obtain and install the support for the igniter lead wires. Again, manufacturing costs were already described earlier, so only the installation labor was considered here. Assuming that a thin ring of adhesive must be painted on the end surface of the support, then the support inserted into the motor cavity until it seats against the core bulb, an allowance of one minute of labor per motor was included for this operation. The next operation is to inspect and clean the core after it was removed from the motor. As for the Viper and 2.75-inch rocket motor cost comparisons for the original scope of work, it was assumed that core cleaning and handling would be done in semi-automated cleaning equipment such that "hands-on" labor would be limited to about one minute per motor. Visual inspection of each core was assumed to add one more minute of labor. The final operation that must be considered is to refurbish the core or return it to the line for reuse. The labor and materials costs involved in this operation have already been described earlier in this report. Therefore, the net additional recurring labor costs to be added to those previously developed is four minutes of labor per motor produced, or 0.0667 manhours per motor produced, or $0.8567 per motor produced.

Summing up the various recurring cost increments, from fabrication of the core bulbs and wire supports, from the core refurbishment operations, and from the specific motor manufacturing labor operations described above, gives the following:

Nominal Yearly Production Rate	Nominal Uses Before Refurbishment	Net Recurring Cost Per Motor Produced
50,000	20	$6.8912
50,000	60	$6.4778
100,000	20	$7.1622
100,000	60	$6.5068

These recurring costs and the previously calculated non-recurring costs are summarized and combined in Table 57, to give net costs per motor produced, for production periods of one to six years. The net cost per use data were also plotted, as shown in Figure 86, to give a visual indication of the effect that production period has on the four process conditions studied.

Motor Manufacture

Six TX707 motors were successfully loaded from a 50-gallon mix of TP-H8266 propellant (Mix W-90). Radiographic inspection of the motors revealed several small voids randomly scattered in each motor but the voids are of no consequence relative to motor performance.

A single TX707 motor had been loaded on another program and had encountered two problems: (1) the polyethylene grain former sleeve had collapsed during propellant cure and was oval in cross section rather than circular and (2) propellant had bonded to two foamed core tips for about half the length of the motor. Both problems were eliminated from the 50-gallon loading by (1) filling the grain former sleeves with silicone rubber and (2) applying an extra heavy coating of mold release agent to the foamed mandrels.

The six loaded cases were prepared for assembly and delivered to MICOM, along with eighteen of the "production run" foamed mandrels.

CONCLUSIONS

The net per use cost for reusable tooling, as compared to the procurement cost per leave-in-place foam core, varies from a low of about \$7.30 up to over \$14.20 depending upon the conditions attainable and/or contracted for. Thus, using a leave-in-place (disposable) polyurethane foamed mandrel with unit costs of \$7.60, \$7.10, and \$6.60 for quantities of 10,000, 20,000 and 50,000 units per year, respectively, (exclusive of support rod costs) is a less expensive motor loading concept than reusable tooling for short periods of production (four years or less). The net per use cost for reusable tooling approaches the unit cost for disposable mandrels at the longer production periods. Thus, the leave-in-place foam concept may be the lowest cost approach for short periods of production and is definitely a viable alternate to the frequently used rope-and-rubber grain former approach.

CONTRIBUTORS

The following Thiokol personnel contributed significantly to the program and to the preparation of this report:

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TABLE 1

EXPLORATORY EVALUATION OF MOLD RELEASE MATERIALS TO POLYURETHANE MANDREL MATERIAL

Mold Release	Tensile Adhesion psi	Mode of Failure[1]
CTF- Compounded TFE	66	2 B
Crown 6075 -Dry Fluorocarbon	43	2 B
IMS-Pure Silicone Spray	56	2 B
MS-122-Fluorocarbon	33	2 B
Poly-Lease 77-Polyethylene	78	1 B, 1 P
Fluoroglide-Fluorocarbon	40	2 TCP
MR-221 - Solvent/Silicone	81	2 P
Johnson Wax - Petroleum Wax Paste	80	2 P

(1) The number of samples and the mode of failure are indicated:

P = propellant
B = bond
TCP = thin coat of propellant

TABLE 2

LIST OF CANDIDATE DISPOSABLE MANDREL MATERIAL

Polyethylene (high density, HDPE) Fiberfil	Ethofil G90/40 (40% glass filled)
Polypropylene Fiberfil LNP	Profil G60/40 (40% glass filled) MFX-1008 (40% glass filled)
Polycarbonate G. E. LNP	Lexan 101 (unfilled) Lexan (40% glass filled) DF-1006 FR (40% glass filled)
Polypropylene oxide G. E. LNP	Noryl SE-100 (unfilled) Noryl GFN3 (30% glass filled) ZF-1006 (30% glass filled)
Acetal Fiberfil	Formaldafil AL-80/ TF/44 (TFE-Glass)
Phenolic Reichold Chemical	RCI 25406 (cellulose filled)
Nylon	Zytel 101 Minlon 10B-40 (mineral filled)
Acrylonitrile Borg-Warner	Cycopac 920
Thermoplastic polyester (PTMT or PBT) Eastman's "Tenite" LNP	6 PRO (unfilled) 6 H91 (20% glass reinforced) WF-1006 FR (30% glass reinforced)
Polyester (thermoset)	HATCO GR 14021
Melamine Fiberite	M2015 (cellulose filled) M2840 (glass filled)

TABLE 3

LIST OF PROPERTIES

Property	Table No.
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TABLE 4. SPECIFIC GRAVITY/DENSITY

Ranking	Specific gravity, ρ (lb/in^3) Representative Value	Material: Kind	Material: Grade
1	0.65 (0.023)	Polypropylene (PP-G-F)	Foam, 30% Glass Filled
2	0.80 (0.029)	Polyphenylene Oxide (PPO)	Structural Foam
3	0.90 (0.032)	Polypropylene (PP)	Unfilled
4	1.20 (0.033)	Thermoplastic Polyester (PTMT-G)	Structural Foam
5	0.95 (0.034)	Polyethylene	High density (HDPE)
6	1.08 (0.039)	Polyphenylene oxide (PPO)	Modified
7	1.13 (0.041)	Polypropylene (PP-G-F)	30% Glass Filled
8	1.13 (0.041)	Polythelene (HDPE)	30% Glass Filled
9	1.13 (0.041)	Nylon 6 (PA) Polyamide	Unmodified
10	1.20 (0.043)	Polycarbonate (PC)	Unfilled
11	1.34 (0.048)	Thermoplastic polyester (PTMT)	Unfilled
12	1.39 (0.050)	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled

TABLE 4. SPECIFIC GRAVITY/DENSITY (Continued)

Specific gravity, ρ (lb/in^3)		Material	
Ranking	Representative Value	Kind	Grade
13	1.42 (0.051)	Polyacetal (POM)	Homopolymer
14	1.49 (0.054)	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
15	1.83 (0.066)	Magnesium (AZ91)	Die Cast (Mg)
16	6.64 (0.24)	Zinc (SAE 903)	Die Cast (Zn)

TABLE 5. TENSILE STRENGTH, kg/cm^2 (ksi)

Tensile Strength		Material	
Ranking	Representative Value	Kind	Grade
1	2800 (41)	Zinc (SAE 903)	Die Cast (Zn)
2	2100 (30)	Magnesium (AZ91)	Die Cast (Mg)
3	780 (11.1)	Nylon 6 (PA) Polyamide	Unmodified
4	710 (10.1)	Polyacetal (POM)	Homopolymer
5	710 (10.1)	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
6	620 (8.8)	Polycarbonate (PC)	Unfilled
7	620 (8.8)	Polyphenylene oxide (PPO)	Modified
8	580 (8.2)	Thermoplastic polyester (PTMT)	Unfilled
9	540 (7.8)	Polypropylene (PP-G)	30% Glass Filled
10	500 (7.1)	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled
11	480 (7.0)	Polyethylene (HDPE)	30% Glass Filled
12	430 (6.3)	Thermoplastic Polyester (PTMT-T)	Structural Foam
13	350 (5.0)	Polypropylene (PP)	Unfilled

See Figure 1

TABLE 5. TENSILE STRENGTH, kg/cm^2 (ksi) (Continued)

Tensile Strength		Material	
Ranking	Representative Value	Kind	Grade
14	310 (4.4)	Poly: hylene	High density (HDPE)
15	230 (3.3)	Polypropylene Oxide (PPO-F)	Structural Foam
16	230 (3.3)	Polypropylene (PP-G-F)	Foam, 30% Glass Filled

TABLE 6. TENSILE ELASTIC MODULUS, kg/cm^2 (10^5 psi)

Tensile elastic modulus		Material	
Ranking	Representative Value	Kind	Grade
1	985,000 (140)	Zinc (SAE 903)	Die Cast (Zn)
2	100,000 (65)	Magnesium (AZ 91)	Die Cast (Mg)
3	95,000 (13.5)	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
4	90,000 (12.8)	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled
5	71,000 (10.0)	Polypropylene (PP-G)	30% Glass Filled
6	58,000 (8.2)	Thermoplastic polyester (PTMT-F)	Structural Foam
7	37,000 (5.3)	Polyacetal	Hompopolymer
8	34,000 (5.0)	Polyethylene (HDPE-G)	30% Glass Filled
9	29,000 (4.3)	Polypropylene (PP-G-F)	Foam, 30% Glass
10	26,000 (3.7)	Polyphenylene oxide (PPO)	Modified
11	23,000 (3.3)	Polycarbonate (PC)	Unfilled

TABLE 6. TENSILE ELASTIC MODULUS, kg/cm^2 (10^5 psi) - Continued

Tensile elastic modulus		Material	
Ranking	Representative Value	Kind	Grade
12	20,000 (2.8)	Thermoplastic polyester (PTMT)	Unfilled
13	17,000 (2.4)	Nylon 6 (PA) Polyamide	Unmodified
14	14,000 (2.3)	Polyphenylene Oxide (PPO-F)	Structural Foam
15	13,000 (1.8)	Polypropylene (PP)	Unfilled
16	8,000 (1.1)	Polyethylene	High density (HDPE)

TABLE 7. ELONGATION, %

Elongation		Material	
Ranking	Representative Value	Kind	Grade
1	650	Polyethylene	High density (HDPE)
2	450	Polypropylene (PP)	Unfilled
3	200	Nylon 6 (PA) Polyamide	Unmodified
4	175	Thermoplastic polyester (PTMT)	Unfilled
5	115	Polycarbonate (PC)	Unfilled
6	50	Polyacetal	Homopolymer
7	55	Polyphenylene oxide (PPO)	Modified
8	15	Polyphenylene oxide (PPO-F)	Structural foam
9	5	Magnesium (AZ91)	Die Cast (Mg)
10	3	Zinc (SAE 903)	Die Cast (Zn)
11	3.0	Polyethylene (HDPE-G)	30% Glass Filled
12	2.3	Thermoplastic Polyester (PTMT-F)	Structural Foam
13	2.0	Polypropylene (PP-G)	30% Glass Filled
14	1.2	Polypropylene (PP-G-F)	Foam, 30% Glass
15	0.8	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
16	0.6	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled

TABLE 8. DEFLECTION TEMPERATURE, °C (°F) 18.5 kg/cm^2 (264 psi) FIBER STRESS

Deflection temperature		Material	
Ranking	Representative Value	Kind	Grade
1	182 (360)	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
2	179 (360)	Thermoplastic Polyester (PTMT-F)	Structural Foam
3	168 (334)	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled
4	156 (295)	Polypropylene (PP-G)	30% Glass Filled
5	135 (275)	Polycarbonate (PC)	Unfilled
6	129 (260)	Polyethylene (HDPE-G)	30% Glass Filled
7	124 (255)	Polyacetal (POM)	Homopolymer
8	115 (239)	Polyphenylene oxide (PPO)	Modified
9	114 (238)	Polypropylene (PP-G-F)	Foam, 30% Glass Filled
10	82 (180)	Polyphenylene Oxide (PPO-F)	Structural Foam
11	68 (154)	Nylon 6 (PA) Polyamide	Unmodified
12	68 (154)	Thermoplastic polyester (PTMT)	Unfilled
13	56 (133)	Polypropylene (PP)	Unfilled
14	49 (120)	Polyethylene	High density (HDPE)

TABLE 9. THERMAL EXPANSION, 10^{-5} cm/cm/°C (10^{-5} in/in °F)

Thermal expansion		Material	
Ranking	Representative Value	Kind	Grade
1	1,200 (7.2)	Polyethylene	High density (HDPE)
Ref.	900 (5.25)	Propellant	TP-H8208 (Reference)
2	830 (4.8)	Nylon 6 (PA) Polyamide	Unmodified
3	810 (4.5)	Polyacetal (POM)	Homopolymer
4	800 (4.5)	(PP-G-F) Polypropylene	Foam, 30% Glass Filled
5	800 (4.2)	Polypropylene (PP)	Unfilled
6	780 (3.3)	Thermoplastic polyester (PTMT)	Unfilled
7	660 (3.6)	Polycarbonate (PC)	Unfilled
8	520 (3.3)	Polyphenylene oxide (PPO)	Modified
9	400 (2.7)	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
10	390 (2.2)	Polyethylene (HDPE-G)	30% Glass Filled
11	380 (2.1)	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled

TABLE 9. THERMAL EXPANSION, 10^{-5} cm/cm/°C (10^{-5} in/in °F) - (Continued)

Thermal expansion		Material	
Ranking	Representative Value	Kind	Grade
12	370 (2.1)	Polypropylene (PP-G)	30% Glass Filled
13	275 (1.5)	Zinc (SAE 903)	Die Cast (Zn)
14	250 (1.4)	Magnesium (AZ91)	Die Cast (Mg)
Ref.	250 (1.3)	Aluminum	2024-T3 (Reference)

TABLE 10. EFFECT OF ORGANIC SOLVENTS

Effect of organic solvents		Material	
Rank	Evaluation	Kind	Grade
1	No change	Polyacetal (POM)	Homopolymer
2	No change	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
3	Substantially no change	Nylon 6 (PA) Polyamide	Unmodified
4	Substantially no change	Thermoplastic polyester (PTMT)	Unfilled
5	A small change	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled
6	A small change	Polycarbonate (PC)	Unfilled
7	A small change	Polyethylene	High density (HDPE)
8	A small change	Polypropylene (PP)	Unfilled
Ref.	Remarkable change	Acrylonitrile butadiene styrene (ABS)	High-impact
9	Remarkable change	Polyphenylene oxide (PPO)	Modified
Ref.	Remarkable change	Polystyrene (PS) Reference	Impact-resistant, Heat-resistant
Ref.	Remarkable change	Polyurethane (PU)	Cast grade, Unsaturated

TABLE 11. WATER ABSORPTION, % 24 HRS, 3.2 mm (0.125 in) THICK

Water absorption		Material	
Ranking	Representative Value	Kind	Grade
1	0.01	Polyethylene	High density (HDPE)
2	0.02	Polypropylene (PP)	Unfilled
3	0.03	Polypropylene (PP-G)	30% Glass Filled
4	0.03	Polyethylene (HDPE-G)	30% Glass Filled
5	0.07	Polyphenylene oxide (PPO)	Modified
6	0.09	Thermoplastic polyester (PTMT)	Unfilled
7	0.17	Polycarbonate (PC)	Unfilled
8	0.25	Polyacetal (POM)	Homopolymer
Ref.	0.33	Acrylonitrile butadiene styrene (ABS)	High heat-resistant
Ref.	0.33	Polystyrene (PS)	Impact-resistant, Heat resistant
9	0.35	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
10	0.75	Phenol-formaldehyde resin	Woodflour and cotton flock filled
11	1.6	Nylon 6 (PA) Polyamide	Unmodified

TABLE 12. MOLD (LINEAR) SHRINKAGE, %

Mold (linear) shrinkage		Material	
Ranking	Representative Value	Kind	Grade
1	0. 5	Polyethylene (HD)	30% Glass Filled
2	0.5	Polypropylene (PP-G)	30% Glass Filled
3	0.6	Thermoplastic Polyester (PTMT)	Structural Form
4	0.6	Phenol-formaldehyde resin (PF-C)	Woodflour and cotton flock filled
5	0.6	Polyphenylene oxide (PPO)	Modified
6	0.6	Polycarbonate (PC)	Unfilled
7	0.7	Polyphenylene Oxide (PPO-F)	Structural Foam
8	1.0	Nylon 6 (PA) Polyamide	Unmodified
9	1.0	Melamine-formaldehyde resin (MF-C)	Alpha cellulose filled
10	1.2	Polypropylene (PP-G-F)	Foam, 30% Glass Filled
11	1.7	Thermoplastic polyester (PTMT)	Unfilled
12	1.7	Polypropylene (PP)	Unfilled
13	2.2	Polyacetal (POM)	Homopolymer
14	3.5	Polyethylene (PE)	High density (HDPE)

TABLE 13. MATERIAL COSTS

Cost Rank	Material	ρ (lb/in^3)	Cost ($/in^3)
1	Polypropylene (PP)	0.032	0.008
2	Polyethylene (HDPE)	0.034	0.010
3	Polypropylene (PP-G-F) Foam, 30% Glass	0.023	0.017
4	Polypropylene (PP-G), 30% Glass	0.041	0.020
5	Polyethylene (HDPE-G), 30% Glass	0.043	0.022
6	Polyester (PTMT-F) Foam	0.039	0.035
7	Polyphenylene Oxide (PPO)	0.039	0.038
8	Polyamide (Nylon) (PA)	0.041	0.044
9	Polyacetal (POM)	0.051	0.045
10	Polycarbonate (PC)	0.043	0.047
11	Polyester (PTMT)	0.047	0.051
12	Magnesium (AZ91)	0.066	0.059
13	Zinc (SAE 903)	0.24	0.105

TABLE 14

ABSORPTION TEST

Sample Type and Condition	Percent Weight Change				
	24 Hours	96 Hours	216 Hours	336 Hours	504 Hours
(1) No Coating in DOA					
TEF/ALUM	0.0059	+0.0094	0.0130	-0.0024	0.0012
Polyphenylene	0.0827	0.1480	0.1960	0.1524	0.1785
Polypropylene	0.0524	0.1258	0.1626	0.1416	0.1363
Polyethylene	0.1612	0.2633	0.3439	0.3546	0.3976
Polycarbonate	0.0549	0.1857	0.2322	0.0675	0.1393
G-10 Phenolic	0.1452	0.1589	0.1616	0.1425	0.1507
Nylon	0.0553	0.0978	0.1786	0.1403	0.1616
Acetol	0.0492	0.0584	0.0738	0.0861	0.1168
(2) No Coating in NHC					
TEF/ALUM	0.0049	0.0168	0.0178	0.0049	0.0099
Polyphenylene	0.1107	0.1660	0.2043	0.1873	0.1873
Polypropylene	0.0202	0.0656	0.1212	0.0404	0.0858
Polyethylene	0.1548	0.3204	0.3417	0.3310	0.0404
Polycarbonate	0.0931	0.1378	0.1750	0.1638	0.1564
G-10 Phenolic	0.1509	0.1729	0.2112	0.2030	0.1591
Nylon	0.0426	0.0681	0.1235	0.1405	0.1704
Acetol	0.0402	0.0345	0.0669	0.0345	0.0736
(3) No Coating in IPDI					
TEF/ALUM	-0.0148	-0.0210	0.0012	-0.0185	-0.0086
Polyphenylene	0.0428	0.1241	0.1541	0.3509	0.1712
Polypropylene	-0.0311	0.0000	0.0570	0.0104	0.0311
Polyethylene	0.1334	0.2028	0.2455	0.2028	0.2882
Polycarbonate	0.0488	0.2969	0.5002	0.6466	0.7198
G-10 Phenolic	0.1719	0.1446	0.1774	0.1637	0.1282
Nylon	0.1360	0.1488	0.1743	0.1360	0.1743
Acetol	-0.0407	-0.0250	0.0125	-0.0344	-0.0156

TABLE 14. (Continued)

ABSORPTION TEST

Sample Type and Condition	Percent Weight Change 24 Hours	96 Hours	216 Hours	336 Hours	504 Hours
(4) No Coating in DOA					
TEF/ALUM	-0.2045	-0.2132	-0.2120	-0.2332	-0.2295
Polyphenylene	-0.3802	-0.3311	-0.2616	-0.3025	-0.2698
Polypropylene	-0.7891	-0.7484	-0.6618	-0.7025	-0.6516
Polyethylene	-0.1149	-0.0109	0.0658	-0.0274	0.0109
Polycarbonate	-0.6019	-0.5854	-0.1368	-0.5854	-0.5772
G-10 Phenolic	-0.1076	-0.1159	-0.1352	-0.1711	-0.2208
Nylon	-0.2692	-0.2339	-0.2295	-0.2781	-0.2604
Acetol	-0.0796	-0.0918	-0.0735	-0.0857	-0.0980
(5) Coated W/IMS in NHC					
TEF/ALUM	-0.2196	-0.2196	-0.2216	-0.2361	-0.2216
Polyphenylene	-0.4739	-0.4348	-0.4087	-0.4391	-0.3261
Polypropylene	-0.6964	-0.6859	-0.6388	-0.7016	-0.5759
Polyethylene	-0.2640	-0.3071	-0.2586	-0.2219	0.1401
Polycarbonate	-0.6162	-0.5754	-0.5223	-0.5754	0.5183
G-10 Phenolic	-	-0.0357	-0.0768	-0.1372	-0.0274
Nylon	-0.2619	-0.3233	-0.3396	-0.3478	-0.3028
Acetol	0.1351	0.1532	0.1321	0.1261	0.1862
(6) Coated W/MS-122 in DOA					
TEF/ALUM	-0.0137	-0.0205	-0.0264	-0.0361	-0.0322
Polyphenylene	-0.0426	-0.0170	0.0213	-0.0426	0.0085
Polypropylene	-	-0.1525	-0.1067	-0.1372	-0.1016
Polyethylene	0.0374	0.0640	0.1494	0.0960	0.1174
Polycarbonate	-0.1594	-0.1293	-0.1638	-0.2413	-0.1378
G-10 Phenolic	0.2049	0.1366	0.0792	0.0109	0.1338
Nylon	0.1342	0.1082	0.0563	0.0260	0.0692
Acetol	-0.0486	-0.0334	-0.0426	-0.0790	-0.0334

TABLE 14. (Continued)

ABSORPTION TEST

Sample Type and Condition	Percent Weight Change 24 Hours	96 Hours	216 Hours	336 Hours	504 Hours
(7) Coated W/MS-122 in NHC					
TEF/ALUM	-0.0023	-0.0113	-0.0045	-0.0113	-0.0057
Polyphenylene	0.1136	-0.0095	-0.0426	-0.0426	-
Polypropylene	-0.0970	-0.1991	-0.1582	-0.2093	-0.1786
Polyethylen	0.2349	0.0107	0.0587	0.0534	0.0801
Polycarbonate	0.0161	-0.1649	-0.1729	-0.2051	-0.1649
G-10 Phenolic	0.1396	0.1150	0.0602	0.0657	0.0088
Nylon	0.2148	0.0816	0.1460	0.1[illegible]32	0.1675
Acetol	0.0792	0.0264	0.0462	0.0198	0.0528
(8) Coated W/Crown 6075DOA					
TEF/ALUM	-0.0018	-0.0073	-0.0036	-0.0228	-0.0082
Polyphenylene	0.1056	0.1233	0.1453	0.1056	0.2025
Polypropylene	-0.0868	-0.1447	-0.1061	-0.1833	-0.1447
Polyethylene	0.1537	0.1537	0.2086	-0.2416	0.2635
Polycarbonate	-0.0170	-0.0723	-0.0809	-0.0723	-0.0553
G-10 Phenolic	0.2195	0.1536	0.1070	0.0640	0.1207
Nylon	0.2150	0.0331	0.0538	0.0496	0.0538
Acetol	0.0675	-0.0064	0.0386	0.0289	0.0358
(9) Coated W/Crown 6075 in NHC					
TEF/ALUM	0.0118	0.0108	0.0162	0.0097	0.0162
Polyphenylene	0.1598	0.1093	0.1514	0.1346	0.1640
Polypropylene	0.0405	-0.0506	-0.0608	-0.1114	0.1093
Polyethylene	0.1708	0.1578	0.2241	0.2081	0.2615
Polycarbonate	0.0384	0.0940	0.0726	-	0.1068
G-10 Phenolic	0.2814	0.2400	0.2317	0.1324	0.1876
Nylon	0.2253	0.1828	0.2331	0.2083	0.2551
Acetol	0.1360	0.0998	0.1300	0.0967	0.1360

TABLE 14. (Continued)

ABSORPTION TEST

Sample Type and Condition	Percent Weight Change 24 Hours	96 Hours	216 Hours	336 Hours	504 Hours
(10) Coated W/EA-934 in DOA					
TEF/ALUM	0.0510	0.0683	0.0879	0.0900	0.3706
Polyphenylene	0.1068	0.1602	0.2237	0.2337	0.3004
Polypropylene	0.8484	1.9847	2.4415	2.8216	2.8954
Polyethylen	0.4625	1.0528	1.2596	1.4701	1.5453
Polycarbonate	0.1186	0.1714	0.2472	0.2109	0.2834
G-10 Phenolic	0.0937	0.1326	0.1577	0.1714	0.1897
Nylcn	0.1869	0.1869	0.2416	0.2243	0.2502
Acetol	0.0926	0.1228	0.1586	0.1970	0.2225
(11) Coated W/EA-934 in NHC					
TEF/ALUM	0.0323	0.0364	0.0636	0.0677	0.0950
Polyphenylene	0.1114	0.1283	0.2025	0.2262	0.3207
Polypropylene	1.3444	2.3788	2.7619	3.2530	3.2913
Polyethylene	0.3501	0.9191	1.3209	1.7307	1.7586
Polycarbonate	0.0993	0.1026	0.1754	0.1887	0.2615
G-10 Phenolic	0.954	0.1022	0.1568	0.1704	0.2250
Nylon	0.1093	0.1027	0.1856	0.2518	0.2850
Acetol	0.2129	0.2340	0.2948	0.3299	0.3813
(12) Coated W/EA-9309 in DOA					
TEF/ALUM	0.0709	0.0946	0.1024	0.1033	0.1208
Polyphenylene	0.2713	0.3550	0.4488	0.4756	0.4789
Polypropylene	0.3937	0.5118	0.5826	0.6299	0.6574
Polyethylene	0.4183	0.5086	0.5332	0.5865	0.6480
Pclycarbonate	0.2833	0.2638	0.3354	0.3517	0.3940
G-10 Phenolic	0.2279	0.1988	0.2521	0.2376	0.2909
Nylon	0.2116	0.2284	0.3224	0.3459	0.3997
Acetol	0.1556	0.1939	0.2430	0.2239	0.2430

TABLE 14. (Continued)

ABSORPTION TEST

Sample Type and Condition	Percent Weight Change 24 Hours	96 Hours	216 Hours	336 Hours	504 Hours
(13) Coated W/EA-9309 in NHC					
TEF/ ALUM	0.1319	0.1949	0.2202	0.1455	0.2541
Polyphenylene	0.4373	0.5364	0.6936	0.7243	0.8268
Polypropylene	0.4272	0.5499	0.6527	0.6527	1.1868
Polyethylene	0.4767	0.2844	0.5018	1.9571	2.0616
Polycarbonate	0.3276	0.4038	0.4699	0.4832	0.5593
G-10 Phenolic	0.2361	0.3050	0.3616	0.3689	0.3960
Nylon	0.3098	0.4594	0.5235	0.5342	0.5698
Acetol	0.2221	0.3156	0.3660	0.3736	0.4342
(14) Coated W/EA-919 in DOA					
TEF/ALUM	0.0348	0.0577	0.0995	0.1114	0.1422
Polyphenylene	0.1072	0.1833	0.3147	0.3665	0.4564
Polypropylene	0.1072	0.1833	0.3147	0.3665	0.4564
Polypropylene	0.1104	0.2165	0.4160	0.4712	0.5688
Polyethylene	0.1334	0.2102	0.3355	0.3961	0.5295
Polycarbonate	0.1205	0.1883	0.3276	0.3728	0.4482
G-10 Phenolic	0.0752	0.1103	0.2182	0.2257	0.2909
Nylon	0.1227	0.2021	0.3501	0.4331	0.5053
Acetol	0.0884	0.1434	0.2727	0.3064	0.4020
(15) Coated W/EA-919 in NHC					
TEF/ALUM	0.0405	0.0608	0.1081	0.1329	0.1667
Polyphenylene	0.1051	0.1331	0.2557	0.3083	0.3959
Polypropylene	0.1172	0.1423	0.3139	0.3892	0.4939
Polyethylene	0.1299	0.2254	0.3820	0.5106	0.6073
Polycarbonate	0.0945	0.1308	0.2653	0.3234	0.4506
G-10 Phenolic	0.0671	0.0745	0.1615	0.1963	0.2758
Nylon	0.0956	0.1381	0.2792	0.3505	0.4992
Acetol	0.1062	0.1206	0.2297	0.2728	0.3819

TABLE 15

PHYSICAL PROPERTIES OF CANDIDATE MANDREL MATERIALS

Material	Stress (psi)/Strain (%) -65°F	77°F	100°F	145°F	170°F
Polyphenylene	8154/5.6	7305/9.1	5950/11.5	4908/12.9	4564/31.1
Polypropylene	10281/4.8	4120/22.3	3562/28.0	2807/27.4	2302/26.4
Polyethylene	6861/11.5	3301/16.1	3002/21.3	2050/40.4	1723/36.0
Polycarbonate	11861/15.0	8228/4.2	6898/7.7	6950/6.7	6646/7.5
G-10 Phenolic	41294/7.0	41294/4.6	36116/5.1	34455/5.1	35642/4.4
Nylon	11439/5.1	8116/31.4	7594/37.1	6087/42.3	5980/45.0
Acetal	15039/16.1	10706/22.8	9244/21.5	8379/36.9	———

TABLE 16

EVALUATION OF MANDREL MATERIALS FOR DOA PROPELLANT DTS-8338 (2.75" MOTOR)

Mandrel Material	Mold Release	Coatings	% Absorption of DOA @ 336 Hrs.	Tensile Strength @ 77°F Stress (psi)	Tensile Strength @ 77°F Strain (%)	Adhesion to Propellant Avg. (psi)	Adhesion to Propellant Range	Approximate Cost $/in³
Teflon/Aluminum	None		-.0024			45	35 - 51	
	IMS		-.2332					
	MS-122		-.0361					
	Crown 6075		-.0228					
		EA-934	.0900					
		EA-9309	.1033					
		EA-919	.1114					
Polyphenylene	None		.1524	7305	9.1	80	76 - 85	.10
	IMS		-.3025					
	MS-122		-.0426			38	36 - 40	
	Crown 6075		.1056			71	65 - 75	
		EA-934	.2337					
		EA-9309	.4756					
		EA-919	.3665					
Polypropylene	None		.1416	4120	22.3	55	50 - 62	.04
	IMS		-.7025					
	MS-122		-.1372			36	36 - 36	
	Crown 6075		-.1833			41	39 - 43	
		EA-934	2.8216					
		EA-9309	.6299					
		EA-919	.4712					
Polyethylene	None		.3546	3301	16.1	51	47 - 57	.03
	IMS		.0274					
	MS-122		.0960			40	35 - 44	
	Crown 6075		-.2416			44	42 - 46	
		EA-934	1.4701					
		EA-9309	.5865					
		EA-919	.3967					
Polycarbonate	None		.0675	8228	4.2	70	64 - 74	.13
	IMS		-.5854					
	MS-122		-.2413			36	23 - 47	
	Crown 6075		-.0723			50	46 - 57	
		EA-934	.2109					
		EA-9309	.3517					
		EA-919	.3961					
G-10 Phenolic	None		.3728	41,294	4.6	85	81 - 88	.12
	IMS		-.1711					
	MS-122		.0109			64	61 - 66	
	Crown 6075		.0640			69	59 - 83	
		EA-934	.1714					
		EA-9309	.2376					
		EA-919	.2257					
Nylon	None		.1403	8116	31.4	20	18 - 23	.06
	IMS		-.2781					
	MS-122		.0260			29	24 - 33	
	Crown 6075		.0496			16	13 - 19	
		EA-934	.2243					
		EA-9309	.3459					
		EA-919	.4331					
Acetal	None		.0861	10,706	22.8	79	73 - 87	.08
	IMS		-.0857					
	MS-122		.0790			65	57 - 76	
	Crown 6075		.0289			82	79 - 85	
		EA-934	.1970					
		EA-9309	.2239					
		EA-919	.3064					

TABLE 17

EVALUATION OF MANDREL MATERIALS AND MOLD RELEASES FOR NHC PROPELLANT (VIPER)

Mandrel Material	Mold Release	Coatings	% Absorption of NHC After 336 Hrs.	Tensile Strength @ 77°F Stress (psi)	Tensile Strength @ 77°F Strain (%)	Adhesion to TP-H8248 Avg. (psi)	Adhesion to TP-H8248 Range	Approximate Cost $/in³
Teflon/Aluminum	None		.0049			36	0.36	
	IMS		-.2361					
	MS-122		-.0113					
	Crown 6075		.0097					
		EA-934	.0677					
		EA-9309	.1455					
		EA-919	.1329					
Polyphenylene	None		.1873	7305	9.1	99	98 - 100	.10
	IMS		.4391					
	MS-122		-.0426			38	0 - 41	
	Crown 6075		.1346			73	60 - 95	
Polypropylene	None		.0404	4120	22.3	49	0 - 59 *2nd	.04
	IMS		.7016					
	MS-122		-.2093			14	0 - 16	
	Crown 6075		-.1114			28	20 - 41	
Polyethylene	None		.3310	3301	16.1	46	32 - 64	.03
	IMS		.2219					
	MS-122		.0534			22	13 - 34	
	Crown 6075		.2081			15	13 - 18	
Polycarbonate	None		.1638	8228	4.2	2	73 - 92	.13
	IMS		.5754					
	MS-122		.2051			0	0 - 0	
	Crown 6075		---			34	28 - 44	
G-10 Phenolic	None		.2030	41,294	4.6	129	121 - 142	.12
	IMS		.1372					
	MS-122		.0657			0	0 - 0 *1st	
	Crown 6075		.1324			106	93 - 127	
Nylon	None		.1405	8116	31.4	44	0 - 53	.06
	IMS		.3478					
	MS-122		.1532			31	24 - 36	
	Crown 6075		.2083			58	0 - 58	
Acetal	None		.0345	10,706	22.8	76	74 - 76	.08
	IMS		.1261					
	MS-122		.0198			31	0 - 57	
	Crown 6075		.0967			56	53 - 61	

Decisions: 1a. Delete epoxy coatings from further testing. Will absorb more than plastic with no coating.
b. Delete IMS mold release from further testing. High absorption.
2a. All tensile properties look good. Continue test with all mandrel materials.
3a. Select G-10 Phenolic/MS-122.
b. Select polypropylene for further testing with no coating.

TABLE 18

MANDREL PULL TEST

LOADING PLAN

2.75" (SEAS) Motor Propellant

Mix #1

No. of TX-395's	Mandrel Material/Coating
2	Aluminum/Teflon*
2	Polypropylene/Bare
2	Polypropylene/MS122
2	PTMT (Polyester)/Bare
2	PTMT (Polyester)/MS122
2	Nylon/Bare
2	Nylon/MS122 or Crown
14	

Mix #2

No. of TX-395's	Mandrel Material/Coating
2	Aluminum/Teflon*
2	Polypropylene/Bare
2	Polypropylene/MS122**
2	PTMT (Polyester)/Bare
2	PTMT (Polyester/MS122
2	Nylon/Bare
2	Nylon/MS122 or Crown
14	

Viper Motor Propellant	Mandrel Material/Coating
No. of TX 395's	Mandrel Material/Coating
4	Aluminum/Teflon
4	Phenolic G-10/MS122
4	Aluminum/Teflon/IMS

* Standard test - Conventional method

TABLE 19

INJECTION MOLDED CORE MANDREL, P/N 55222, DIMENSIONAL SURVEY

Material	Length			O.D.		I.D.		t_{wall}		
	Ave.							Ave.		
	Method	Method II	Range	Ave.	Range	Ave.	Range	Method I	Method II	Range
Nylon	5.346	5.352	±0.014	1.490	±0.010	1.184	±0.006	0.153	0.155	±0.003
Phenolic	5.375	5.365	±0.029	1.493	±0.011	1.186	±0.005	0.154	0.154	±0.006
Polyester	5.337	5.333	±0.024	1.485	±0.012	1.180	±0.005	0.152	0.155	±0.003
Propylene	5.347	5.350	±0.015	1.486	±0.008	1.187	±0.007	0.150	0.147	±0.003

NOTE: All dimensions in inches, at room temperature.
(Nylon) Zytel 101, E. I. duPont deNemours Co., Inc.
(Polypropylene) Tenite 421E, Eastman Chemical Products, Inc.
(Polyester) Valox 310, General Electric Co.
(Phenolic) SI 111 Black, 18 plasticity, Durez Plastics Division of Hooker Chemicals and Plastics Corporation.

TABLE 20

COMPARISON OF DIE AND PART (R-55222) DIMENSIONS

Material - Measurement / Dimension	Measurement (in.)		Ave. Shrinkage		Measurement (in.)	Ave. Shrinkage		Measurement (in.)	Ave. Shrinkage		Measurement (in.)	Ave. Shrinkage	
	Die	Nylon	(in.)	(%)	Phenolic	(in.)	(%)	Polyester	(in.)	(%)	Propylene	(in.)	(%)
Length	5.435	5.346	0.089	1.6	5.375	0.060	1.1	5.337	0.098	1.8	5.347	0.088	1.6
O.D.	1.5.1	1.490	0.021	1.4	1.493	0.018	1.2	1.485	0.026	1.7	1 486	0.025	1.6
I.D.	1.200	1.184	0.016	1.3	1.186	0.014	1.2	1.180	0.020	1.7	1.187	0.013	1.1
t_{wall}	0.156	0.15	0.003	1.9	0.154	0.002	1.3	0.152	0.004	2.6	0 150	0.006	3.8

TABLE 21

TX-395 MOTORS WITH DISPOSABLE PLASTIC CORES - DISASSEMBLY

				Core Pulling Operations			Visual Examination of Surfaces After Pulling	
Mix No.	Charge No.	Propellant Designation[a]	Core Type	Maximum Force, Pounds[b]	Time Seconds[c]	Conditions Encountered	Motor Cavity	Core
16Q-602[d]	1	DTS-8623	Teflon-coated steel	175	8.0	No problems	Not examined	Not examined
16Q-602[d]	2	"	"	313	8.7	No problems	Not examined	Not examined
16Q-607[g]	1	TP-H8248	"	185	2.3	No problems	Good. Some minor roughness.	Good
16Q-607[g]	3	"	"	255	3.0	No problems	Good	Good
16Q-607[g]	5	"	"	180	2.8	No problems	Good	Good
16Q-607[g]	9	"	"	172	2.6	No problems	Good	Good
16Q-607[g]	7	"	Teflon-coated steel with IMS spray	31	2.6	No problems	Excellent. Shiny surface.	Good
16Q-607[g]	8	"	"	35	1.9	No problems	Excellent. Shiny surface.	Good
16Q-607[g]	10	"	"	28	2.1	No problems	Excellent. Shiny surface.	Good
16Q-607[g]	11	"	"	39	2.3	No problems	Excellent. Shiny surface.	Good
16Q-607[g]	2	"	Phenolic with MS-122	270	2.6	No problems	Good	Good
16Q-607[g]	4	"	"	178	2.3	No problems	Good	Good. Film of propellant on fwd. cone.
16Q-607[g]	12	"	"	250	2.8	No problems	Good	Good
16Q-607	6[e]	"	"	N/A	N/A	Not pulled; for delivery to MICOM	N/A	N/A
16Q-609[g]	1	DTS-8338	Teflon-coated steel	223	3.5	No problems	Good	Good
16Q-609[g]	5	"	"	388	3.3	No problems	Good	Good
16Q-609[g]	8	"	"	181	3.3	No problems	Good	Good
16Q-610[g]	9	"	"	161	3.0	No problems	Good	Good
16Q-609[g]	2	"	Polypropylene	448	9.8	Pulled with sustained load	Slightly rough where core sanded	Thin film of propellant on fwd. cone
16Q-609[g]	6	"	"	428	19.7	Pulled with sustained load	Slightly rough where core sanded	Good
16Q-609[g]	10	"	"	447	7.5	Pulled with sustained load	Slightly rough where core sanded	Thin film of propellant on fwd. cone

TABLE 21 (Continued)

Mix No.	Charge No.	Propellant Designation[a]	Core Type	Core Pulling Operations: Maximum Force, Pounds[b]	Core Pulling Operations: Time Seconds[c]	Core Pulling Operations: Conditions Encountered	Visual Examination of Surfaces After Pulling: Motor Cavity	Visual Examination of Surfaces After Pulling: Core
16Q-609[g]	4	DTS-8338	Polypropylene with MS-122	406	2.6	No problems	Some rough areas.	Thin film of propellant on fwd. cone. Non-sticky residues on cylindrical wall.
16Q-609[g]	7	"	"	316	6.6	No problems	Good	Thin film of propellant on fwd. cone. Non-sticky residues on cylindrical walls.
16Q-610[g]	3	"	"	416	1.2	No problems	Fairly good; some roughness where core sanded.	Thin film of propellant on fwd. cone.
16Q-610[g]	8	"	"	420	3.8	No problems	Good	Thin film of propellant on fwd. cone. Sticky residues on cylindrical walls.
16Q-609	3	"	Nylon	402	7.3	No problems	Very rough. Unsuitable for ballistic use.	Sticky surface, with propellant residues all over.
16Q-610	1	"	"	470	3.5	Wrench would not engage on first attempt. No problems using better wrench.	Very rough. Unsuitable for ballistic use.	Sticky surface, with propellant residues all over.
16Q-610	10	"	"	437	5.2	No problems	Very rough. Unsuitable for ballistic use.	Sticky surface, with propellant residues all over.
16Q-610	4	"	Nylon with MS-122	389	3.8	No problems	Very rough. Unsuitable for ballistic use.	Sticky surface, with heavy propellant residues all over.
16Q-610	5[e]	"	"	N/A	N/A	Not pulled; for delivery to MIRADCOM.	N/A	N/A
16Q-610	11	"	"	384	6.1	No problems	Very rough on one side. Unsuitable for ballistic use.	Sticky surface, with heavy propellant residues all over.
16Q-610	12	"	"	385	4.4	No problems	Very rough on one side. Unsuitable for ballistic use.	Sticky surface, with heavy propellant residues all over.
16Q-609	9	"	PTMT	459	53.4	Did not pull initially under sustained load of 430 to 459 lbs.		
				453	121.6	Did not pull in 2nd attempt under sustained load of 430 to 453 lbs.		
				1003	41.5	Pulled under sustained load of 975 to 1003 lbs. on 3rd attempt.	Very rough and scarred up. Unsuitable for ballistic use.	Non-sticky residues all over cylindrical walls. Thin film of propellant on fwd. cone. All aft sprues stuck on cylindrical walls.
16Q-610	2	"	"	418	69.6	Did not pull initially under sustained load of 402 to 418 lbs.		

TABLE 21 (Continued)

Mix No.	Charge No.	Propellant Designation[a]	Core Type	Core Pulling Operations: Maximum Force, Pounds[b]	Time Seconds[c]	Conditions Encountered	Visual Examination of Surfaces After Pulling: Motor Cavity	Core
16Q-610	2	DTS-8338	PTMT	469	113.9	Did not pull in 2nd attempt under sustained load of 420 to 448 lbs.		
				993	36.1	Pulled under sustained load of 960 to 993 lbs. on 3rd attempt.	Very rough and scarred up. Unsuitable for ballistic use.	Sticky residues all over surfaces of core. All aft sprues stuck on cylindrical walls.
16Q-609[g]	11	"	PTMT with MS-122	425	28.4	Pulled under sustained load of 415 to 425 lbs.	Fairly good	Sticky surface residues. Thin film of propellant c. fwd. cone and one aft sprue on cylindrical wall.
16Q-609	12	"	"	N/A	N/A	Core split open during cure.[f] Could not be pulled.	N/A	N/A
16Q-610[g]	6	"	"	417	15.2	Pulled under sustained load of 413 to 417 lbs.	Fairly good	Sticky surface residues Thin film of propellant on fwd. cone
16Q-610[g]	7	"	"	N/A	N/A	First attempts at pulling failed due to faulty wrench. Applied up to 423 lbs. but wrench slipped off twice.		
				206	2.8	With better wrench, core pulled easily on 3rd attempt. Pulling forces applied for a total of 36.1 seconds.	Fairly good	Sticky surface residues. Thin film of propellant on fwd. cone.

NOTES:
a. DTS-8623 is a GSRS-type composition. TP-H8248 is Viper propellant composition. DTS-8338 is SEAS propellant composition.
b. Maximum force applied, as recorded from strain gage load cell reading.
c. Time from application of pulling force until core removed, as taken from recorder chart.
d. These motors used to check out pulling force measurement system.
e. These two motors set aside for delivery to MIRADCOM for pulling cores per 3.1.7 of Program Plan.
f. Plastic split through threaded section, allowing core cap to come loose completely. Will have to be soaked out.
g. Selected for static test to obtain ignition and ballistic data.

TABLE 22
TX395 BALLISTIC DATA
MANDREL PULL TEST STUDY

Mix No./Chg.	Core Type	TSPR, sec.	T500, sec.	T9090, sec.	PMAX, psig	P9090, psig
SEAS Propellant						
16Q609-1	Teflon/Stl.	0.0125	0.025	0.4268	1129.4	1080.8
16Q609-5	Teflon/Stl.	0.0107	0.025	0.4827	1119.7	1074.3
16Q609-8	Teflon/Stl.	0.0150	0.025	0.4377	1139.8	1095.2
16Q610-9	Teflon/Stl.	0.0145	0.035	0.4737	1103.3	1048.7
16Q609-2	Polypropylene	0.0100	0.030	0.4958	1091.6	1051.4
16Q609-6	Polypropylene	0.0315	0.030	0.4930	1092.4	1050.3
16Q609-10	Polypropylene	0.0172	0.025	0.5515	1093.9	1061.1
16Q609-4	Polypr./MS122	0.0105	0.025	0.5190	1106.9	1069.2
16Q609-7	Polypr./MS122	0.0117	0.030	0.5342	1048.6	1026.2
16Q610-3	Polypr./MS122	0.0120	0.035	0.5100	1091.2	1052.8
16Q610-8	Polypr./MS122	0.0192	0.035	0.5145	1102.8	1069.6
16Q609-11	PTMT/MS122	0.0125	0.030	0.5227	1079.0	1032.5
16Q610-6	PTMT/MS122	0.0112	0.035	0.5322	1053.4	1019.5
16Q610-7	PTMT/MS122	0.0137	0.040	0.4758	1084.4	1034.5
Viper Propellant						
16Q607-1	Teflon/Stl.	0.0232	0.011	0.0225	2408.4	2330.6
16Q607-3	Teflon/Stl.	0.0312	0.016	0.0225	2388.5	2307.8
16Q607-5	Teflon/Stl.	0.3370*	0.013	0.0197	2478.0	2396.0
16Q607-9	Teflon/Stl.	0.0235	0.015	0.0217	2346.7	2265.4
16Q607-7	Teflon/Stl/IMS	0.0260	0.014	0.0230	2597.3	2517.9
16Q607-8	Teflon/Stl/IMS	0.0305	0.014	0.0235	2453.2	2375.7
16Q607-10	Teflon/Stl/IMS	0.0255	0.015	0.0220	2365.3	2289.6
16Q607-11	Teflon/Stl/IMS	0.0200	0.015	0.0227	2416.9	2331.5
16Q607-2	Phenolic/MS122	0.0332	0.035	0.0225	2419.1	2360.7
16Q607-4	Phenolic/MS122	0.0382	0.030	0.0228	2283.7	2204.0
16Q607-12	Phenolic/MS122	0.0300	0.033	0.0230	2253.2	2177.8

TSPR - time, in sec., from current application to first sustained pressure rise.
T500 - time, in sec., from first sustained pressure rise to 500 psig on the ascending portion of the pressure curve.
T9090 - time, in sec., from 90 percent pressure rise to 90 percent pressure decay.
PMAX - maximum recorded pressure, psig.
P9090 - average pressure, psig, during T9090.

*Long delay time due to squib delay, not to surface differences.

TABLE 23

SUMMARY OF PROTOTYPE (TX395) CORE/BORE MEASUREMENTS

Material	Total Avg. Bore	Bore Range	Total Avg. Core	Core Range	Avg. Gap	Gap Range
Nylon	1.504	± .0060	1.485	± .0045	0.019	± 0.004
Phenolic	1.506	± .0065	1.490	± .0025	0.015	± 0.002
Polyester	1.498	± .0135	1.482	± .0085	0.017	± 0.002
Polypropylene	1.496	± .0060	1.478	± .0085	0.018	± 0.004
Steel	1.510	± .0050	1.500	± .0045	0.010	± 0.003

TABLE 24

PRODUCTION TOLERANCES OBTAINABLE ON DRAWING R55237

(See Page 24)

TABLE 25

MELT PROCESSABLE STRUCTURAL FOAM MOLDER REPLIES (2.75 CORE) DRAWING R-55237

Jobber Identification	Production Tooling ($)	Nylon		Polypropylene		T. P. Polyester		Glass Filled Polypropylene		Comments
		6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	
Structo-Plast Co. Fountain Valley, CA	24 K	-----	-----	3.85	~1.30	-----	-----	-----	-----	4 parts from 8 cavity mold
ACME Molding Co. Inc. Houston, TX	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
American Plastics, Inc. Salt Lake City, UT	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Kaiser Ind. San Leandro, CA	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
The Valspar Corp. Rockford, IL	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Amos Molded Plastics Edinburg, IN	98.5 K	2.06	2.06	0.87	0.87	2.27	2.27	0.79	0.79	8 parts from 8 cavity mold
Amoco Chemicals Corp. St. Paul, MN	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Midland Ross Cincinnati, OH	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
S. F. Plastics, Inc. North Branch, NJ	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
The Jamison Plastic Corp. North Bellmore, NY	No reply	-----	--	-----	-----	-----	-----	-----	-----	

TABLE 26

RELATIONSHIP OF PRODUCTION RATES AND CASTING WALL THICKNESS*

Wall Thickness in (mm)	Production Rate (Casting/Hr.)
0.047 - 0.12 (1.2 - 3.0)	60 - 150
0.039 - 0.078 (1.0 - 2.0)	100 - 400
0.023 - 0.047 (0.6 - 1.2)	250 - 1000
0.012 - 0.039 (0.3 - 1.0)	500 - 1000

(6)"Materials Engineering", March 1977

TABLE 27. STATUS OF DIE CASTING JOBBER REPLIES

	Jobber Reply	
	Motor	
Jobber Identification	2.75 (R54509)	Viper (R54886)
Teledyne-ABCO Melrose Park, Ill.	Machines too small to handle one-piece casting. Would look at a 2 piece approach.	Requires longitudinal draft angle which would exceed allowable dimensions.
HBA Cast Products Springfield, Mass.	Too large for equipment	Requires longitudinal draft angle which would exceed allowable dimensions.
Peat Manufacturing Norwalk Ca.	No reply	No reply
General Die Casting Peninsular, Ohio	2 piece, longitudinally joined, or 1 piece with 1° longitudinal draft	Redesign to eliminate radial fin configuration
Specialty Die Casting Co. Gardena, Ca.	Too large for equipment	Requires longitudinal draft angle which would exceed allowable tolerances.
Universal Die Casting Saline, Mich.	Equipment is large enough part is too comple for their experience, i.e. automotive decor	Part is too complex for their experience, i.e. automotive decor
Gilbarco, Inc. Greensboro, N.C.	No reply	No reply
Stewart Warner Corp. Winston-Salem, N.C.	Equipment is large enough Part is too complex for their experience, i.e. furniture hardware	Part is too complex for their experience, i.e. furniture hardware

TABLE 28

METHODOLOGY FOR LOW COST/DISPOSABLE MANDREL

COMPRESSION/TRANSFER/INJECTION (C, T, IM) THERMOSET MOLDER REPLIES (2.75 CORE) DRAWING R55284

Jobber Identification	Production Tooling ($)	G.P. Phenolic		I. M. Phenolic		Melamine		Alkyd		Comments
		6.0×10^5 ($/Unit)	3.0×10^5 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^5 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^5 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^5 ($/Unit)	
LEPCO Plastics, Inc. 303 Knowlton Street Bridgeport, Ct. 06608 203-333-1581										
Olympic Plastics Co., Inc. 5800 T West Jefferson Blvd. L. A. Ca. 90016 213-837-5321										
S. C. I. 600 S. Mem. Pkwy. Huntsville, Al. 35802 205-536-1611										
TCM&E P.O. Box 515 (Hwy. 43, So) Tuscumbia, Al. 205-381-3271										
Milross Controls, Inc. 711 2nd St. Pike Southampton, Pa, 18966 215-355-0200										
Starglo Industries, Inc. 4 Carlton Ave. East Rutherford, N.J. 07073 201-939-6162										
Garfield Manufacturing Co. 12 Midland Ave. Garfield, N.J., 07026 201-777-5700										
Custom Molded Prod. Midland-Ross 10607 Chester Road Cincinnati, Oh 45215 513-772-1313										
American Insulator Corp. NSA New Freedom, Pa. 17349 717-235-3831										
Kent Molded Plastics 1275 Ethan Avenue Streetsboro, Oh. 44240 216-562-5215										
The Glastic Corp. 4319 Glenridge Cleveland, Ohio 44121 216-486-0100										

TABLE 29

THERMOSET 2.75 CORE MATERIALS COSTS

Material	Material Costs		
	$/Lb	$/In^3	Part Cost $/Unit
G. P. Phenolic	0.42	0.0209	0.31
Inj. Mold Phenolic	0.43	0.0218	0.33
Melamine	0.53	0.0283	0.42
Alkyd	0.46	0.0361	0.54
Urea	0.38	0.0203	0.30
Unsat. Ester	0.87	0.0400	0.60
Ref. Polypropylene	0.26	0.009	0.14

TABLE 30

TYPICAL THERMOPLASTIC INJECTION MOLDING CYCLE TIMES

(See Page 30)

TABLE 31

TOLERANCES ON 2.75 MOTOR CORE BY PROFILE EXTRUSION

Part No.	Material	Tolerance on Diameter (+ In)		Tolerance on Straightness (In/Length)	Thermal Wall Thickness (In)
		2.036	.846		
FR55273	Thermoplastic Polyester				
FR55673-1	Polypropylene	± 0.020	± 0.015	TBD	TBD
FR55273-2	High Density Polyethylene	± 0.030	± 0.010	0.030	0.100
FR55273-3	Nylon				
FR55273-4	Rigid P.V.C.	± 0.010	± 0.010	0.020	0.125
---	Rigid P.V.C.	± 0.020	± 0.015	0.31	0.030
---	Rigid P.V.C.	± 0.015	± 0.010	0.0625	0.045
---	Mod PPO	± 0.020	± 0.015	0.185	TBD

TABLE 32

PROFILE EXTRUDER REPLIES (2.75 AND VIPER CORES) DRAWINGS R-55273 and R-55272

Jobber Identification	Production Tooling $	Nylon 6.0 x 10^5 ($/Unit)	Nylon 3.0 x 10^6 ($/Unit)	Polypropylene 6.0 x 10^5 ($/Unit)	Polypropylene 3.0 x 10^6 ($/Unit)	T. P. Polyester 6.0 x 10^5 ($/Unit)	T. P. Polyester 3.0 x 10^6 ($/Unit)	H. D. Polyethylene (3) 6.0 x 10^5 ($/Unit)	H. D. Polyethylene (3) 3.0 x 10^6 ($/Unit)	RIGID PVC 6.0 x 105 ($/Unit)	Comments
2.75 Core											
Crane Plastics, Columbus, OH (1) Unreinforced (2) Metal Embedment	No reply	-----	-----	-----	-----	-----	-----	-----	-----	-----	
Lakeland Plastics, Inc, Bensenville, IL (1) Unreinforced (2) Wood Core	2.295 K	-----	-----	-----	-----	-----	-----	-----	-----	0.53	Finished
Plastiglide Mfg. Corp., Hawthorne, CA	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(1)
Essex International, Plainwell, MI	6.5 K	-----	-----	0.408	0.408	-----	-----	-----	-----	-----	Finished
Clare De Lune Plastics, Tuscumbia, AL	1.5 K	-----	-----	0.274	0.254	0.368	0.348	-----	-----	0.32	Extruded only (2)
Vinylex Corp., Knoxville, TN	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(4)
Custom Plastics Extr. Co. Inc., Ravenna, OH	No reply	-----	-----	-----	-----	-----	-----	-----	-----	-----	
Dande Plastics, Inc., Sommerville, NJ	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(4)
Denver Plastics, Inc., Denver, CO	1.1-2.2 K	0.43	-----	0.20	-----	0.40	-----	0.20	-----	0.28	Extruded only (2)
Adam Spence Corp., Wall, NJ	1.875 K	0.81	0.75	0.48	0.44	-----	-----	0.48	0.44	0.57	Extruded only
Petro Plastics Co., Inc., Garwood, NJ	0.75	-----	-----	-----	-----	-----	-----	-----	-----	0.26	Finished
PLEXCO, Franklin Park, IL	No costs	-----	-----	-----	-----	No costs	-----	No costs	-----	No costs	
Glass Laboratories, Inc., Brooklyn, NY	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(1)
VIPER Core											
Adam Spence Corp., Wall, NJ	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(4)
Petro Plastics Co., Inc, Garwood, NJ	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(4)
PLEXCO, Franklin Park, IL	→	→	→	→	→	→	→	→	→	→	(5)
Glass Laboratories, Inc., Brooklyn, NY	No bid	-----	-----	-----	-----	-----	-----	-----	-----	-----	(1)

(1) Does not possess capability to develop a product

(2) After product development

(3) Modified polyphenylene oxide (PPO) ex. Noryl by General Electric Co.

(4) Tolerances too tight

(5) Possible with research and development

TABLE 33

EXTRUSION BLOW MOLDER REPLIES (2.75 CORE) DRAWING R-55264

Jobber Identification	Production Tooling ($)	Nylon		Polypropylene		T. P. Polyester		H. D. Polyethylene		Comments
		6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	6.0×10^5 ($/Unit)	3.0×10^6 ($/Unit)	
Sewell Plastics, Inc. Atlanta, GA	No reply	-----	-----	-----	-----	-----	-----	-----	-----	△2
Bekum Plastics Machy. Carlstadt, NJ	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Newton Plastics Newton, NJ	No reply	-----	-----	-----	-----	-----	-----	-----	-----	△2
Electroformex Labs, Inc. Franklin, MA	No reply	-----	-----	-----	-----	-----	-----	-----	-----	△2
Air Lock Plastics, Inc. Tonawanda, NY	No reply	-----	-----	-----	-----	-----	--- -	-----	-----	△2
Advanced Plastics Hialeah, FL	4.2 K	No bid	No bid	No bid	No bid	No bid	No bid	0.48	TBD △1	1 cavity △3 mold
Mark IV Ind. Inc. Plainsville, OH	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Captive Plastics, Inc. Piscataway, NJ	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Yates Company Erie, PA	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Borse Plastics Prod. Corp. Hinsdale, IL	No reply	-----	-----	-----	-----	-----	-----	-----	-----	
Geauga Plastics Co. Crestline, OH	10.8 K	No bid	No bid	No bid	No bid	No bid	No bid	0.48	TBD	2 cavity mold

△1 To be determined

△2 Refused to reply: Parison extrusion not state-of-the-art

△3 Tolerances TBD from a development effort

TABLE 34

CHARACTERIZATION OF CASTING PROCESSES

Category	Major Alternatives	Example Possible Sub-groups
1. Propellant Grain Securement	1.1 Case-Bonded	
	1.2 External Molded	1.2.1 Cartridge, or Discrete Moldings 1.2.2 Continuous Length Extrusions
2. Core Position during Casting	2.1 In-place	2.1.1 Fixed Position 2.1.2 Movable within Fixtures 2.1.3 Sequential Assembly
	2.2 Inserted after Casting	
3. Pressure Environment	3.1 Atmospheric Pressure	
	3.2 Vacuum Assisted	
4. Propellant Entry	4.1 Through Aft Opening (Large End)	4.1.1 Submerged Bayonet 4.1.2 Fixed Nozzle Dispensing 4.1.3 Extrusion through Entire Opening
	4.2 Through Forward Opening (Small End)	

TABLE 35

BASIC CORE QUANTITIES REQUIRED, WITHOUT SPARES

(SEAS)

Production Rate, Rounds Per Year	Pot Life, Hours		8			12	
	Cure Time, Days	2	3	4	2	3	4
100,000		890	1780	1780	890	1780	1780
500,000		4010	5340	6680	3860	5340	6530

TABLE 36

INITIAL CORE PROCUREMENT QUANTITIES

(SEAS)

Nominal Average Uses Before Refurbishment	Nominal Production Rate, Rounds/Year	Pot Life, Hours / Cure Time, Days	8 / 2	8 / 3	8 / 4	12 / 2	12 / 3	12 / 4
20	100,000		996	1922	1922	996	1922	1922
	500,000		4814	6145	7487	4184	6145	7337
60	100,000		996	1887	1887	996	1887	1887
	500,000		4294	5625	7327	4144	5625	7177
100	100,000		996	1887	1887	996	1887	1887
	500,000		4154	5625	6967	4004	5625	6817

TABLE 37

PER USE COST OF REFURBISHING CORES
(SEAS)

Nominal Avg. Uses before Refurbishment	Nominal Production Rate, rds/yr	Pot Life, Hrs	8			12		
		Cure Time, Days	2	3	4	2	3	4
20	100,000		$0.3473	$0.3473	$0.3473	$0.3473	$0.3473	$0.3473
	500,000		0.3092	0.2322	0.2784	0.3213	0.2322	0.2848
60	100,000		0.3473	0.1736	0.1736	0.3473	0.1736	0.1736
	500,000		0.1028	0.0772	0.0928	0.1067	0.0772	0.0949
100	100,000		0.3473	0.1736	0.1736	0.3473	0.1736	0.1736
	500,000		0.0514	0.0772	0.0617	0.0534	0.0772	0.0631

TABLE 38

NET RECURRING COST PER MOTOR LOADED WITH REUSABLE CORES (SEAS)

Nominal Avg. Uses before Refurbishment	Nominal Production Rate Rounds/Year	Pot Life, Hrs: 8			12		
	Cure Time, Days	2	3	4	2	3	4
20	100,000	$0.5229	$0.5229	$0.5229	$0.5229	$0.5229	$0.5229
	500,000	0.4848	0.4078	0.4540	0.4969	0.4078	0.4604
60	100,000	0.5229	0.3492	0.3492	0.5229	0.3492	0.3492
	500,000	0.2784	0.2528	0.2684	0.2823	0.2528	0.2705
100	100,000	0.5229	0.3492	0.3492	0.5229	0.3492	0.3492
	500,000	0.2270	0.2528	0.2373	0.2290	0.2528	0.2387

TABLE 39

NET COST PER USE FOR FIVE YEAR PRODUCTION
(SEAS)

Nominal Avg. Uses before Refurbishment	Nominal Production Rate Rds/Year	Pot Life, Hrs.	8			12		
		Cure Time, Days	2	3	4	2	3	4
20	100,000		$0.5921	$0,6606	$0.6606	$0.5921	$0.6606	$0.6606
	500,000		0.5532	0.4951	0.5584	0.5653	0.4951	0.5627
60	100,000		0.5921	0.4797	0.4797	0.5921	0.4797	0.4797
	500,000		0.3394	0.3327	0.3706	0.3412	0.3327	0.3706
100	100,000		0.5921	0.4797	0.4797	0.5921	0.4797	0.4797
	500,000		0.2860	0.3327	0.3349	0.2859	0.3327	0.3355

TABLE 40

INITIAL CORE PROCUREMENT QUANTITIES

VIPER

Nominal Production Rate, rounds/year	Nominal Uses Before Refurbishment	Procurement Quantity for Cure Time of 2. Days	3 Days	4 Days
100,000	20	1384	1384	2631
	60	1333	1333	2614
	100	1330	1330	2614
500,000	20	5932	7275	8556
	60	5870	7151	8432
	100	5498	6779	8060

TABLE 41

REFURBISHMENT COST SUMMARY

(VIPER)

Nominal Yearly Production, rounds	Nominal Uses	Parameter Specified	Parameter Value for Cure Time of 2 Days	3 Days	4 Days
100,000	20	Cost per refurbishment	$11.2486	$11.2486	$11.2486
		Refurbishment rate, %	6.202	6.202	4.652
		Refurbishment cost per use	$0.6976	$ 0.6976	$ 0.5233
	60	Cost per refurbishment	$11.2486	$11.2486	$11.2486
		Refurbishment rate, %	3.101	3.101	1.550
		Refurbishment cost per use	$ 0.3488	$ 0.3488	$ 0.1744
	100	Cost per refurbishment	$11.2486	$11.2486	$11.2486
		Refurbishment rate, %	3.101	3.101	1.550
		Refurbishment cost per use	$ 0.3488	$ 0.3488	$ 0.1744
500,000	20	Cost per refurbishment	$10.8490	$10.8490	$10.8490
		Refurbishment rate, %	4.844	5.812	4.844
		Refurbishment cost per use	$ 0.5255	$ 0.6305	$ 0.5255
	60	Cost per refurbishment	$10.8490	$10.8490	$10.8490
		Refurbishment rate, %	2.422	1.938	1.614
		Refurbishment cost per use	$ 0.2628	$ 0.2102	$ 0.1752
	100	Cost per refurbishment	$10.8490	$10.8490	$10.8490
		Refurbishment rate, %	1.211	0.969	0.807
		Refurbishment cost per use	$ 0.1314	$ 0.1051	$ 0.0876

TABLE 42

NET RECURRING COST PER MOTOR LOADED WITH REUSABLE CORES

(VIPER)

Nominal Production Rate, rounds/year	Nominal Avg. Uses Before Refurbishment	Recurring Cost for Cure Times of 2 Days	3 Days	4 Days
100,000	20	$1.0478	$1.0478	$0.8735
	60	$0.6990	$0.6990	$0.5246
	100	$0.6990	$0.6990	$0.5246
500,000	20	$0.8757	$0.9807	$0.8757
	60	$0.6130	$0.5604	$0.5254
	100	$0.4816	$0.4553	$0.4378

TABLE 43

NONRECURRING CORE COSTS, PER USE, FOR ONE YEAR PRODUCTION
VIPER REUSABLE TOOLING MOTOR

Nominal Production Rate, Rounds/Year	Nominal Uses Before Refurbishment	Nonrecurring Cost, in Dollars, for Cure Times of 2 Days	3 Days	4 Days
100,000	20	$0.3666	$0.3666	$0.6278
	60	0.3531	0.3531	0.6238
	100	0.3523	0.3523	0.6238
500,000	20	0.2824	0.3416	0.4017
	60	0.2795	0.3357	0.3959
	100	0.2618	0.3203	0.3784

TABLE 44

NET COST PER USE FOR FIVE YEAR PRODUCTION
VIPER REUSABLE CORES

Nominal Production Rate, Rounds/Year	Nominal Uses Before Refurbishment	Net Cost, in Dollars, for Cure Times of		
		2 Days	3 Days	4 Days
100,000	20	$1.1211	$1.1211	$0.9991
	60	0.7696	0.7696	0.6494
	100	0.7695	0.7695	0.6494
500,000	20	0.9322	1.0490	0.9560
	60	0.6689	0.6275	0.6046
	100	0.5340	0.5194	0.5135

TABLE 45

TX707 MOTOR BALLISTIC DATA

	Temperature		
	-50°F	70°F	+145°F
Maximum Pressure, psia	1,280	1,553	1,774
Total Impulse, lbf-sec	12,525	12,773	12,934
Weight of Propellant, lbm	←	53.17	→
I_{sp} Del, lb/sec/lbm	235.6	240.2	243.3
t_a, sec	3.62	3.05	2.62
t_w, sec	2.41	1.95	1.66

Notes:

π_k (70° 145°) = .201%/degree F

π_k (70° -50°) = .172%/degree F

Run Sequences 46,500 (+145°F), 46,399 (+70°F) and 46,501 (-50°F)

TABLE 46

FOAMED MANDREL MATERIAL

EVALUATION AND FABRICATION

WORK STATEMENT

Basic Program

Item 1. Evaluate Freon and CO_2 blown polyurethane foams to establish a dimensionally stable foam that is compatible with R45HT polymers cured with IPDI and make recommendation to Thiokol. Mean foam densities shall fall in the range of 5 ± 2 pounds per cubic foot.

Item 2. Provide the following foam test samples for Thiokol laboratory evaluation in each of three mean densities within the range of 3 to 7 pounds per cubic foot.

Flat Plate* - 2" x 2-1/2" x 1/2"		Quantity
Density #1		15
Density #2		58
Density #3		15
	Total	88
Flat Plate* - 1" x 5" x 1/2"		
Density #1		15
Density #2		15
Density #3		15
	Total	45
Cylinder (Per Drawing R55222)		
Density #1		23
Density #2		28
Density #3		23
	Total	74

* Flat Plates may be cut from sheet stock.

TABLE 46 - Continued

Item 3. Design and fabricate a permanent, low rate production mold (500 part life) to produce mandrel parts shown in drawing SK-78-6-21-HM, revised 10 July 1978.

Item 4. Produce and deliver twenty (20) mandrels using mold fabricated under Item 3. Teflon coated rods to be supplied by Thiokol. Foam material and density to be mutually agreed to based on results of Item 1 and Thiokol evaluation of Item 2 samples. Dimensional control is to be based on dimensional inspection of mold fabricated in Item 3. Results of dimensional inspection are to be provided with the fabricated parts.

Item 5. Provide a recurring and non-recurring cost estimates to produce mandrels at rates of 1,000, 10,000 and 50,000 units per year.

Production Sample Option

Item 1. Fabricate 50 parts per drawing SK-78-6-21-HM

Item 2. Fabricate 25 flat specimens (2" x 21/2" x 1/2") and 50 cylinders per drawing R55222.

Delivery Schedule

Basic Program

Item 1 - 2 months after purchase order
Item 2 - 3 months after purchase order
Item 3 - 5 months after purchase order
Item 4 - 5 months after purchase order
Item 5 - 6 months after purchase order

Production Sample Option

Item 1 - Two months after exercise of option but no sooner than six months after purchase order.

Item 2 - With Item 1 parts.

T

LABORATORY MAN

Test Name and Number	Purpose	Foam Mandrel Specimen	Experimental Variables	Test Matrix	Special Comment
1. Propellant-Mandrel Adhesion Bond Test	Establish chemical compatibility	2" x 2-1/2" flat plate	Surface preparation. As received and "cleaned" specimens.	3 baked, 3 progressively baked and 3 not baked of both as received and cleaned. (3+3+3) x 2 = 18	Watch for indicat blistering outgas
2. Dimensional Stability	Evaluate effects of cure temperature on dimensional stability	6" long x 1" dia. cylinder	Temperature 77, 145 and 175° F.	3 specimens at each of 3 temperatures and 3 densities (3 x 3 x 3)	77° sample to be retained for long measurement.
3. Propellant-Mandrel Release Agent Tests Adhesion	Evaluate release	2" x 2-1/2" x 1/2" flat plate	Release agent	5 release agents and 5 samples each	Use bake out pro established in Te
4. Temperature Cycling	Evaluate release agent in closed configuration in TX695 case.	6" long x 1" dia. cylinder	Temperature -45 to +145	5 samples, 3 temperature cycles each sample. Extended storage on two samples at 145° F.	X-ray for casting
5 Linear Coefficient of Thermal Expansion (LCTE)	Establish LCTE	6" long x 1" dia. cylinder	Test temperature 70° F to 200° F	3 samples and 3 densities	Watch for effect loss and swelling temperature
Density	Establish average density of foams	1" x 5" x 1/2" flat plate	3 avg. densities	3 samples each density (3 x 3)	
Tensile Test	Establish tensile strength	1" x 5" x 1/2" flat plate	3 avg. densities	5 samples each density at 3 temperatures (5 x 3 x 3)	
Compressive Test	Establish compressive strength	2" x 2-1/2" x 1/2" flat plate	3 avg. densities	5 samples each, 3 densities at 3 temperatures (5 x 3 x 3)	
Outgassing	Evaluate potential for forming voids in propellant during motor manufacture.	6" long by 1" dia. cylinder	Cure temperature, pre-bakeout and density	2 cure temperatures, with and without bakeout, and 3 densities (2 x 2 x 3)	Make note of blist Control temperat rate.
Mandrel Cure Shrinkage Allowance	Evaluate mandrel dimensional cure shrinkage	6" long x 1" dia. cylinder	3 average foam densities	5 diameter measurements of one sample at each density (5 x 3)	

Notes: (1) Non-destructive test. Samples may be used for other tests after taking measurements.

(2) Use TP-H 8266 propellant.

TABLE 47

ANDREL MATERIAL EVALUATION

...ents	No. of Test Specimens	Decision	Justification	Measurement	Propellant Mixes (2)
...ications of ...gassing	18 plates 1 density	Establish if mandrels must be cleaned of vendor mold release agent.	Vendor uses mold release in fabricating mandrel. Must establish chemical compatibility and cleaning method to be used if such is required.	Weight change of baked samples and load versus deflection	1-1 gallon for 25 specimens
...e be ... long term ...t.	27 cyl. (3 densities)	Establish if vendor selected foam is stable at use temperature.	Vendor to select foam material and process. Tests needed to establish if a dimensionally stable product is produced.	Diameters - 5 locations BOW - Maximum	
...t procedure ...in Test 1, above	25 plates (1 density)	Select release agent.	Release agent needed to insure that propellant grain separates from mandrel prior to setting-up destructive forces in propellant or mandrel.	Load versus deflection	1-1 gallon
...sting voids	5 cyl. (1 density)	Establish if mandrel can be expected to release from propellant in service environment.	Failure of the mandrel to release from propellant grain in operational environment would change stress field and may lead to propellant or mandrel failure.	Visual note of propellant cylinder separation and effects and propellant bore surface properties. Change in length with temperature and weight loss.	1-gallon mix
...ffect of weight ...elling with ...e	9 cyl. (3 densities)	None	Needed to establish mandrel dimensions at time of propellant loading (propellant configuration) and to calculate "contact" with propellant under field environment.		
	9 cyl. (3 densities)	None. Data gathering	Needed for weight calculations.	Weight and volume of liquid displaced.	
	45 plates (3 densities)	None. Data gathering.	Needed for propellant stress analyses and evaluation of allowable processing loads.	Deflection vs Load	
	45 plates (3 densities)	None. Data gathering.	Same as above.	Deflection vs Load	
... of blistering. ...mperature rise	12 cyl. (3 densities)	Establish if backout required prior to motor casting operation.	Needed to identify if outgassing is a potential void problem and to see if pre-bakeout prior to propellant loading is effective in reducing gasing.	Weight loss and non-condensable gas volume generated.	
	15(1) cyl. (3 densities)	None. Data gathering.	Provide information for design of future mandrels to meet fixed ballistic requirements.	Measure sample diameter at known locations. Use mold dimensions at cure temperature and LCTE to calculate "cure shrinkage if any"	

TABLE 48

MANDREL INSPECTION PLAN

1. Measure volume displacement of core (100%) to establish reproducibility.

2. Measure bow between section D-D and E-E (100%).

3. Measure width across opposing star points at sections D-D (3.141 inches) and E-E (3.007 inches) (100%).

4. Measure mandrel foam length (36.24 inches) (100%).

5. Weigh (100%). (Thiokol supplied, teflоned rods will be serial-numbered and weighed after teflon coating so that net foam weight can be established.)

6. Dimensionally inspect one randomly selected mandrel 100% to establish general conformance to drawing SK-78-6-21-HM.

TABLE 49

ABSORPTION TEST OF POLYURETHANE

(5 lbs./cu ft)

TIME (Days)	Polyurethane Soaked in: NHC Wt Change (%)	DOA Wt Change (%)
1	+16.49	+16.59
2	+16.05	+16.94
3	+16.14	+17.20
4	+16.28	+17.39
5	+16.34	+17.56

TABLE 50

ABSORPTION TEST OF POLYURETHANE
(7 lbs./cu ft)

TIME (Days)	Polyurethane Soaked in: NHC Wt Change (%)	DOA Wt Change (%)
1	+8.73	+13.05
2	+9.25	+13.33
3	+10.38	+13.92
4	+10.42	+14.02
7	+10.47	+14.08
8	+10.46	+14.08
9	+10.46	+14.08

TABLE 51

DIMENSIONAL STABILITY AND WEIGHT LOSS

TEST FOR POLYURETHANE

(5 lbs./cu ft)

TIME (Days)	WT CHANGE (%)			DIMENSIONAL STABILITY (%)						
	0°F	77°F	170°F	0°F			77°F	170°F		
				L	W	T		L	W	T
7	+.49	0	-2.93	-.49	-.6	-4.6	No Change	+.49	-1.78	+13.4
14	+.62	-.13	-3.78	-1.0	-.3	-3.5	No Change	+.40	-.5	+10.0
21	+.27	-.10	-4.54	-1.0	-.8	-4.1	No Change	+.37	-.8	+9.4
28	+.75	-.06	-5.88	-1.0	-.2	-.77	No Change	+.35	-.5	+9.6

Visual at 0°F and 77°F - No Change
Visual at +170°F - Blistered and Warped
L = Length; W = Width; T = Thickness

TABLE 52

DIMENSIONAL STABILITY AND WEIGHT LOSS

TEST FOR POLYURETHANE

(7 lbs/cu ft Density)

TIME (Days	WT CHANGE (%)			DIMENSIONAL STABILITY (%)								
	0°F	77°F	170°F	0°F			77°F			170°F		
				L	W	T	L	W	T	L	W	T
7	+0.7	+0.17	-1.73	---------No Change---------						+4.7	+0.1	+2.6
14	+0.7	+0.04	-1.86		↓			↓		+5.3	+0.7	+5.6
21	+0.6	+0.23	-1.74							+4.0	0	+2.9
28	+0.9	+0.23	-2.16							+4.6	0	+2.7

Visual at 0° and 77°F - No Change
Visual at 170°F Material - Blistered and Warped

TABLE 53

PHYSICAL PROPERTIES OF POLYURETHANE

MATERIAL	COMPRESSIVE STRENGTH (PSI) 77°F	TENSILE PROPERTIES STRESS (PSI) -30°F	77	+170	STRAIN (%) -30	77	+170
Polyurethane 5 lbs./cu ft	71	71.7	70	40.6	0.7	1.4	4.8
Polyurethane 7 lbs./cu ft	167	156	222	103	0.8	1.8	6.4

TABLE 54

BOND OF TP-H8266 PROPELLANT TO POLYURETHANE[1]

MOLD RELEASE	TYPE	ADHESION (PSI)
NONE	----	59 (3P)
IMS	Silicone	32 (3 TCP)
MS-122	Fluorocarbon	49 (3 B&P)
Crown 6075	Fluorocarbon	60 (3 B&P)

[1] Density of Polyurethane Foam 7 lbs./cu ft.

TABLE 55

COMPARISON OF INSPECTION RESULTS FROM METAL AND FOAMED MANDRELS

Station	Metal Mandrel R56547*	Foamed Mandrel R56661** S/N 1	S/N 2
4.100 ± .010 Dia	4.107 to 4.108	4.128 to 4.150	4.128 to 4.15
1.790 ± .002 Dia	1.791	1.775	1.775
3.020 ± .010 R	ok	ok	ok
3.008 ± .010 Dia	3.003	3.018 to 3.036	3.162 to 3.16
2.136 ± .010 Dia	2.141	2.136	2.130
3.136 ± .010 Dia	3.141	3.158 to 3.168	3.162 to 3.16
.713 ± .010	.755	ok	ok
0 32' - 32" taper	ok	ok	ok

* See drawing given in Figure 84.
** See drawing given in Figure 83.

TABLE 56

SELECTED SPARES ALLOWANCES FOR CORE REFURBISHMENT

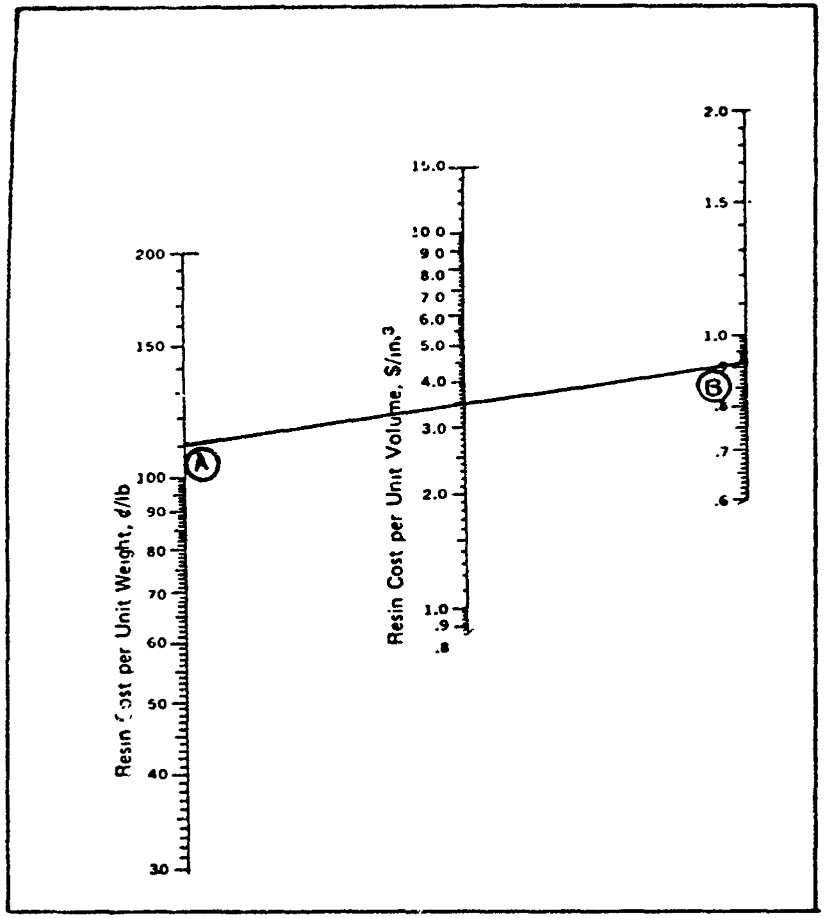
Nominal Production Conditions	50,000 rds/year		100,000 rds/year	
	20 Uses	60 Uses	20 Uses	60 Uses
Basic Operating Quantities	672	672	960	960
Nominal Daily Refurbishment Rate	67.2	22.4	145.4	48.6
Selected Refurbishment Crew				
men per crew	7	1	7	7
shifts per day	1	3	3	1
actual refurbishment rate	62	25.5	186	62
Associated Spares Allowance	372	68	434	372
Associated Refurbishment Labor, manhours per core	0.9032	0.9412	0.9032	0.9032
Actual Uses Between Refurbishment	22	53	16	47

TABLE 57

RECURRING, NONRECURRING, AND NET PRODUCTION COSTS*

Total Production Period, Years	1	2	3	4	5	6
Nominal 50,000 Rounds/Year, 20 uses Before Refurbishment						
Nonrecurring Cost	$7.3276	$3.6638	$2.4425	$1.8319	$1.4655	$1.2213
Recurring Cost	6.8912	6.8912	6.8912	6.8912	6.8912	6.8912
Net Cost per Motor Produced	$14.2188	$10.5550	$9.3337	$8.7231	$8.3567	$8.1125
Nominal 50,000 Rounds/Year, 60 Uses Before Refurbishment						
Nonrecurring Cost	$5.6982	$2.8491	$1.8994	$1.4246	$1.1396	$0.9497
Recurring Cost	6.4778	6.4778	6.4778	6.4778	6.4778	6.4778
Net Cost per Motor Produced	$12.1760	$9.3269	$8.3772	$7.9024	$7.6174	$7.4275
Nominal 100,000 Rounds/Year, 20 Uses Before Refurbishment						
Nonrecurring Cost	$4.8259	$2.4130	$1.6086	$1.2065	$0.9652	$0.8043
Recurring Cost	7.1622	7.1622	7.1622	7.1622	7.1622	7.1622
Net Cost per Motor Produced	$11.9881	$9.5752	$8.7708	$8.3687	$8.1274	$7.9665
Nominal 100,000 Rounds/Year, 60 Uses Before Refurbishment						
Nonrecurring Cost	$4.8181	$2.4090	$1.6060	$1.2045	$0.9636	$0.8030
Recurring Cost	6.5068	6.5068	6.5068	6.5068	6.5068	6.5068
Net Cost Per Motor Produced	$11.3249	$8.9158	$8.1128	$7.7113	$7.4704	$7.3098

* Differential cost, for comparison purposes only.



Structural Foam Cost Analysis Nomogram ⚠1

Property	Equation
Tensile Strength	$T_{foam} = T_o \left(\frac{\rho_{foam}}{\rho_o}\right)^2$
Modulus	$E_{foam} :: E_o \left(\frac{\rho_{foam}}{\rho_o}\right)^{3/2}$

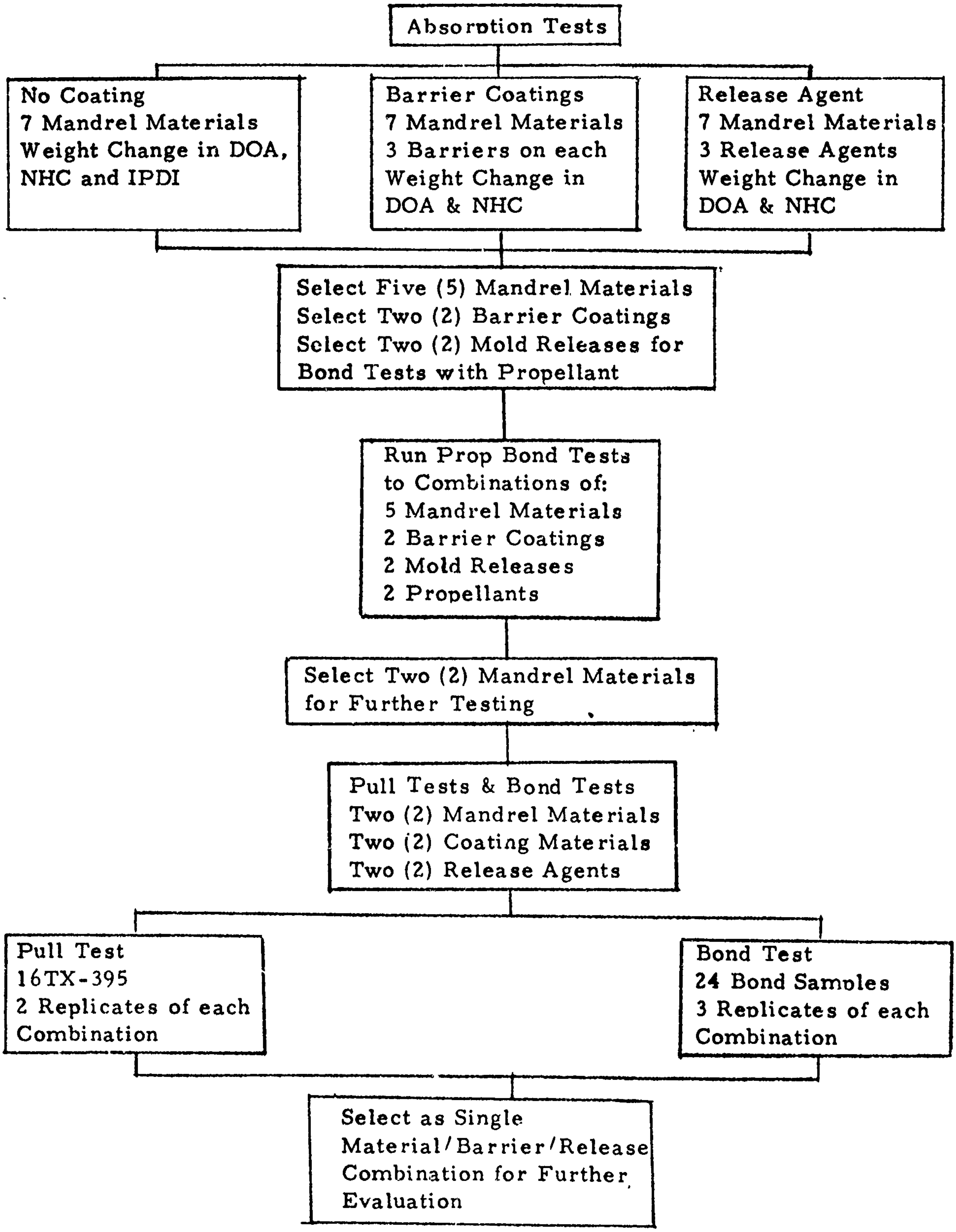
Calculated Structural Foam Properties, Ref. Throne, J. L., p. 20-23 Plastics Design and Processing, Sep. 1976.

⚠1 Technical Information Report, M-158, Hercules, Inc. Feb. 1976.

Figure 1. Cost and Properties Calculations

Figure 2

BLOCK DIAGRAM OF TESTS FOR THE SELECTION OF MANDREL MATERIAL BARRIER COATINGS AND RELEASE AGENTS



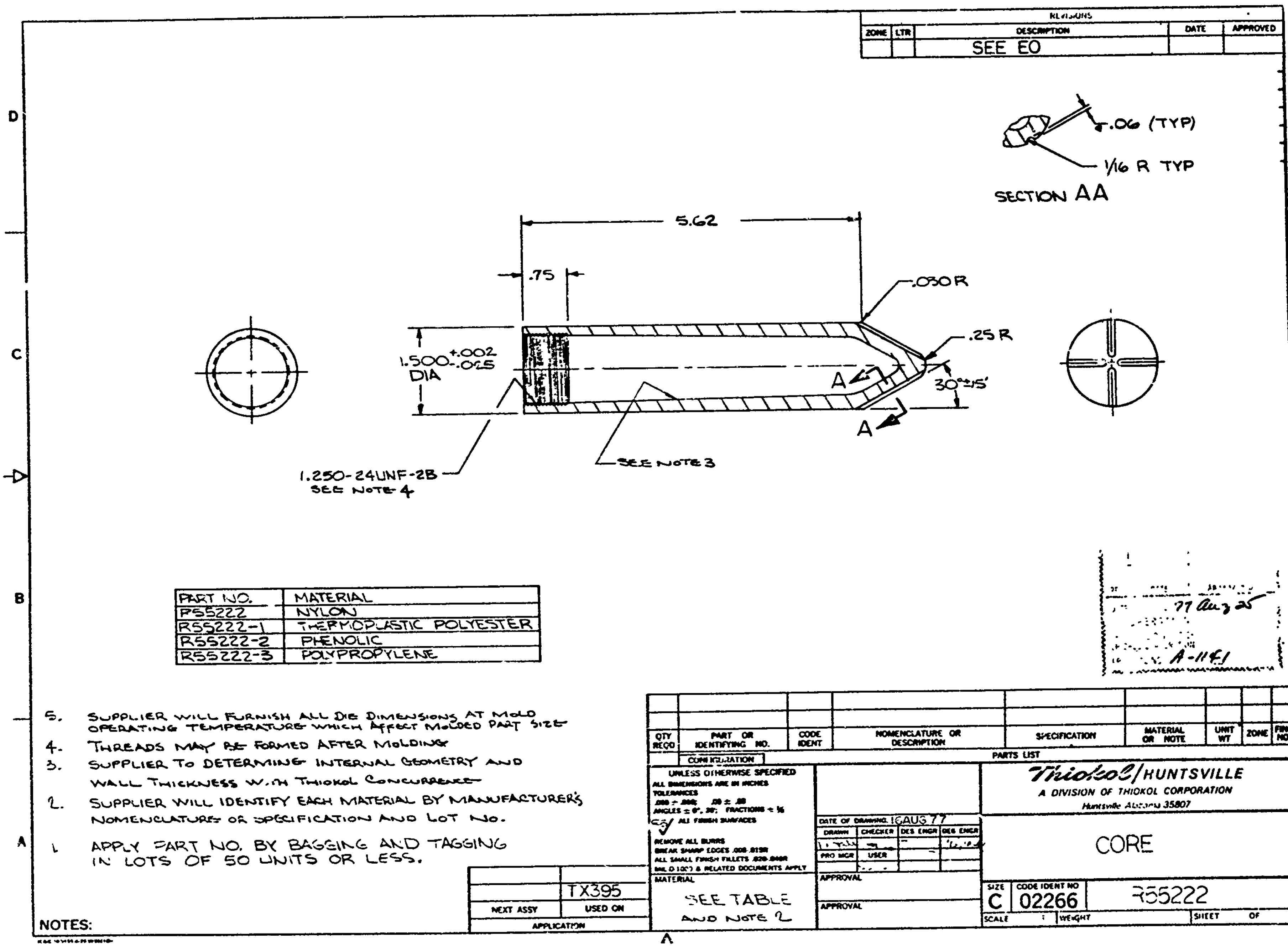


Figure 3. Injection Molded Core, Drawing R55222

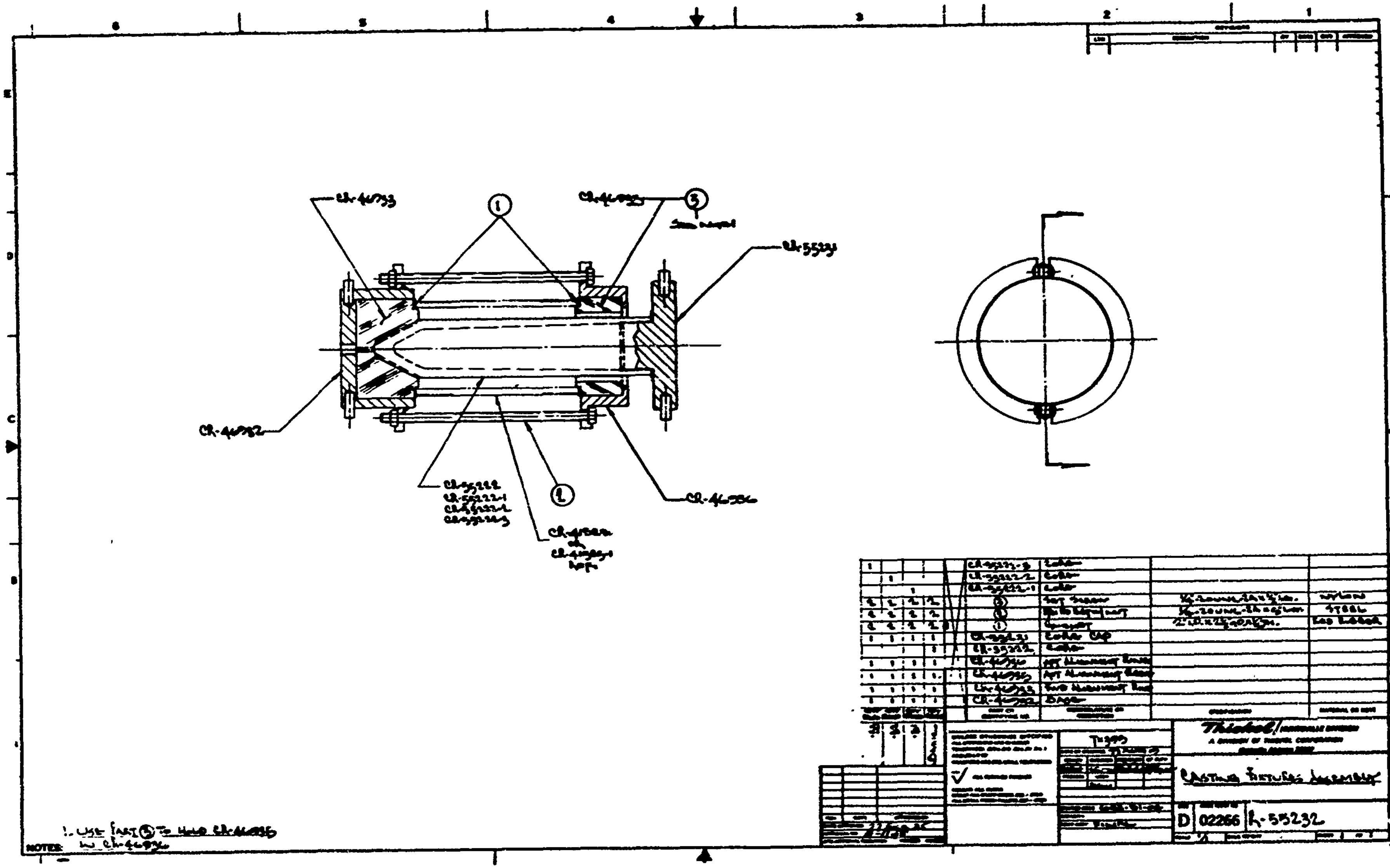


Figure 4. Casting Fixture Assembly, R-55232

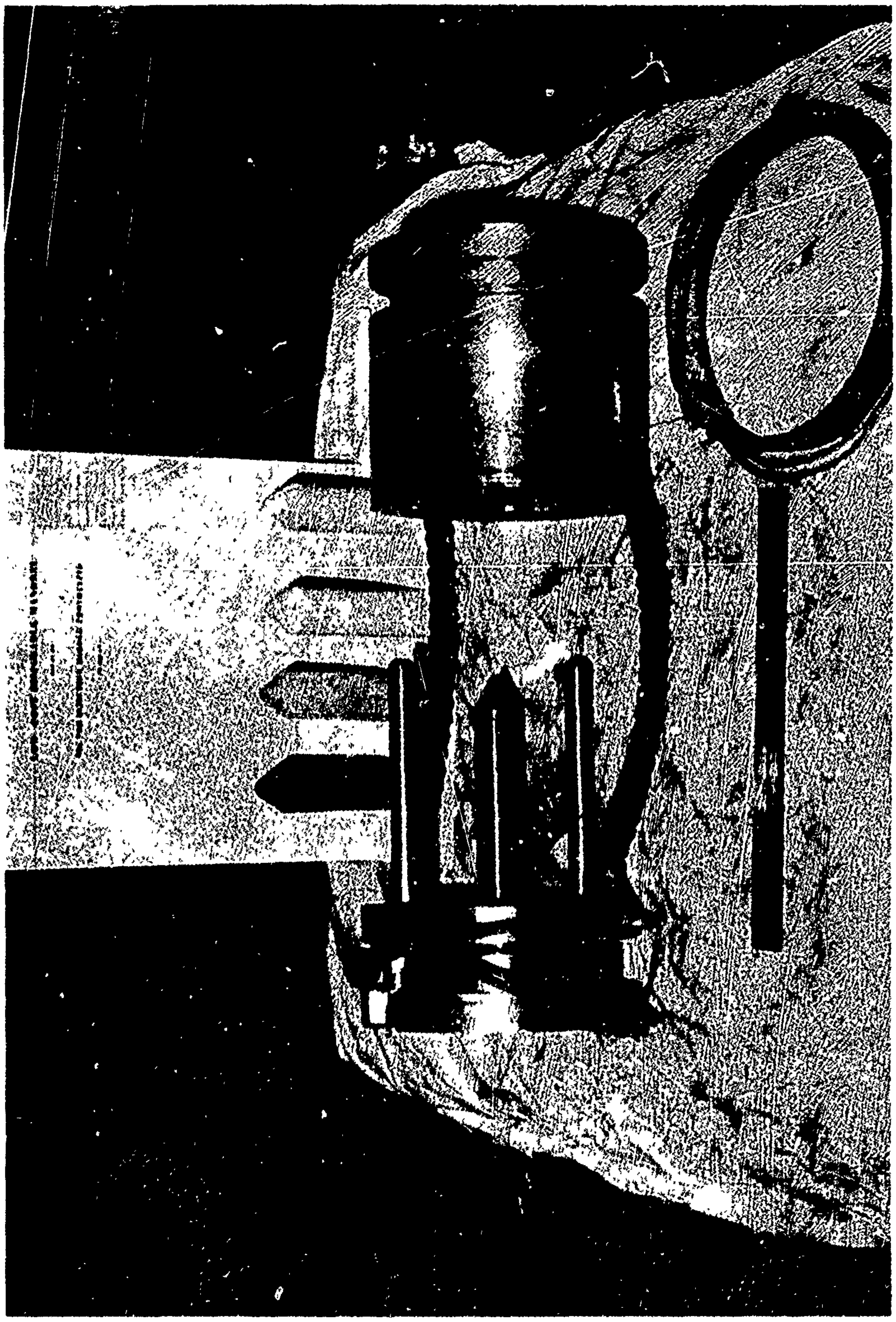


Figure 5. Die for Injection Molding, Prototype Mandrels

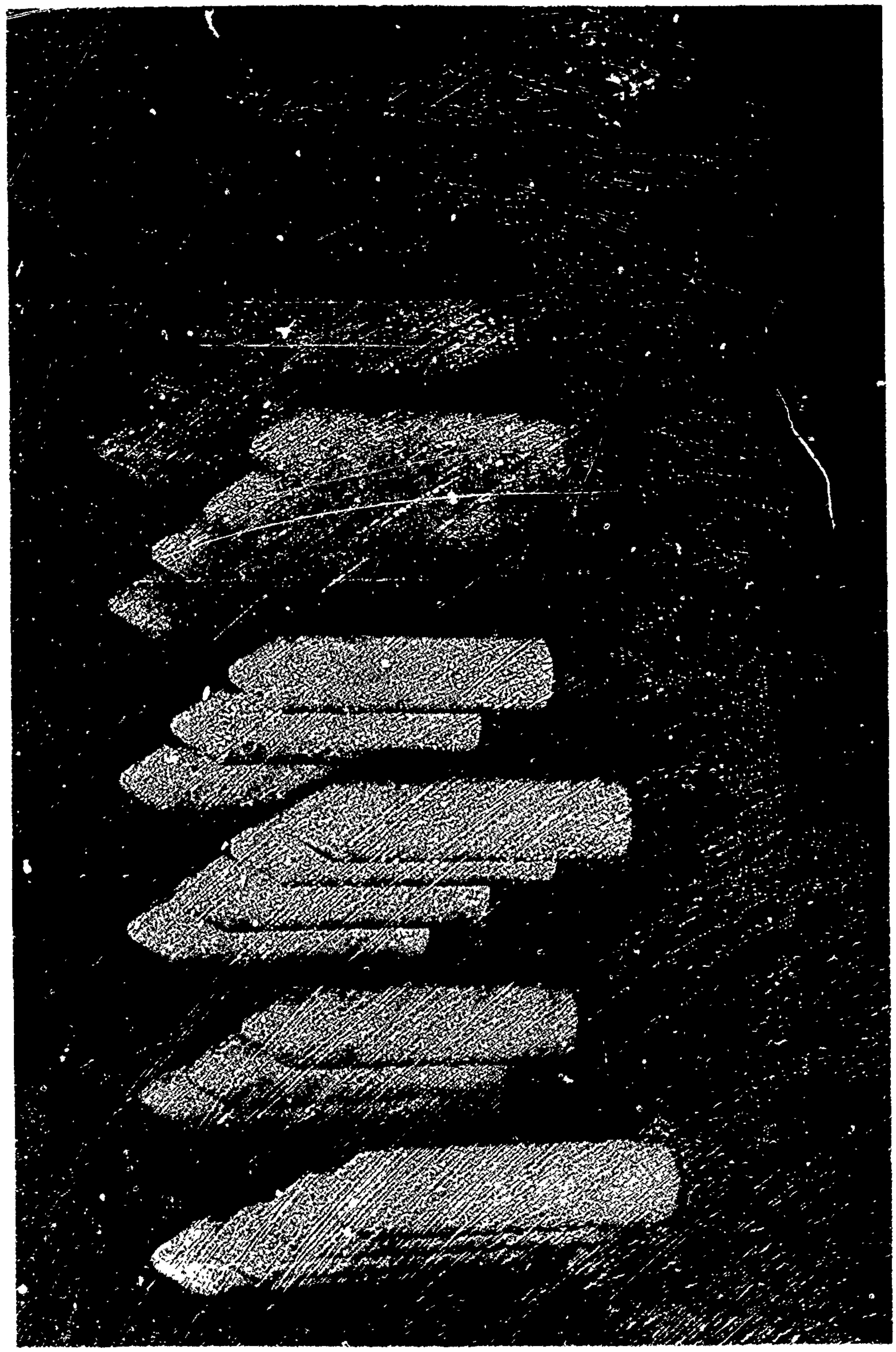


Figure 6. Cores Awaiting Insertion into SEAS-Propellant Motors

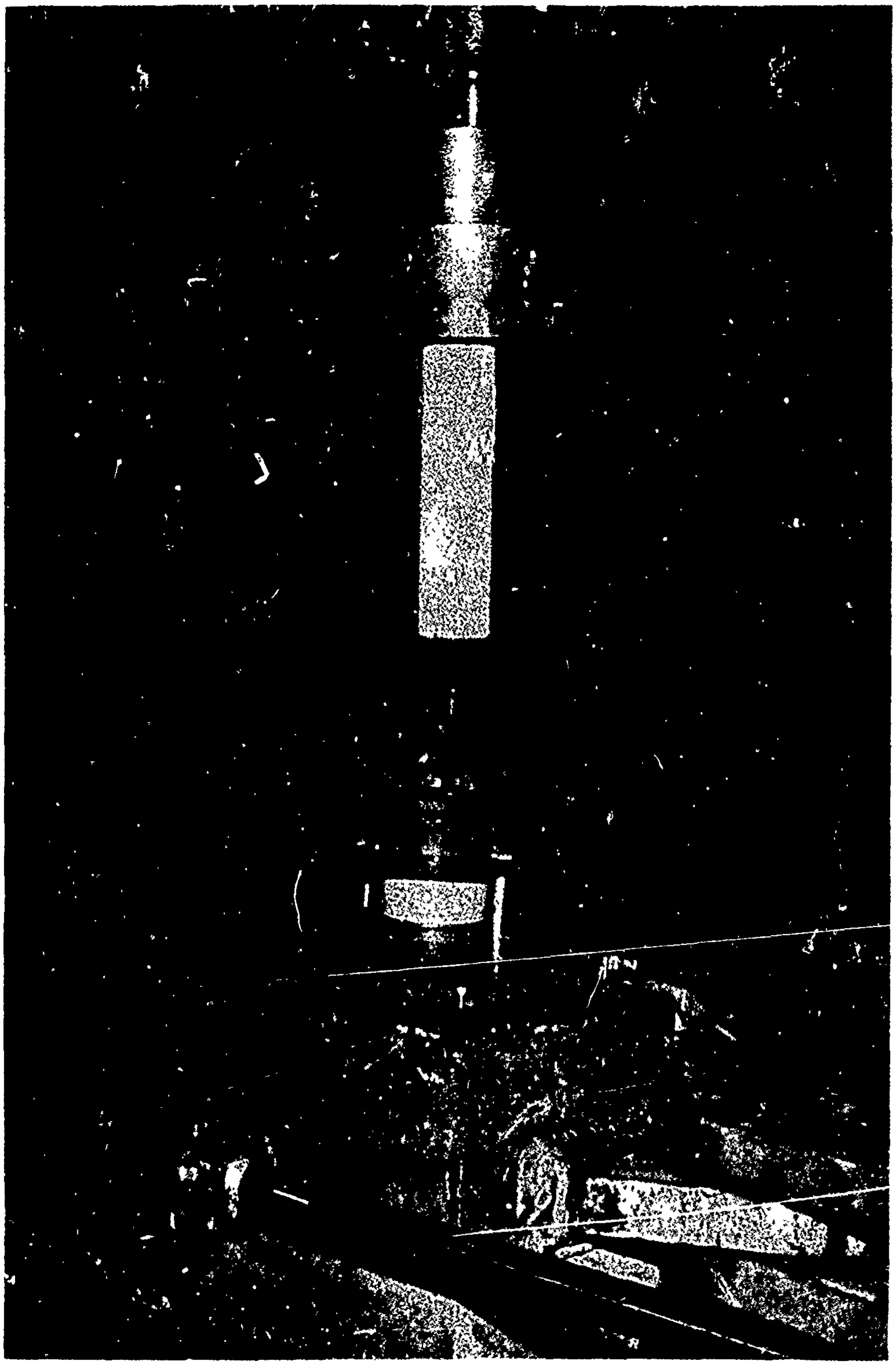


Figure 11. Core after Removal from Motor

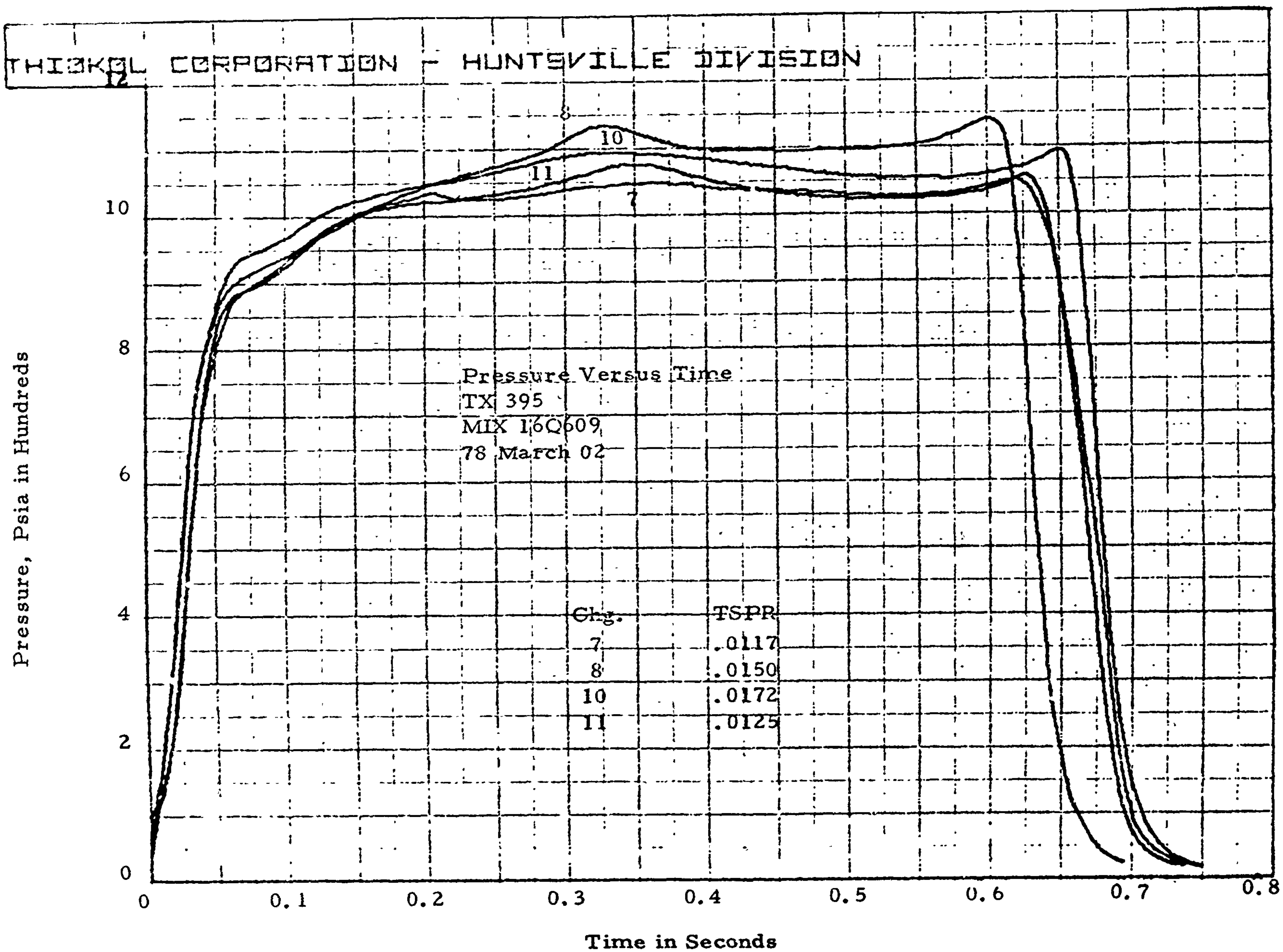


Figure 12. Mandrel Pull Test Ballistic Data, SEAS Propellant (16Q609-7, -8, -10, -11)

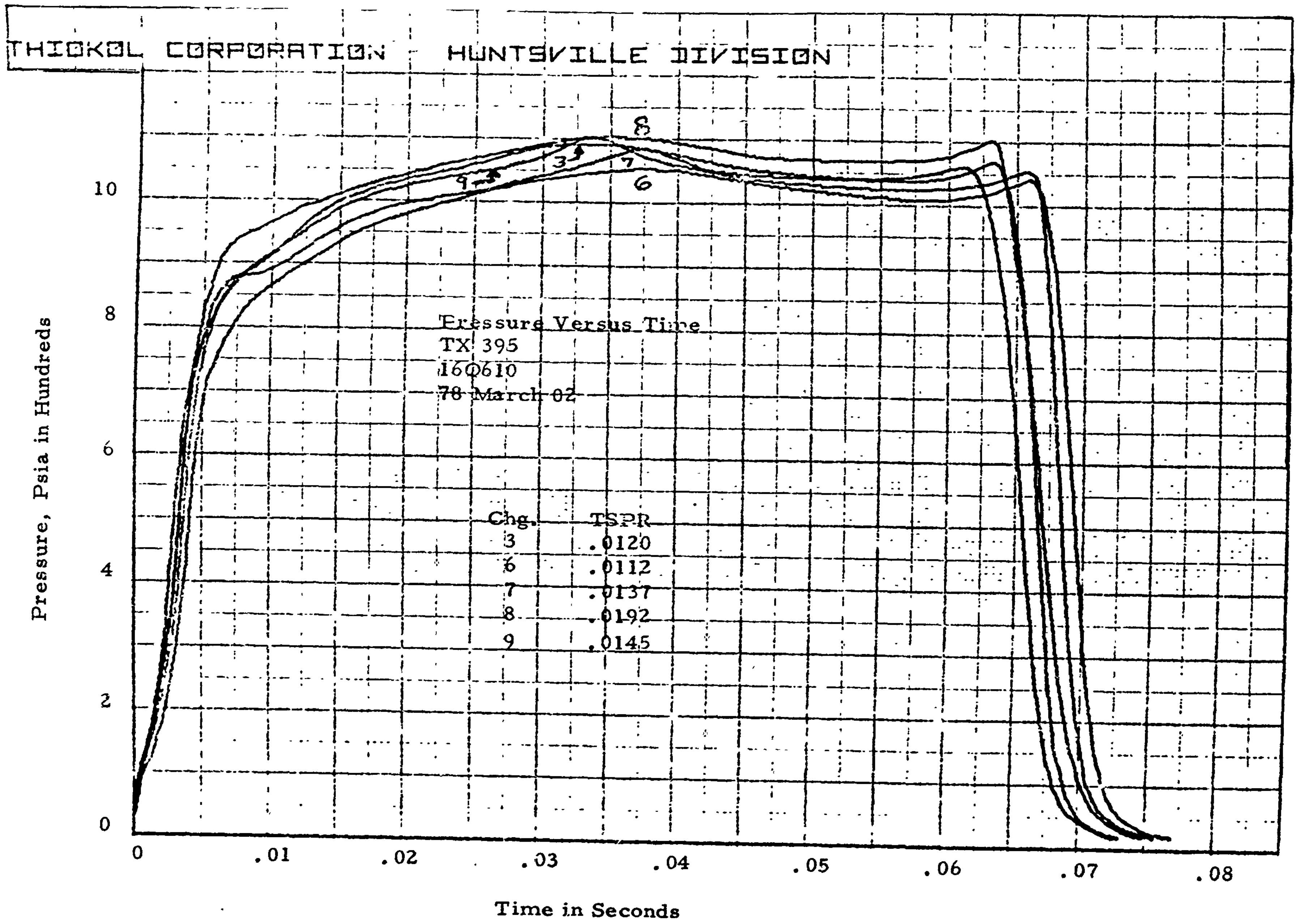


Figure 13. Mandrel Pull Test Ballistic Data, SEAS Propellant (16Q610-3, -6, -7, -8, -9)

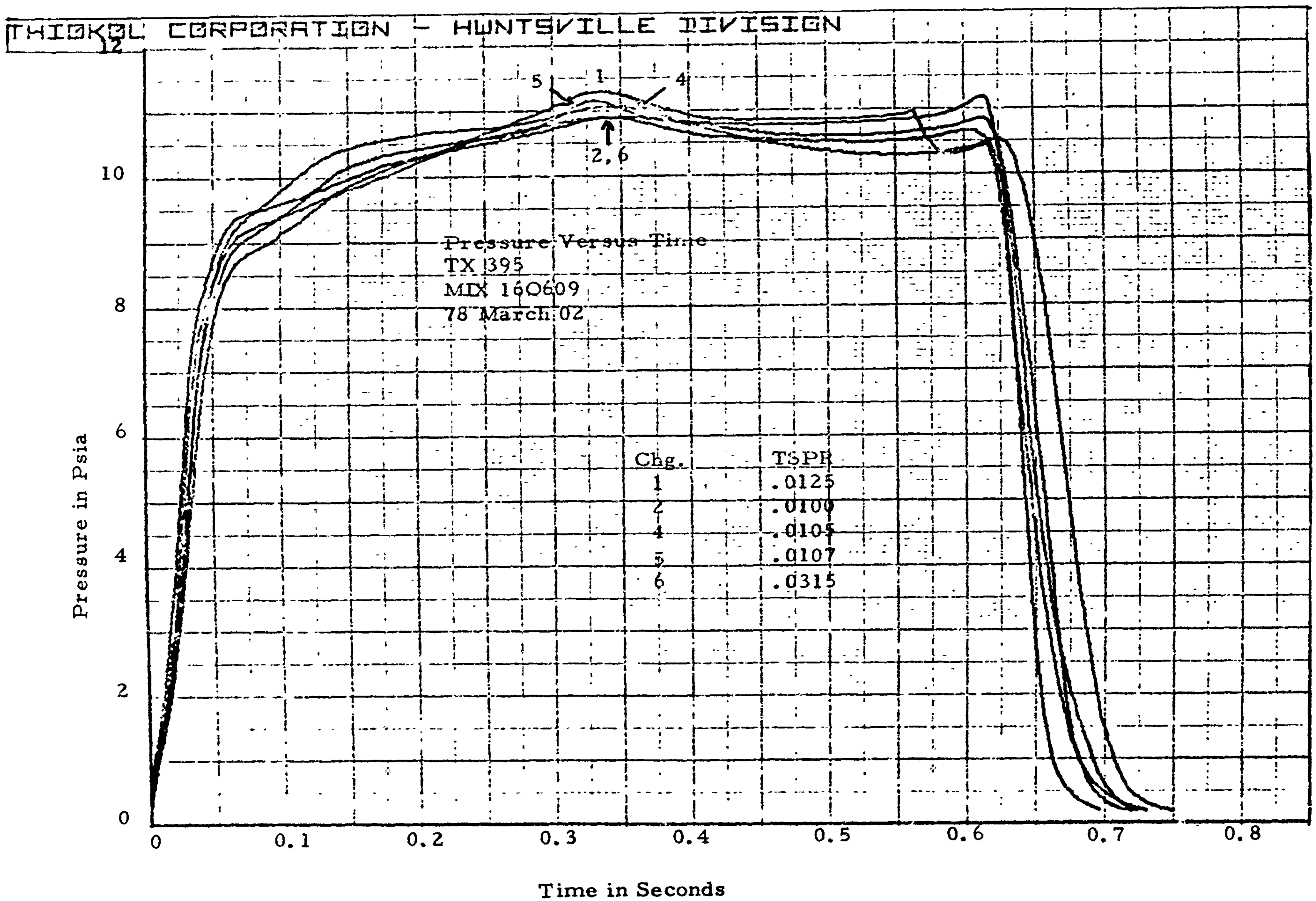


Figure 14. Mandrel Pull Test Ballistic Data, SEAS Propellant (16Q609-1, -2, -4, -5, -6)

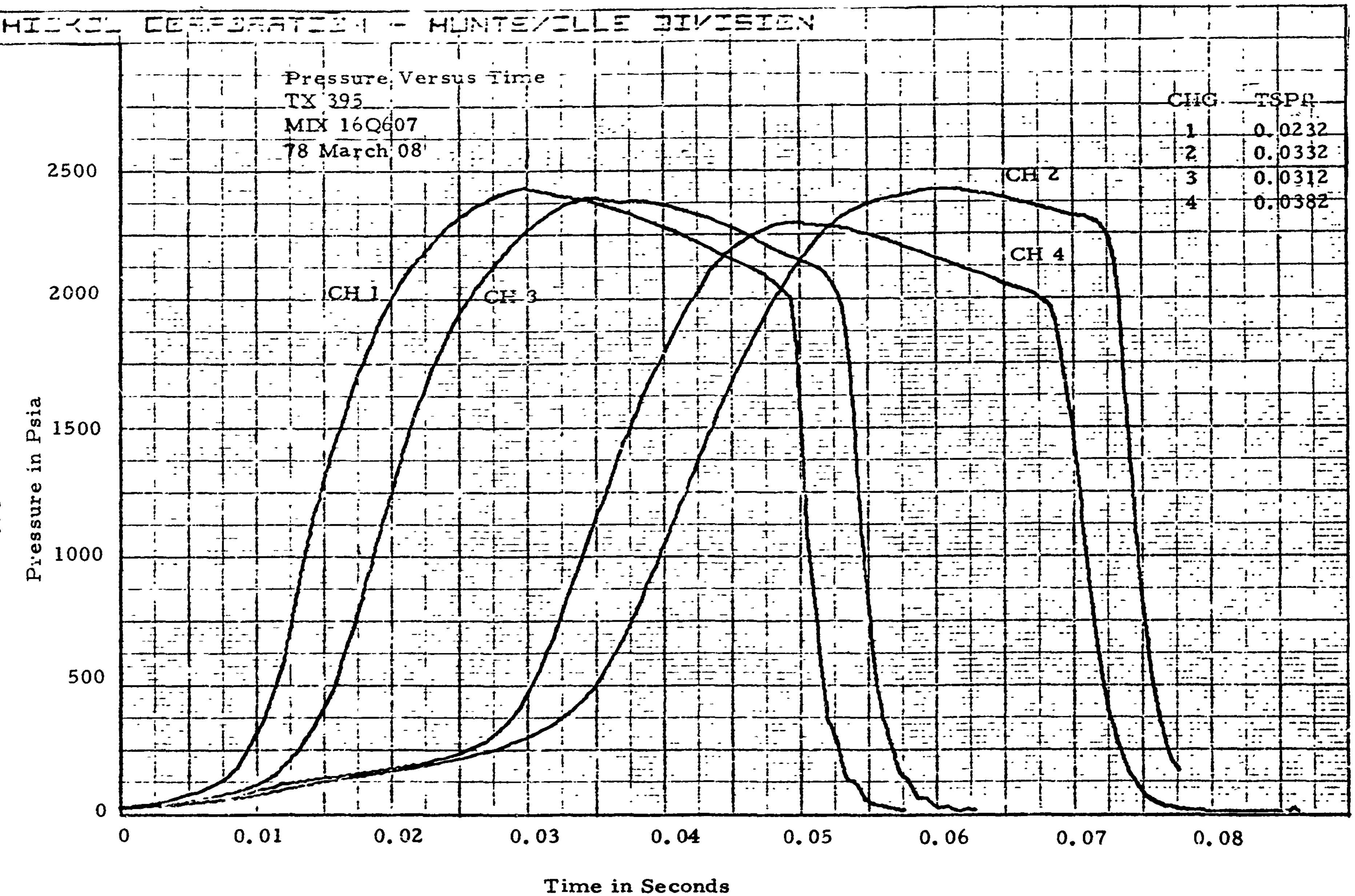


Figure 15. Mandrel Pull Test Ballistic Data, Viper Propellant (16Q607-1, -2, -3, -4)

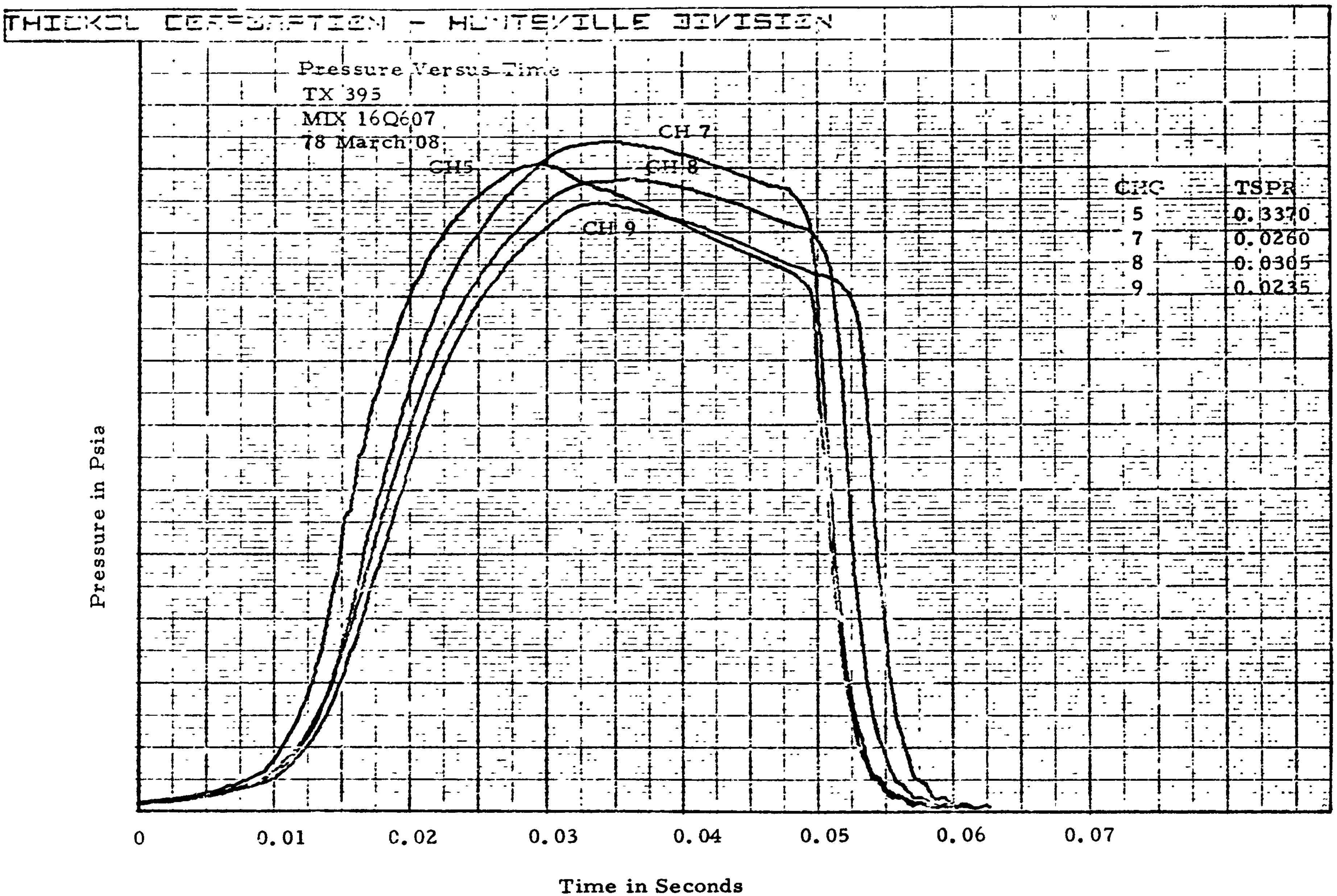


Figure 16. Mandrel Pull Test Ballistic Data, Viper Propellant (16Q607-5, -7, -8, -9)

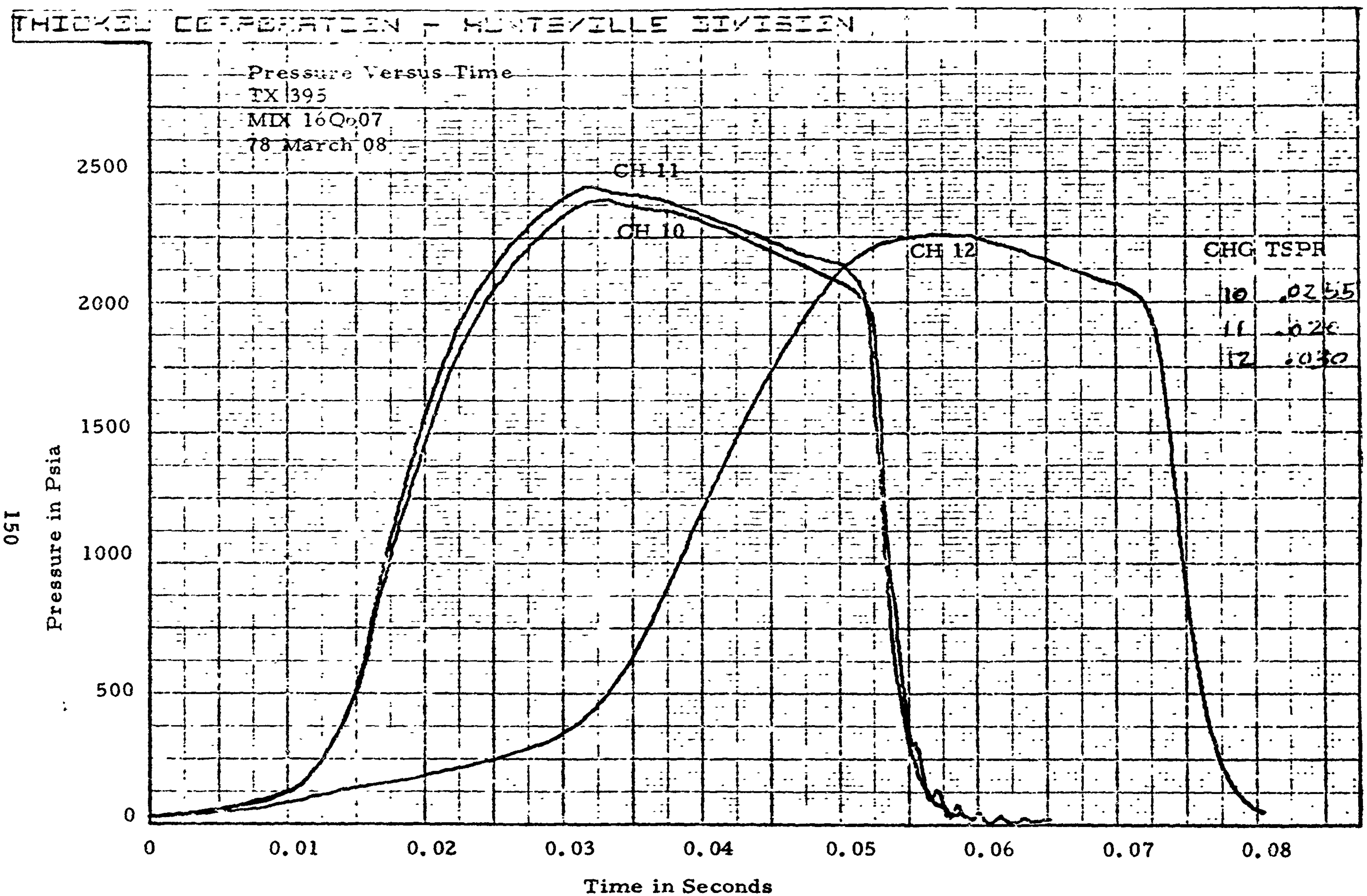


Figure 17. Mandrel Pull Test Ballistic Data, Viper Propellant (16Q607-10, -11, -12)

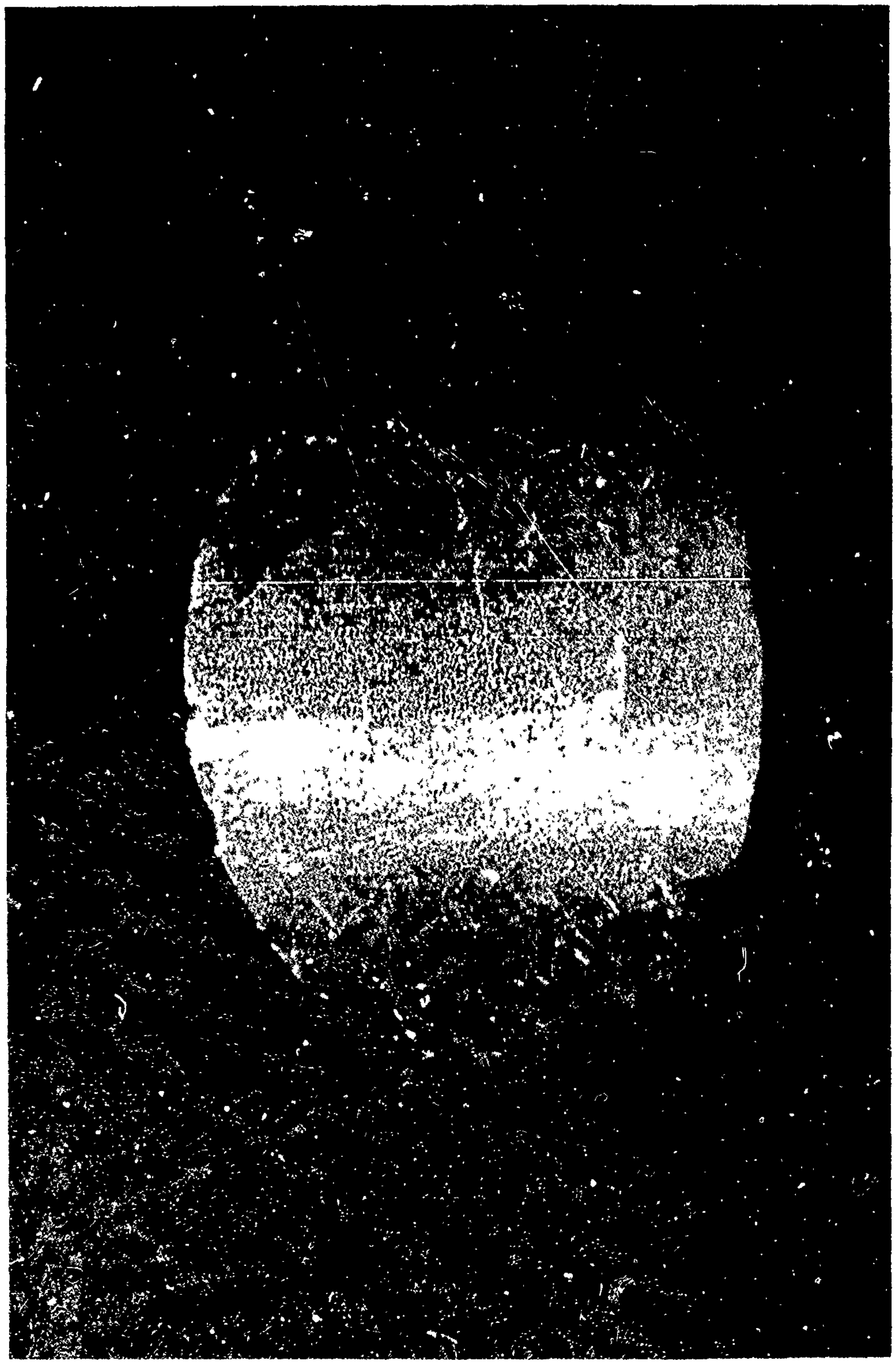


Figure 18. Surface Formed by Teflon-coated Steel Core in Viper Propellant, Motor 16Q-607-3

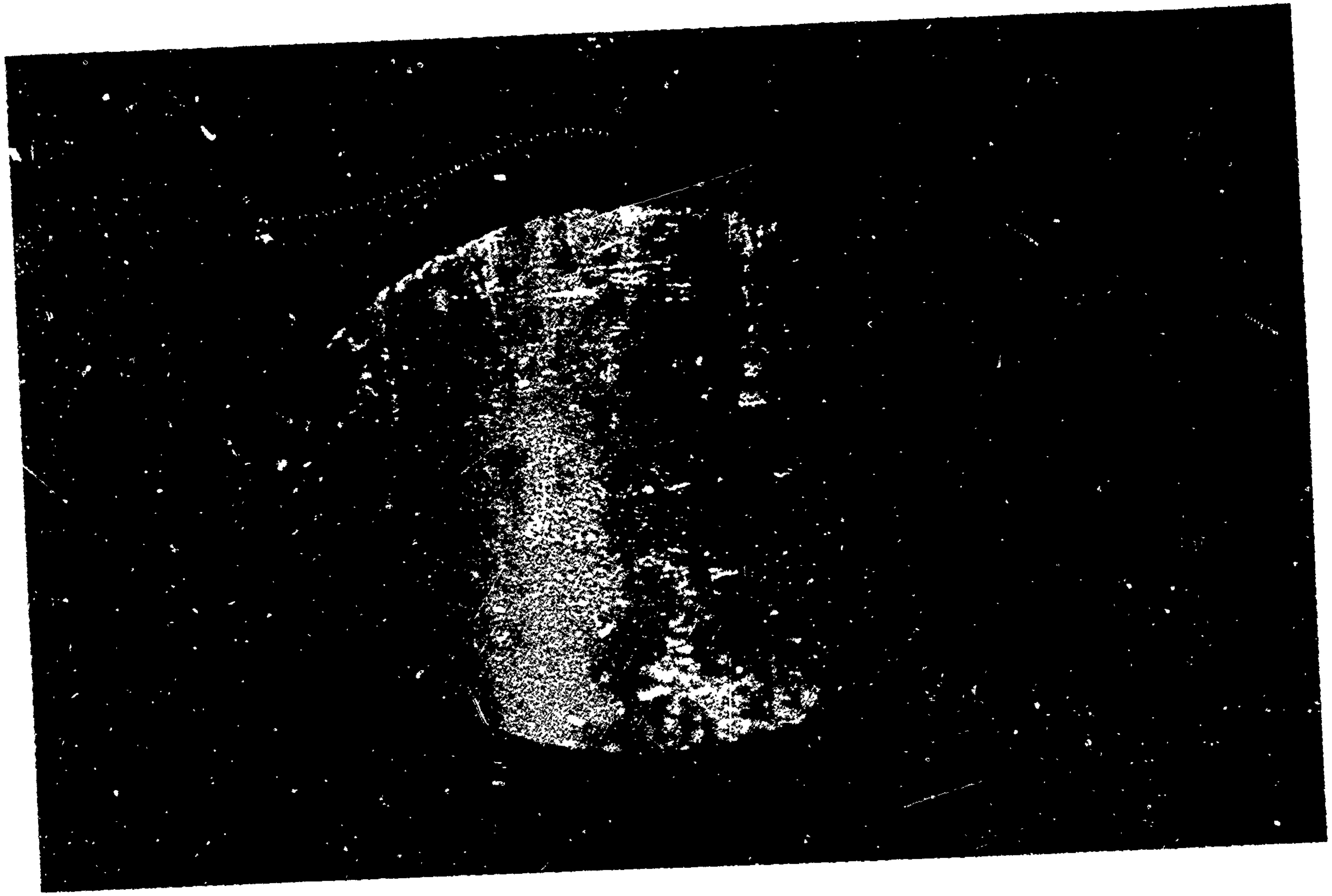


Figure 19. Surface Formed by Teflon-coated Steel Core, Sprayed with IMS, in Viper Propellant, Motor 16Q-607-8

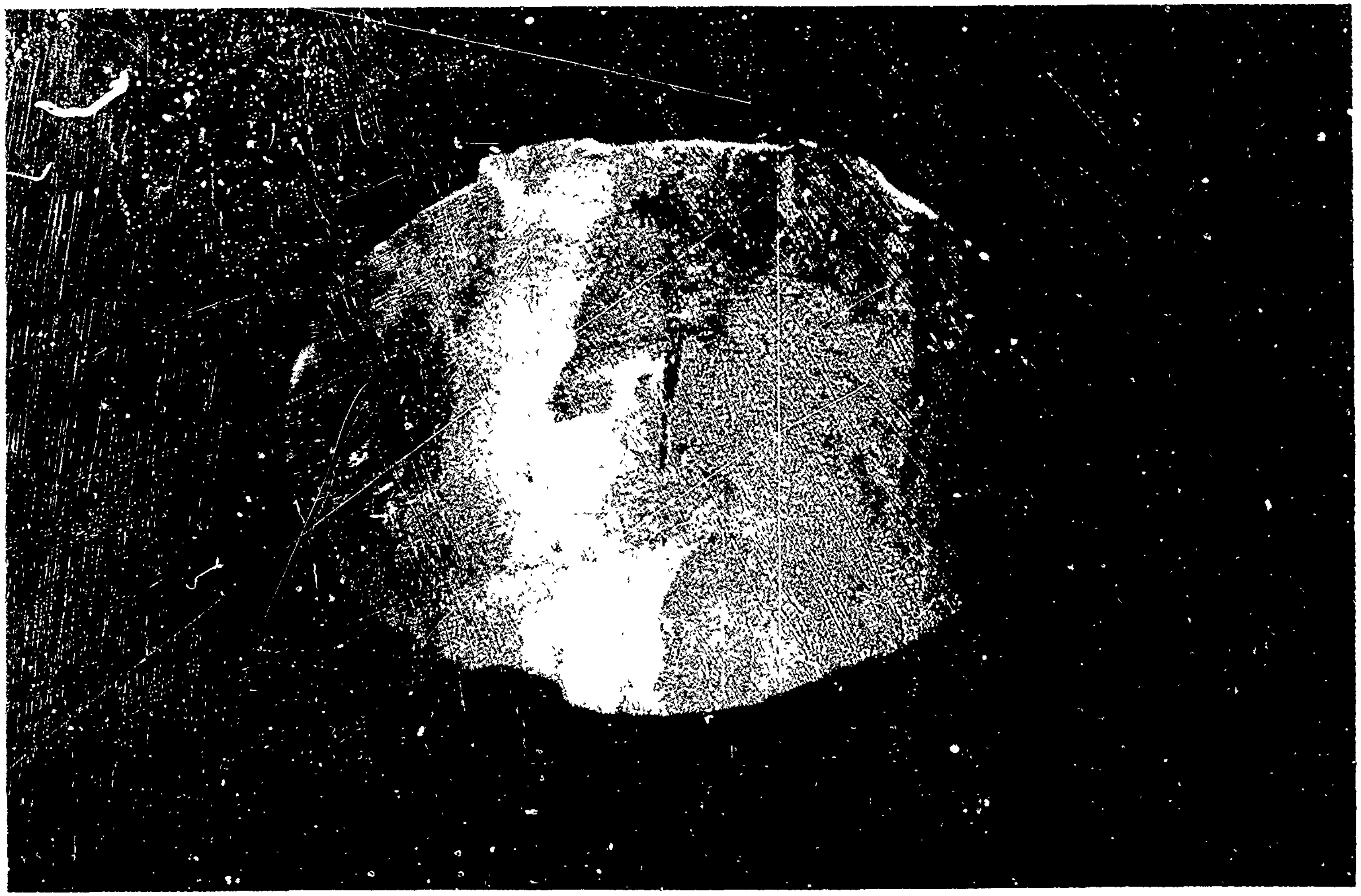


Figure 20. Surface Formed by Phenolic Plastic Core, Sprayed with MS-122, in Viper Propellant, Motor 16Q-607-4

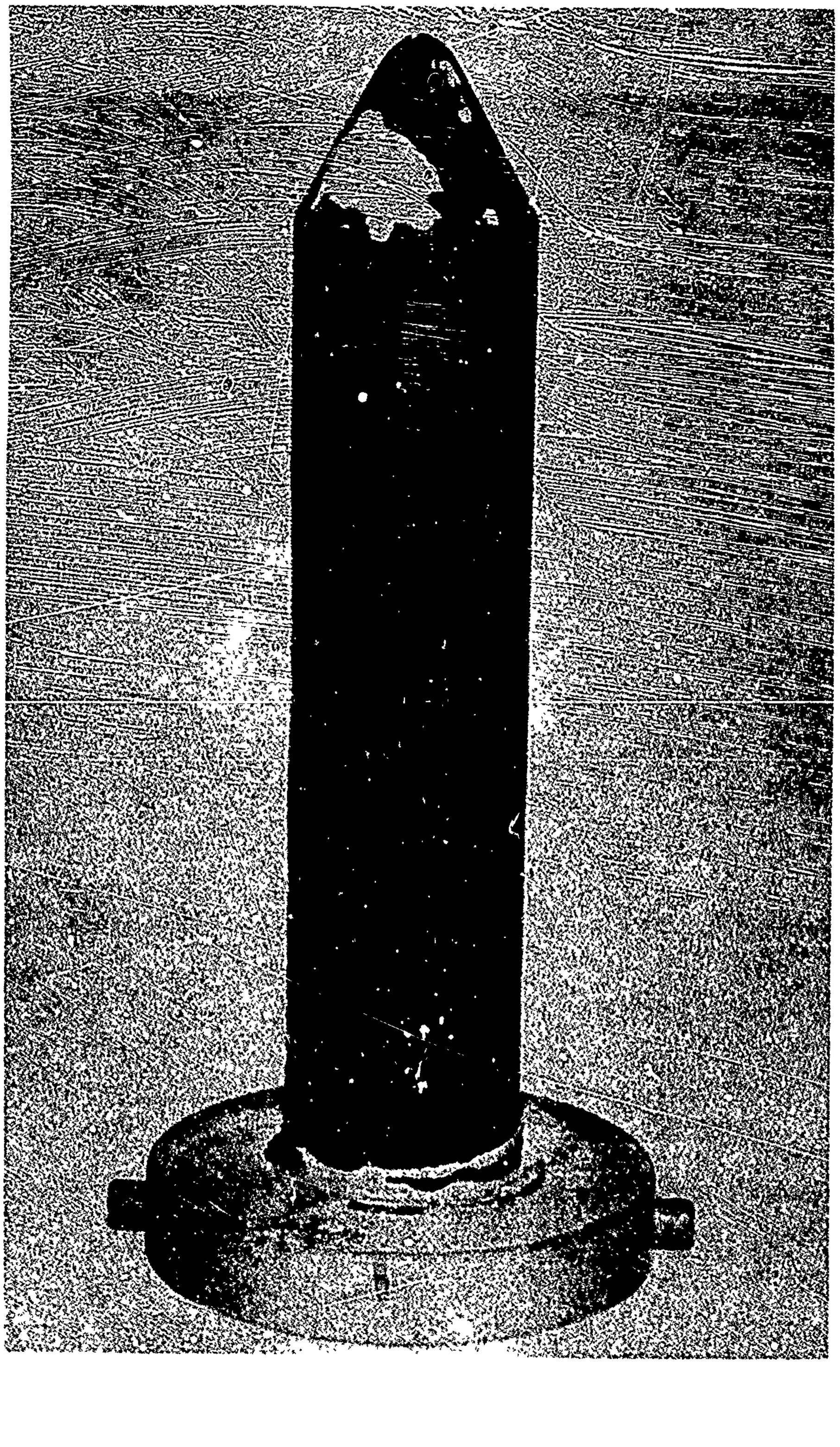


Figure 21. Phenolic Plastic Core, Sprayed with MS-122, After Extraction from Motor 16Q-607-4

Figure 22. Surface Formed by Teflon-coated Steel Core in SEAS-type Propellant Motor 16Q-609-5

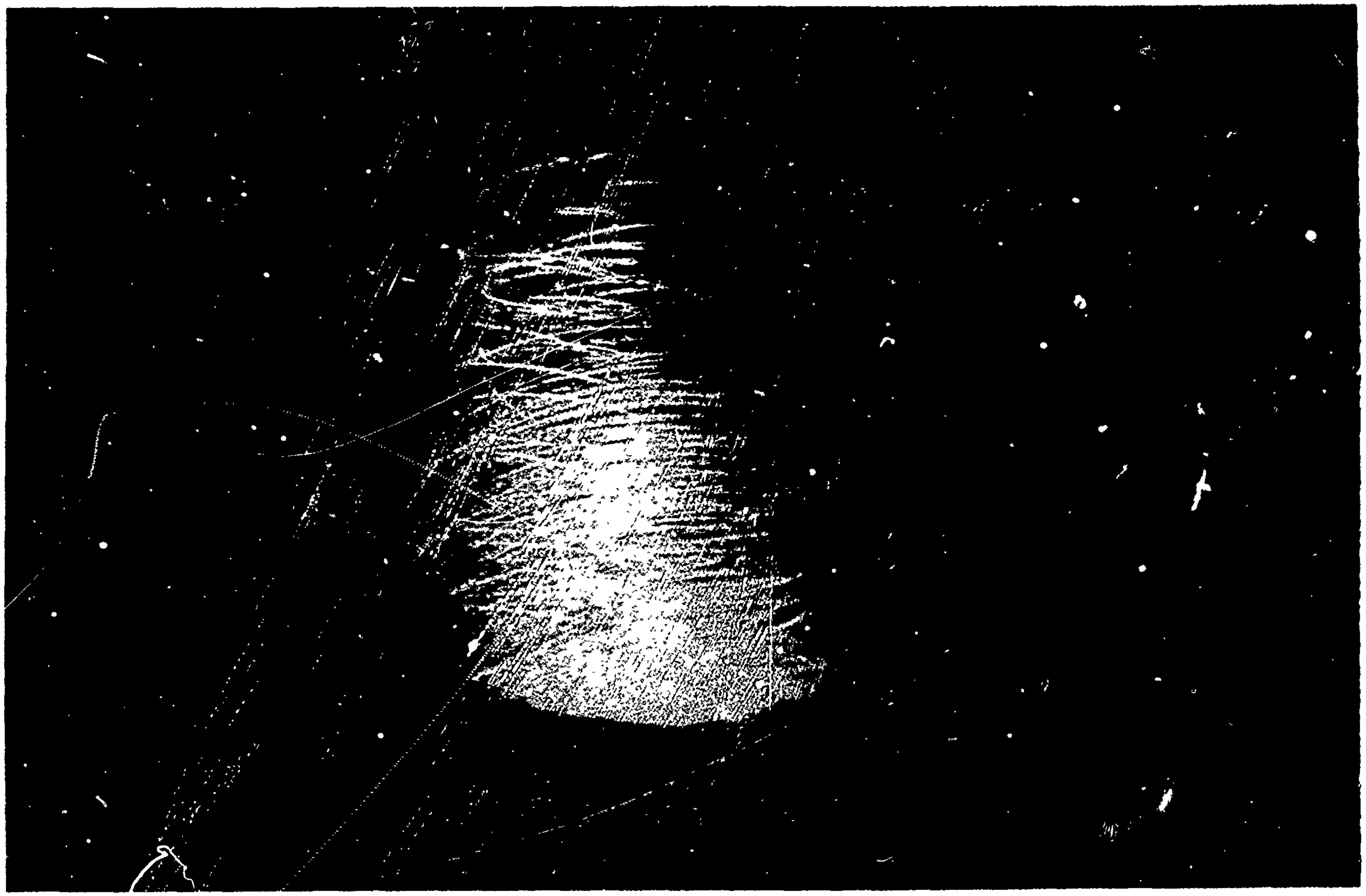


Figure 23. Surface Formed by Polypropylene Core in SEAS-type Propellant Motor 16Q-609-2

Figure 24. Polypropylene Core After Extraction From Motor 16Q-609-2

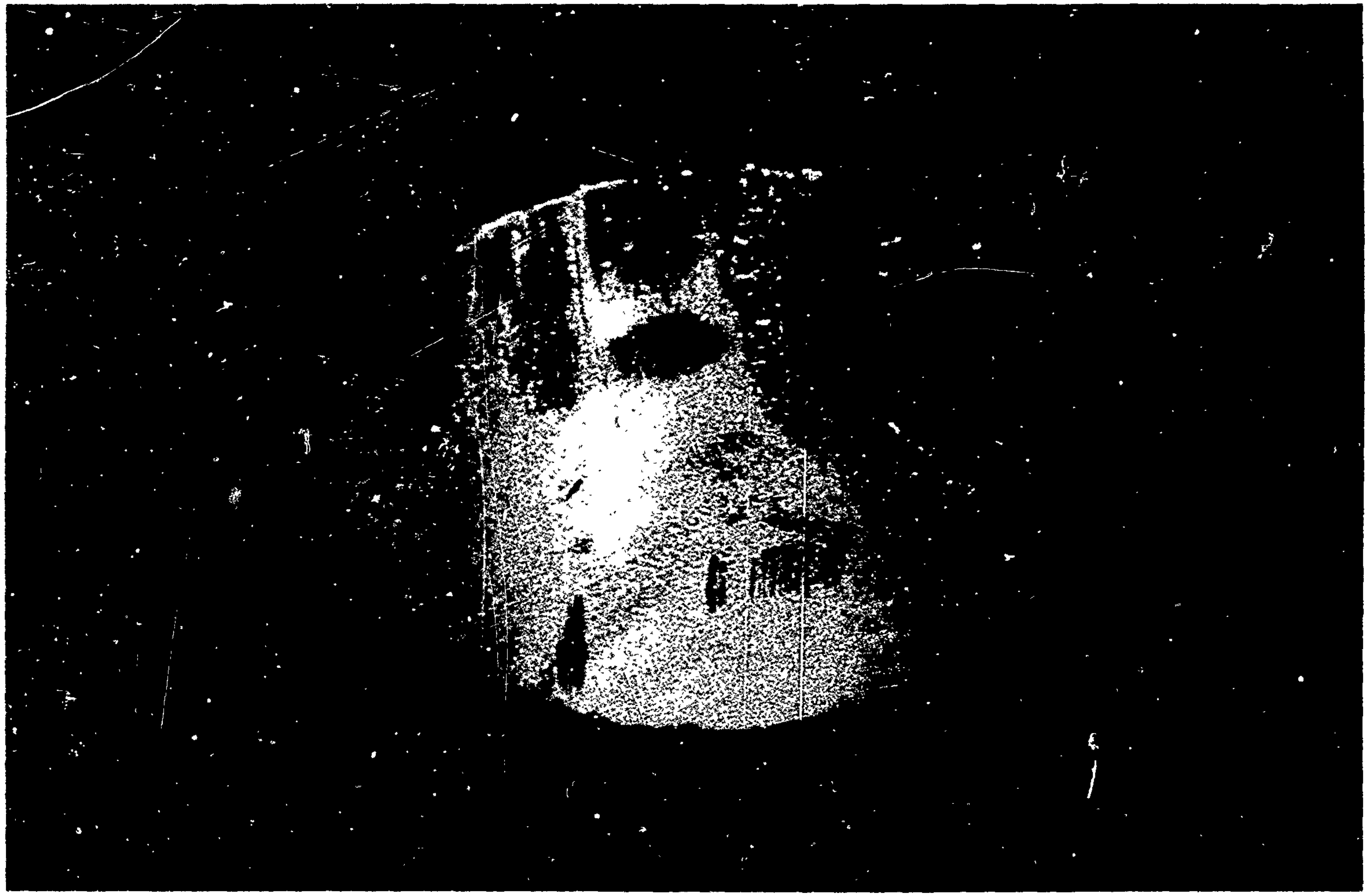


Figure 25. Surface Formed by Polypropylene Core, Sprayed with MS-122, in SEAS-type Propellant Motor 16Q-610-8

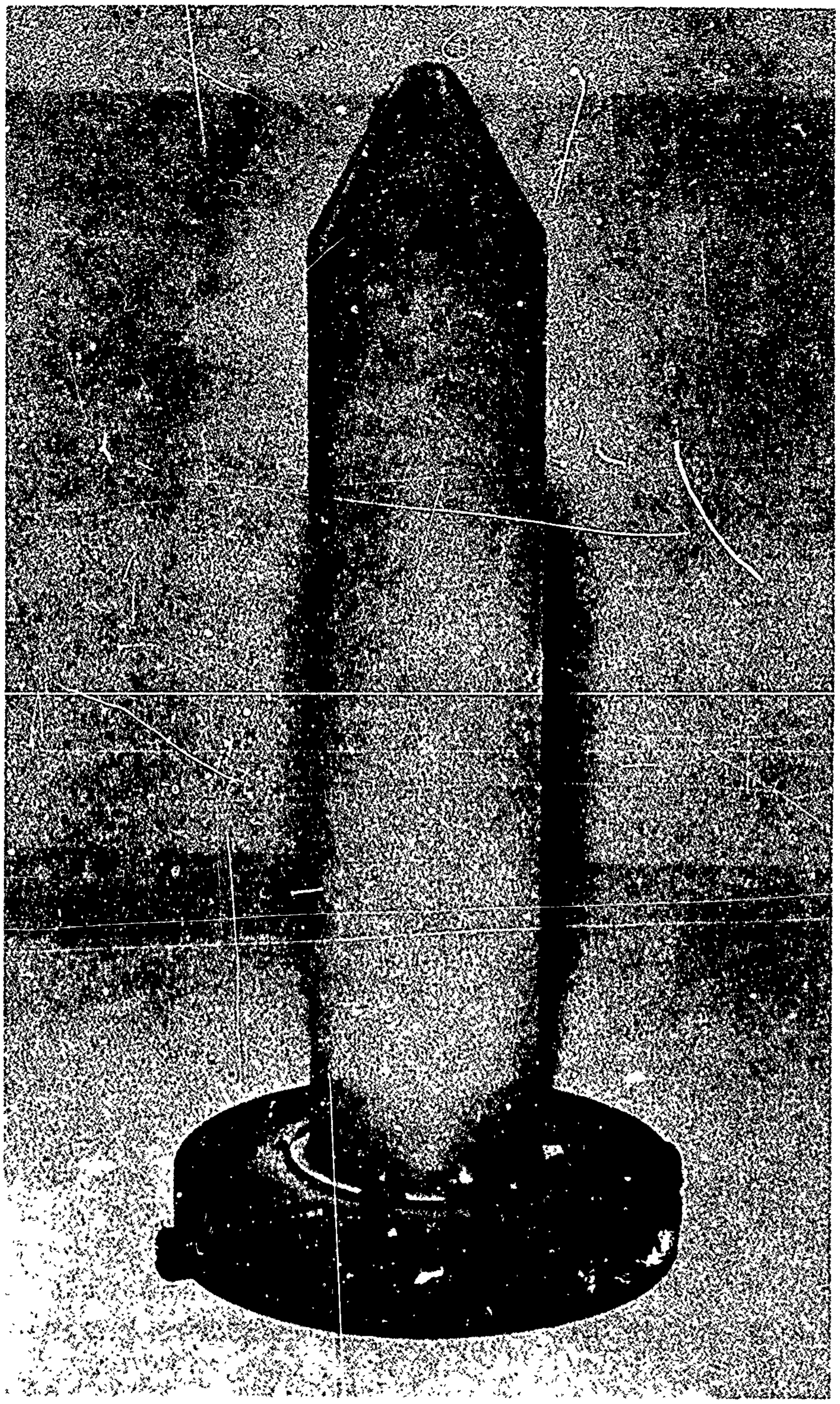


Figure 26. Polypropylene Core, Sprayed with MS-122, After Extraction From Motor 16Q-610-8

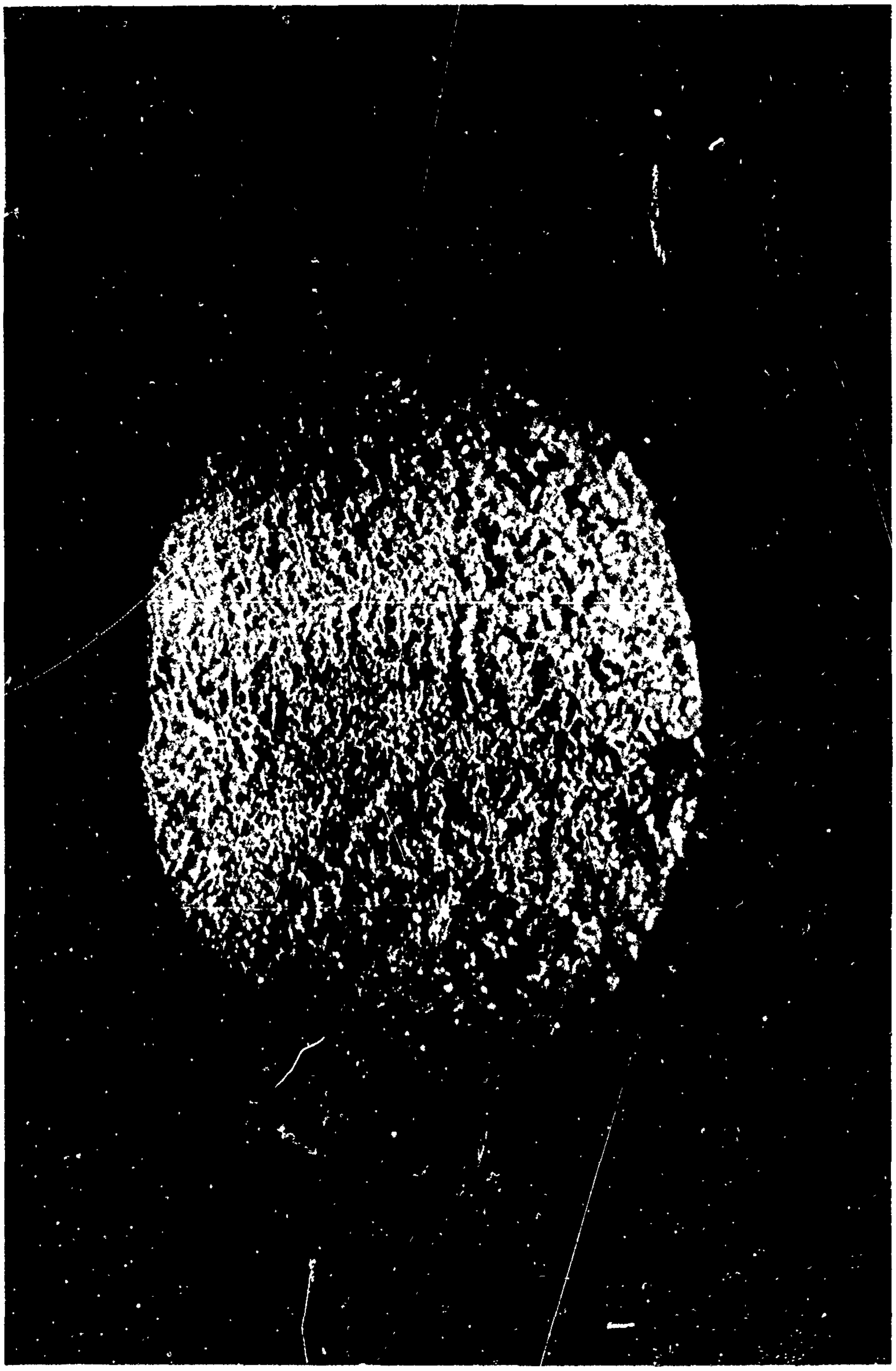


Figure 27. Surface Formed by Nylon Core in SEAS-type Propellant, Motor 16Q-609-3

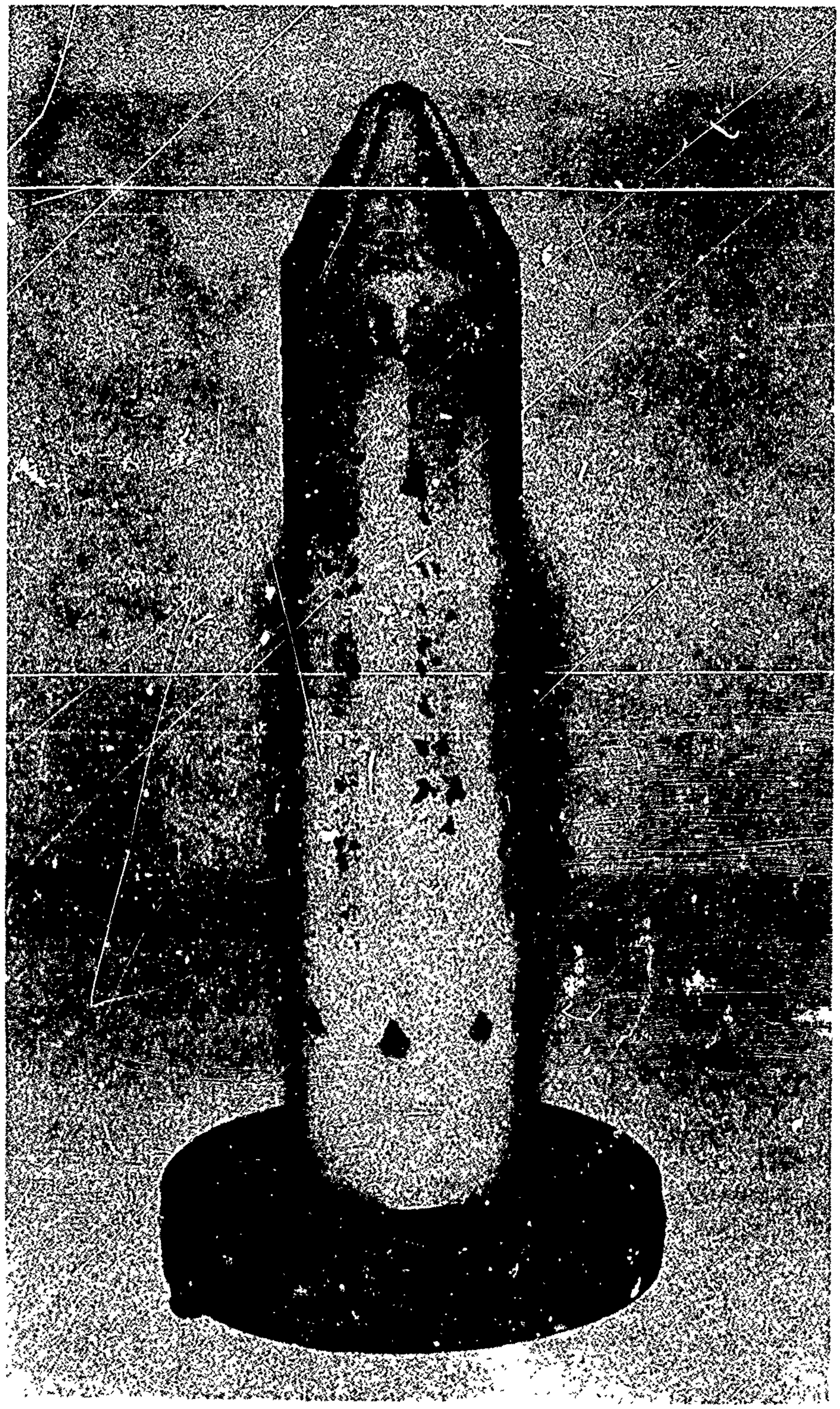


Figure 28. Nylon Core After Extraction From Motor 16Q-609-3

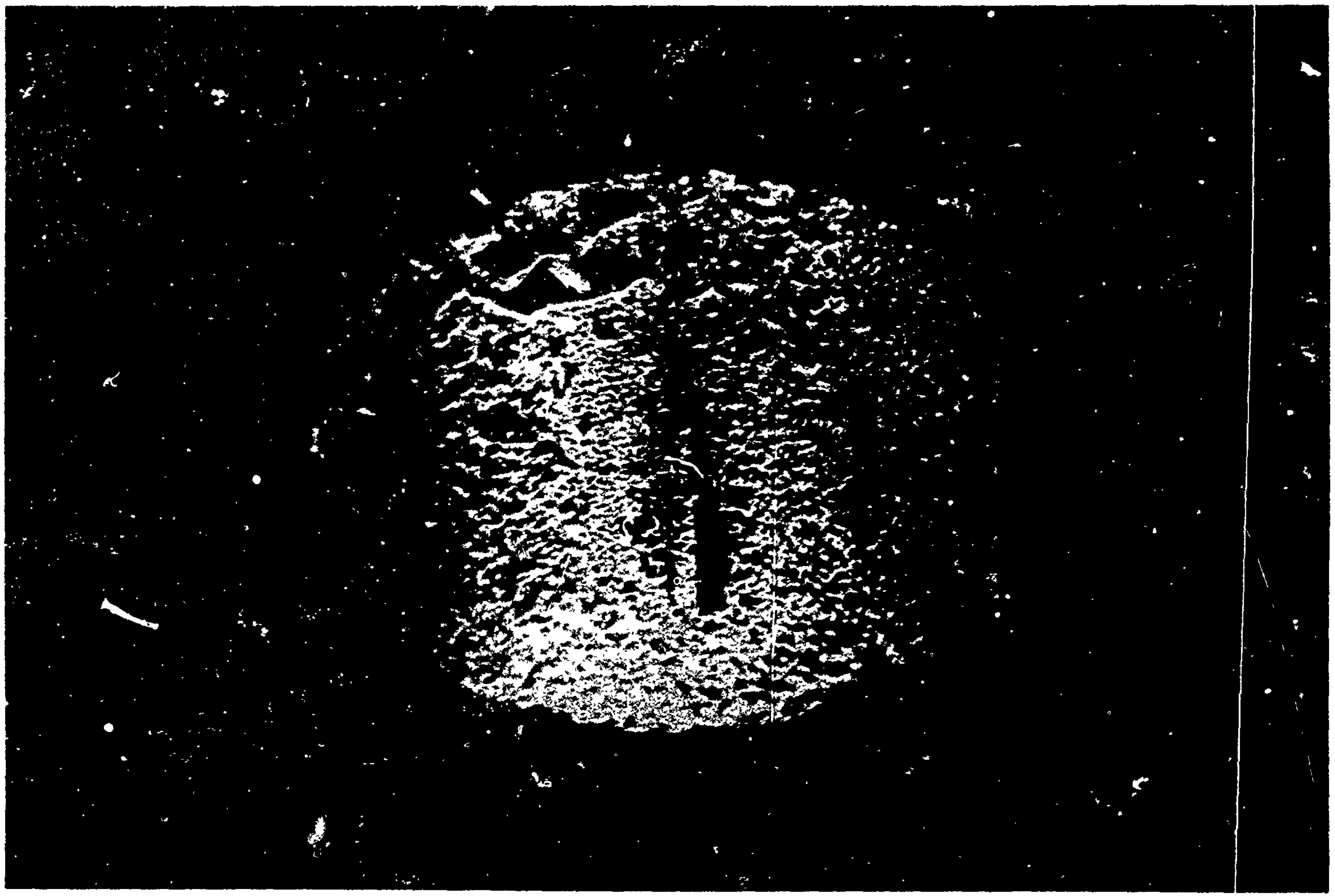


Figure 29. Surface Formed by Nylon Core, Sprayed With MS-122, in SEAS-type Propellant, Motor 16Q-610-

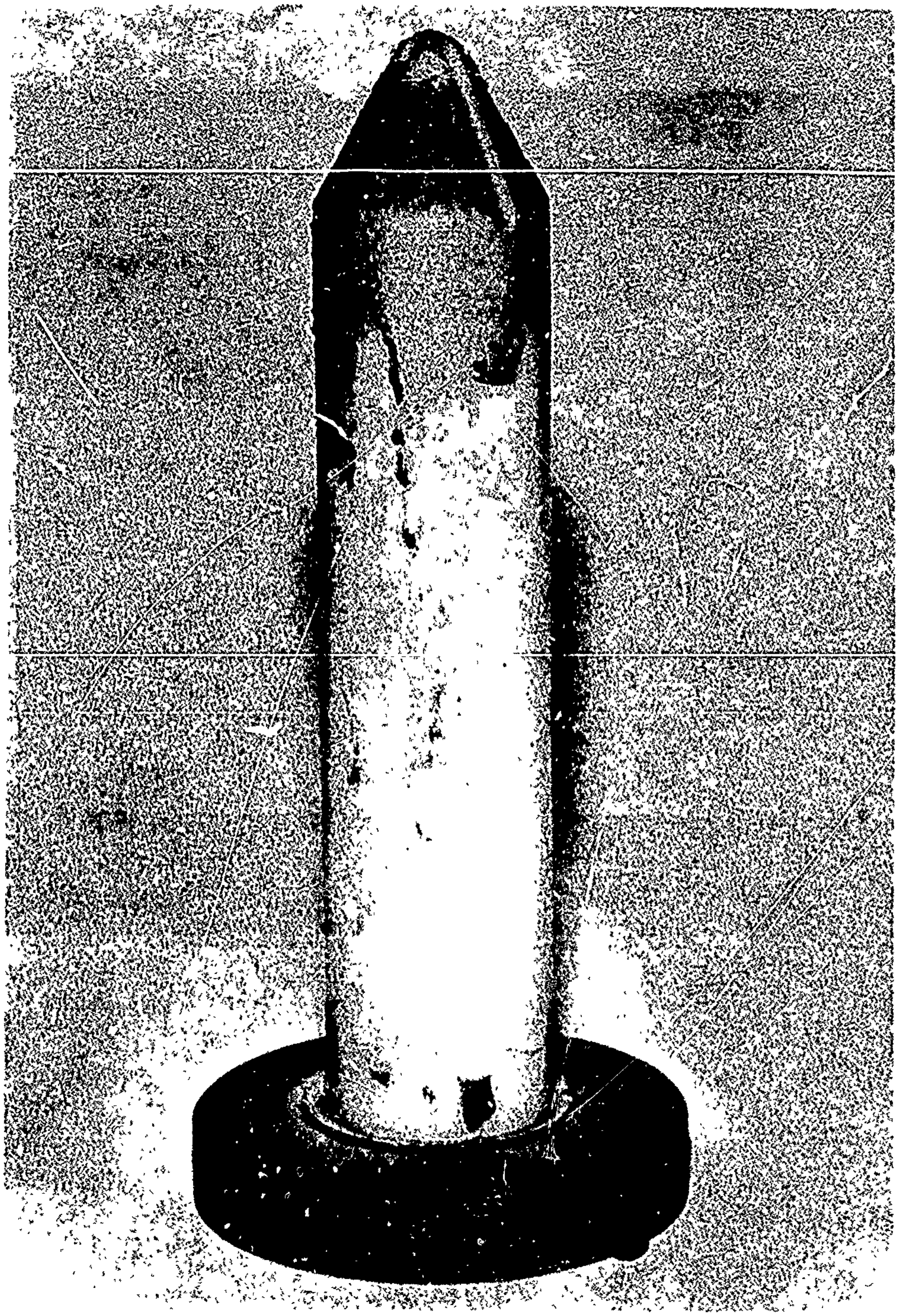


Figure 30. Nylon Core, Sprayed With MS-122, After Extraction From Motor 16Q-610-4

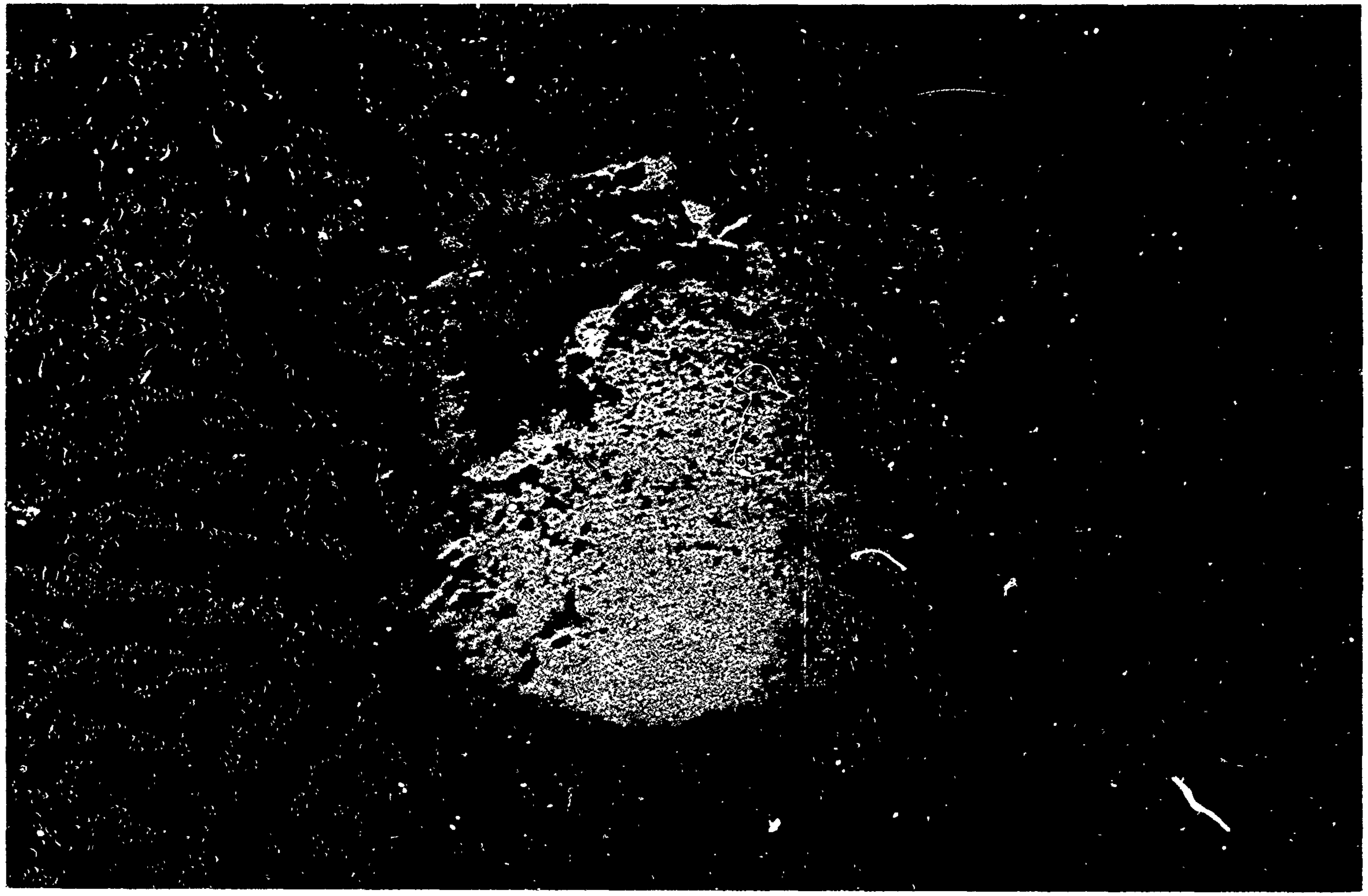


Figure 31. Surface Formed by PTMT Core in SEAS-type Propellant, Motor 16Q-610-2

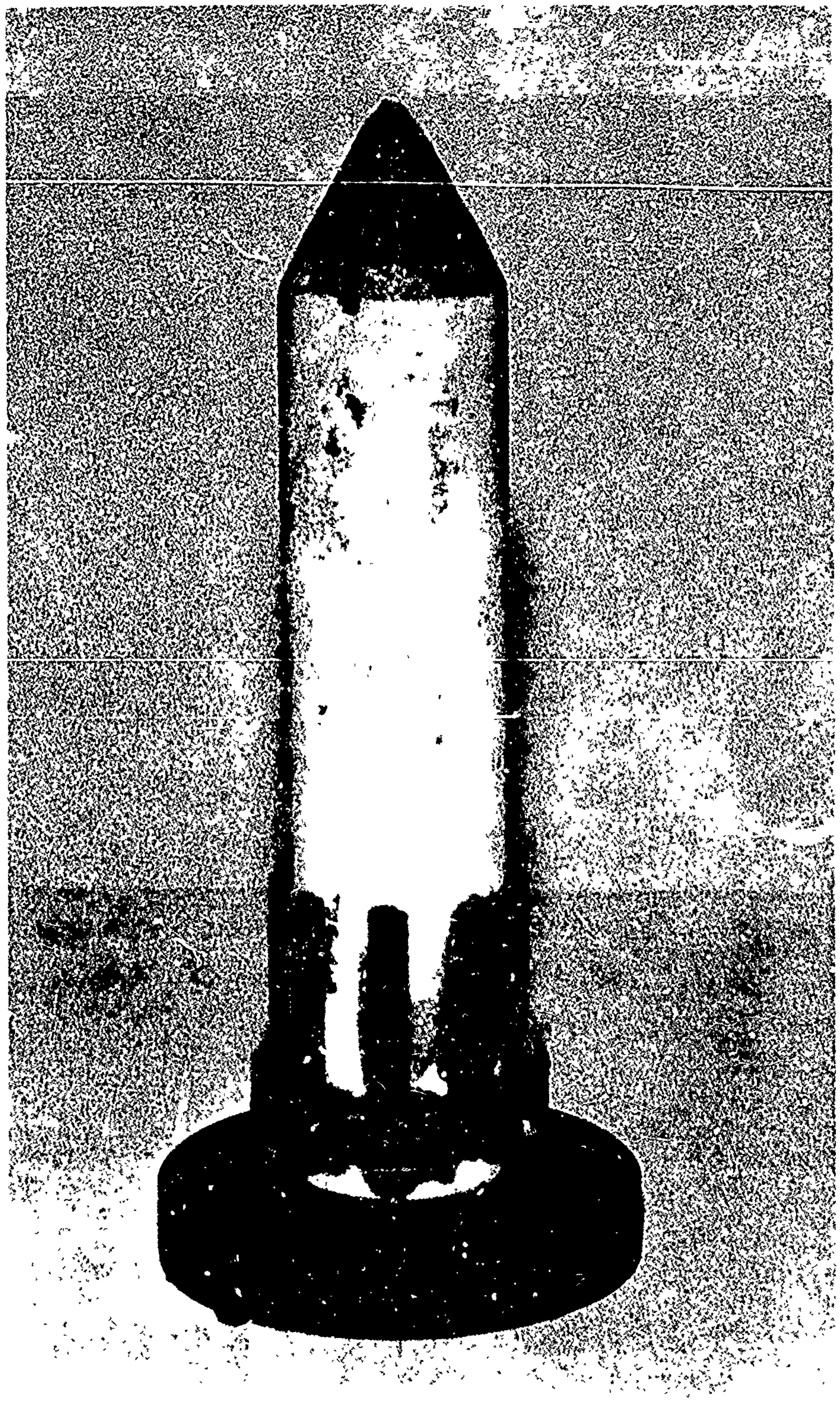


Figure 32. PTMT Core After Extraction From Motor 16Q-610-2

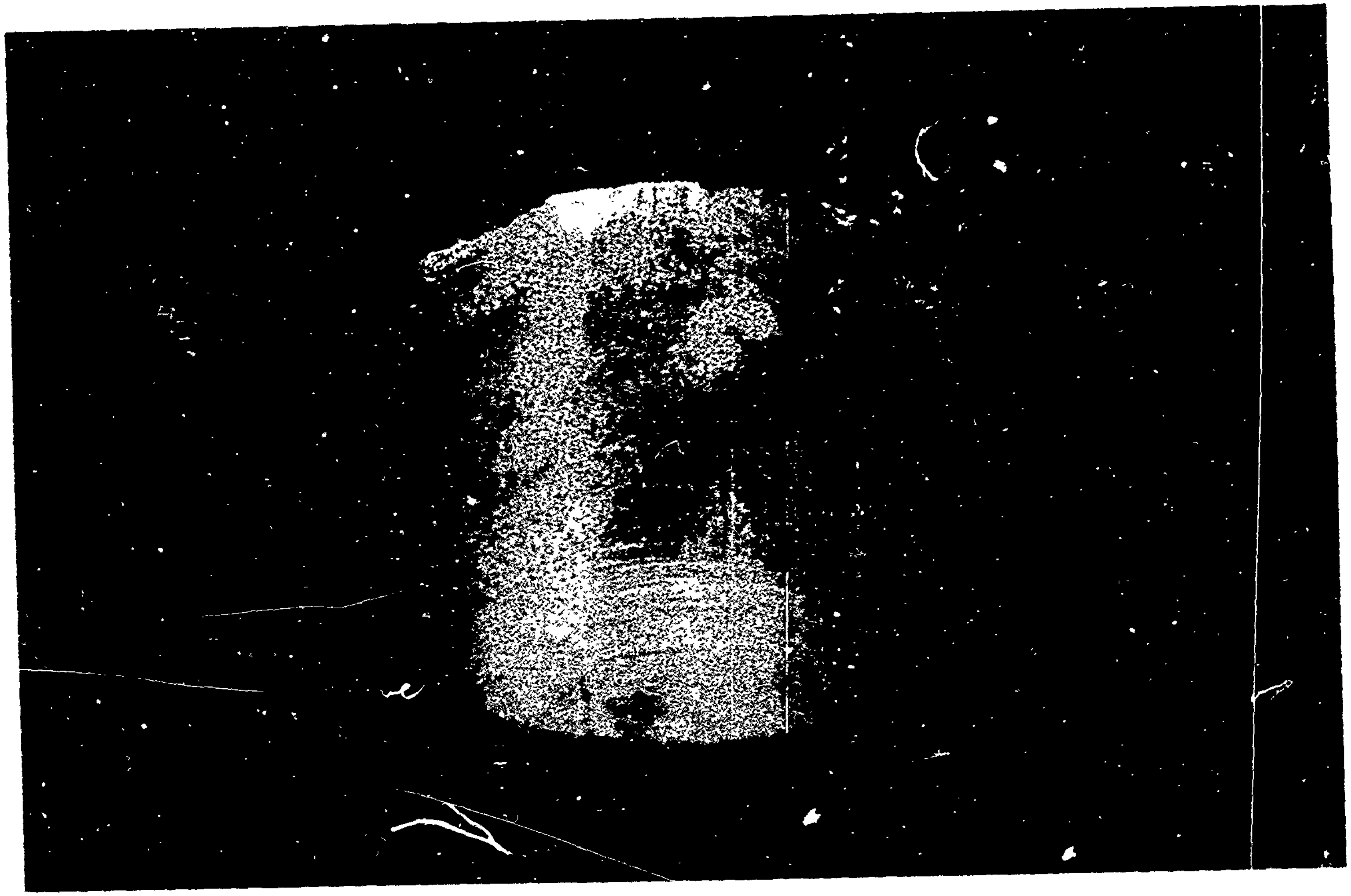


Figure 33. Surface Formed by PTMT Core, Sprayed With MS-122, In SEAS-type Propellant Motor 16Q-610-6

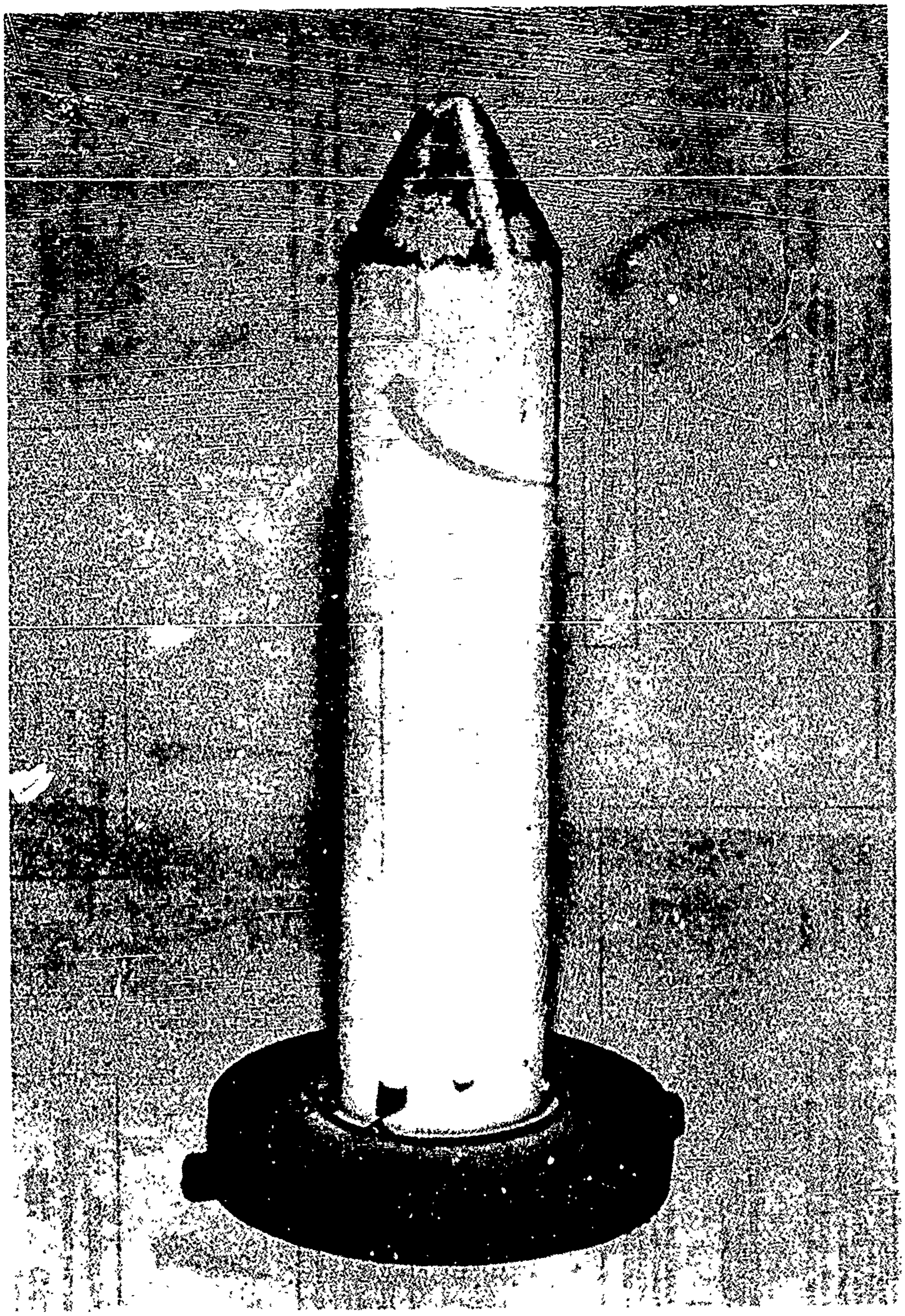


Figure 34. PTMT Core, Sprayed With MS-122, After Extraction From Motor 16Q-610-6

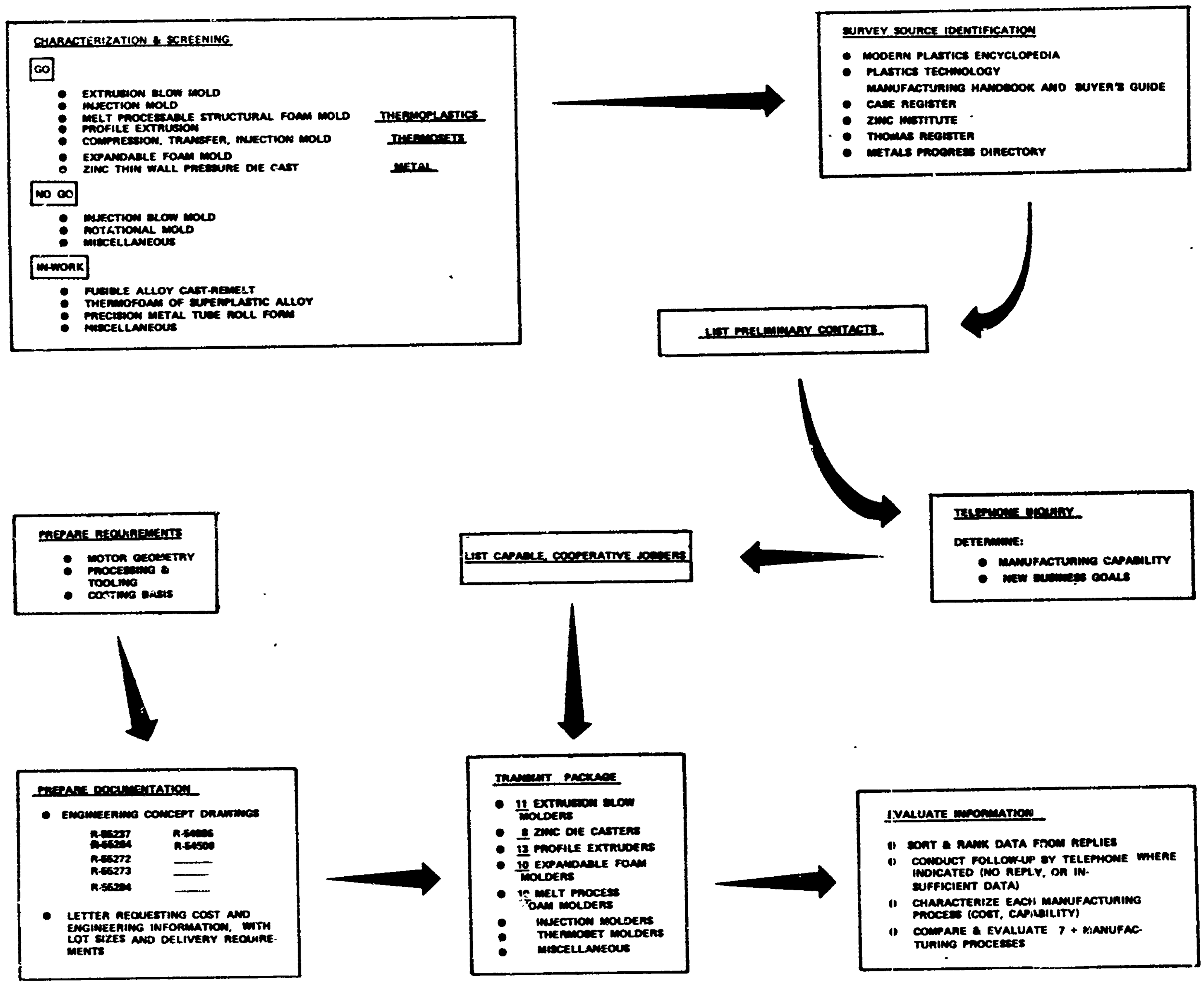


Figure 35. Overview of Manufacturing Methods Survey

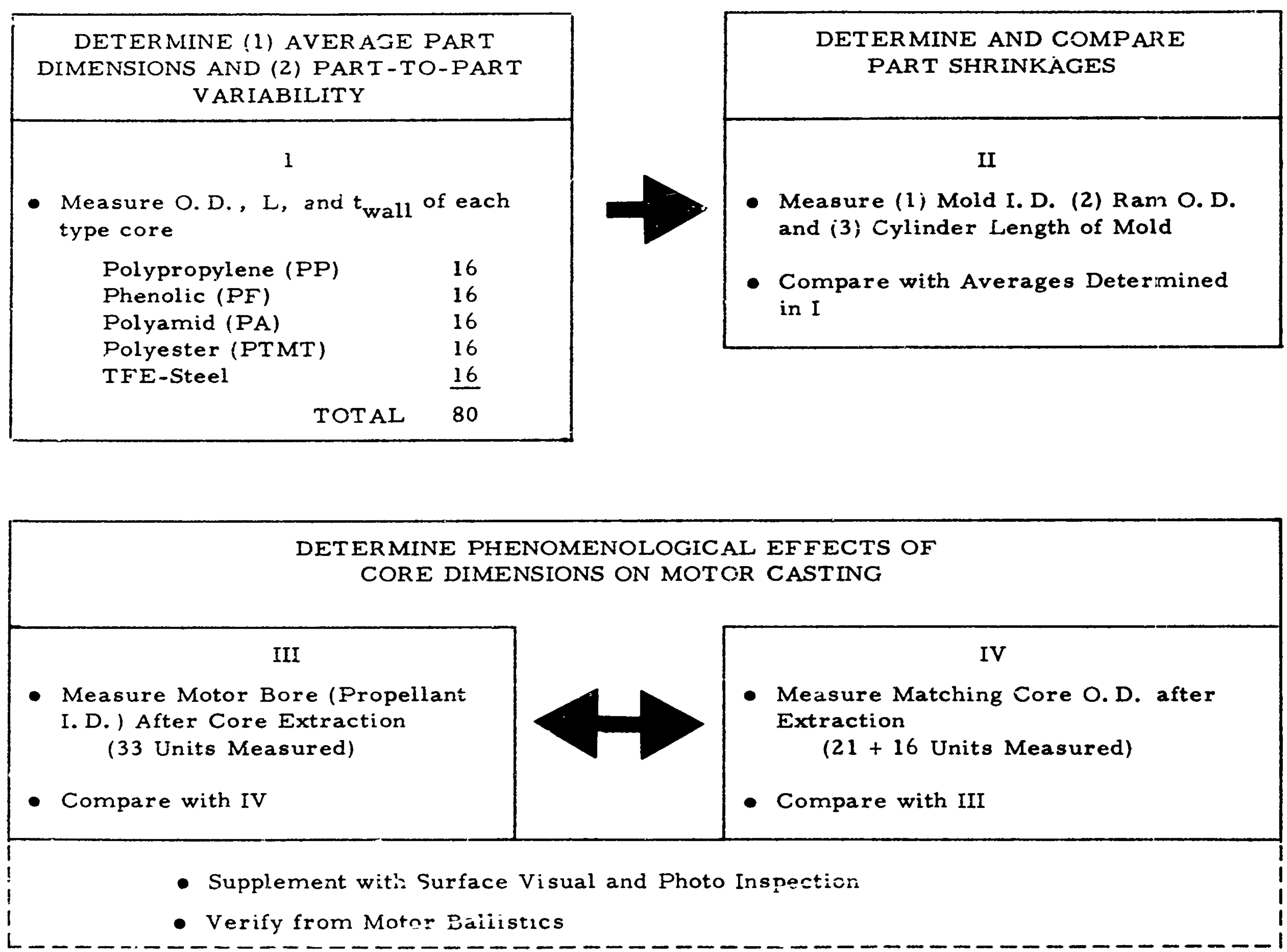


Figure 36. Prototype (TX395) Component Measurement Survey

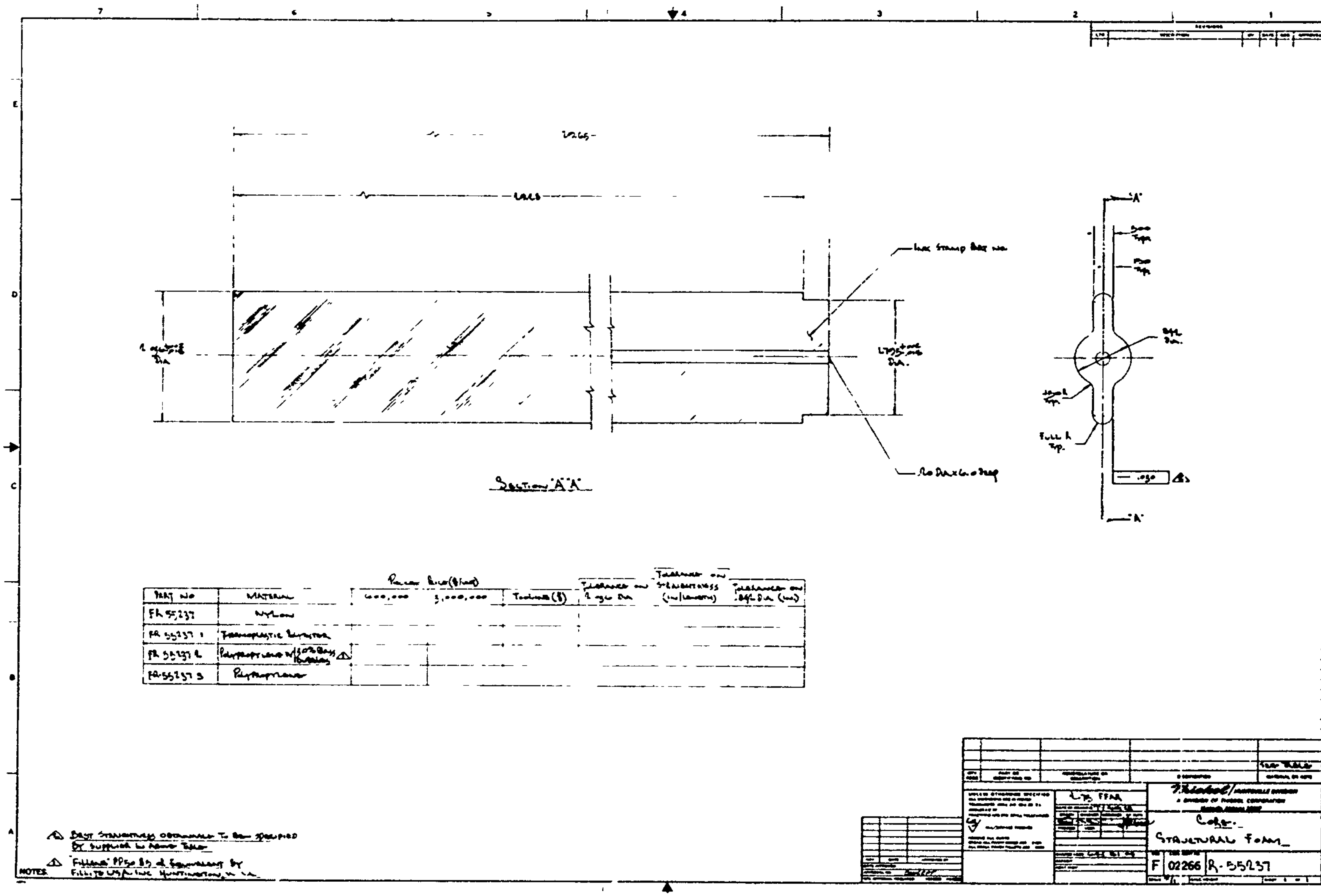


Figure 37. 2.75 Extruded Core Drawing, R-55237

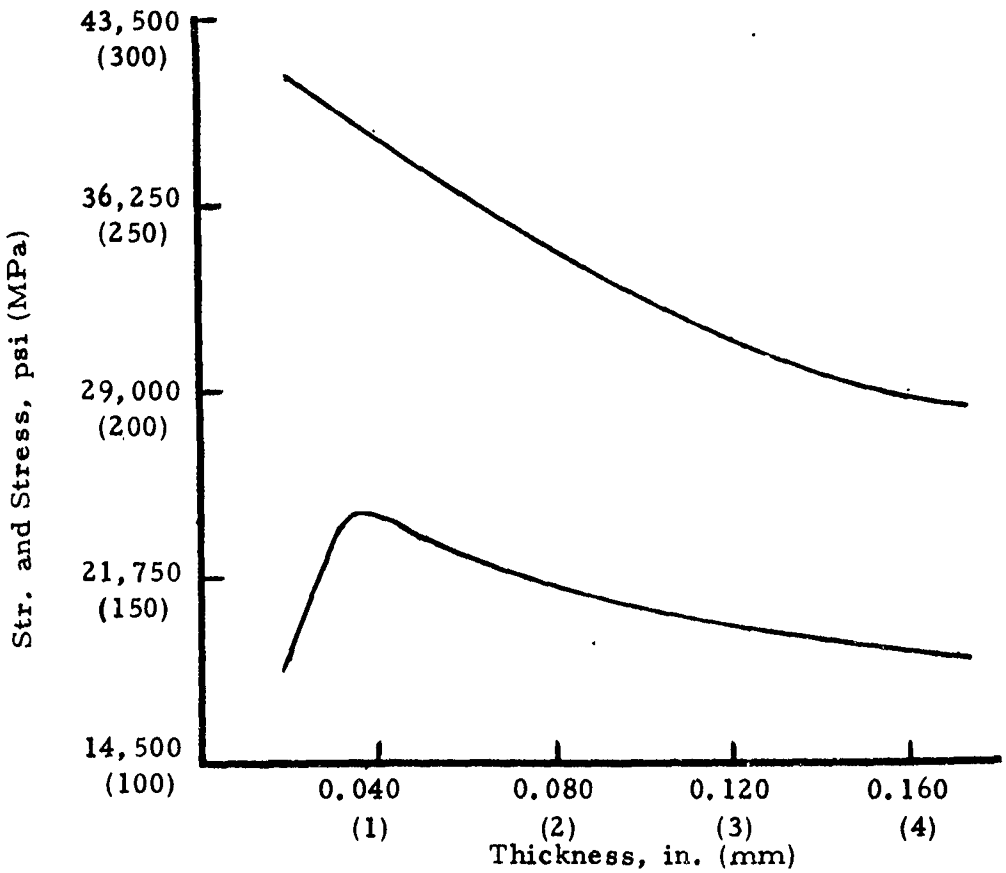


Figure 38. Ultimate Tensile Strength and Proof Strength as They Relate to Casting Wall Thickness*

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*"Materials Engineering", March 1977

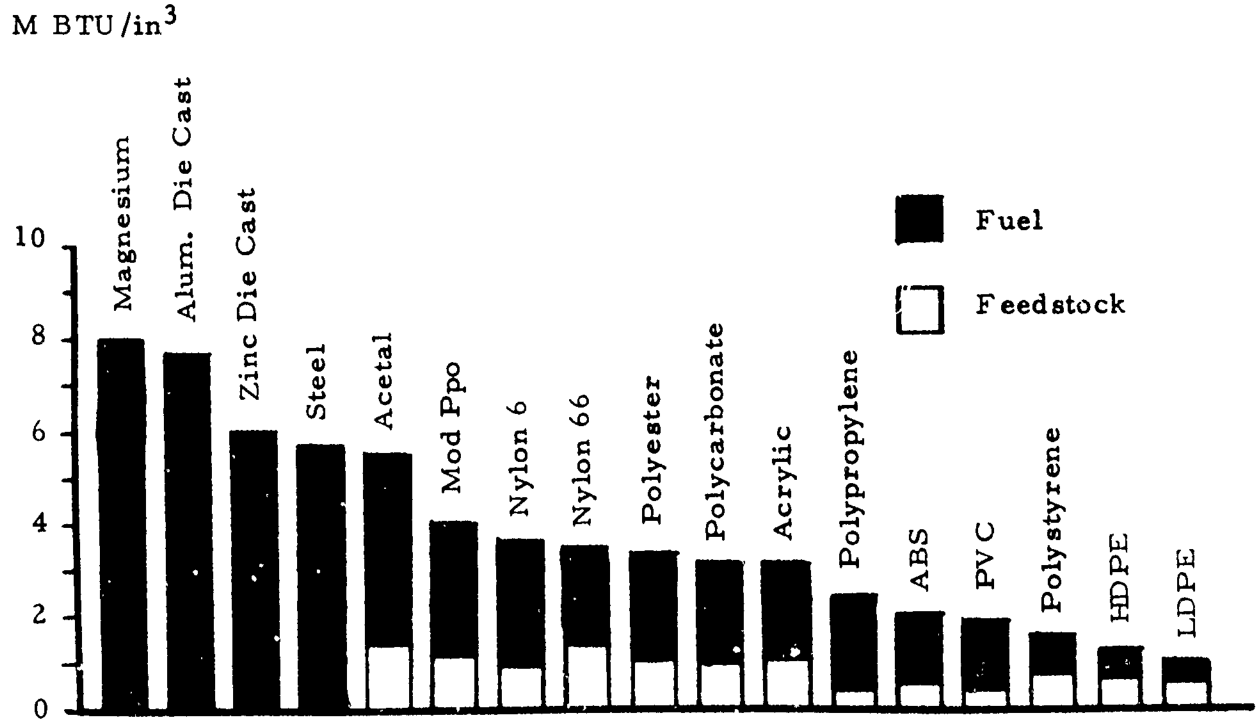

Figure 39. Energy Requirements of Engineering Materials by Volume*

*"Precision Metal", February 1977

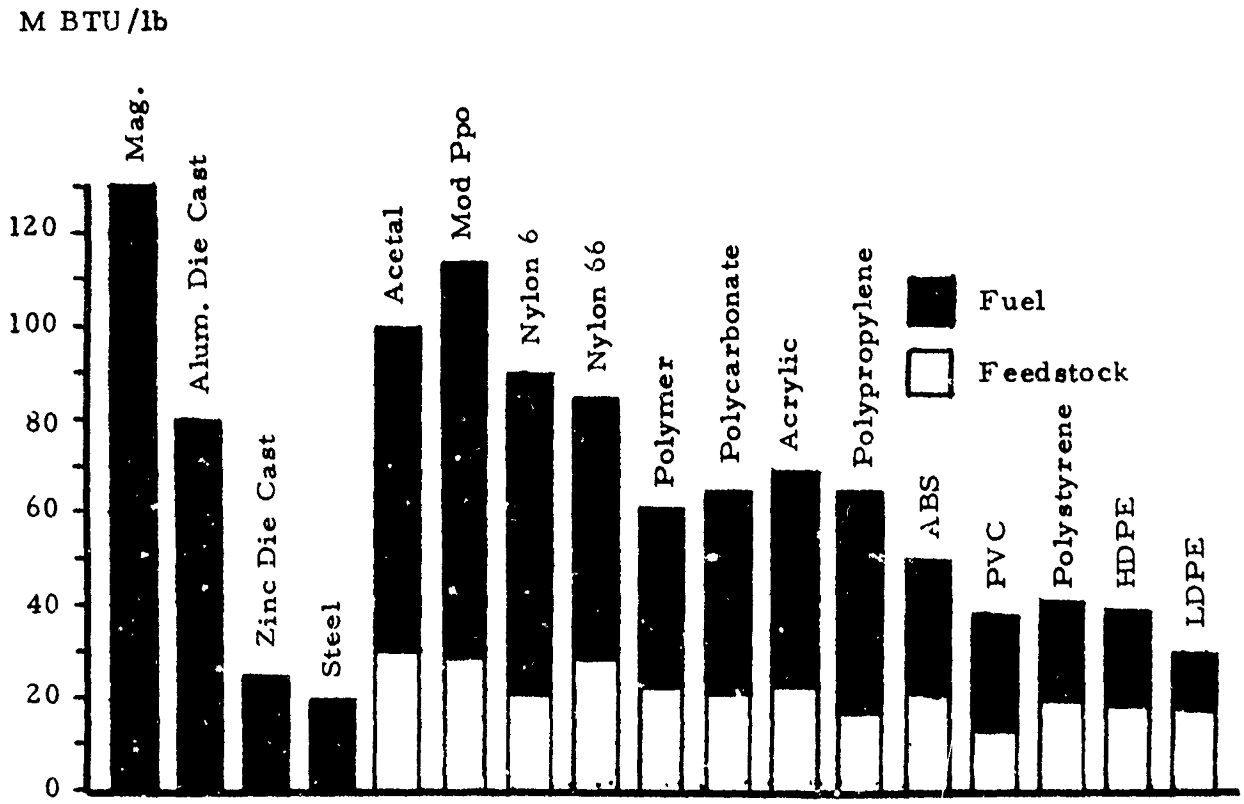

Figure 40. Energy Requirements of Engineering Materials by Weight*

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*"Precision Metal", February 1977

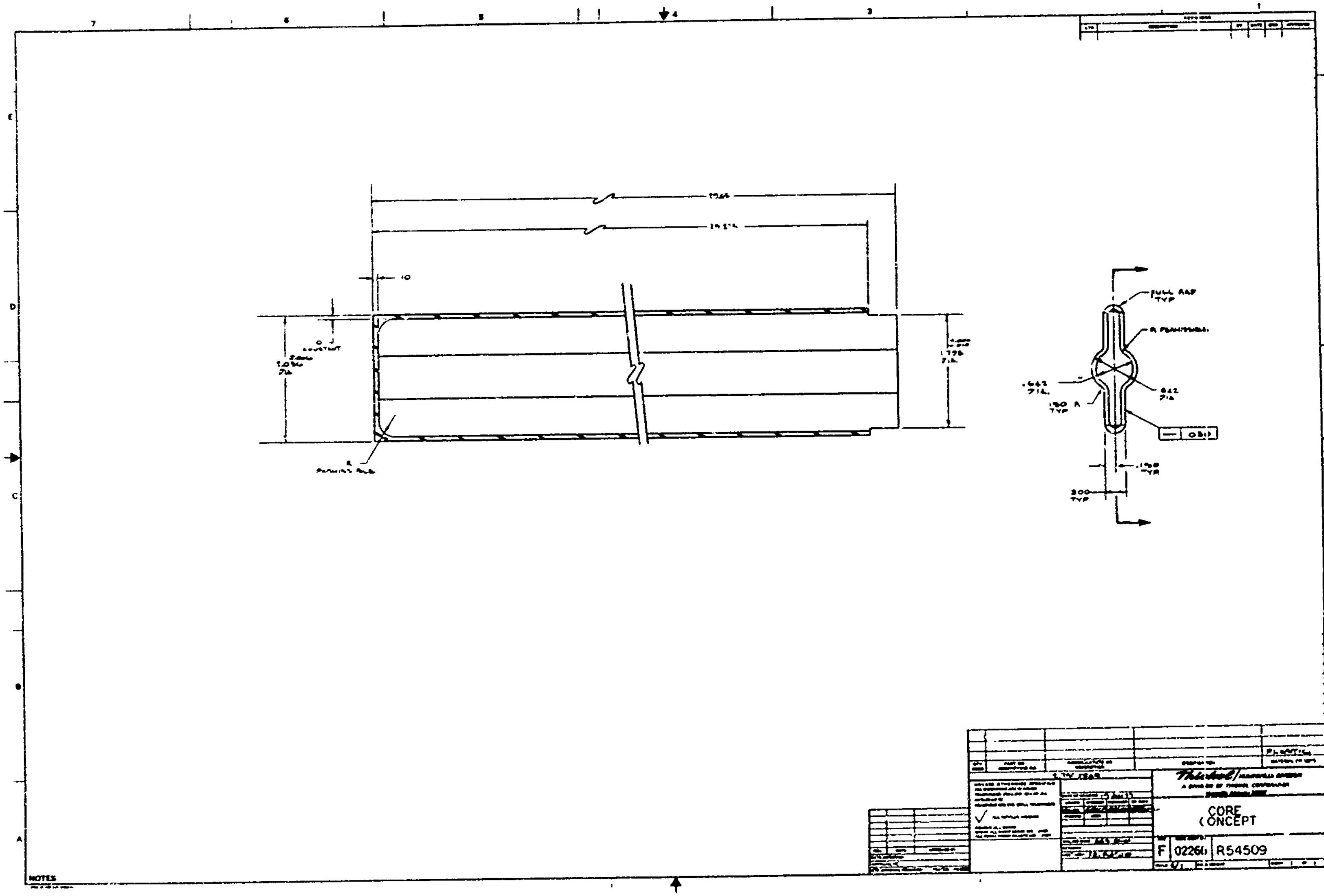

Figure 41. Core Concept, R54509

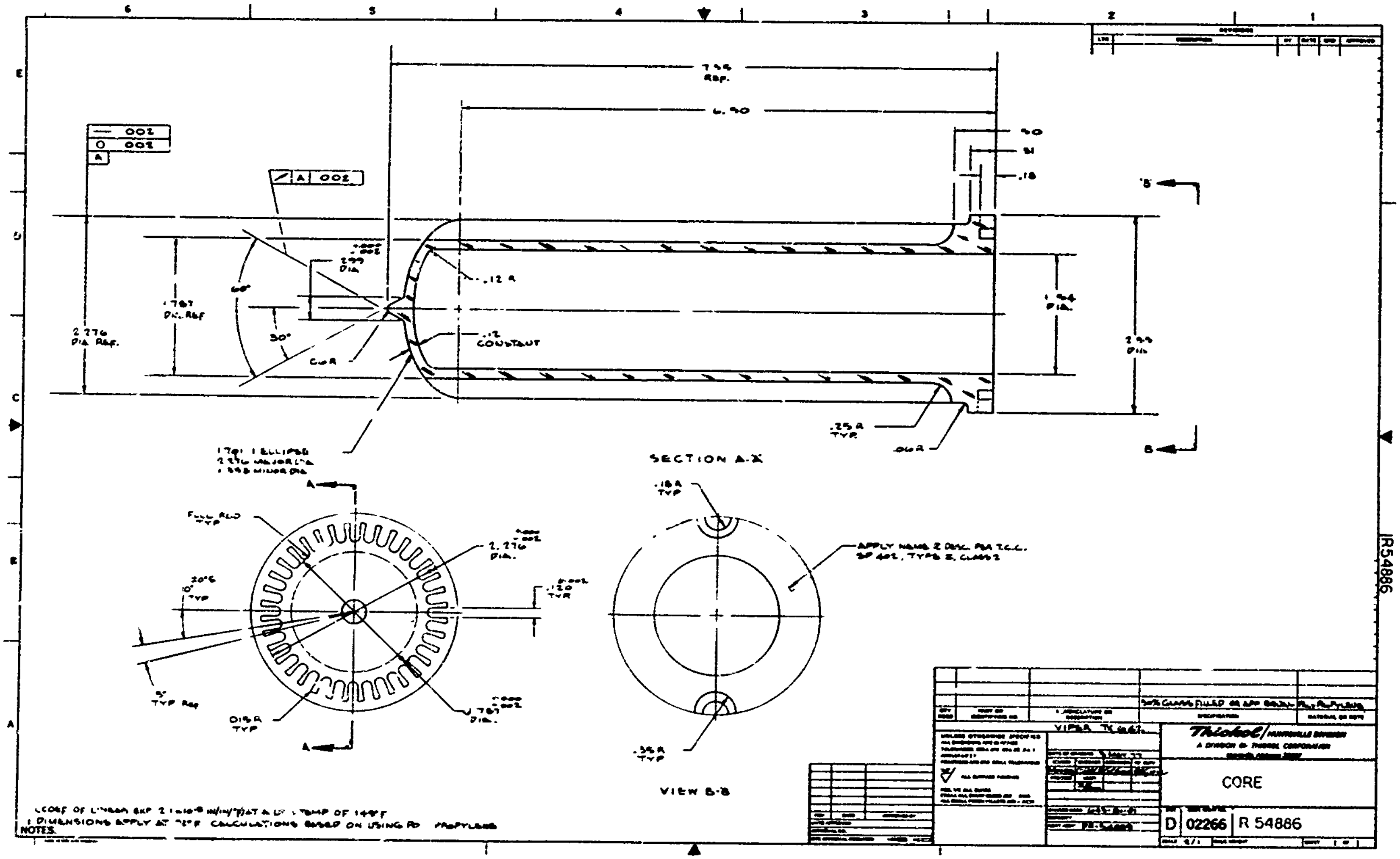

Figure 42. Disposable Viper Core (DR-54886)

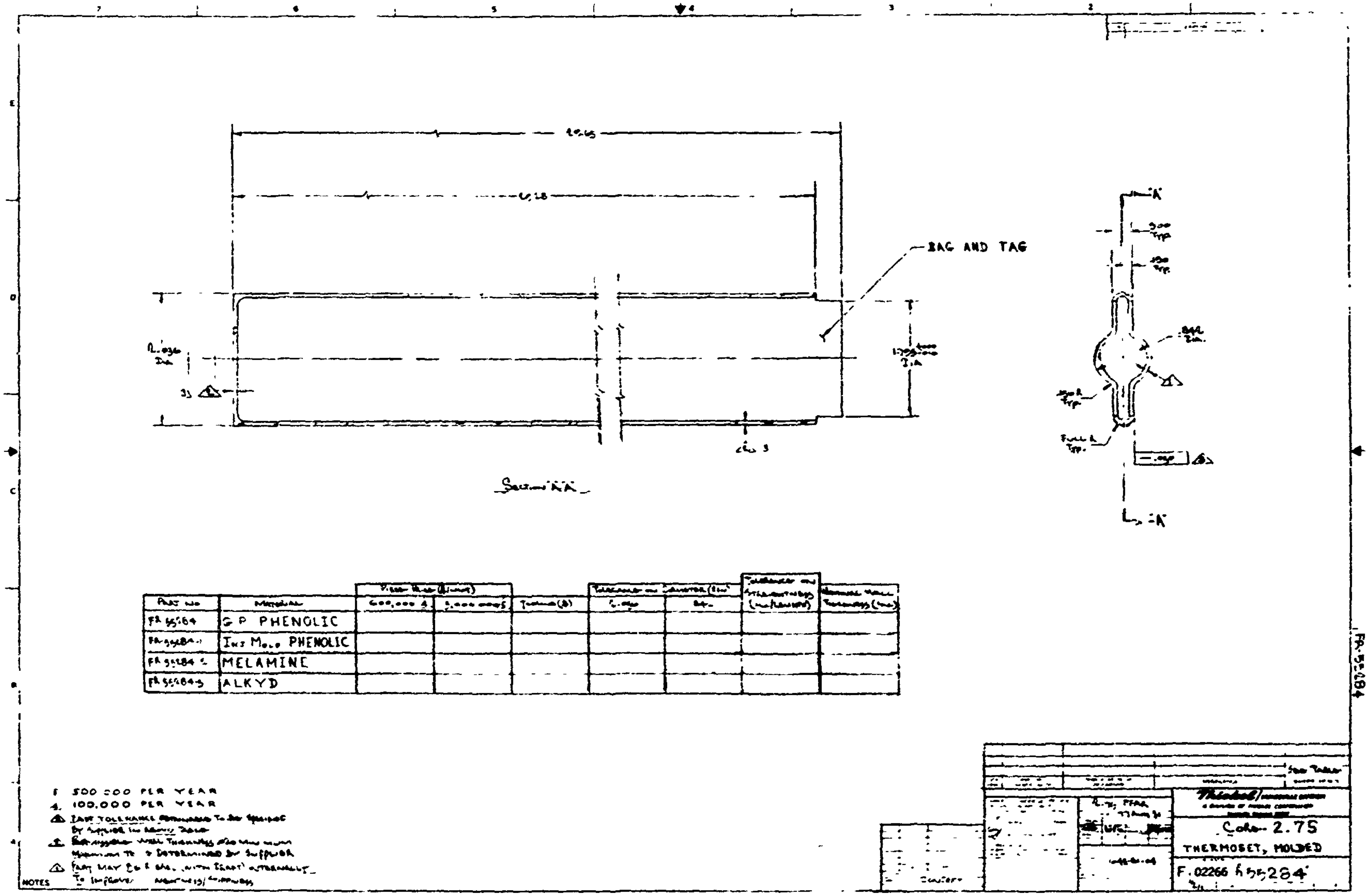

Figure 43. Compression, Transfer, or Inspection Molded Thermoset Core for 2.75 Motor.

(See Page 29)

Figure 44. Typical Thermoset Molding Cycles

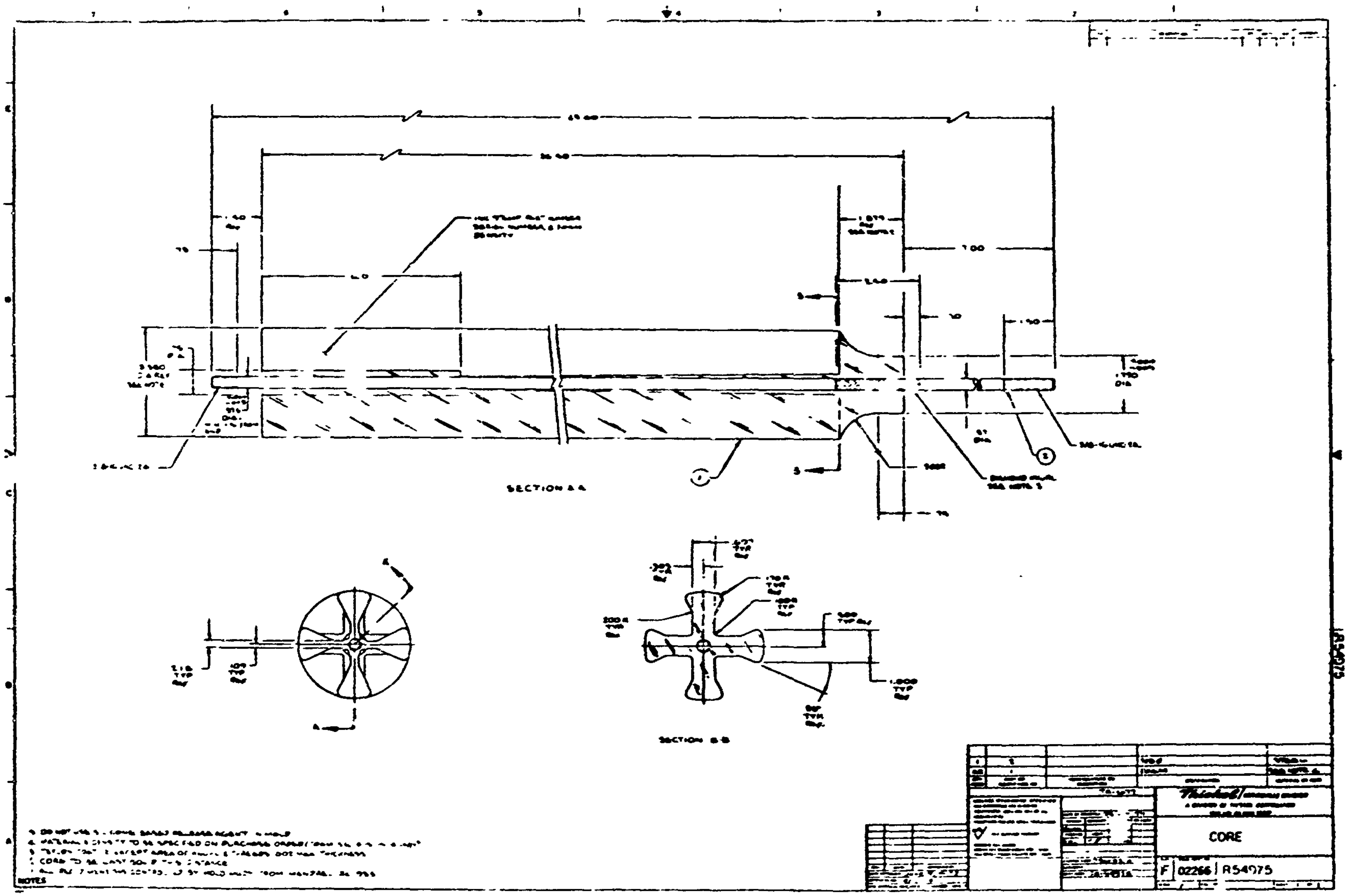

Figure 45. Drawing of Core for FFR Motor (R54975)

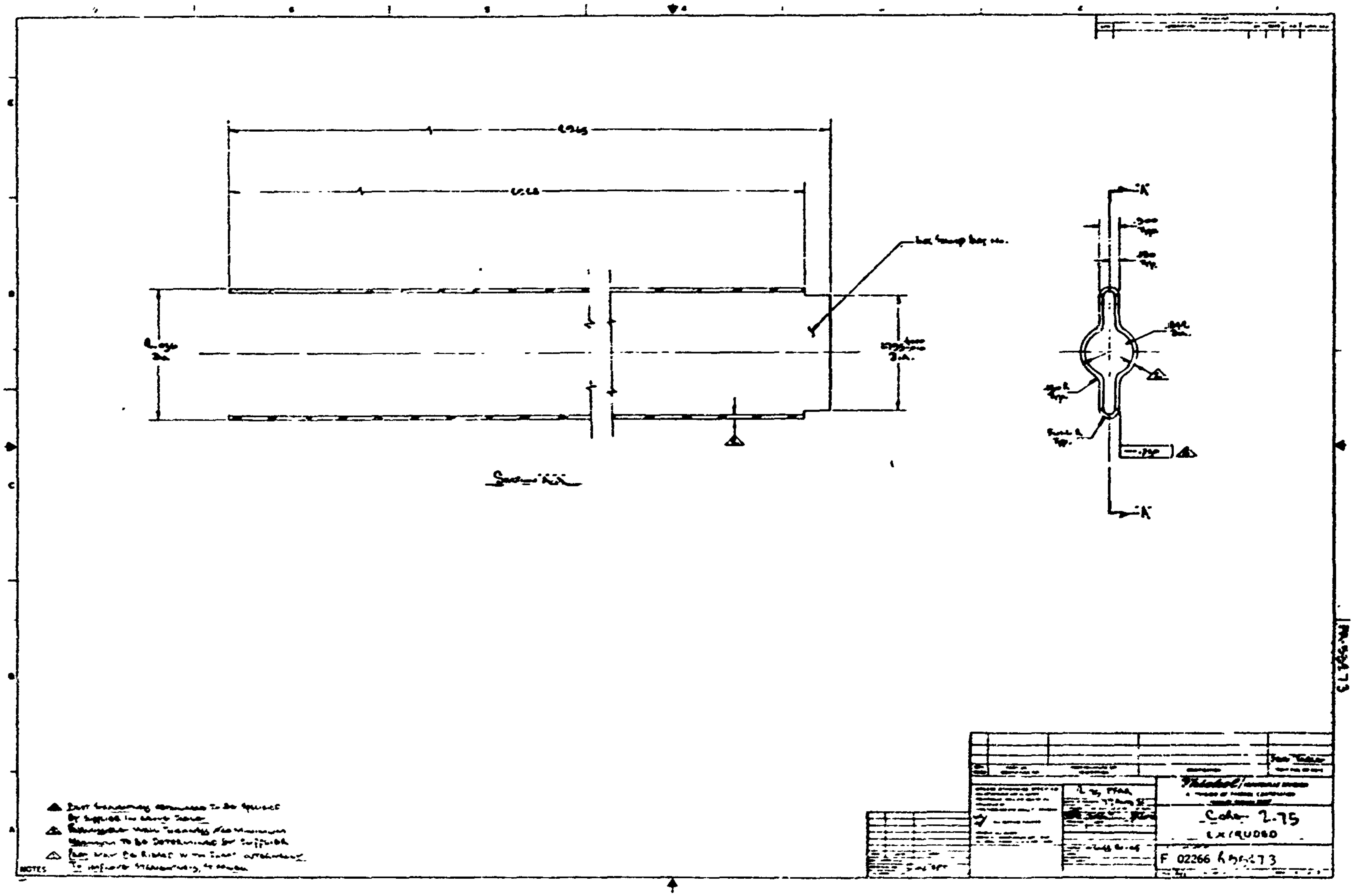

Figure 46. Core Drawing, 2.75 FFAR, R-55273 (Extruded)

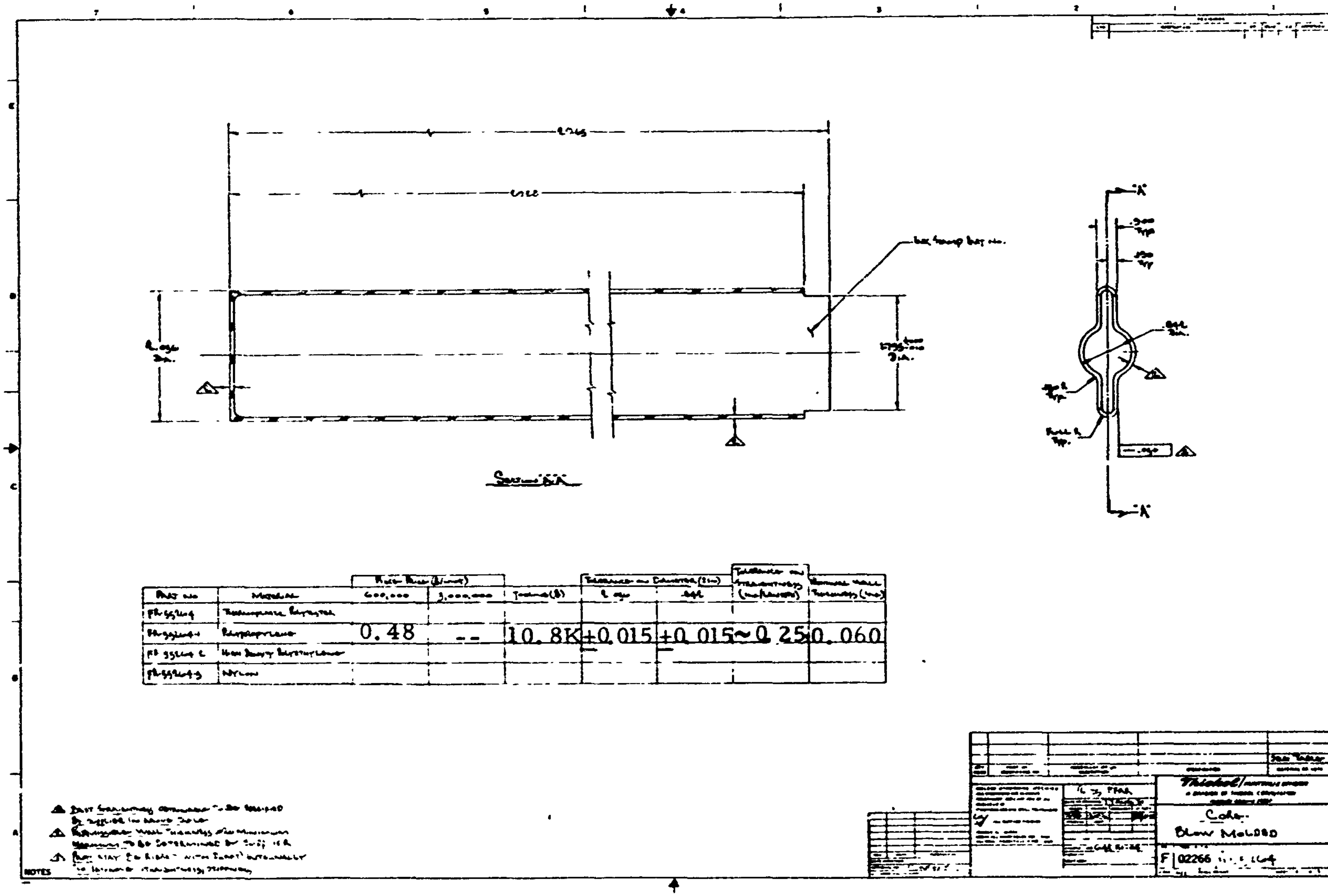

Figure 47. 2.75 Core (Blow Molded) Drawing, R-55264. Quoted Tolerances and Costs from Geauga Plastics

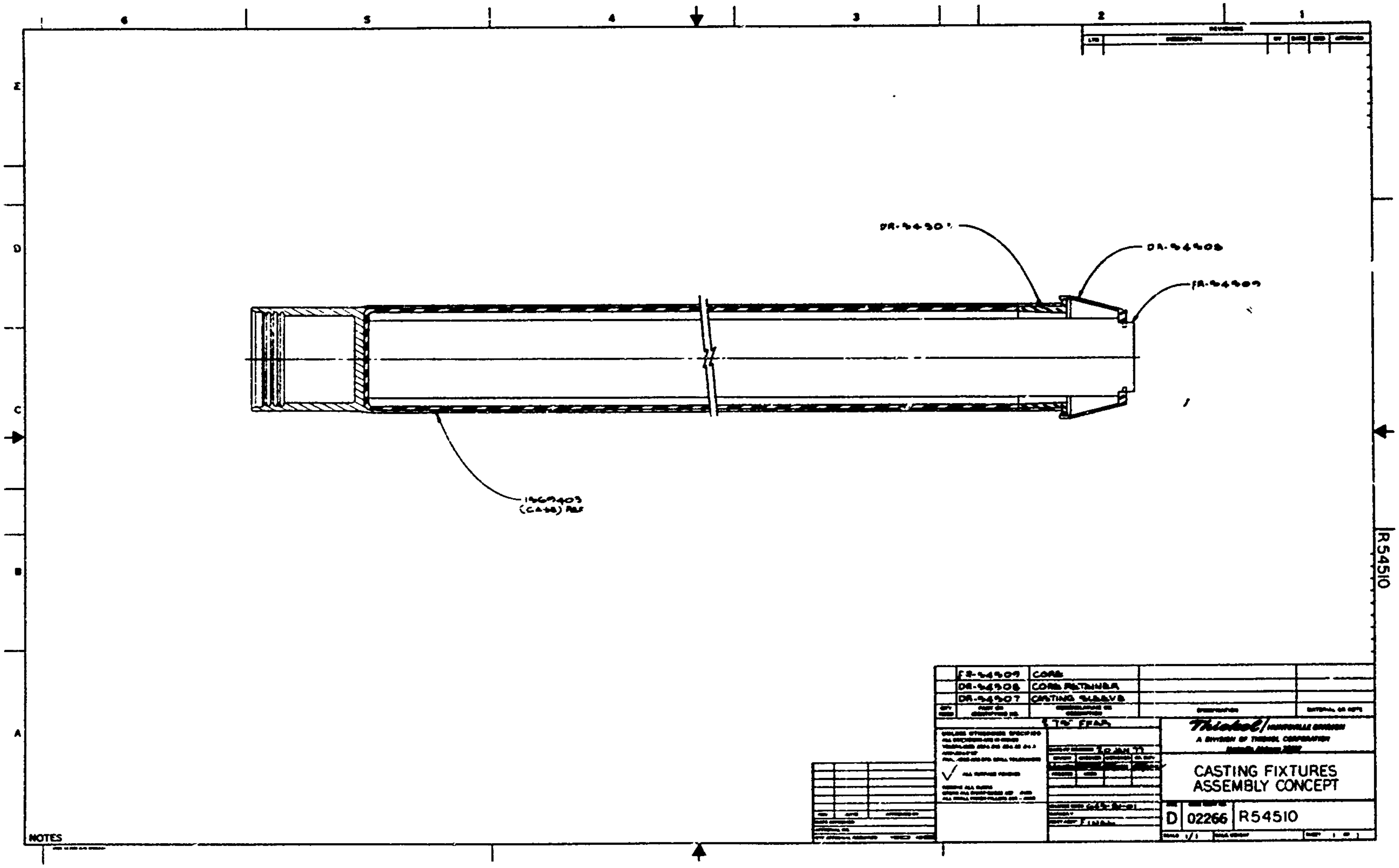

Figure 48. Casting Fixtures Assembly Concept, R54510

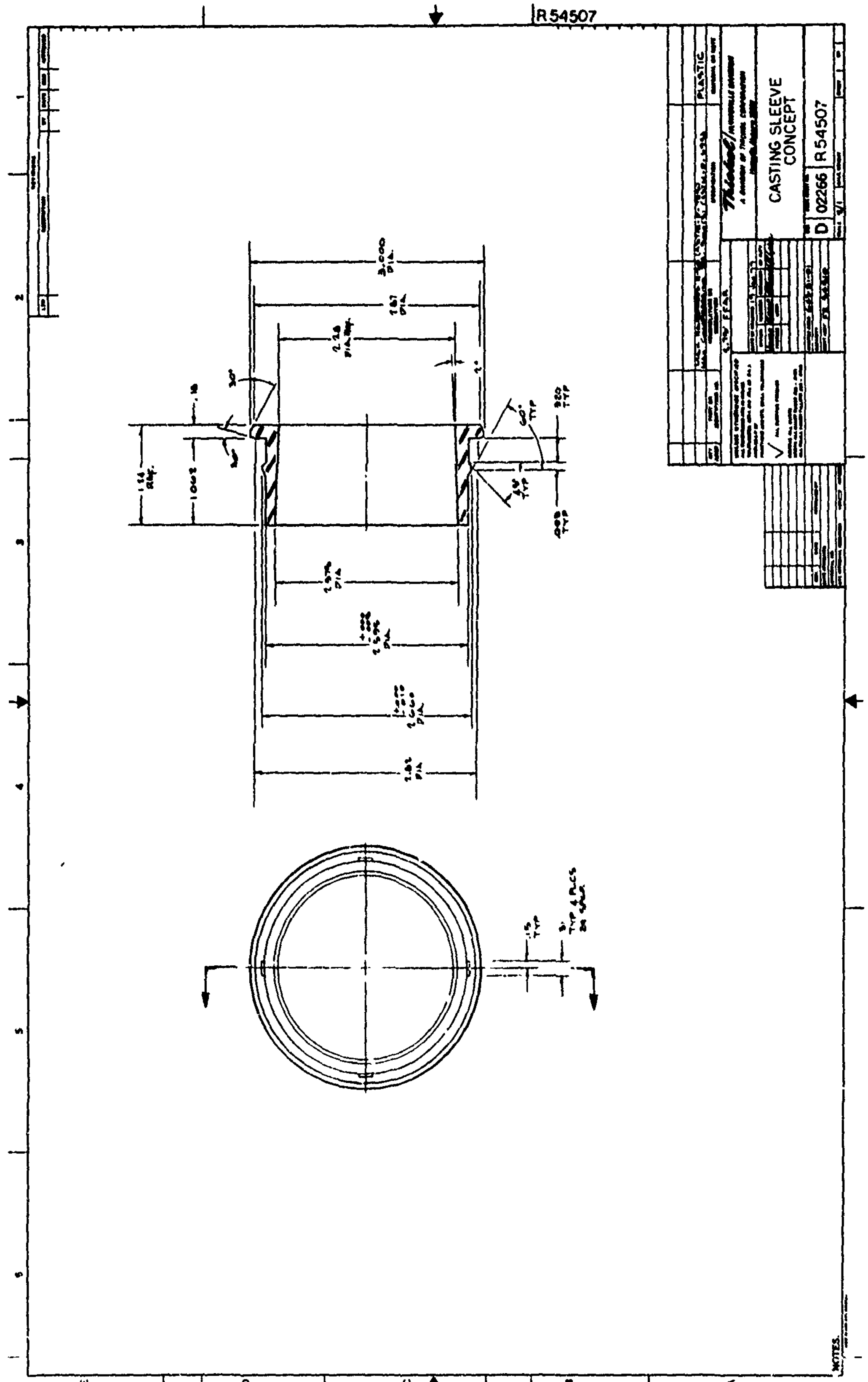

Figure 49. Casting Sleeve Concept, R54507

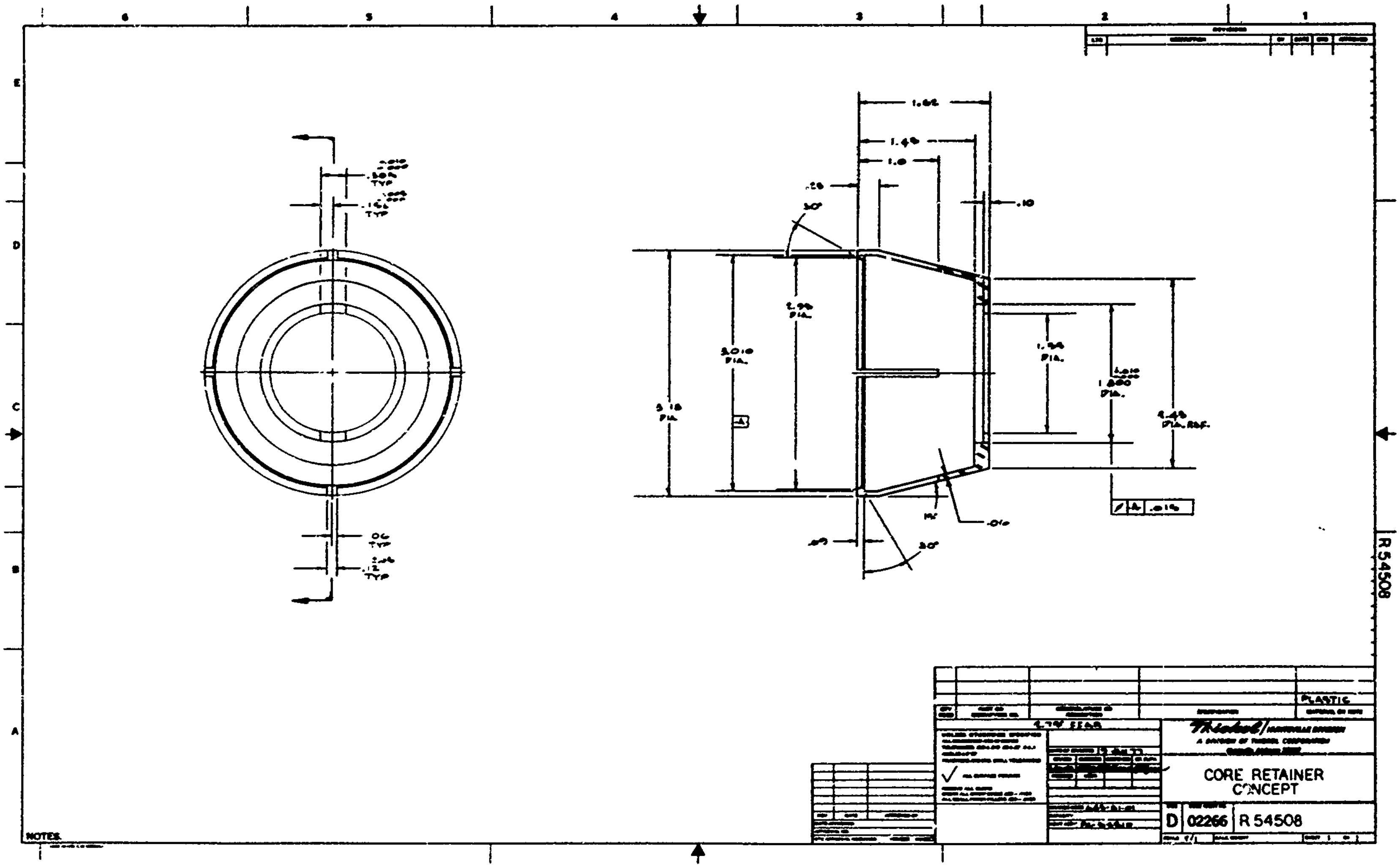

Figure 50. Core Retainer Concept, R54508

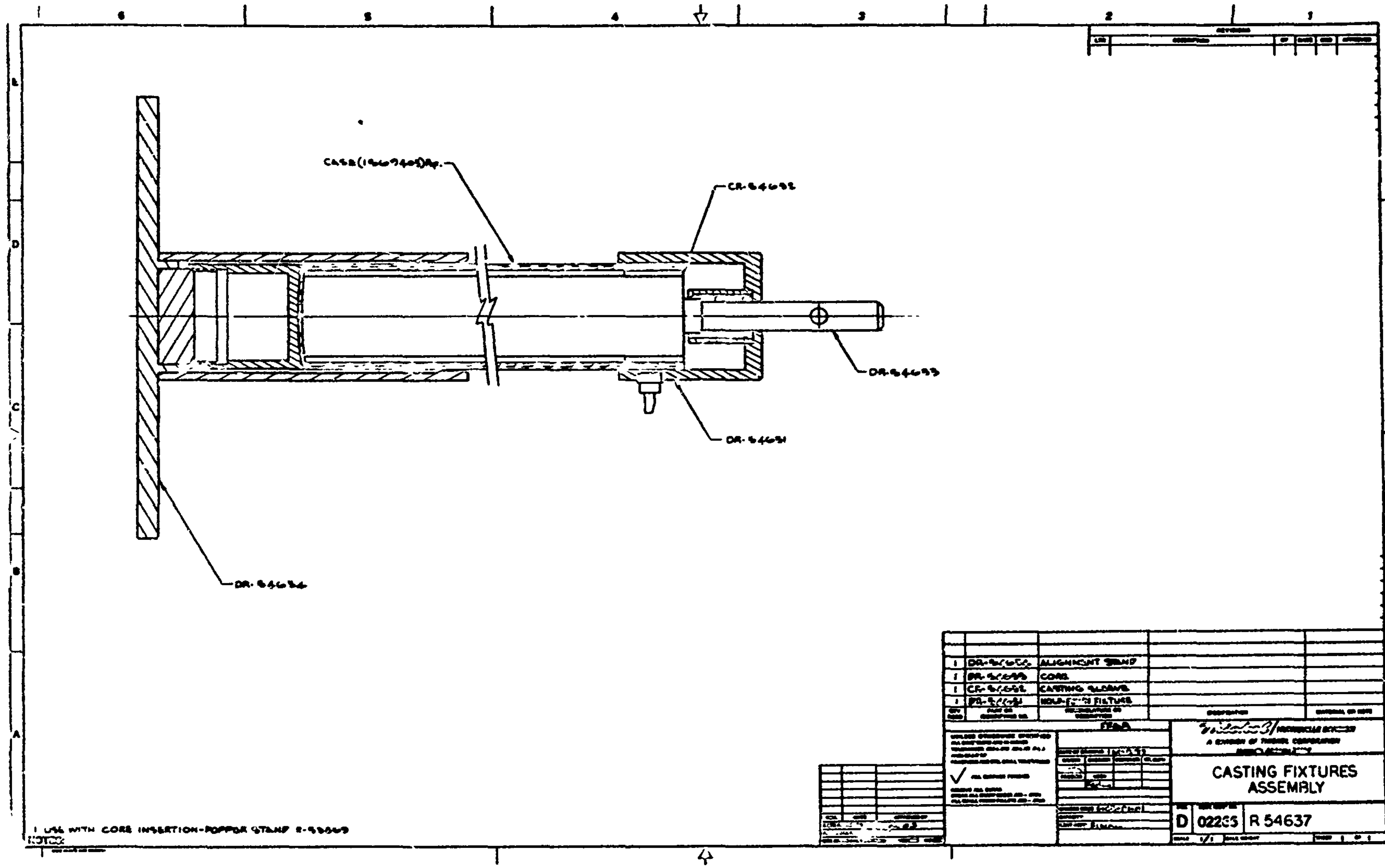

Figure 51. DR-54637, Casting Fixtures Assembly

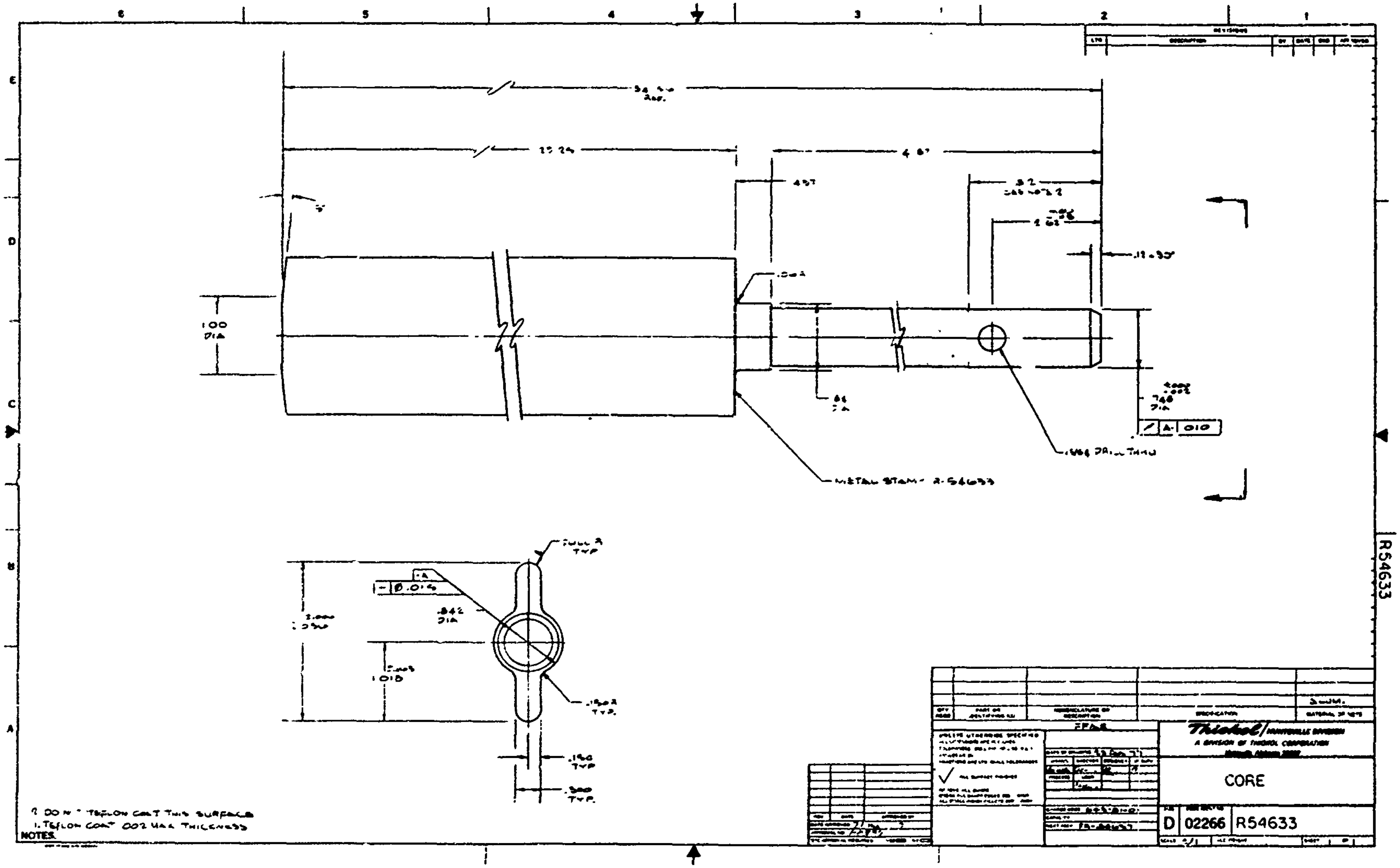

Figure 52. DR-54633, Core

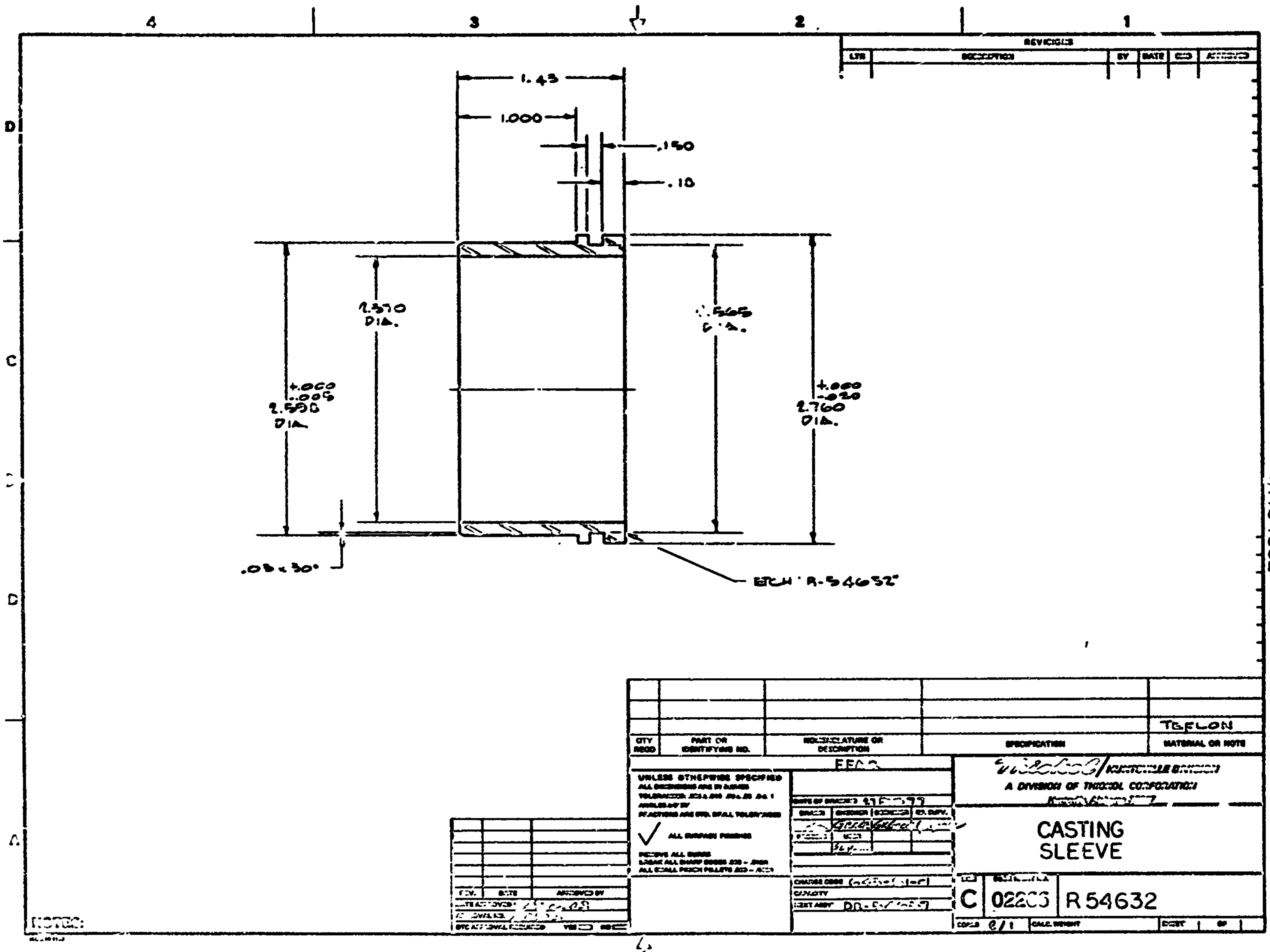

Figure 54. CR-54632, Casting Sleeve

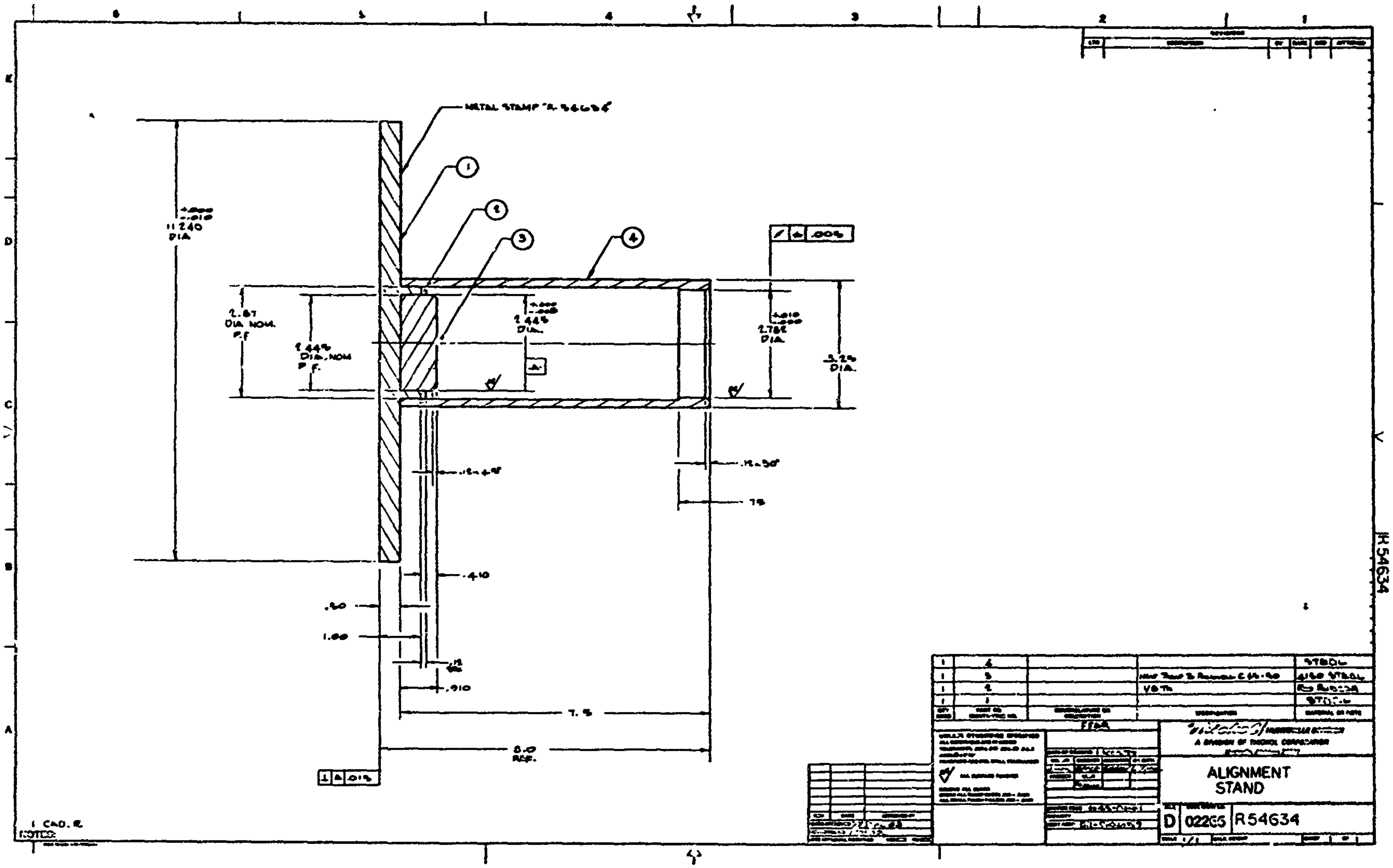

Figure 55. DR-54634, Alignment Stand

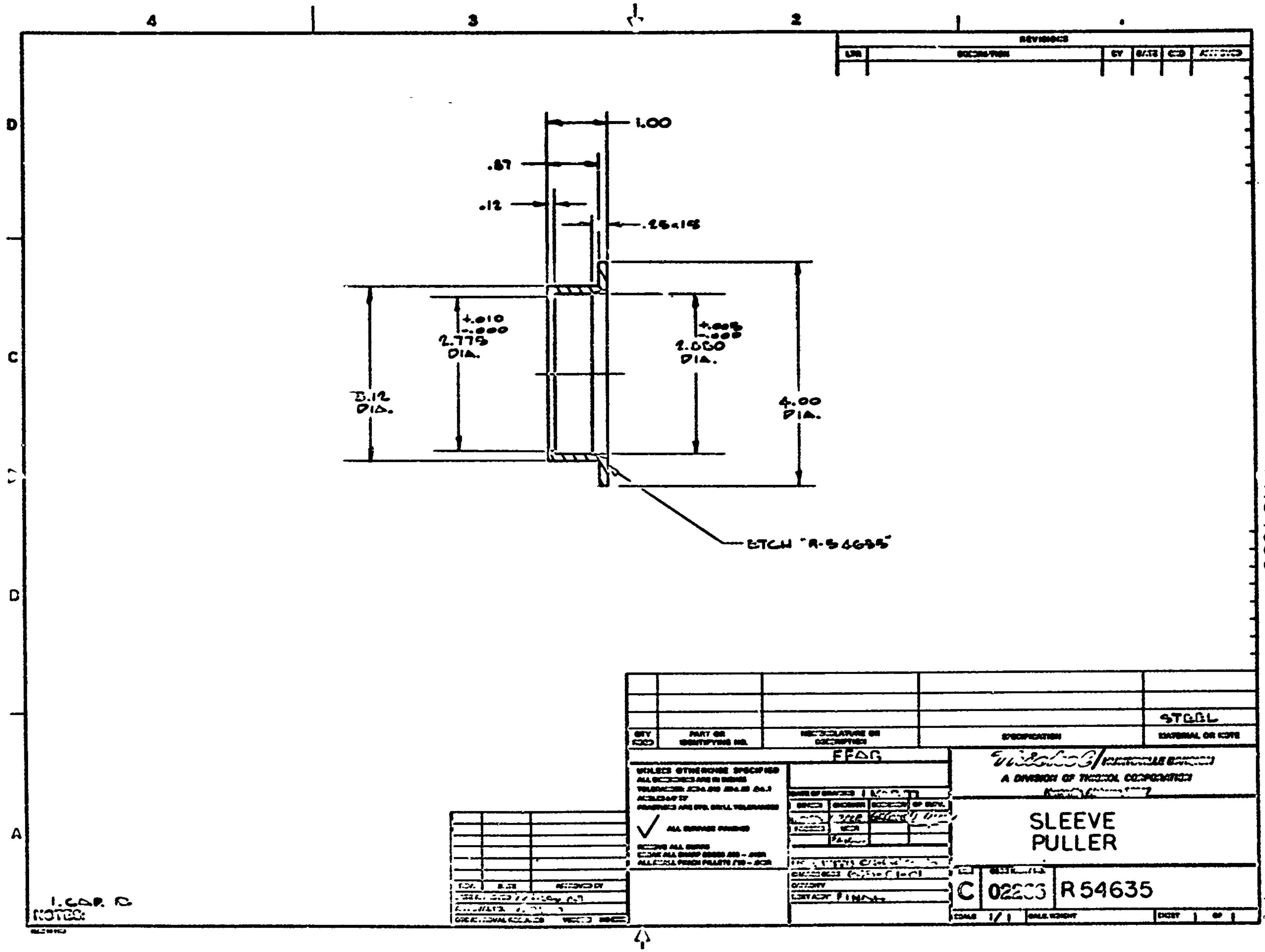

Figure 56. CR-54635, Sleeve Puller

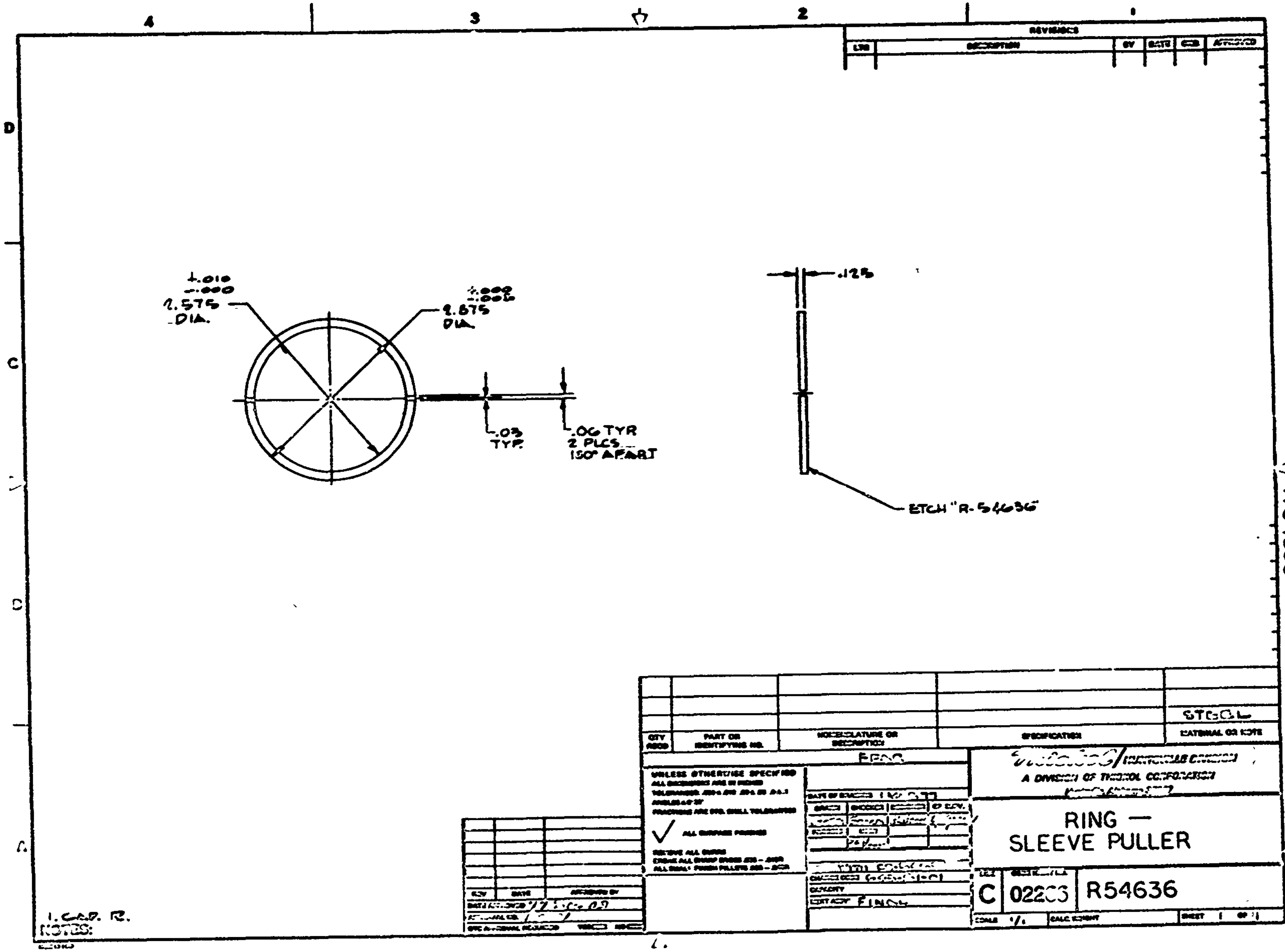

Figure 57. CR-54636, Ring-Sleeve Puller

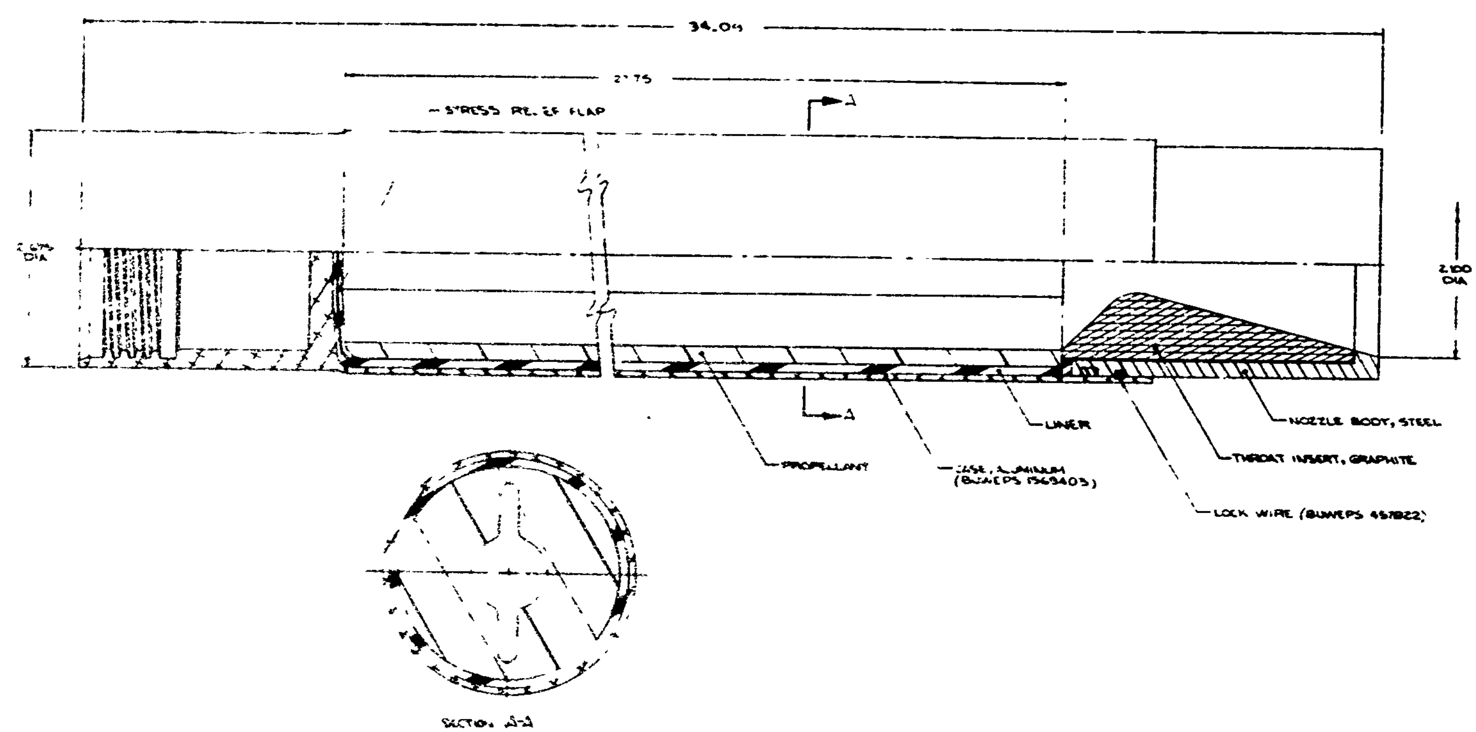

Figure 58. 2.75" Case Bonded Rocket Motor Concept (Drawing 53939)

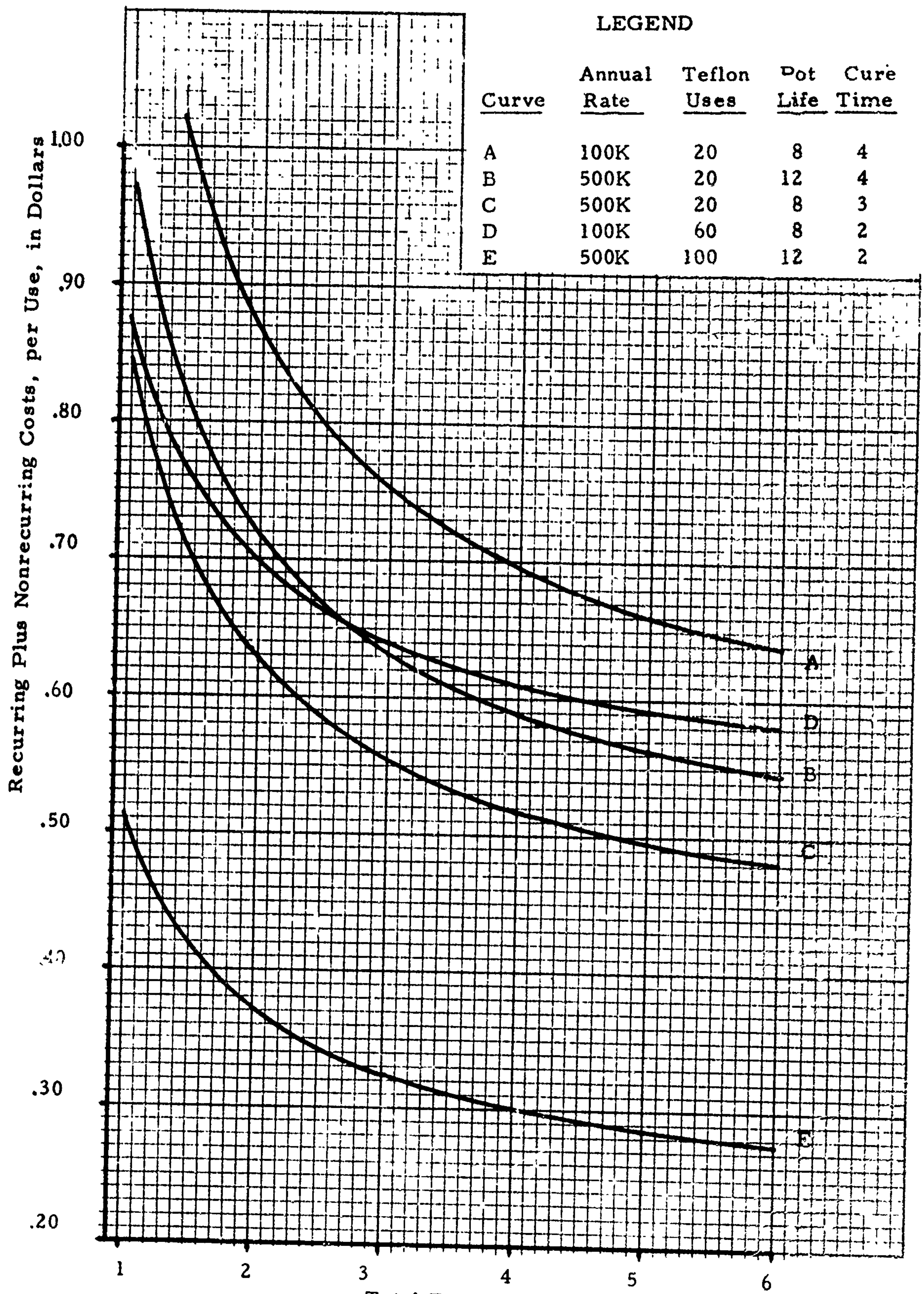

Figure 59. Net, Per Use, Cost - Typical Curves, 2.75" Rocket Reusable Tooling

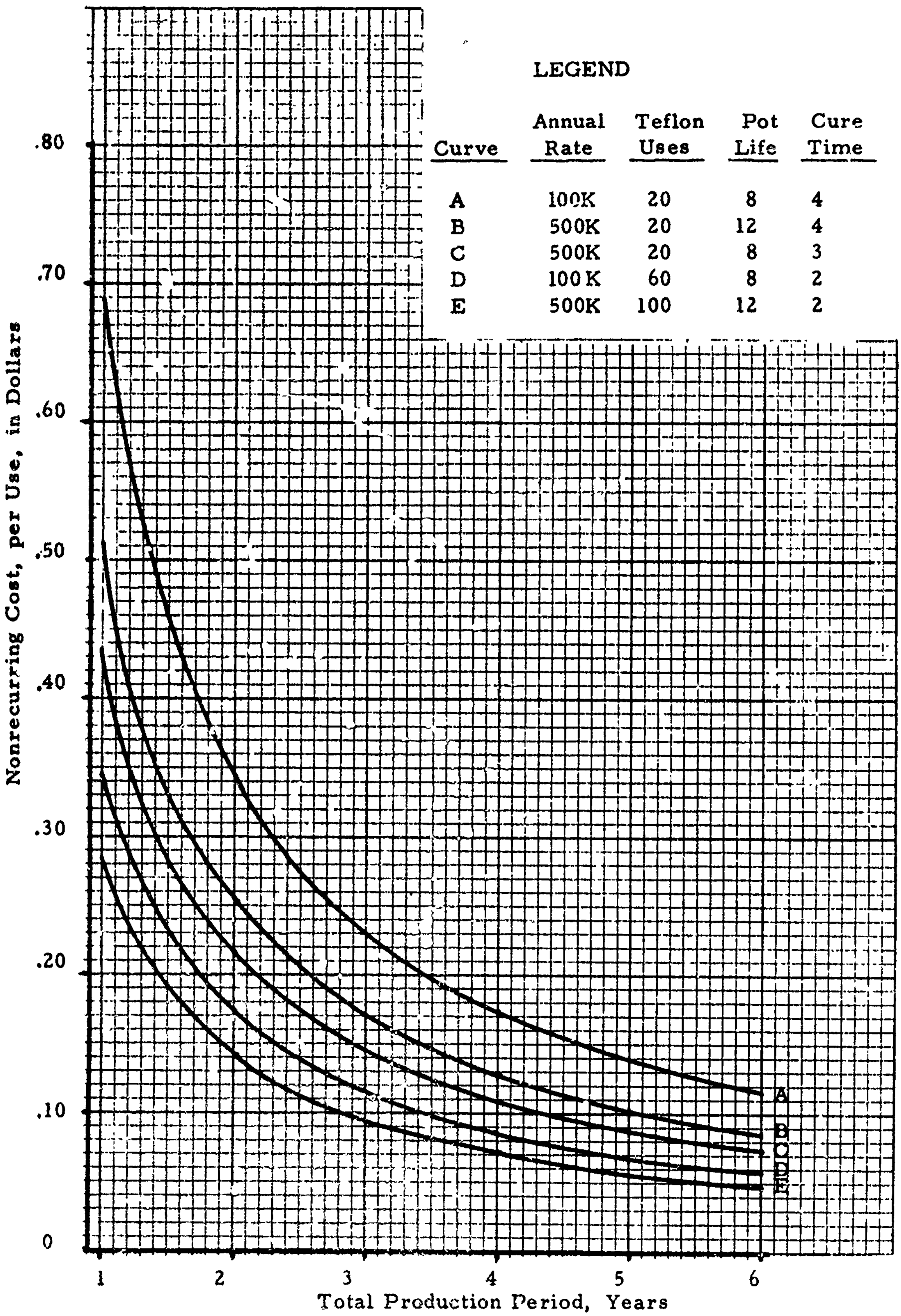

Figure 60. Nonrecurring Costs per Use, Typical Curves

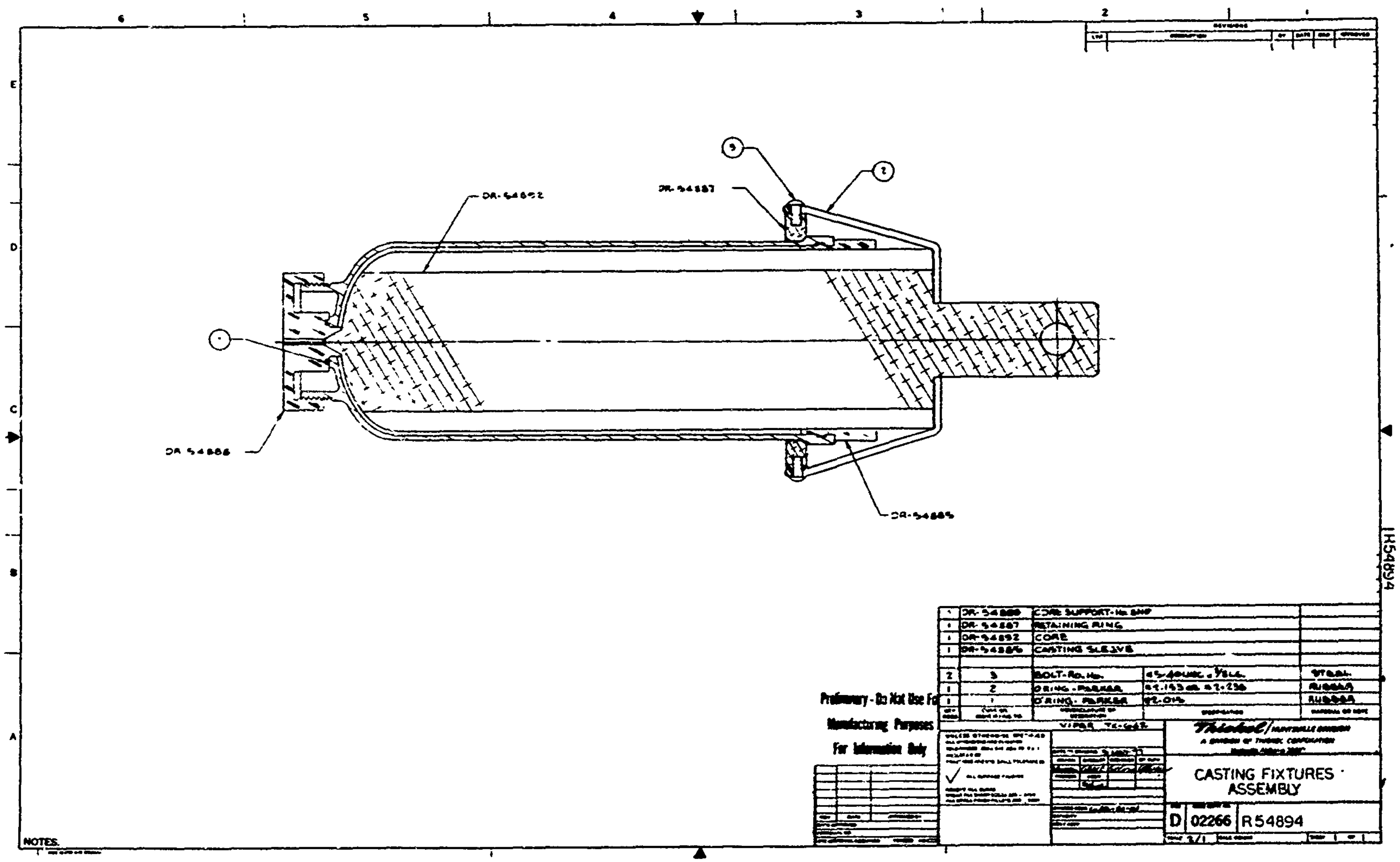

Figure 61. Reusable Viper Tooling Assembly (DR 54894)

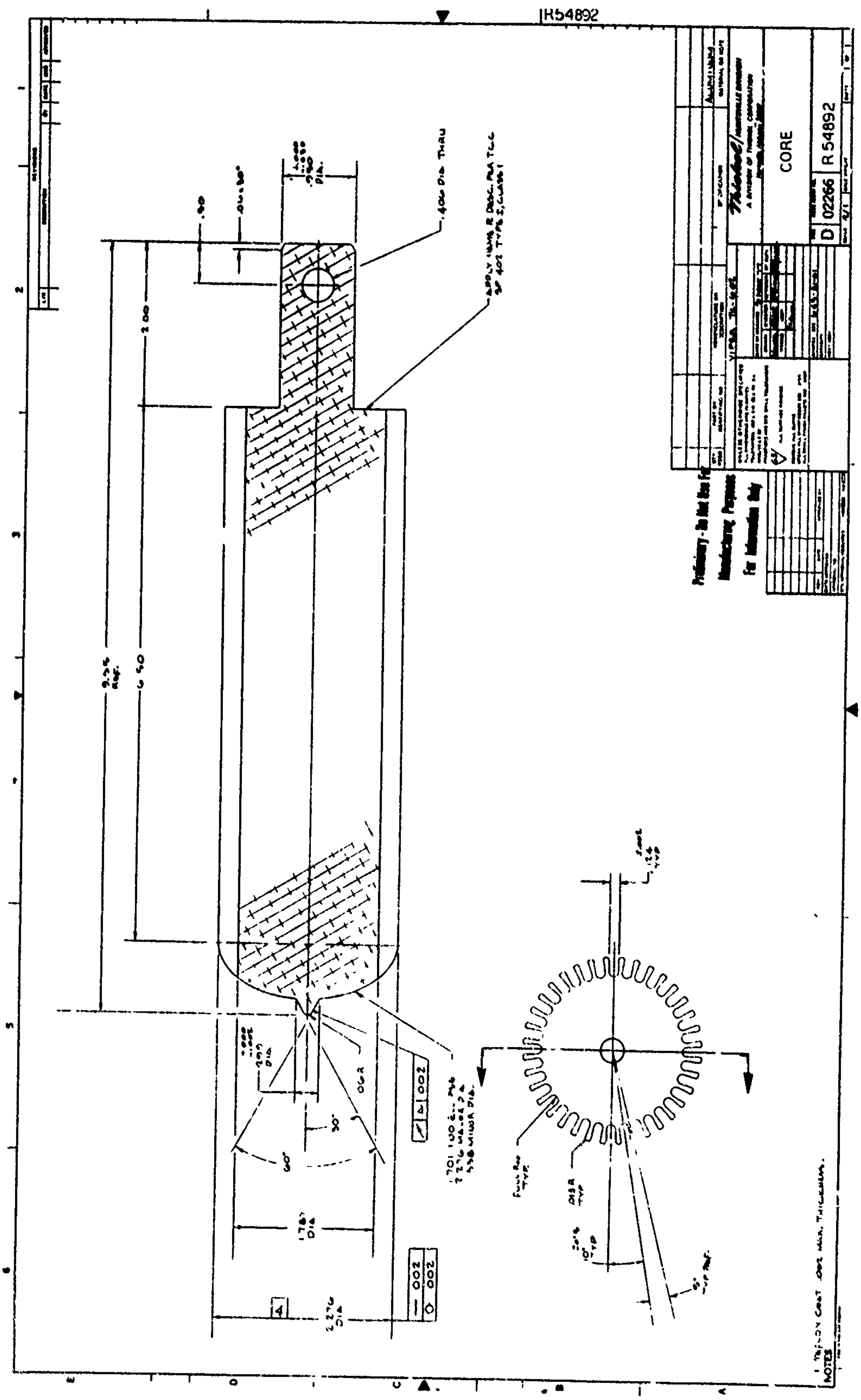

Figure 62. Reusable Viper Core (DR-54892)

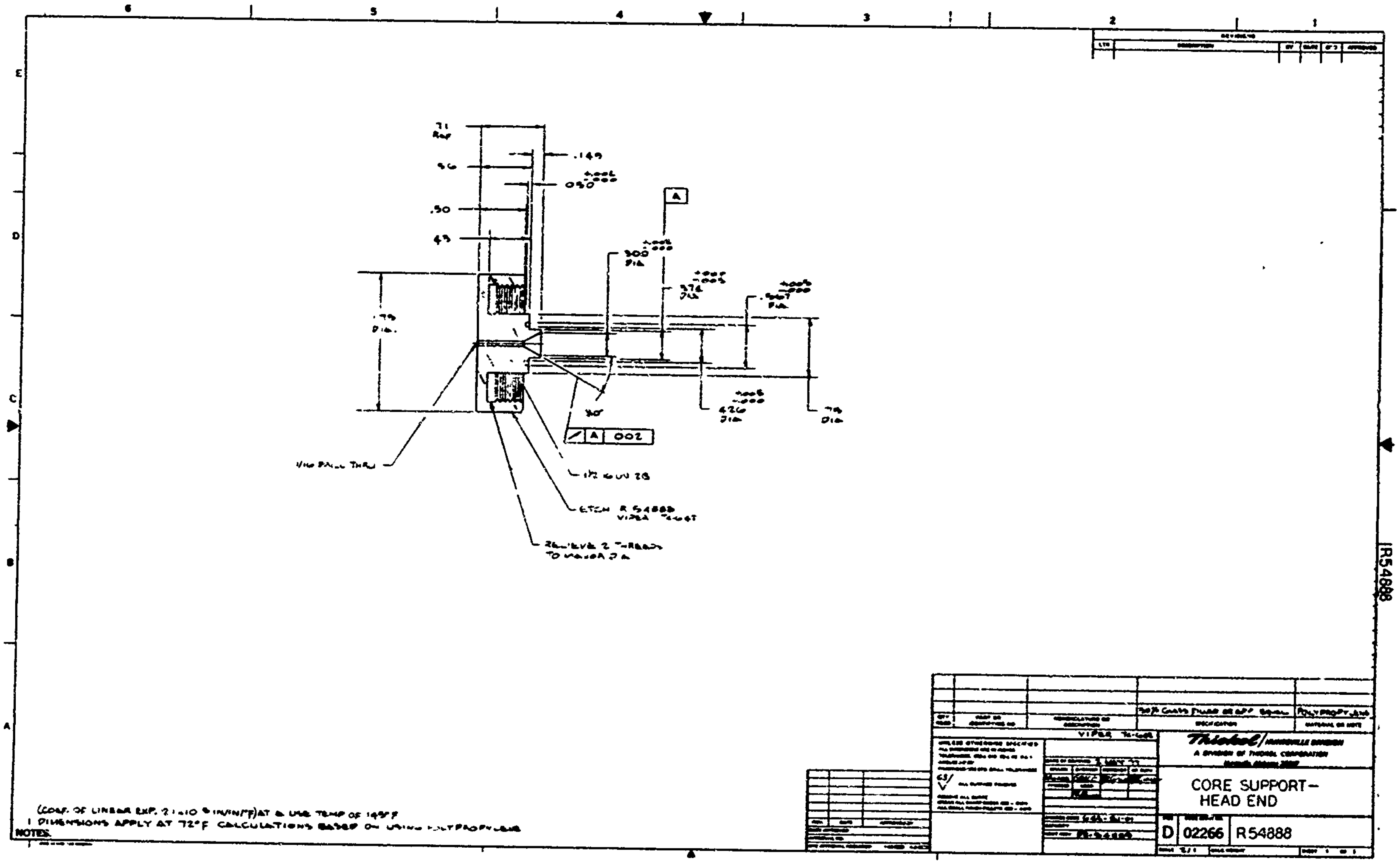

Figure 63. Core Support (DR-54888)

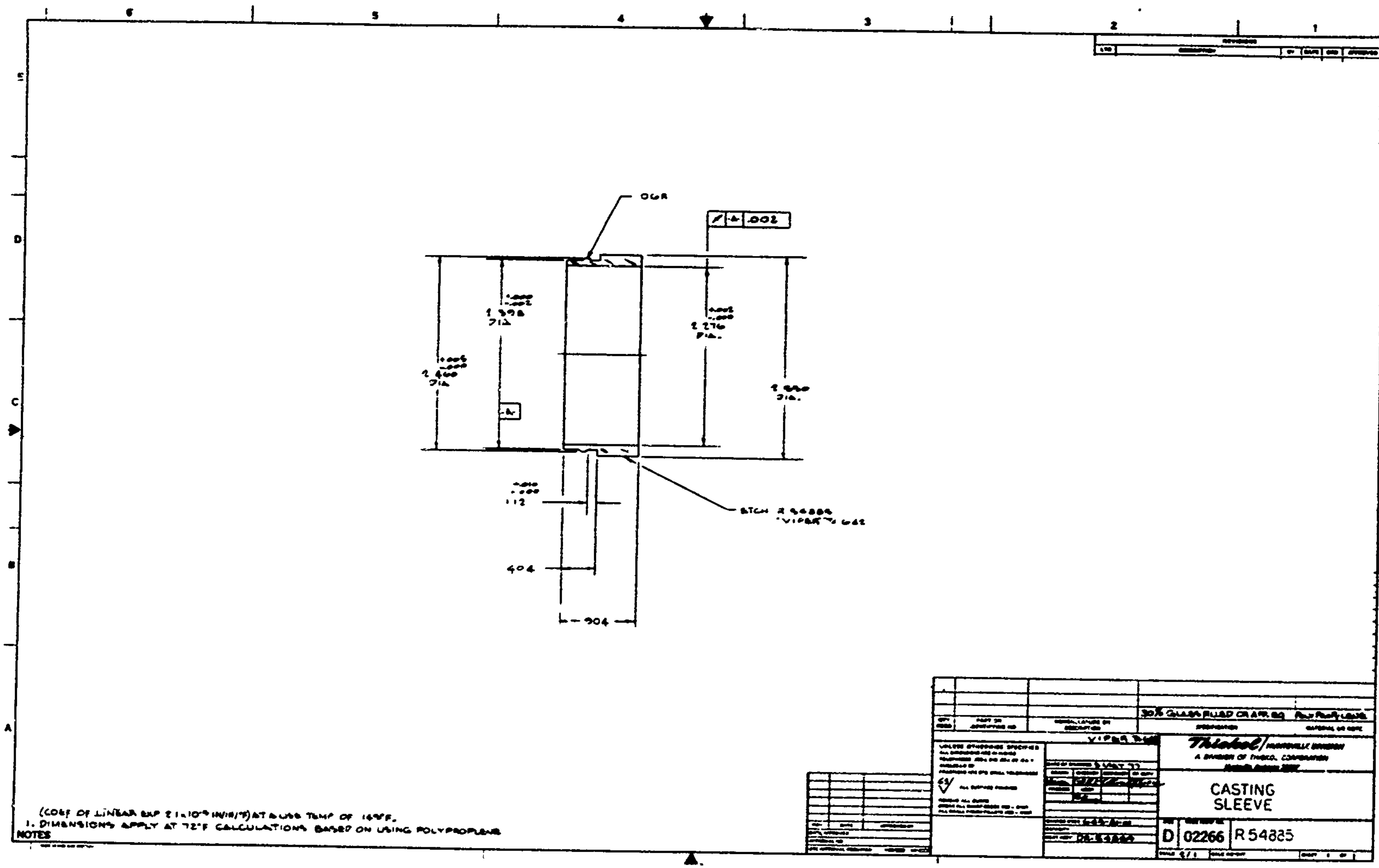

Figure 64. Casting Sleeve (DR-54885)

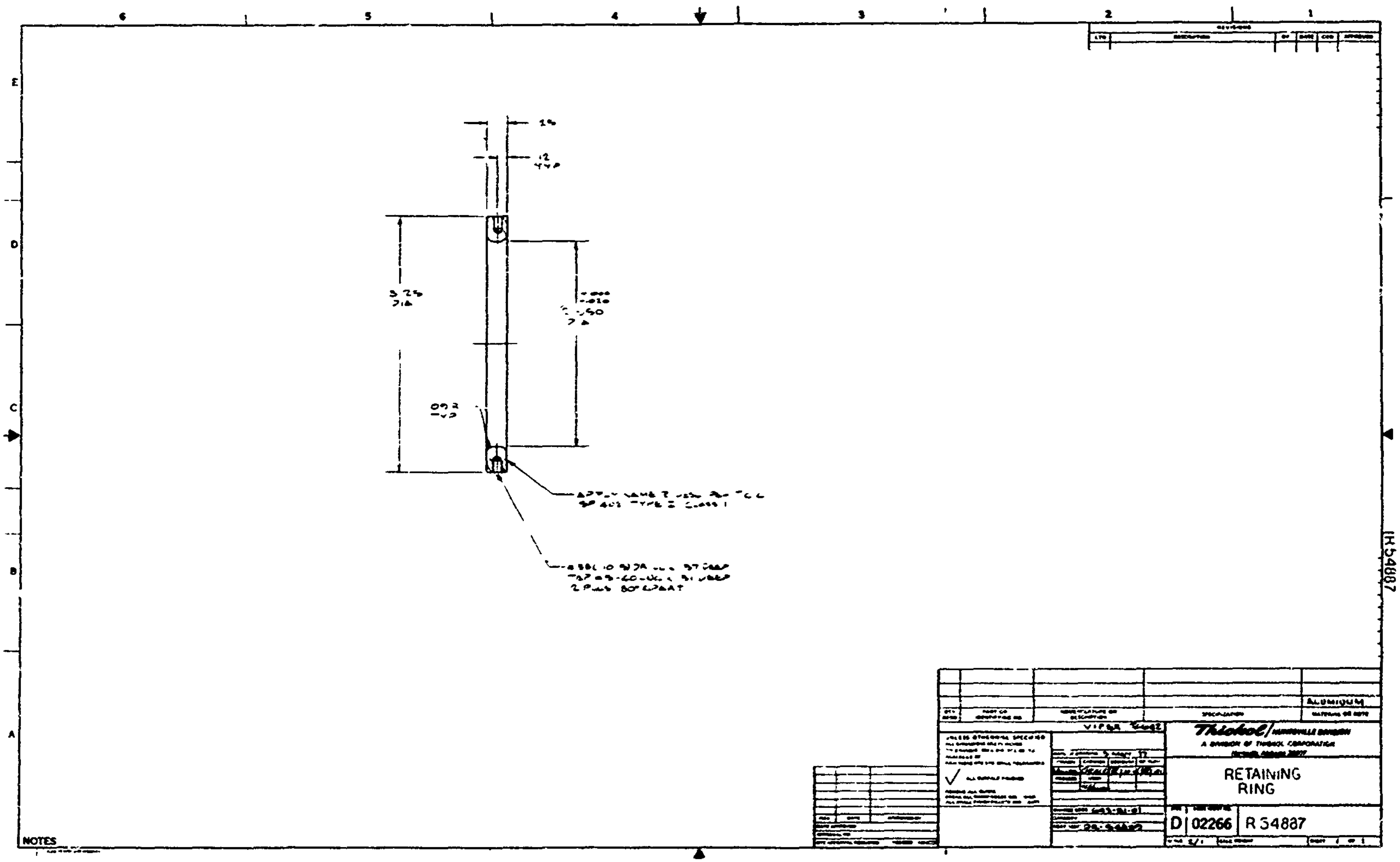

Figure 65. Retaining Ring (DR-54887)

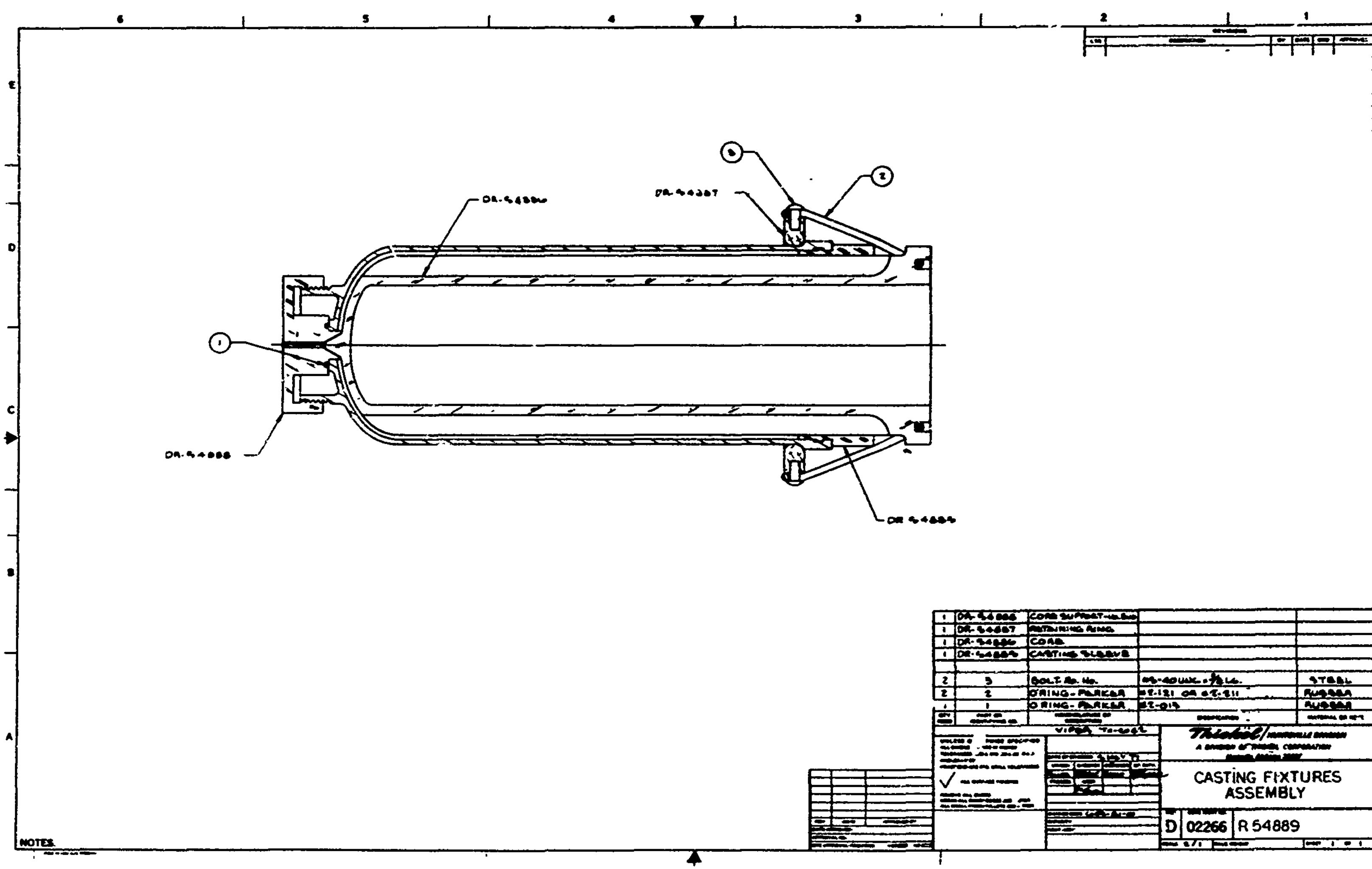

Figure 66. Disposable Viper Tooling Assy. (DR-54889)

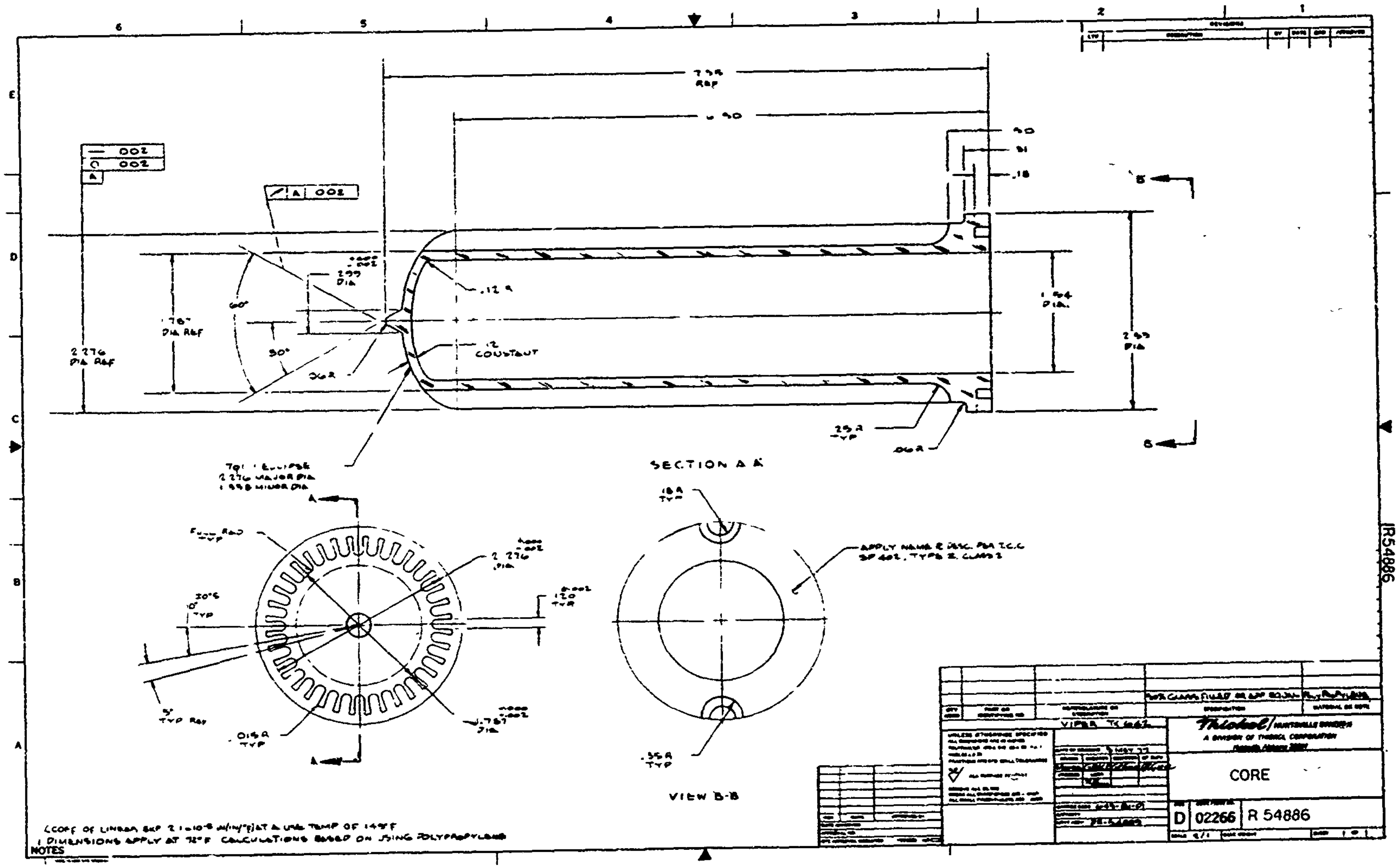

Figure 67. Disposable Viper Core (DR-54886)

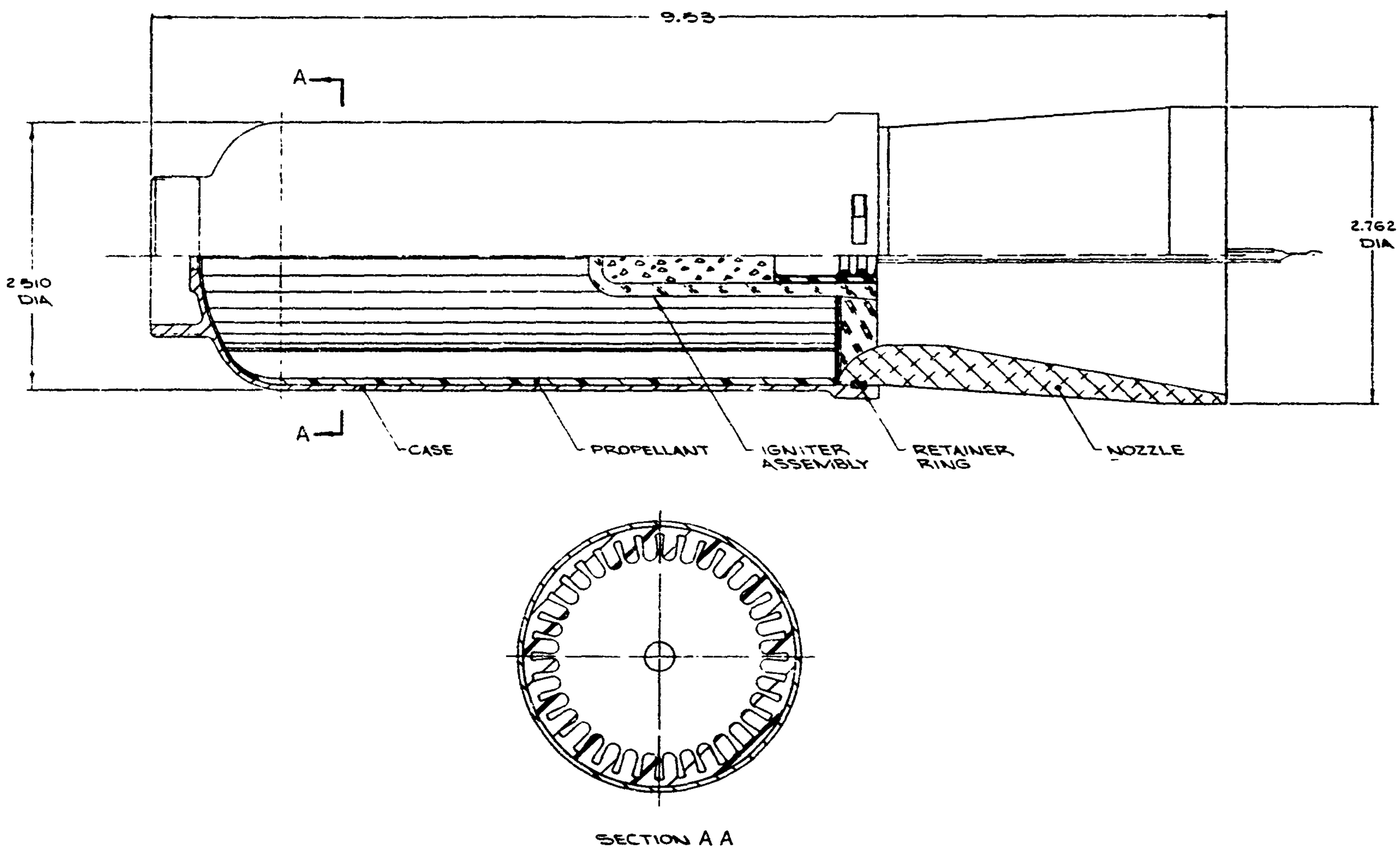

Figure 68. Viper Case Bonded Rocket Motor Concept

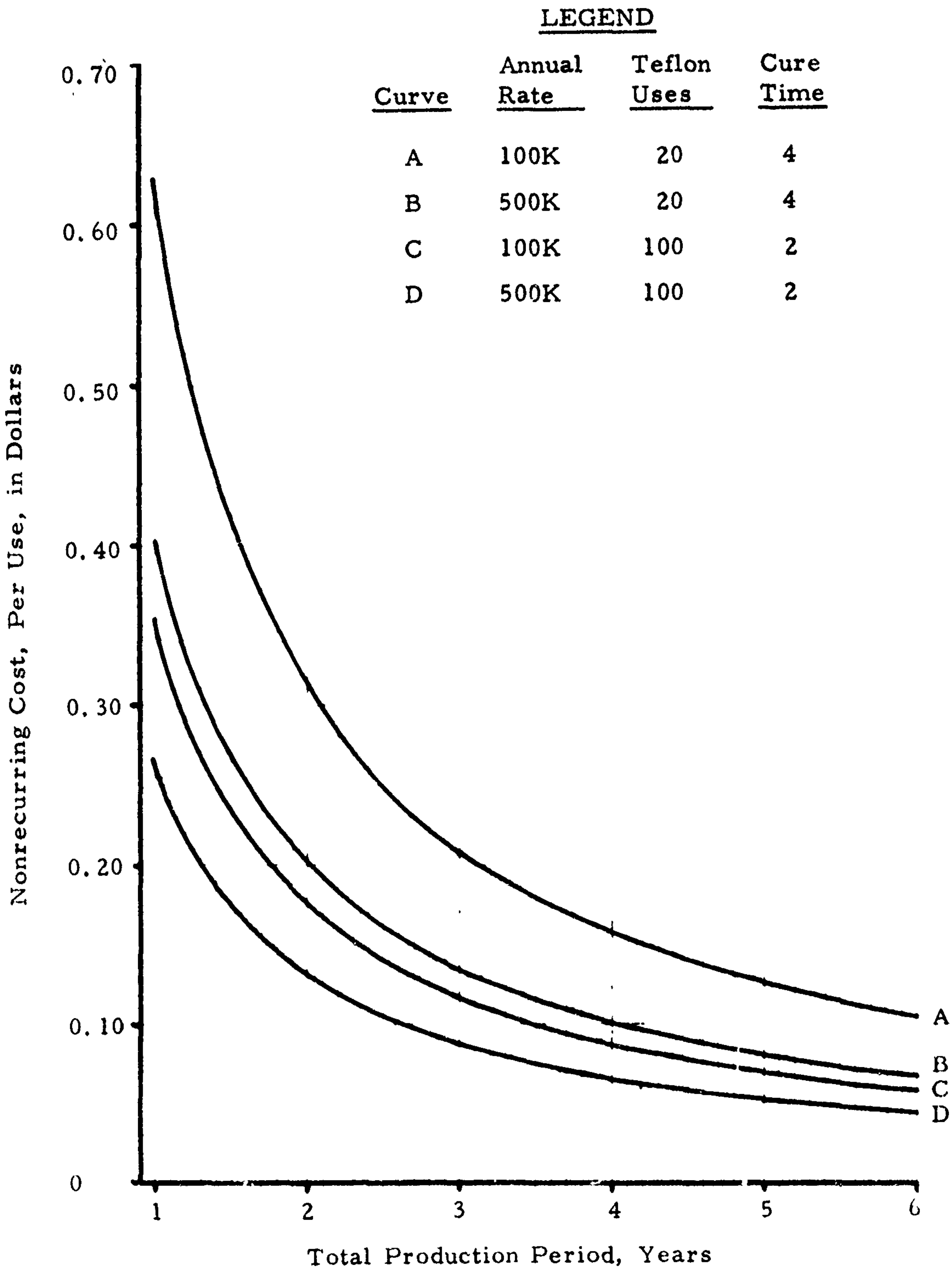

Figure 69. Nonrecurring Costs Per Use, Typical Curves, Viper Reusable Tooling Concept

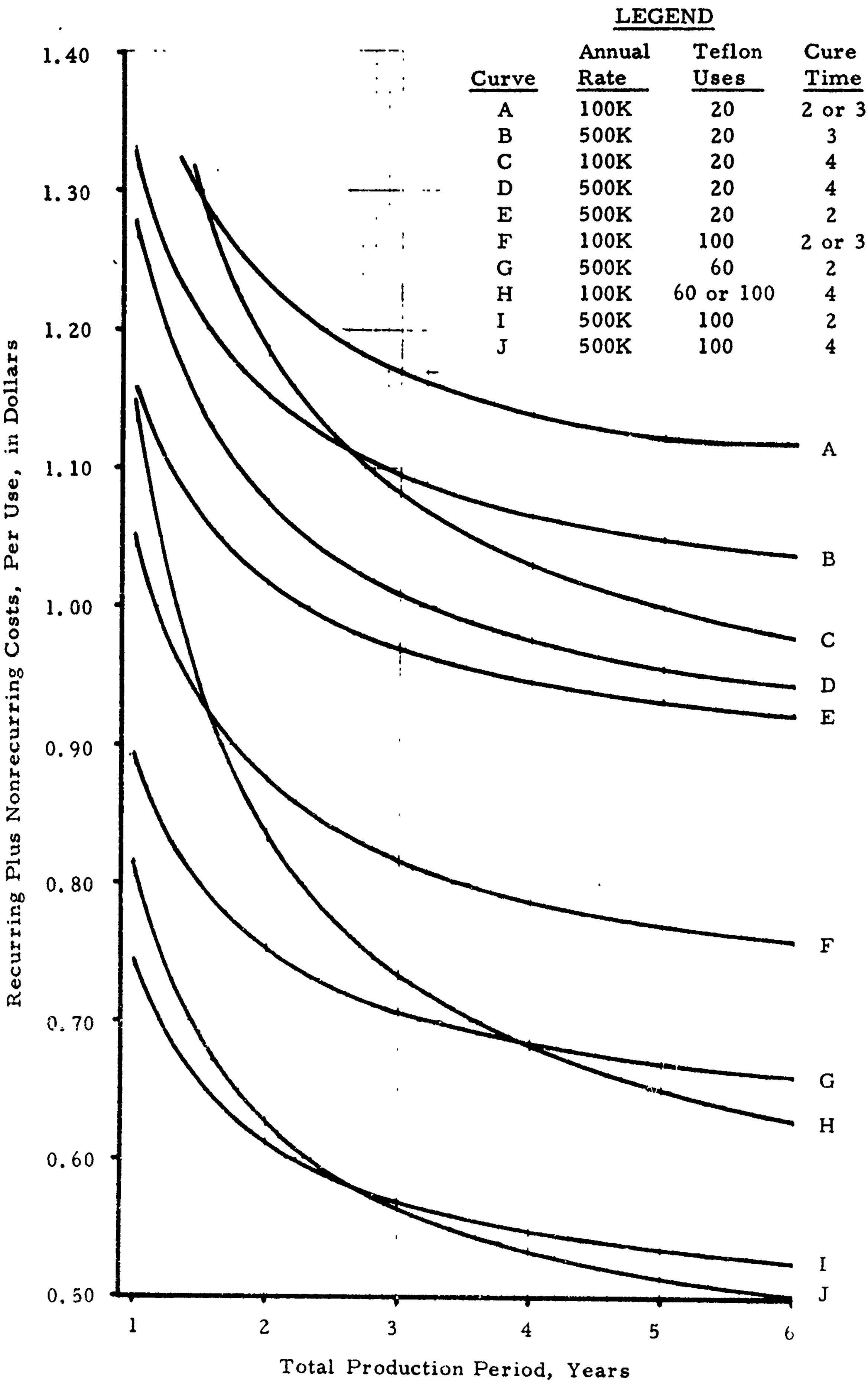

Figure 70. Net Per Use Cost, Typical Curves, Viper Reusable Tooling Concept

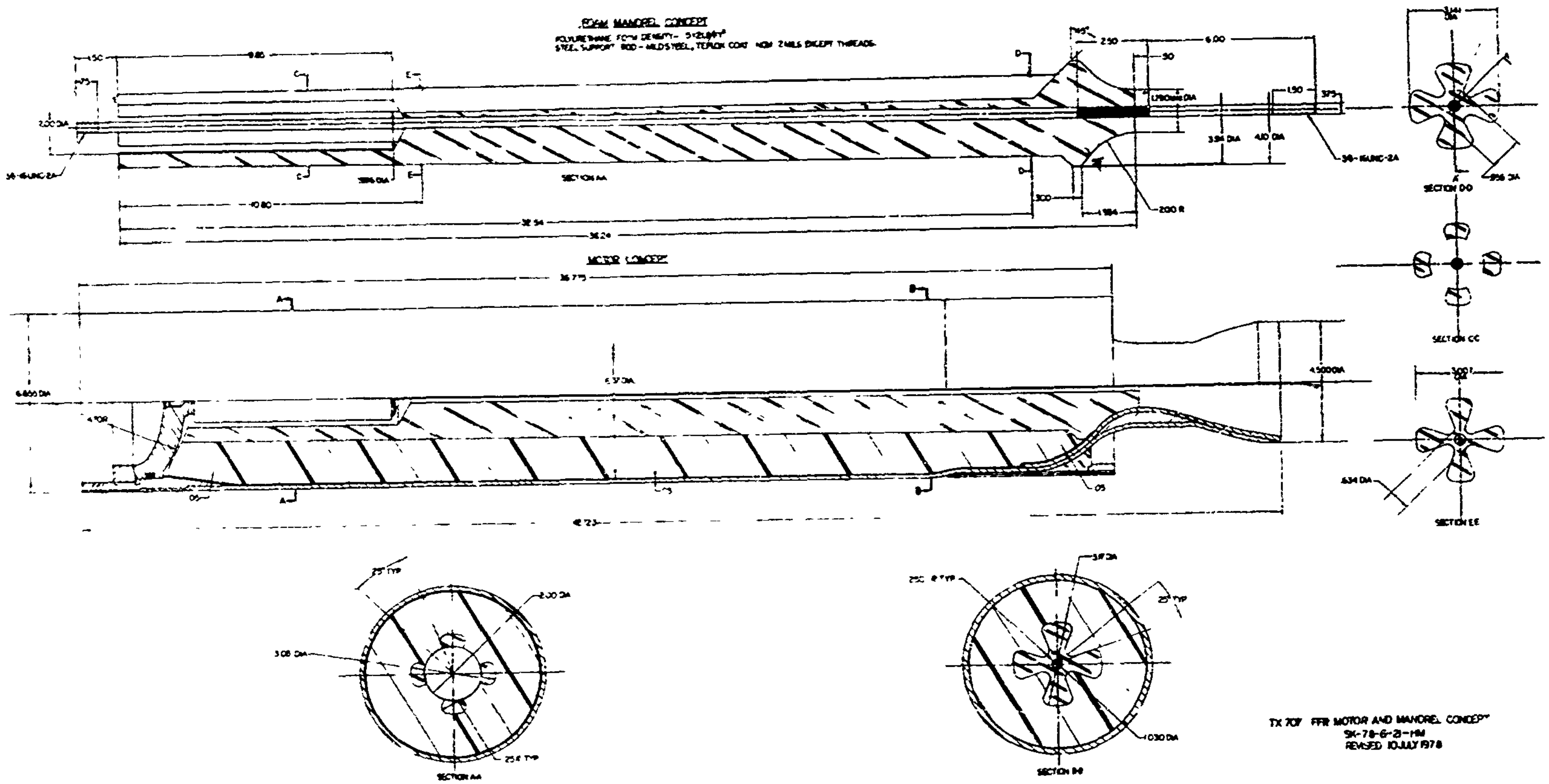

Figure 71. TX 707 FFR Motor and Mandrel Concept

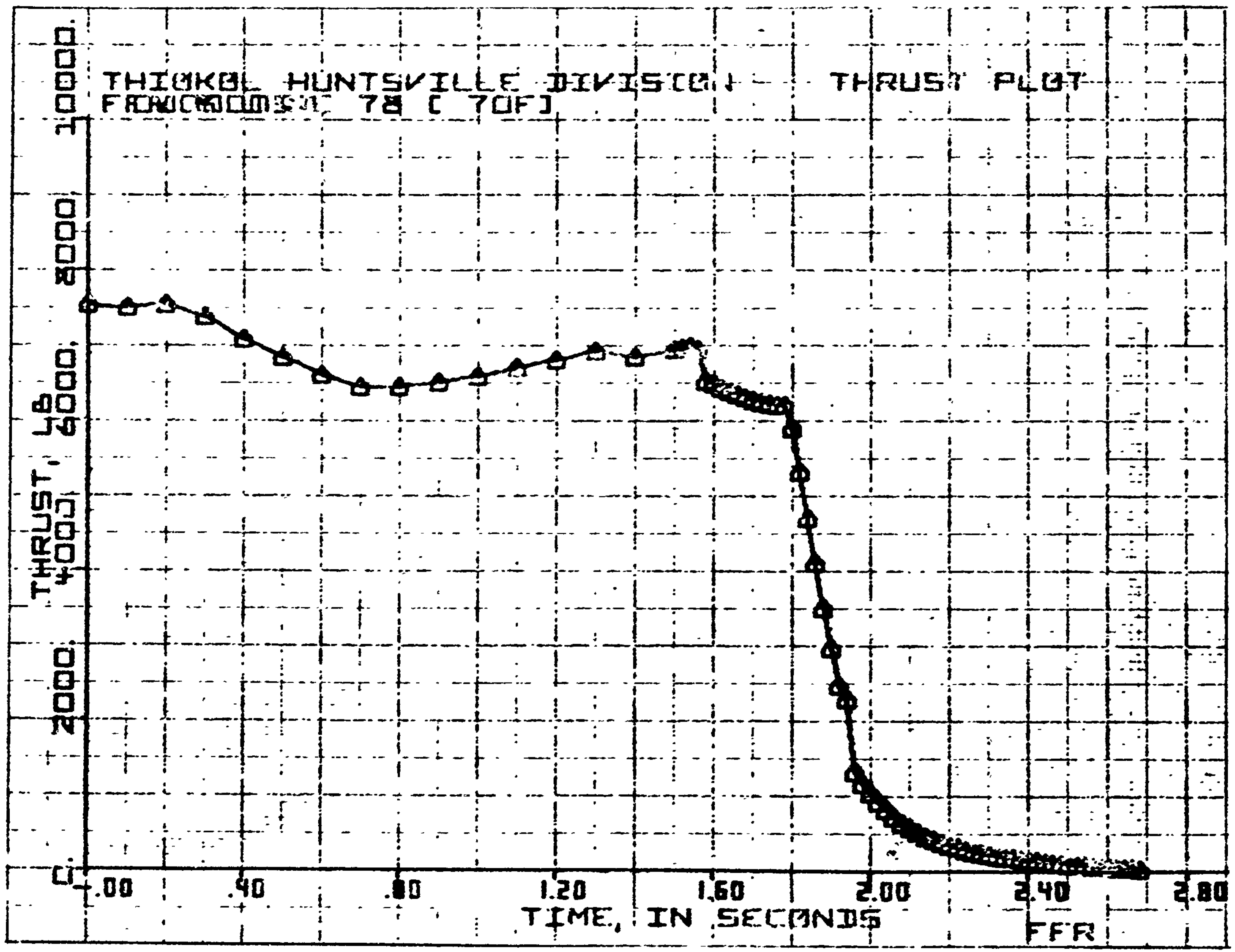

Figure 72. Free Flight Rocket Motor Preliminary Thrust Profile (70°F)

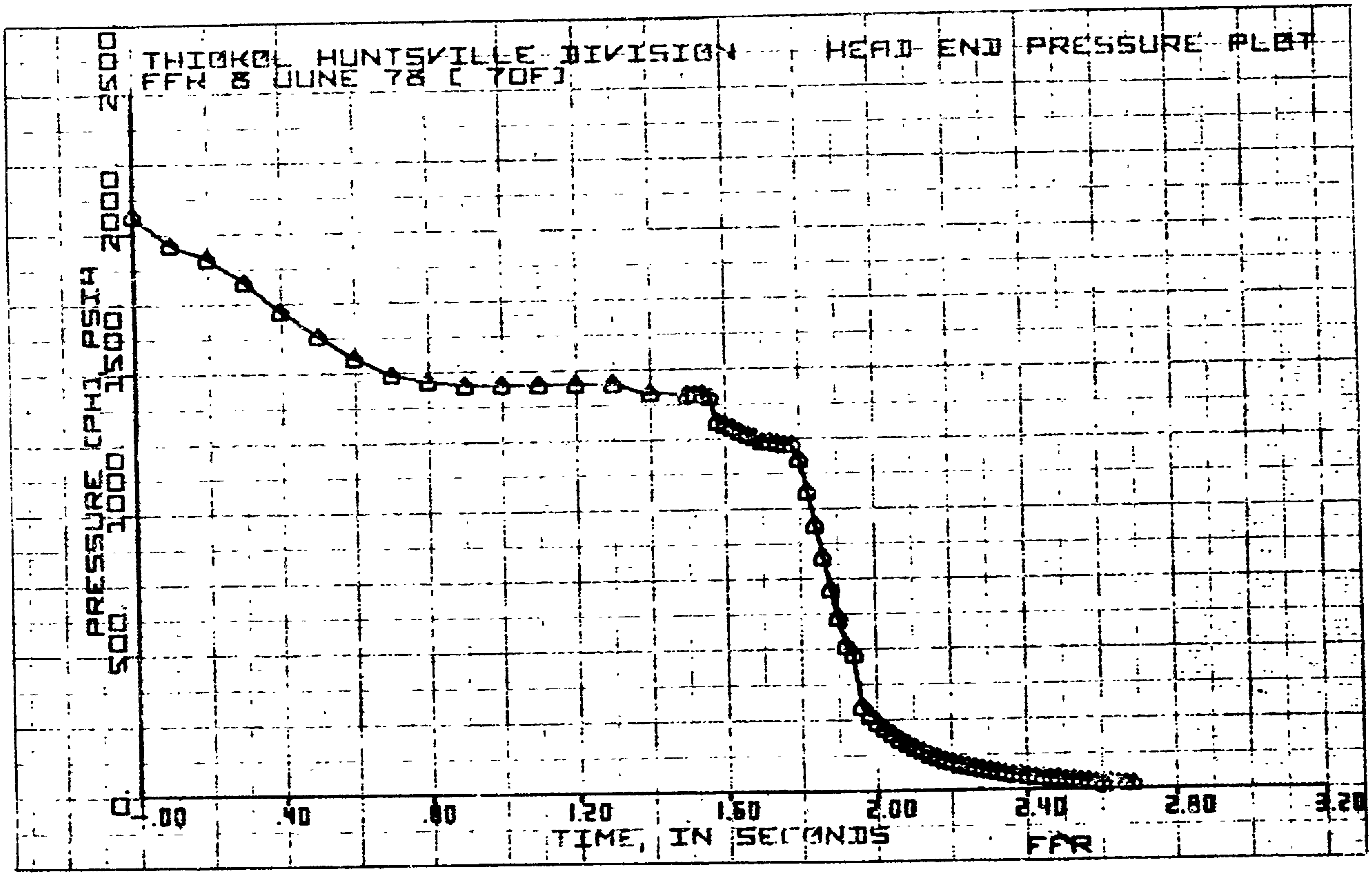

Figure 73. Free Flig' ' Rocket Motor Preliminary Pressure Profile (70°F)

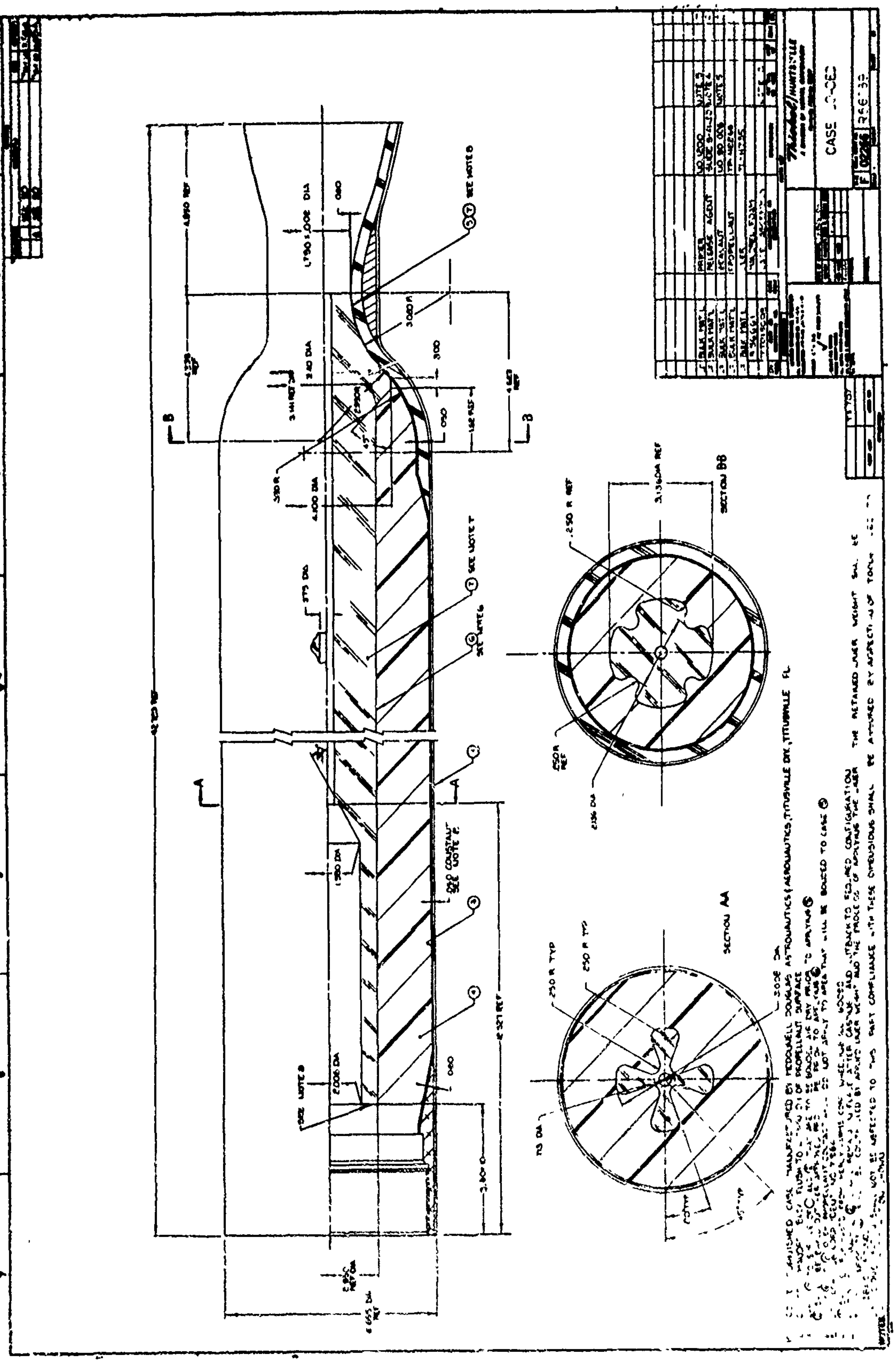

Figure 74. TX707 Loaded Case Drawing (R56789)

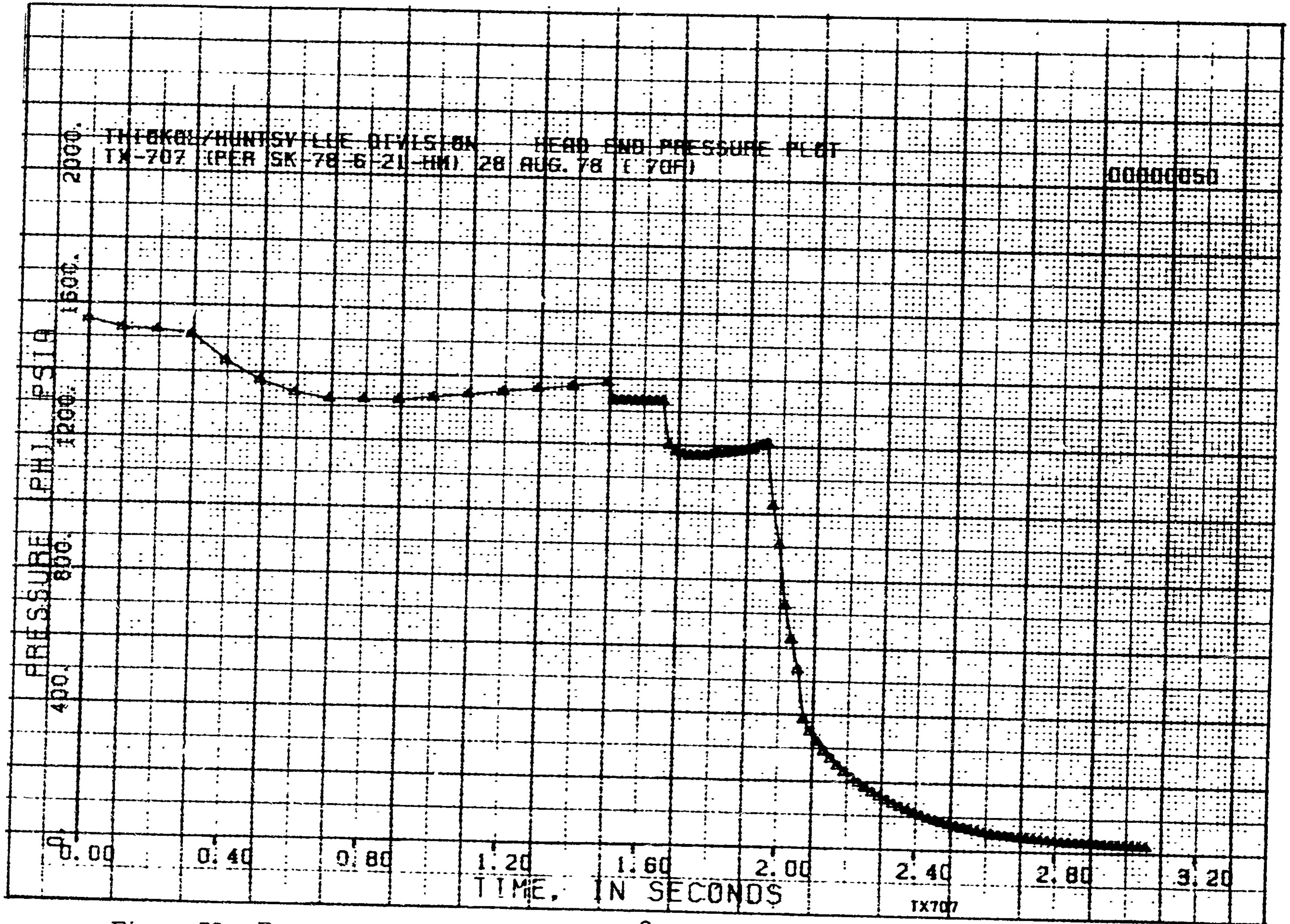

Figure 75. Pressure vs. Time, TX-707, 70°F

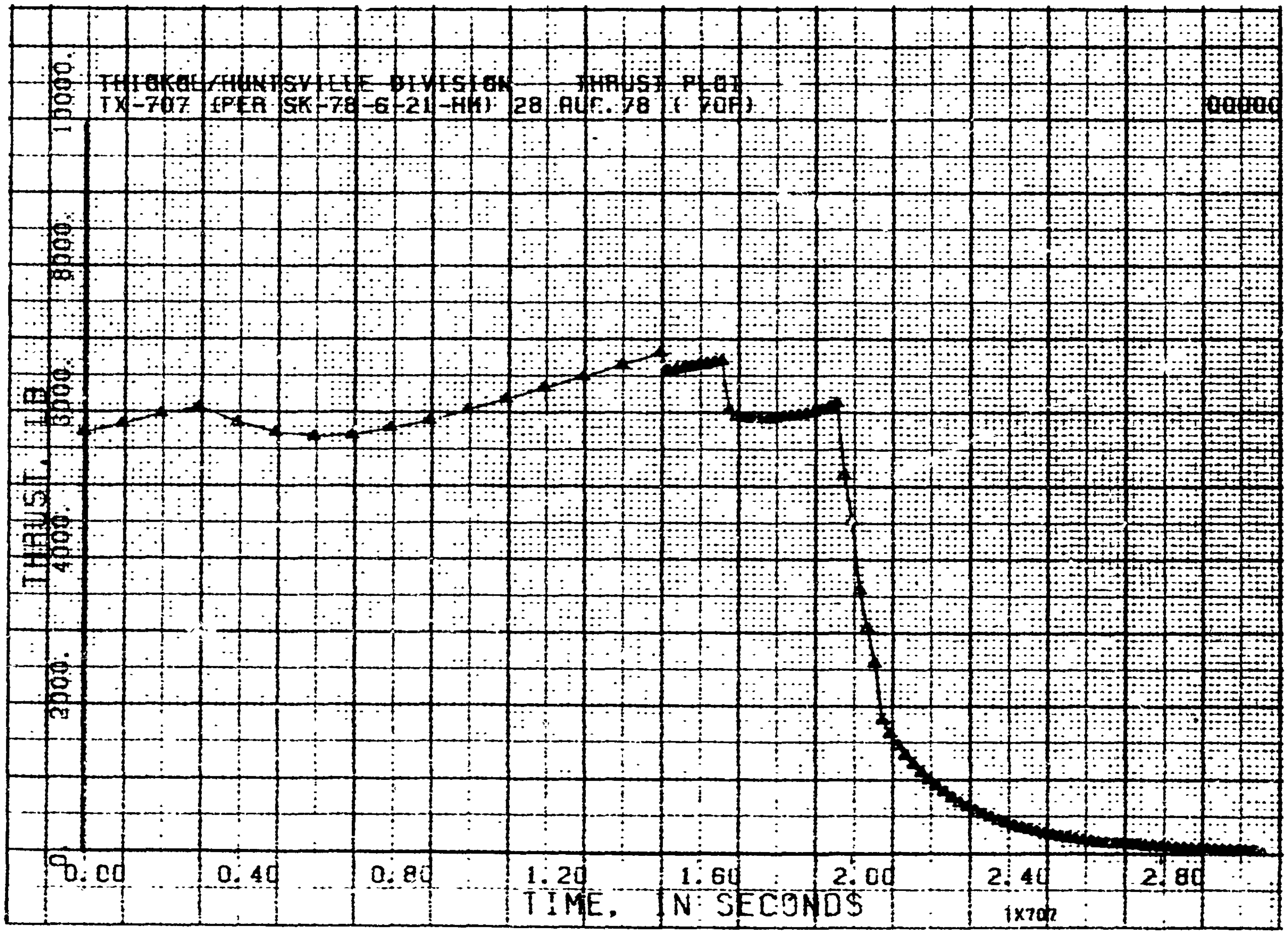

Figure 76. Thrust vs. Time, TX-707, 70°F

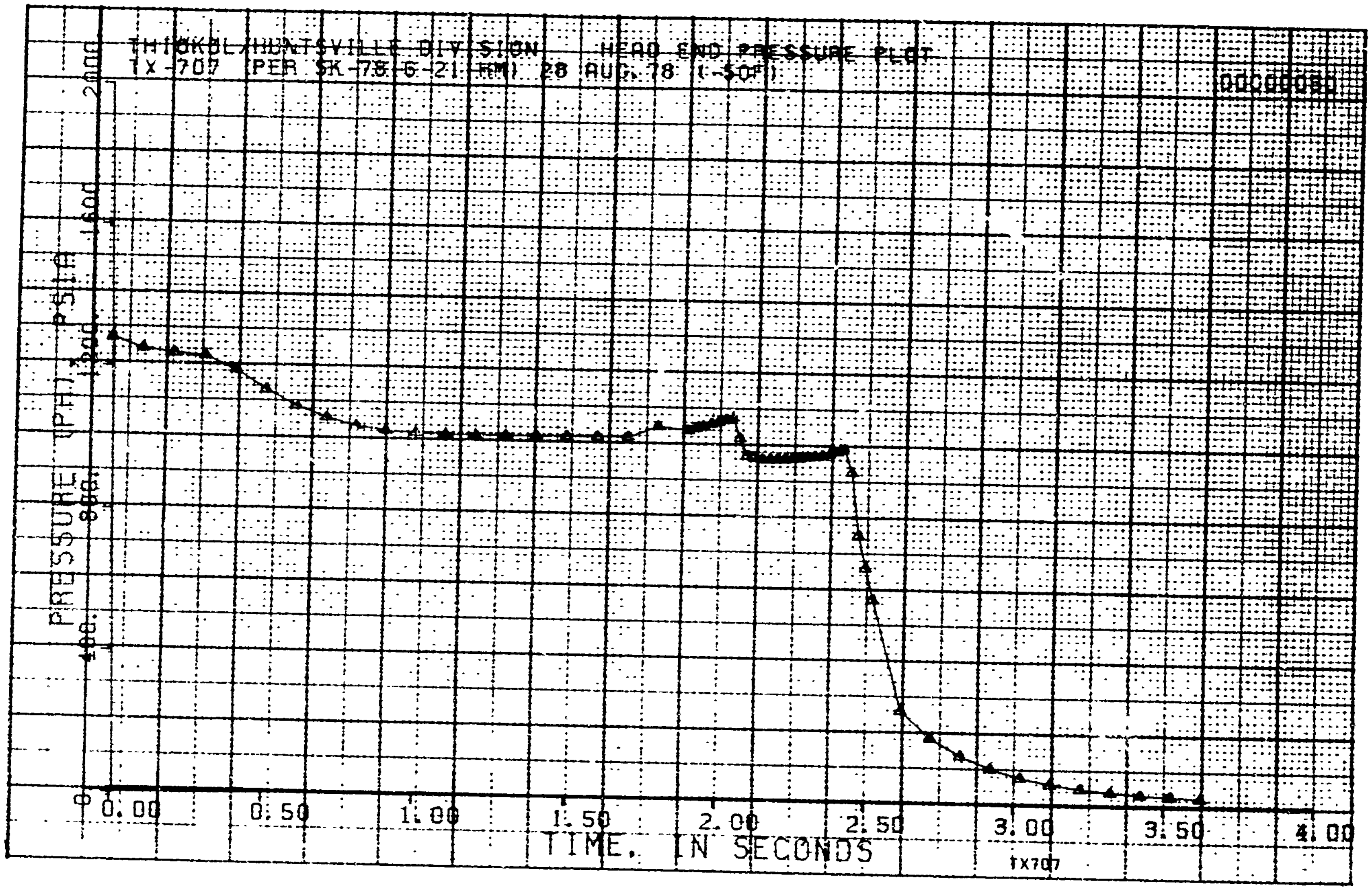

Figure 77. Pressure vs. Time, TX-707, -50°F

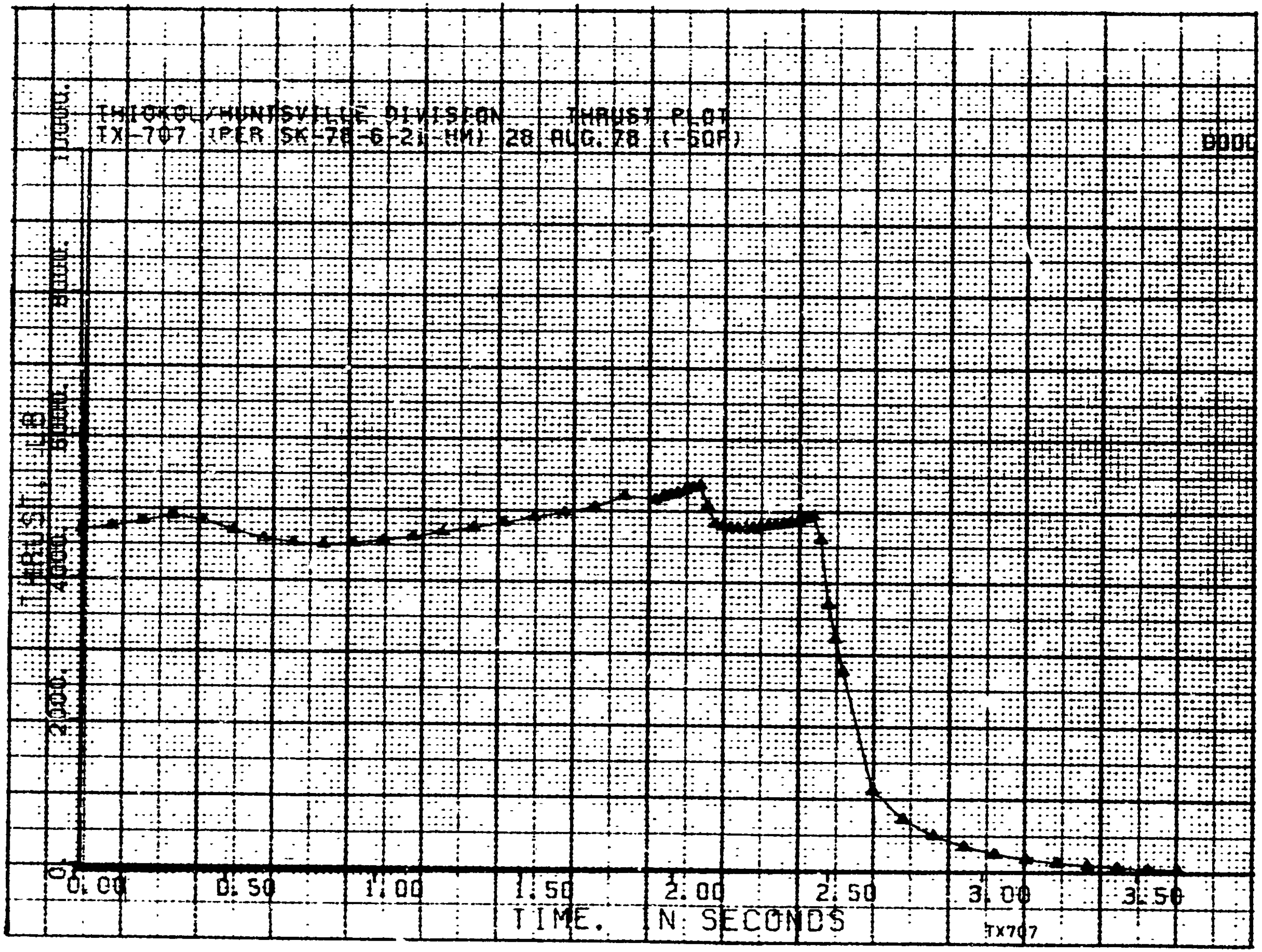

Figure 78. Thrust vs. Time, TX-707, -50°F

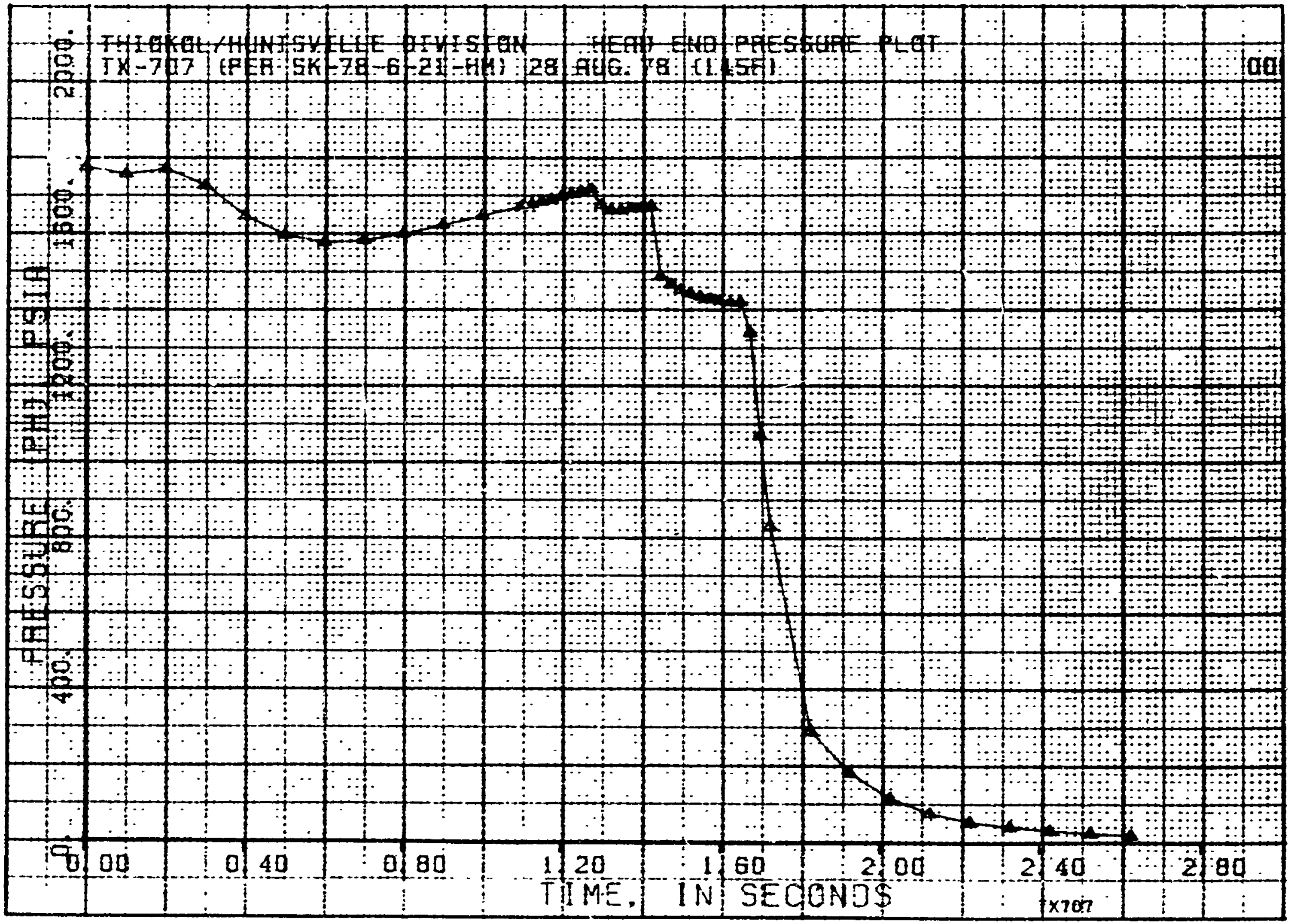

Figure 79. Pressure vs. Time, TX-707, 140°F

Figure 80. Thrust vs. Time, TX-707, 145°F

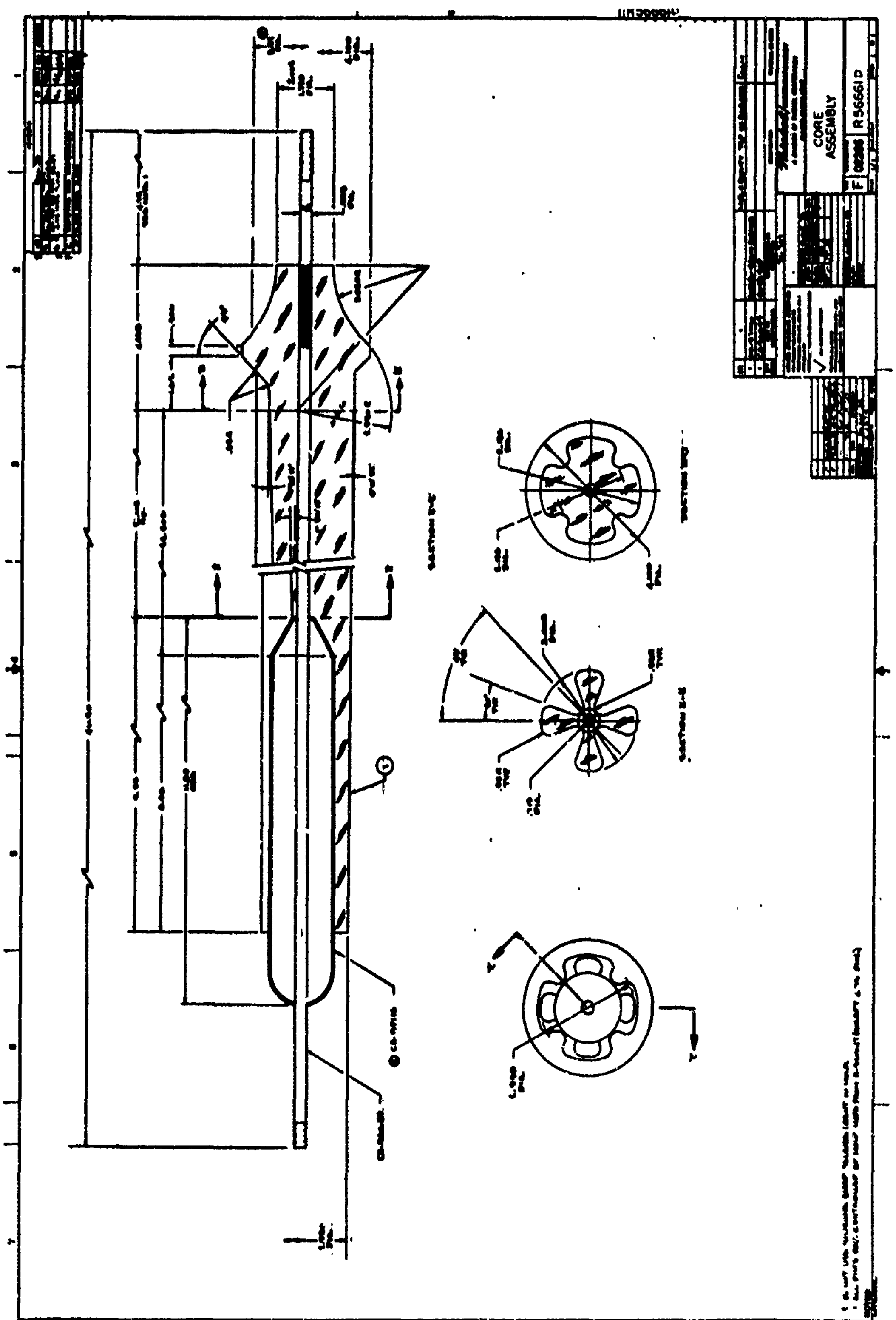

Figure 81. Drawing of TX707 Foamed Core Assembly

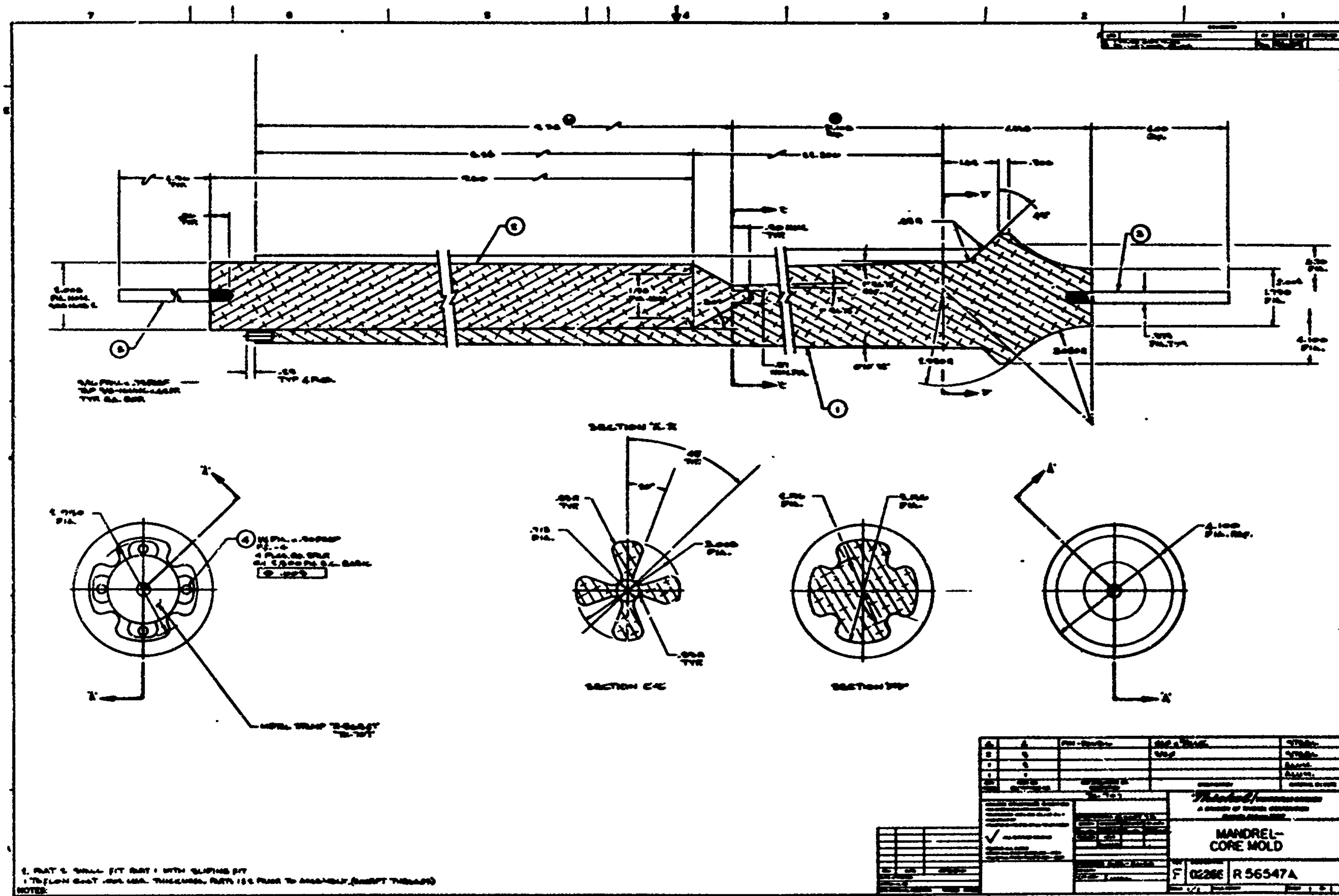

Figure 82. Drawing of Metal Core Mold

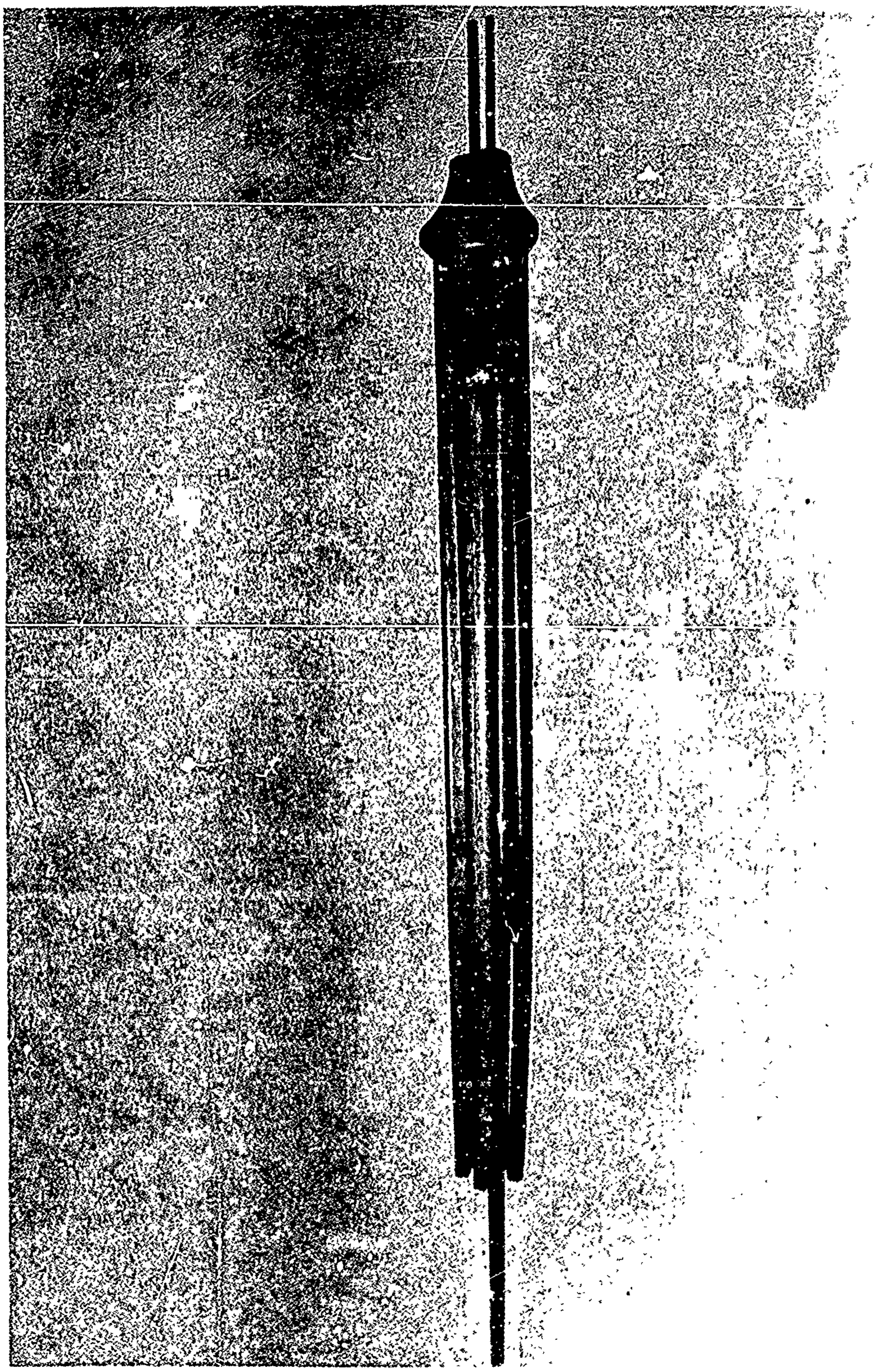

Figure 83. Photograph of Polyurethane Foamed Mandrel

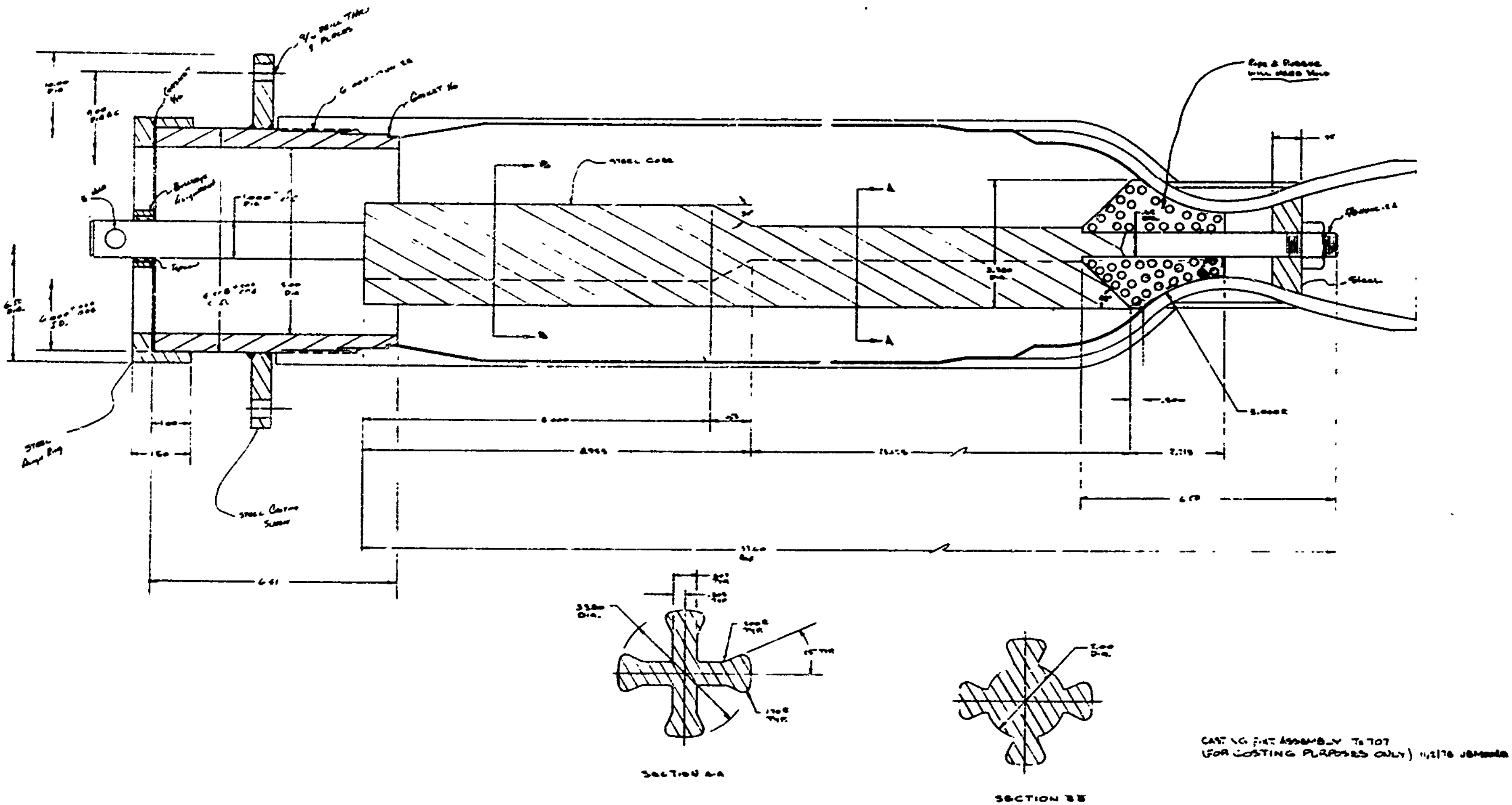

Figure 84. Removable Metal Mandrel for TX707 FFR Motor.

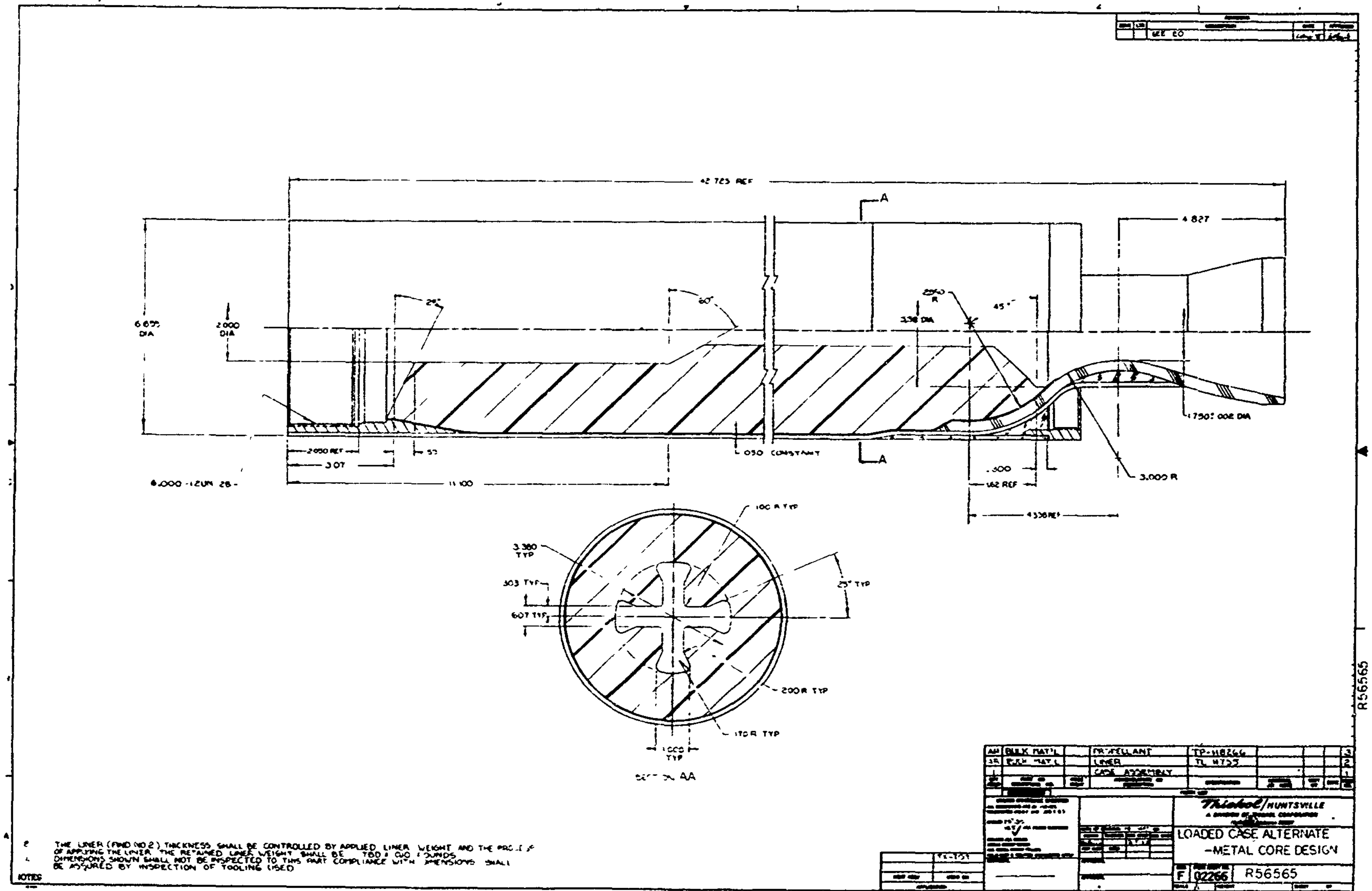

Figure 85. Loaded Case Alternate - Metal Core Design (R56565)

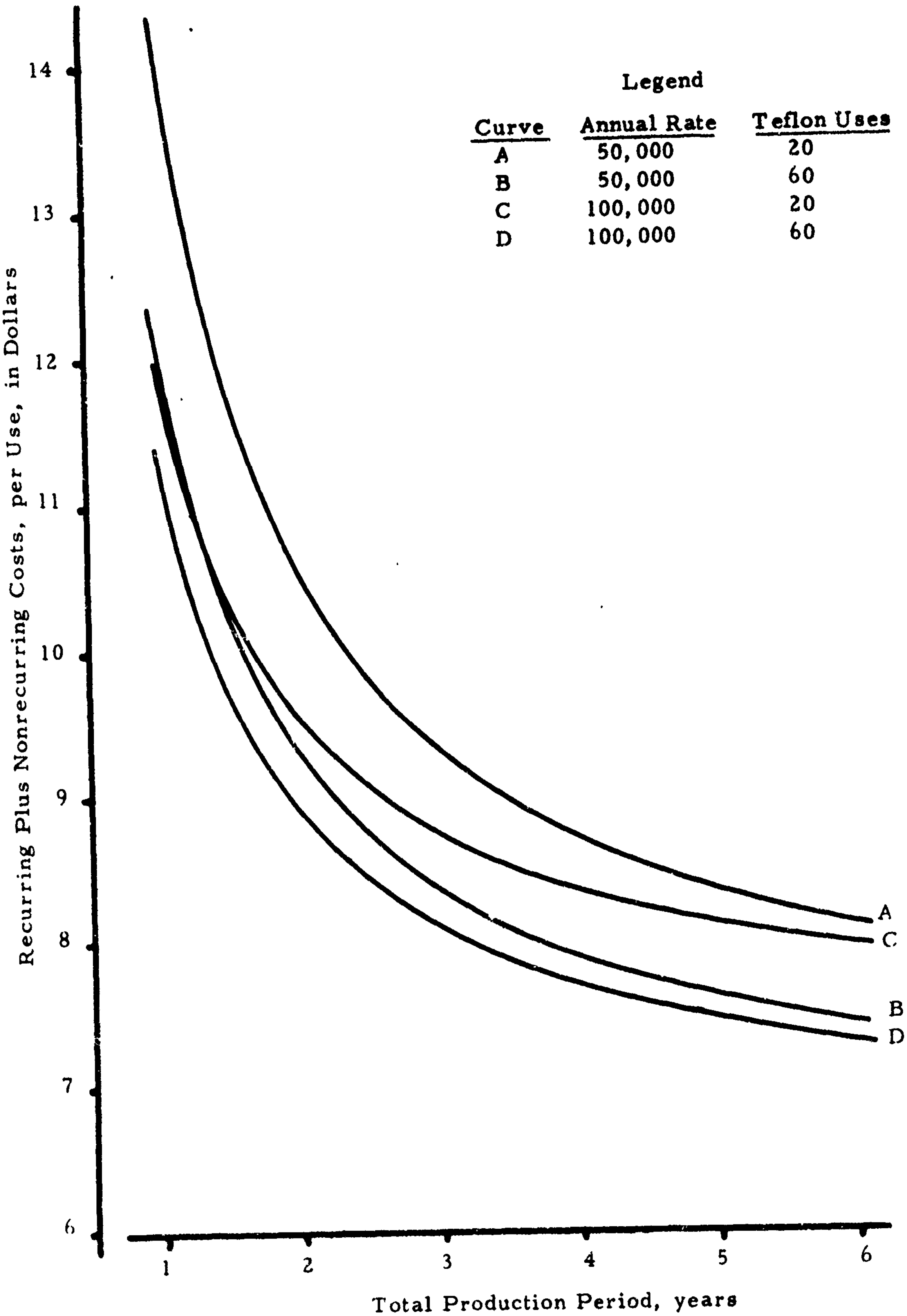

Figure 86. Net Per Use Cost, FFR Reusable Tooling

APPENDIX "A"

FREE FLIGHT MANDREL GOALS/ REQUIREMENTS

The basic requirements for the free flight rocket (FFR) motor leave-in-place disposable mandrel have been established (Table IA). Mandrel dimensional, weight, and density control, processing environment, service life environment, and design functions were considered in establishing these requirements or goals.

Mandrel dimensional goals were established based on the need for impulse reproducibility in the finished motor. The impulse reproducibility budget used in setting these goals was the one reported in Table I, Page 6 of "Technology for Improving Solid Rocket Motor Reproducibility", Technical Report RK-77-2, by A. R. Maykut, dated 1 October 1976. Allowable propellant weight variation (3 CV) is not to exceed 0.24%, therefore, the variation (3 CV) in cure volume was set as being not more than 0.24% such that its contribution to weight variation would be no greater than the desired end results. Mandrel bow was set at 0.010 inch/foot of length. As an approximation, mandrel bow was taken to be equivalent in effect on impulse reproducibility as to that produced by case bow and the selected bow goal falls within the allowable limit of the cited table for grain asymmetry effects. Maximum variation (3σ) of the diameter across the mandrel star points at a given axial location was set as 0.020 inch under the assumptions that such a variation would produce equivalent effect on impulse to an oval case (premature burn through in a web and thus a variation in propellant sliverage).

Mandrel weight control is not critical per se since it is eliminated at ignition prior to first missile motion. However, the weight is critical in that it affects the mandrel foam density which can in turn affect ignition transient. A limit of $\pm$ 10% has, therefore, been set about the nominal density--somewhat arbitrarily. The range is so wide, however, that it should not affect costs of manufacture since it will be feasible to load by volume of ingredients in lieu of weight if so desired. Weight will probably be needed to be controlled more closely to control raw material costs in high volume production.

The desire is to have as low a mandrel nominal density as is technically feasible while still maintaining dimensional stability during fabrication and motor processing. The upper limit of 7 lb./ft.^{3} corresponds to the technology demonstrated to date in the TX677. Successful TX677 motor ignition has been achieved. A lower nominal density is desired to reduce mandrel material costs and to reduce motor ignition system requirements (quantity of igniter material required--costs--and ease of ignition over a wide temperature range).

The mandrel processing environment reflects the conditions and propellant proposed for the TX707 motor. Service environment is that proposed for an existing free flight rocket currently under development.

The mandrel has been "assigned" a number of functions in addition to the normal one of forming the propellant cavity during the propellant processing and propellant curing stages. At the propellant grains aft-end, a "bulb" is provided which serves two functions. The first function is to reduce propellant grain stresses and strains at the nozzle to case wall interface region. The goal is to reduce stresses and strains below those in the main propellant bore so that propellant physical property requirements can be minimized (thus cost reduced for a given performance level). The second function is to control the expansion and flow direction of the high velocity gases immediately ahead of the nozzle section. By doing so, the extent and uniformity of the throat erosion--thus thrust alignment and impulse reproducibility can be better controlled.

The mandrel is also to serve as a nozzle environmental closure to eliminate the costs of a separate system. The closure needs to seal under 25 psi from either direction. It should be impervious to moisture. To accomplish this latter function, an aluminum foil disc can be added after mandrel fabrication.

The mandrel will also serve to support the propellant during transportation shock and vibration as it will also support the igniter lead wires to prevent vibration/shock induced failure.

TABLE IA

FREE FLIGHT ROCKET MANDREL GOALS/REQUIREMENTS

Mandrel Dimensional Control	Goal	Basis of Goal
Volume Repeatability, 3 cv	0.24%	Impulse Reproducibility
Bow, inch/foot	0.010	Impulse Reproducibility
Maximum Variation of Diameter Across Star Points at Given Axial Location, 3σ, inch	0.020	Impulse Reproducibility
Thermal Stability of Dimensions, Goals after Exposure to Processing Temperature	Same As Above	Impulse Reproducibility
Mandrel Weight Control, 3 CV, %	10	Ignition Transient Reproducibility
Mandrel Density		
Nominal Mandrel Density, lb/ft^3	5 ± 2	Desire lowest technically feasible density to reduce material costs and decrease ignition problems
Mandrel Processing Environment		
Processing Temperature, ^oF	170	FFR Propellant Cure Temperature
Time at Cure Temperature, days	5	Maximum Cure Time for FFR @ 170°F
Outgassing @ Cure Temperature,* cubic inches at standard conditions	TBD	Reduce Voids in Propellant
Exposure to R45HT Sinclair Polymer cured with IPDI, Ammonium Perchlorate, Aluminum, and Iron Oxide	No Chemical Reaction	Propellant Major Ingredients

*Mandrel Bake out procedures prior to casting may be used to drive-off gases to meet this requirement. Rate of temperature rise to 170°F shall be controlled to prevent blistering of surface.

TABLE IA

FREE FLIGHT ROCKET MOTOR GOALS/REQUIREMENTS (Cont'd)

Mandrel Functions	Goal	Basis of Goal
Form Propellant Port Cavity During Propellant Cure	Dimensional Repeatability	Basic Function
Provide Stress Relief Cavity at Aft Grain Termination and Provide Propellant Gas Expansion Cavity (Grain Boat-Tailing)	a) Achieve Stress and Strain Below Propellant Bore Values	a) Maintain bond to case (no separation) and minimize propellant physical property requirements
	b) Control combustion gas flow characteristics in nozzle approach section	b) Control nozzle maximum erosion rate
Motor Environmental Closure		
Pressure Capability, psi	± 25	Normal air transported military equipment requirement
Moisture Protection	Impervious Barrier	Prevent moisture degradation of propellant
Provide Propellant Support During Motor Transportation	To Be Established	Achieve increased service life through stress/strain reduction in propellant
Igniter Lead Wire Support	No lead wire breakage during service life	Eliminate need for separate wire support device to prevent breakage

TABLE IA

FREE FLIGHT ROCKET MANDREL GOALS/REQUIREMENTS - (Cont'd)

Service Environment	Goal	Basis of Goal
Storage °C (°F)	-34 to +71 (-61 to +128)	Typical FFR System
Transportation Shock and Vibration	MIL-STD-810 Method 514.2, Procedure V II, Table VI, Cure W (-32°C to 60°C)	Typical FFR System
Service Life	10 Years	Typical FFR System

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