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A STUDY OF PERFORMANCE AND COST IMPROVEMENT POTENTIAL OF THE 120-IN.- (3.05 M) DIAMETER SOLID ROCKET MOTOR

by

S. J. Backlund and J. N. Rossen

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Final Report
Volume II of II: Study Approach and Detailed Results

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FOREWORD

Many studies of launch vehicles with payload capabilities between Saturn IB and Saturn V have been made. Among the candidate vehicles capable of handling low-earth orbital payloads in the 100,000-lb (45,300 kg) range were combinations consisting of solid propellant boosters with a modified Saturn S-IVB upper stage. They were found to provide attractive performance characteristics and cost effectiveness.

These solid rocket motor (SRM)/S-IVB vehicles were studied by McDonnell Douglas Astronautics Co. in a series of contracts sponsored by the National Aeronautics and Space Administration (NASA) starting in 1965. Configurations included booster stages based on clustered 120-in.- (3.05 m) and 156-in.- (3.96 m) diameter SRMs and single 260-in.- (6.6 m) diameter SRMs.

In-house studies in early 1970 by the Office of Advanced Research and Technology (OART)/Mission Analysis Division at NASA Ames Research Center showed the attractiveness of using the SRM/S-IVB in an evolutionary approach to a space transportation system. Their approach emphasized booster stages using the 120-in.- (3.05 m) diameter SRMs because of the advanced development status and operational experience with these SRMs in the Titan system and the low nonrecurring costs anticipated through their use. The study by OART updated the earlier studies of the 120-in.- (3.05 m) diameter SRMs by using data for the current improved models of the five-segment SRM (UA 1205) and the seven-segment SRM (UA 1207) then under development for the Titan system. The improved SRM and methods of clustering and staging resulted in attractive operational flexibility and payload performance characteristics for the family of launch

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This is the final report of a study of performance and cost improvement potential of the 120-in.- (3.05 m) diameter SRM which was initiated on 19 February 1971 to provide specific technical and cost data for SRM booster stages. Areas investigated included motor ballistic design modifications, approaches for building clustered motor stages, development requirements for implementing rocket motor and clustered stage configurations, and economic factors related to development and operation of such configurations. The study was performed for NASA under contract No. NAS2-6330 and was monitored by Mr. Kenji Nishioka and Mr. Harry Hornby of the Advanced Concepts and Missions Division of OART.

This study was related to launch vehicle studies conducted by the Advanced Concepts and Missions Division at NASA Ames Research Center, Moffett Field, California, and by McDonnell Douglas Astronautics Co., Huntington Beach, California. The assistance of personnel from these organizations in carrying out portions of this study is gratefully acknowledged.

SUMMARY

This study, completed under contract No. NAS2-6330, was performed to provide specific data relating to the potential improvement in performance and cost of the 120-in.- (3.05 m) diameter SRMs when used as clustered launch vehicle stages.

The initial phase of the program was a parametric study of ballistic modifications to the 120-in.- (3.05 m) diameter SRMs which are in operational or developmental status as part of the Air Force Titan III system. Each of the basic ballistic parameters was varied within the range allowed by the existing motor case. In this manner, 576 separate designs were defined, of which 24 were selected for detailed analysis. Detailed design descriptions and ballistic performance and mass property data were prepared for each design. The study showed that relatively simple changes in design parameters could provide a wide range of SRM ballistic characteristics of interest for future launch vehicle applications.

The second phase of the study examined the clustering of 120-in.- (3.05 m) diameter SRMs into two-stage boost vehicles with three to seven SRMs. Preliminary structural designs were developed for six clustered configurations. The weight of the required structure was estimated to be about 2% of total stage weight. The amount of insulation required for protection of the stages against base heating was also investigated, and it was determined that about 0.6 in. (1.5 cm) of Dow-Corning silicone insulation will be adequate for the most severe case. The geometric and performance aspects of nozzle size and cant angle were examined, and an optimum nozzle layout was recommended. First-stage SRMs

should utilize the 9.2 nozzle expansion ratio of the current UA 1207 and the minimum cant allowed by physical interference. Second-stage SRMs should utilize an expansion ratio of 15 and be uncanted.

Design data were developed for installation of the UTC TECHROLL® movable nozzle seal into the UA 1207 SRM in place of the current liquid injection thrust vector control (LITVC) system. Advantages of the TECHROLL movable nozzle seal were seen to be a 10,000-lb (4,536 kg) decrease in inert weight per SRM, increased steering capability, and a total reduction in cost of approximately 9% per SRM. A comparison of the two TVC systems with regard to the effects of clustering also revealed advantages for the TECHROLL seal system.

In the third phase of the study, development program tasks, schedules, and costs were identified for each of the designs and modifications studied. Time from program start to first launch of a clustered SRM booster varied from 42 to 57 months, depending on the SRM and vehicle design selected. The range of nonrecurring costs varied from $12 to $44 million. Recurring costs for production of SRM clusters based on UA 1205 and UA 1207 motors were prepared for varying use rates.

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1.0 INTRODUCTION

This study, completed under contract No. NAS2-6330, was undertaken to define data for achieving the performance improvements and cost reduction for the 120-in. SRM-based launch vehicles shown to be desirable in the OART/ Advanced Concepts and Missions Division in-house studies. The investigation was divided into three program phases.

The initial two-month phase of the program was concerned with parametric ballistic modifications. In phase I, a study was conducted on a number of design variations of the UA 1205 (five-segment SRM) and the UA 1207 (seven-segment SRM) which exemplified the flexibility in ballistic performance which is possible through modifications with a low technical risk and low cost. The ballistic modification studies were planned to assist the vehicle designer by (1) showing the range of possible thrust-time characteristics at his disposal to provide those SRM combinations for optimum thrust-time behavior and (2) defining for him the bases for more detailed tailoring studies. All configurations investigated used existing flight hardware designs; only grain geometry, nozzle throat diameters, and propellant burning rates were varied.

In the second two-month phase of the study, methods of clustering three to seven SRMs were studied, and concepts suitable for two-stage operation were defined so that the weights of structural components required for clustering could be estimated. Six two-stage cluster combinations specified by NASA were covered in this investigation. Other aspects of clustered operations were also considered, such as comparison of TECHROLL seal movable nozzle TVC versus LITVC, nozzle clearance, SRM nozzle expansion ratio, and staging and base heating. Analysis of the clustered stage study included investigation of design concepts for parallel staging of the first-stage SRMs strapped to the central core second-stage SRM(s). Design modifications necessary to utilize attachment hardware currently in use on the 120-in.- (3.05 m) diameter SRMs were determined. Any new structural attachment hardware was conceptually designed. Thermal insulation requirements for protection from exhaust radiation, jet interaction, and base recirculation were computed using approximate methods.

During the final two and one-half month phase of the study, development schedules were defined for incorporating the necessary SRM modifications and conducting SRM stage development. Rough order of magnitude cost data were prepared for both the nonrecurring and recurring program elements based on various use rates.

Concurrent with the contract work, UTC undertook an in-house effort to supplement the TVC system trade studies which covered incorporation of the TECHROLL seal movable nozzle into the 120-in.- (3.05 m) diameter SRMs. This study investigated the requirements for integrating the TECHROLL seal into the nozzle of the UA 1207 SRM. Layouts of the TECHROLL seal-nozzle-aft closure-propellant grain were prepared for both straight and canted nozzle designs. The weight and vehicle performance advantages of the designs were calculated.

The work performed, results, and conclusions from this study are summarized in the following sections of this volume.

2.0 INTERNAL BALLISTIC PARAMETRIC ANALYSIS

A parametric analysis of the internal ballistics of the 120-in.- (3.05 m) SRMs was performed. The objective was to define the range of performance variations which could be achieved with the UA 1205 and UA 1207 120-in.- (3.05 m) diameter SRMs currently in operation or development for the Titan III system. The standard UA 1205 and UA 1207 SRM components, illustrated in figure 1, were examined to determine which design parameters could be modified without requiring a major development or qualification program. These standard motors have cylindrically perforated segment grains with a restrictor (inhibitor) only on the forward end face, a cylindrically perforated aft closure grain, and a star-perforated forward closure grain. Changes in propellant burning rate, grain design, restrictor type and location, closure length, and nozzle throat diameter which would not require changes to existing metal parts (motor case and nozzle shell) were selected for detailed investigation. The addition or deletion of thrust termination was examined as an option to all designs.

Figure 2 is a diagramatic presentation of the design parameters which were investigated. Selection of one of the options from each of the levels shown, proceeding from the top to the bottom of the diagram, defines a unique 120-in.- (3.05 m) diameter SRM design. From the 576 designs which could be defined, 24 designs were selected for evaluation based on preliminary estimates of performance characteristics and judgments as to configurations of maximum interest. These 24 design variations, including the baseline UA 1205 and UA 1207 SRMs, were designated as configurations 1 through 24 for this study.

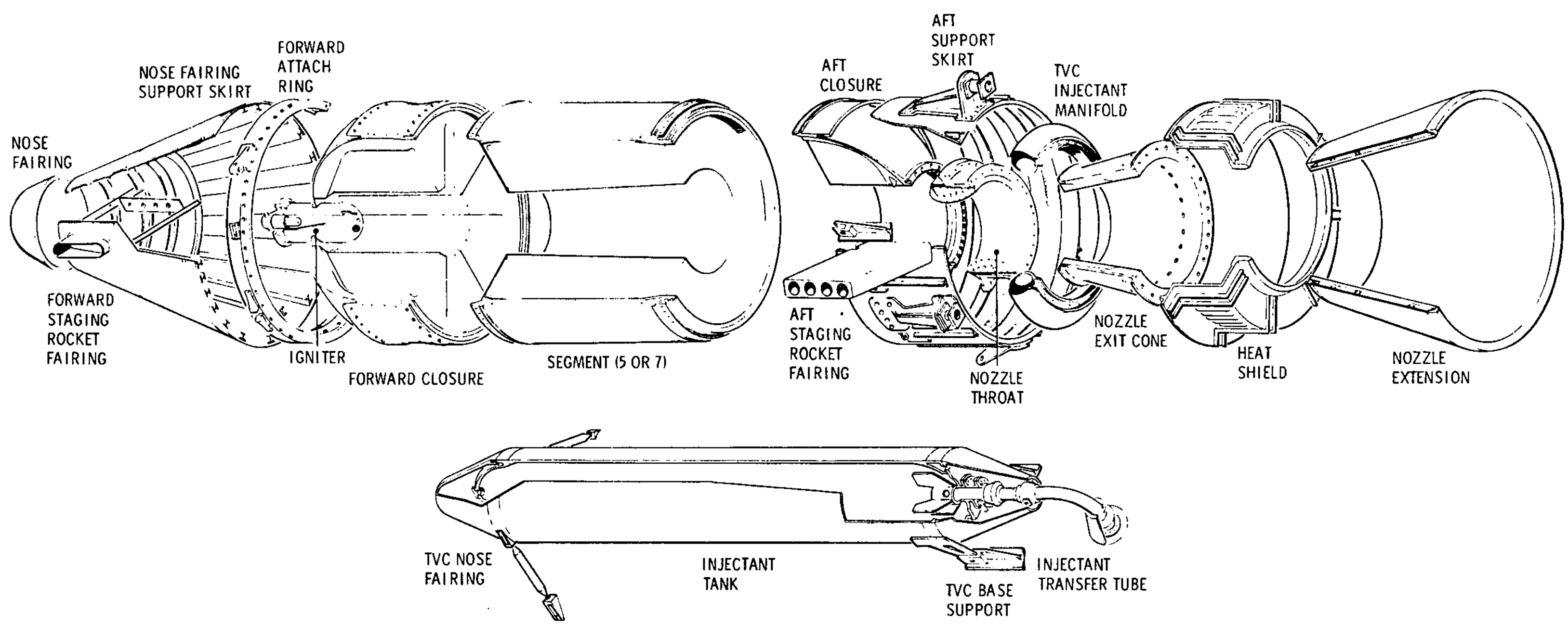

Figure 1. Components of UA 1205 and UA 1207 SRMs

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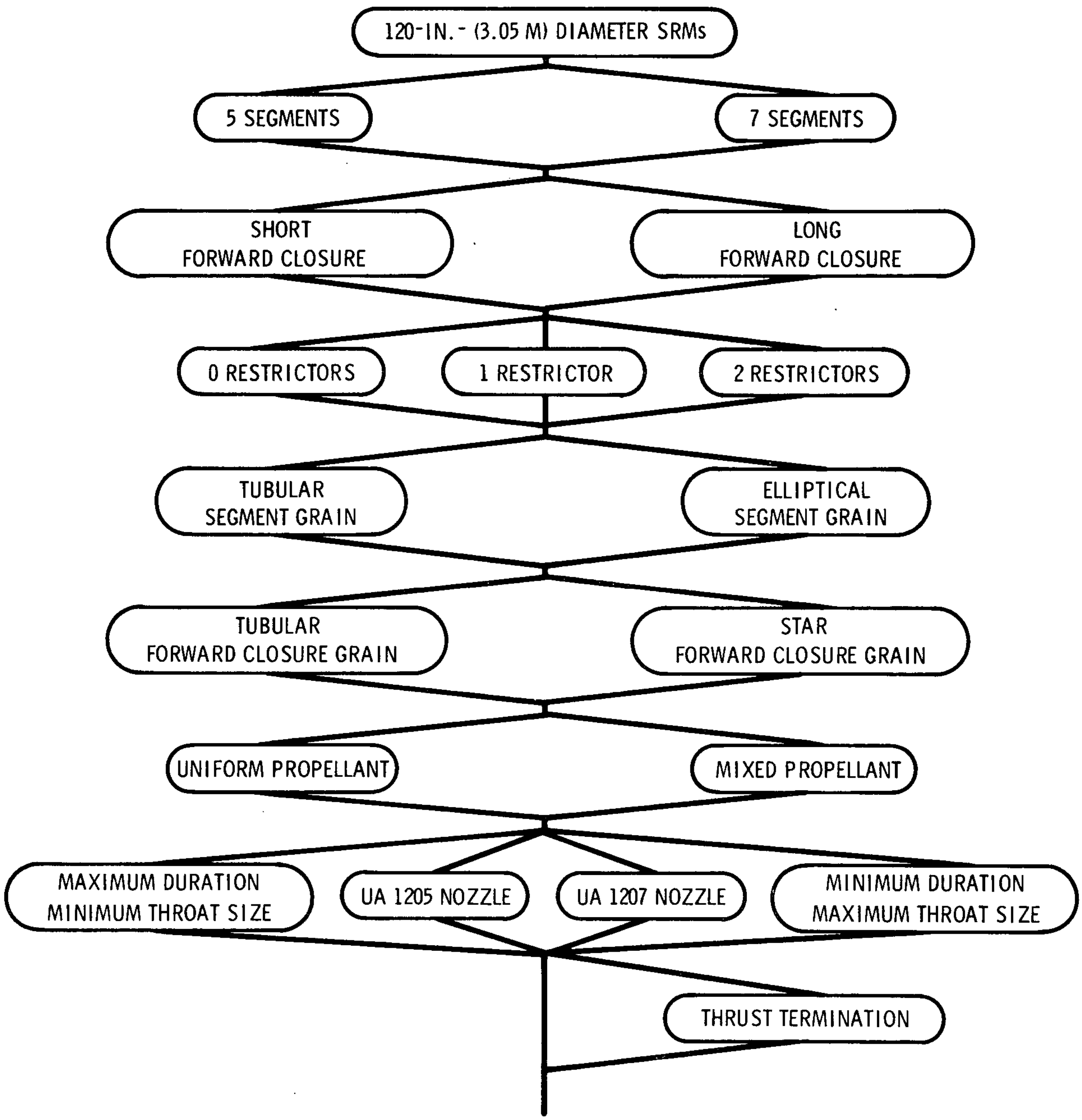

Figure 2. Design Parameters for 120-in.- (3.05 m) Diameter SRMs

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Detailed ballistic data were analytically developed for each design. Calculations were performed on a Burroughs B-5500 computer using the UTC LF12 internal ballistics analysis program. Sufficient data on thrust-time histories, total impulse, duration, specific impulse, and nozzle characteristics were prepared to allow evaluation of the selected designs for specific launch vehicle applications.

Preliminary insulation designs also were prepared for each of the basic grain designs in which the variation in grain geometry or burning time justified such effort. Mass property data were then prepared to provide a complete description of each design. Performance curves and tabulated data for each design are presented in volume II of this report.

Easily applied changes in propellant burning rate, internal port geometry of segments and closures, nozzle throat diameter, and segment inhibitor application were shown to produce significant changes in SRM thrust-time characteristics. Changes could be easily controlled to result in progressive, regressive, neutral, and saddle-shaped thrust histories.

2.1 CURRENT UA-1205 AND UA-1207 BASELINE DESIGNS

The current UTC five- and seven-segment 120-inch (3.05 m) diameter solid rocket motors represent nearly ten years of development and refinement of the basic design. The motors, developed for application as the first or "zero" stage of the Titan IIIC, D and M launch vehicles, contain all necessary propulsion, controls and structural components to act as the complete stage. The five-segment motor has completed the full development and qualification cycle and 34 of these SRMs have flown with total success on seventeen vehicle flights through June 1971. The seven-segment design has completed a development test series although the PFRT series was not completed because of the U. S. Air Force MOL program cancellation. The motor design requires successful completion of only four PFRT static tests to be ready for launch vehicle utilization if the original static firing test criteria are maintained.

The five- and seven-segment motors are depicted in figure 3 as they would appear when used as stage "0" of the Titan launch vehicles. The stage aerodynamic and structural completeness is visible in the inclusion of nose fairings, attachment structures, ground supports and heat shields. Figure 1 will aid in identification of the components. The general arrangement drawings of figures 4 and 5 depict the overall configuration of the basic five- and seven-segment motors without stage accessories. Each of the motors is comprised of a number of identical, interchangeable segments with end closures. The five-segment motor is designed for 853 psig (5.87 MN/m^2) maximum expected operating pressure and the seven-segment motor is 920 psig (6.34 MN/m^2). In actual practice the motor case segments and aft closures of each motor size are identical. The forward closures of the 1205 and 1207 motors have differences in wall thickness, length of the cylindrical portion and provisions for thrust termination. The 1207 forward closure

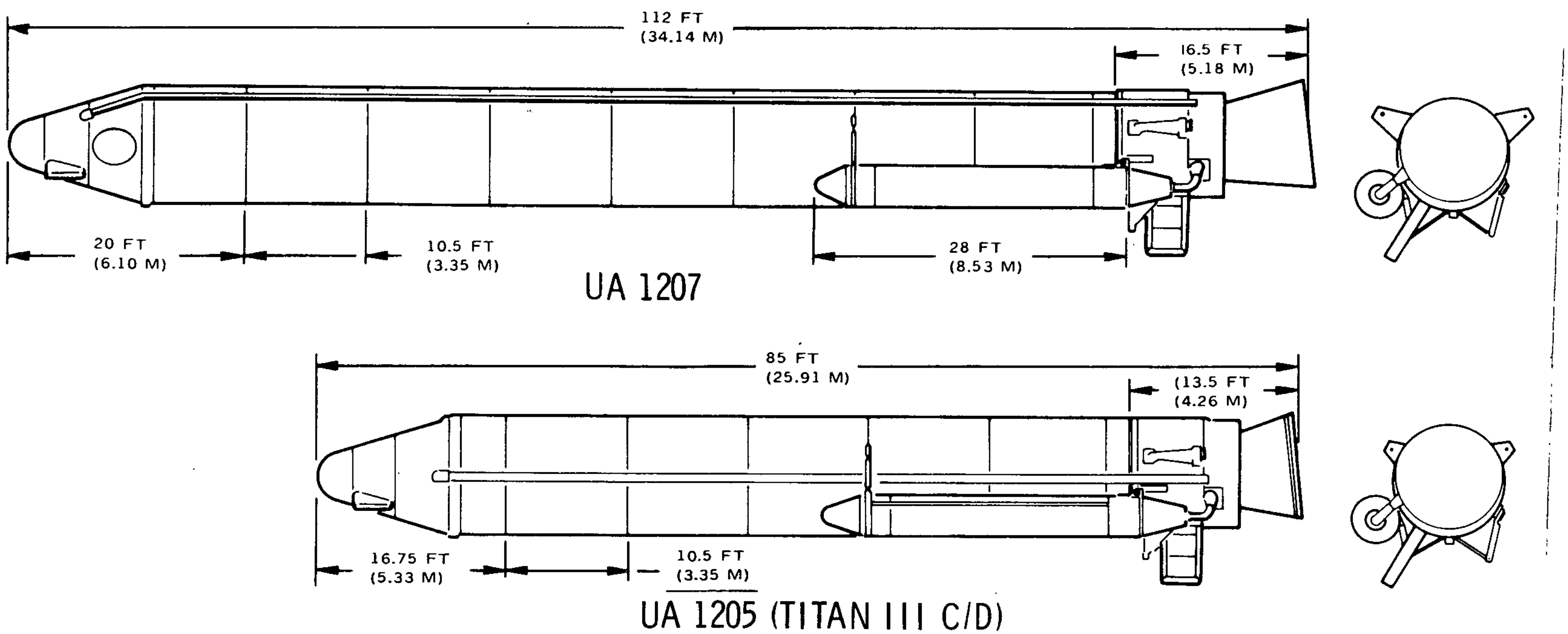


Figure 3. Titan III SRM Stage 0 Configurations

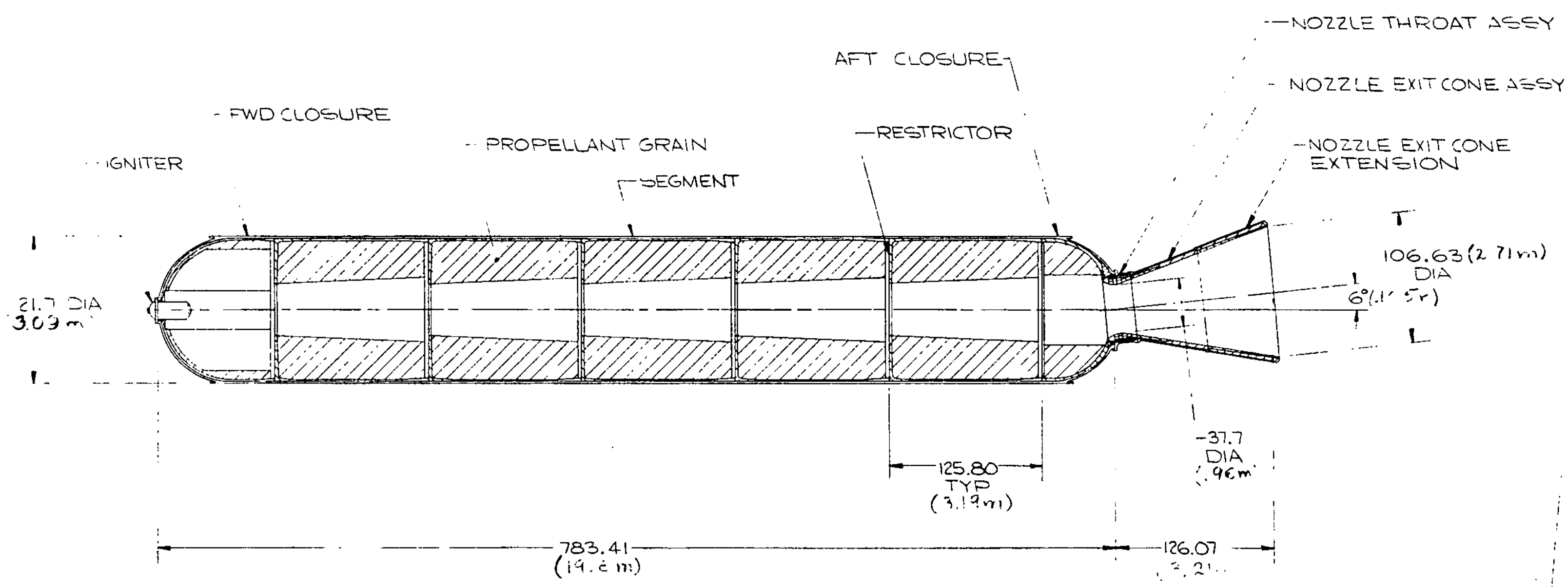


Figure 4. General Arrangement of the UA 1205 SRM

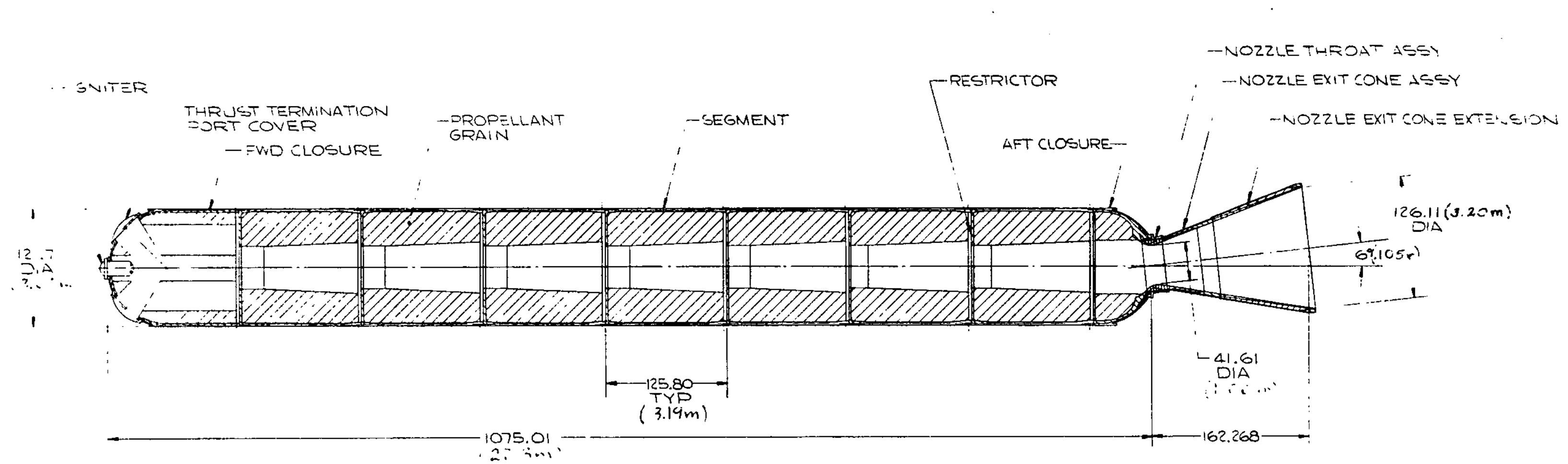


Figure 5. General Arrangement of the UA 1207 SRM

is 40 inches (1.02 m) longer than the 1205 forward closure and contains two 33-in. (.84 m) thrust termination ports. The basic nozzle shells for the two motors are identical while there are differences in the internal throat diameters and the length, diameter, and expansion ratio of the nozzle extension.

Both the 1205 and 1207 motors use an aluminized poly-butadiene-acrylonitrile, PBAN, composite propellant. The five-segment propellant, UTP 3001, has a standard burning rate of 0.393 inches/second (.997 cm/sec) at 1000 psi (6.89 MN/m^2) and a standard delivered specific impulse of 247.7 seconds. Standard specific impulse is measured @ 1000 psi (6.89 MN/m^2) chamber pressure with the exhaust optimally expanded to sea level conditions through a 15^o (.262 rad) nozzle. The seven-segment propellant, UTP 3001B, is identical except for slight changes made in the ammonium perchlorate particle size distribution and iron oxide burning rate catalyst quantity used to produce a standard burning rate of 0.352 inches/second (.895 cm/sec). The propellant grain configuration of the two motors is similar. An eight-point star grain is used in the forward closure to provide high initial thrust. A tapered cylindrical perforation is used in each of the cylindrical segments.

The tapered interior port provides for a gradual reduction in surface area at motor burnout to yield the ten-second, approximately linear tailoff. This tailoff was developed as a solution to the control requirements at burnout of the two-motor stage 0 Titan configurations. The forward face of each segment grain is prevented from burning by a rubber restrictor. This restrictor controls the burning surface exposed to provide the desired thrust-time history. The aft closures of both motors also use the simple tubular perforated grain. Ballistic performances of each of the motors are shown in figures 6 and 7 and tables I and II.

Steering of the 120-inch (3.05 m) diameter solid rocket motor is currently

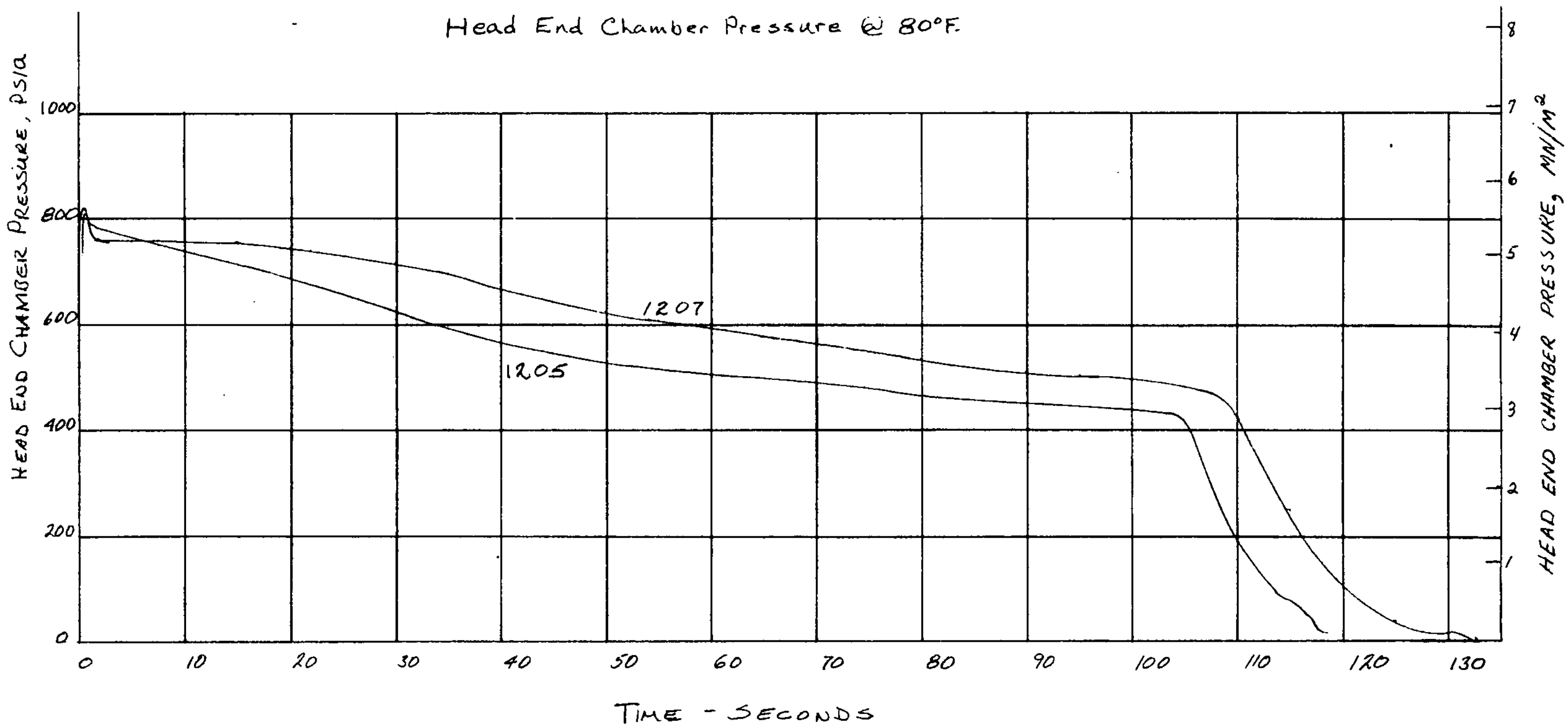


Figure 6. Pressure-Time Performance of the UA 1205 and UA 1207 SRMs

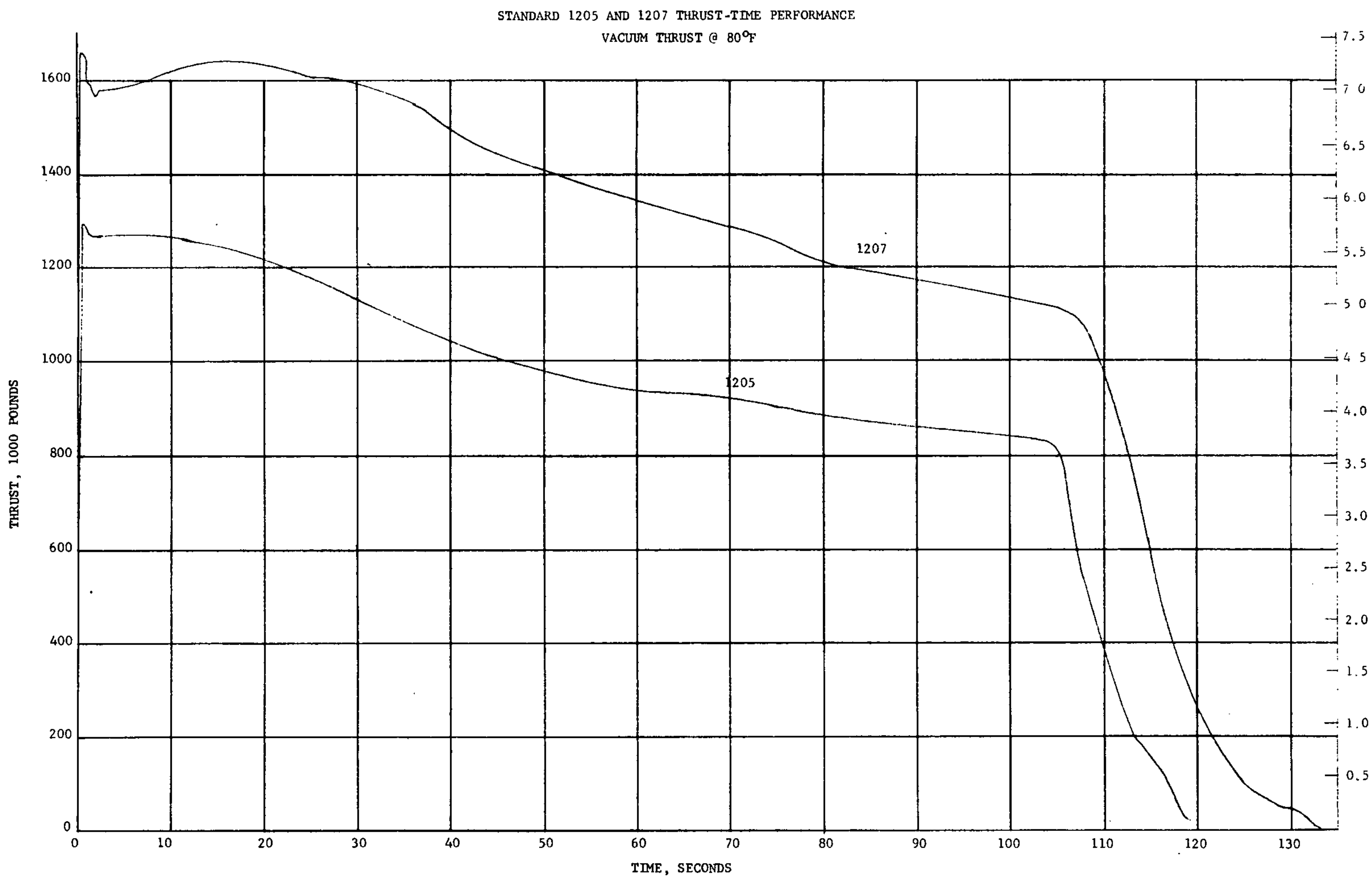


Figure 7. Thrust-Time Performance of the UA 1205 and UA 1207 SRMs

TABLE I

UA 1205 PERFORMANCE SUMMARY

UNAUGMENTED NOZZLE CENTERLINE THRUST, 80°F

Parameter	Nominal	3 Sigma Limits Percent	Limits Minimum	Limits Maximum
Ignition delay, millisec	230	—	150	300
Web action time, sec	104.1	2.16	101.9	106.4
Action time, sec	113.8	3.43	109.8	117.7
Web action time impulse				
lb_f sec x 10^{-6}	108.43	1.0	107.35	109.51
(N-sec)	(482.30)		(477.49)	(487.10)
Action time impulse				
lb_f sec x 10^{-6}	112.52	1.0	111.40	114.20
(N-sec)	(500.48)		(495.50)	(507.96)
Delivered specific impulse				
lb_f sec/lb_m	266.0	0.7	264.1	267.9
Initial sea level thrust				
lb_f	1,199,300	6.23	1,124,600	1,274,000
(N)	(5,334,500)		(5,002,220)	(5,666,752)
Forward end chamber pressure				
psia	812	3.76	781	843
(MN/m^2)	(5.60)		(5.38)	(5.81)

TABLE II

UA 1207 PERFORMANCE SUMMARY

UNAUGMENTED NOZZLE CENTERLINE THRUST, 80°F

Parameter	Nominal	3 Sigma Limits Percent	Limits Minimum	Limits Maximum
Ignition delay, millisec	228	–	150	300
Web action time, sec	110.6	2.16	108.2	113.0
Action time, sec	121.3	3.43	117.1	125.5
Web action time total impulse lb_f sec x 10^{-6} (N-sec)	153.134 (681.14)	1.0	151.603 (674.33)	154.665 (687.949)
Action time total impulse lb_f sec x 10^{-6} (N-sec)	158.797 (706.329)	1.0	157.209 (699.265)	160.385 (713.392)
Delivered specific impulse lb_f-sec/lb_m	269.5	0.7	267.6	271.4
Initial sea level thrust lb_f (N)	1,460,300 (6,495,414)	6.23	1,369,300 (6,090,646)	1,551,300 (6,900,182)
Forward end chamber pressure psia (MN/m^2)	825 (5.68)	3.76	794 (5.47)	856 (5.90)

accomplished by secondary injection of nitrogen tetroxide into the stream in the nozzle. A steering capability (thrust vector control, TVC) of about three degrees (.0524 rad) is provided. The assembled SRM contains all tankage, feed system and controls necessary for the TVC operation. Command authority on the Titan vehicles is provided by the upper stages via electrical umbilicals. Electrical equipment for steering, ordnance and instrumentation operation is mounted on the SRM nozzle and within the nose cone section. Structural components required for ground support, attachment to the upper stages, base heating protection and aerodynamic fairings are shown in the general arrangement drawings of figures 1 and 3. These figures also indicate component construction, geometry and relationship to other components.

A complete weight statement of the 1205 and 1207 SRMs and their stage accessory weights is provided in table III.

2.2 SRM INTERNAL BALLISTICS

The basic SRM internal ballistic parameters which effect motor performance are chamber pressure, burning surface area, nozzle throat area, and propellant burning rate. A simplified discussion of the relationship of these parameters and their relation to SRM design features is presented here to provide a better understanding of this parametric ballistic analysis.

The thrust of a rocket motor is caused by a momentum exchange with the exhaust gases exhausting through the nozzle. In a solid rocket motor these gases are generated at the solid propellant surface by combustion of the propellant. Burning of the propellant occurs at the exposed surfaces and proceeds in a direction normal to the surface as the propellant is consumed. This regression of the burning surface in parallel layers is known as Pioberts law

TABLE III

UA 1205 AND UA 1207 SRM WEIGHT DATA

	UA 1205		UA 1207	
	lb	kg	lb	kg
CASE	(35,832)	(16,253)	(48,313)	(21,915)
Forward closure	4,135	1,876	5,992	2,718
Segments, total	28,240	12,810	38,780	17,591
Aft closure	3,193	1,448	3,193	1,448
Attach provisions	264	120	348	158
INSULATION AND LINER	(9,206)	(4,176)	(13,212)	(5,993)
Forward closure	911	413	1,690	767
Segments, total	5,910	2,681	9,212	4,179
Aft closure	2,385	1,082	2,310	1,048
PROPELLANT	(424,317)	(192,466)	(592,857)	(268,920)
Forward closure	38,150	17,304	60,932	27,639
Segments, total	366,250	166,127	512,085	232,237
Aft closure	19,917	9,034	19,840	8,999
NOZZLE	(7,791)	(3,534)	(9,445)	(4,284)
Throat assembly	2,342	1,062	2,085	946
Exit cone	1,483	673	2,570	1,166
Exit cone support	1,931	876	1,378	625
Extension nozzle	2,035	923	3,412	1,548
TVC SYSTEM	(15,601)	(7,077)	(15,633)	(7,091)
Inerts	(6,541)	(2,967)	(6,573)	(2,982)
Tankage	3,817	1,731	3,817	1,731
Distribution system	1,754	795	1,886	855
Miscellaneous structure	870	395	870	395
Destruct	100	45	—	—
Pressurant	636	288	636	288
Injectant	(8,424)	(3,821)	(8,424)	(3,821)
Usable	7,500	3,402	7,500	3,402
Residual	924	419	924	419
DESTRUCT SYSTEM (Solid Motor)	(266)	121	—	—
THRUST TERMINATION	—	—	(1,356)	(615)
Stacks	—	—	707	321
Covers	—	—	541	245
Attach hardware	—	—	58	26
Mechanism	—	—	50	23
IGNITER	(378)	(171)	(378)	(171)
Inerts	290	132	290	132
Charge	88	40	88	40
ELECTRICAL SYSTEM	(485)	(220)	(624)	(283)
INSTRUMENTATION	(835)	(379)	(816)	(370)
SEPARATION SYSTEM	(1,238)	(562)	(1,238)	(562)
Motors	668	303	668	303
Circuitry	15	7	15	7
Support hardware	555	252	555	252

TABLE III

UA 1205 AND UA 1207 SRM WEIGHT DATA (Continued)

	UA 1205		UA 1207	
	lb	kg	lb	kg
EXTERNAL INSULATION (includes paint)	(620)	(281)	(826)	(375)
ATTACH STRUCTURE & FAIRING SRM	(11,315)	(5,132)	(12,647)	(5,737)
Nose fairing	1,188	539	1,198	543
Motor attachments	(10,127)	(4,594)	(11,449)	(5,193)
Forward ring	1,328	602	1,328	602
Aft skirt/heat shield	8,799	3,991	10,121	4,591
Loaded Weight	507,884	230,371	697,345	316,316
EXPENDED WEIGHT	(436,349)	(197,923)	(607,435)	(275,528)
Nozzle and internal insulation	4,426	2,008	6,964	3,159
Propellant	424,317	192,466	592,857	268,915
Igniter	88	40	88	40
TVC fluid	7,500	3,402	7,500	3,402
External insulation	18	8	26	12
BURNOUT WEIGHT	71,535	32,448	89,910	40,782

OVERALL MASS FRACTION

$$\frac{507,884 - 71,535}{507,884} = 0.859$$

OVERALL MASS FRACTION

$$\frac{697,345 - 89,910}{697,345} = 0.871$$

after Piobert who postulated the effect in 1839. The rate at which the burning surface recedes is termed the linear burning rate and is denoted by r. This burning rate is controlled by propellant composition, temperature, and total pressure but not by propellant geometry. Saint-Robert's law, $r = cp^n$, was first employed in 1883 to define the empirical relationship of burning rate and pressure (p). The constants c and n are principally related to the propellant composition. The constants are secondarily affected by propellant temperature. These constants have values of about c = 0.075 and n = 0.22 for UTC's PBAN propellants.

The weight rate of gas production can be obtained from

$$\dot{W} = A_s \rho r = A_s \rho c p^n$$

where A_s is the propellant burning surface area and ρ is the propellant density. The weight rate of gas discharge from the nozzle is given by

$$\dot{W} = C_w p A_t$$

where C_w is a weight flow coefficient relating to the thermodynamic properties of the combustion gases and A_t is the nozzle throat area. These two weight flow equations can be set equal if the transient effects of chamber filling are ignored.

$$\dot{W} = A_s \rho c p^n = C_w p A_t$$

The equilibrium chamber pressure is then shown to be related to the propellant burning rate, surface area and throat area.

$$P_c = \left(\frac{A_s c \rho}{A_t C_w} \right)^{1/1-n}$$

The solid rocket chamber pressure is thus seen to be directly affected by the ratio of burning surface area to nozzle throat area, the basic burning rate and the burning rate exponent n. The surface area ratio $\frac{A_s}{A_t}$ is sometimes referred to as K_n and can empirically be related to chamber pressure by

$$K_n = bp^{(1-n)}$$

in a manner much like Saint-Robert's law.

By extension, the chamber pressure history of a solid rocket motor is controlled by the surface area exposed when the throat area is nearly constant. Figure 8 portrays the total burning surface exposed as a function of distance burned for a five-segment 120-inch (3.05 m) diameter SRM. The similarity of shape of figure 8 to the resultant SRM thrust as shown in figure 7 should be noted. The total burning surface of figure 8 is a summation of the individual burning surface histories of the SRMs forward closure, aft closure and five identical segments. These component surface area characteristics are also shown on figure 8 to illustrate how they add together to yield the total SRM performance history.

Figure 8 shows that the basic shape of the segment history tends to be dominant in determining resultant SRM ballistics. The contribution of the high surface area short duration star perforation forward closure to achieve higher initial thrust is readily visible. The aft closure plays no significant role in the ballistic design because of its small size and merely serves as filler to add to the initial thrust level.

The ballistic analysis must, of course, use a more rigorous model of the SRM internal ballistics. Factors such as internal gas dynamics, pressure drop due to flow down the motor, pressure drop due to mass addition, pressure

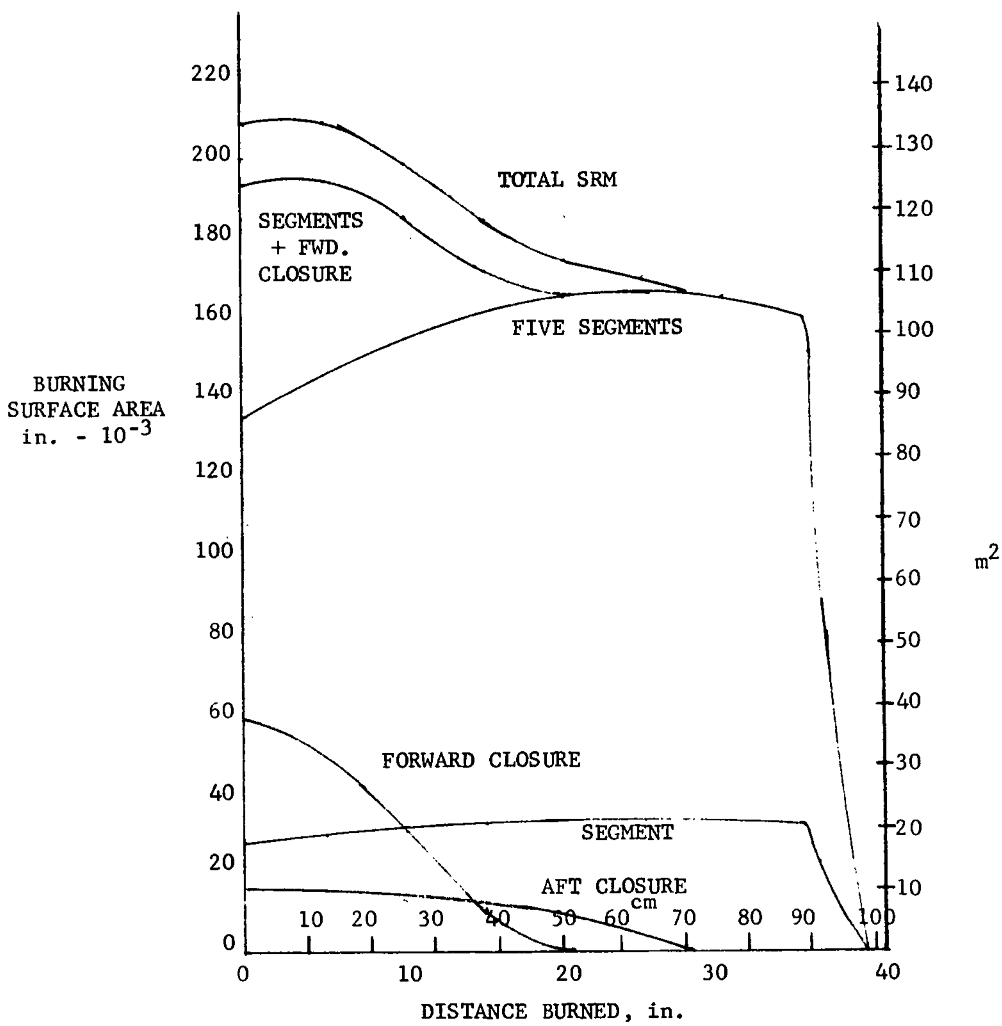


Figure 8. Total Burning Surface History of the UA 1205 SRM

drop due to restrictions in port area, varying local burning rate due to varying local static pressure and throat erosion must all be considered in defining resultant motor performance.

The objective of the ballistic modifications discussion in section 2.3 is the revision of motor ballistic history through revision of its burning surface history. The impact of each of the individual elements on the burning surface history will be examined here as they relate to section 2.3. The two forward closure sizes of 1207 and 1205 are illustrated in figure 9. The larger 1207 closure is seen to produce 25% more surface area but its web thickness or duration is similar to the 1205. The basic characteristic surface histories which may be obtained by varying the use of segment restrictors are shown in figure 10 for a 1207 segment. As seen, shapes from 45% regressive, neutral and 130% progressive are attainable with the standard segment length as depicted. The forward closure share of motor surface history is affected by its perforation much as the segments are by the selection of restrictors. The effect of a star or tubular perforation on a 1207 motor is shown in figure 11. The maximum magnitude of the closure burning surface area is cut in third while its web thickness or duration is doubled when the tubular perforation is used. This tubular closure is actually similar to a singly restricted segment. The effect is to decrease the motor initial thrust. Use of an elliptical segment bore instead of a tube provides little discernible difference in resultant surface history. Figure 12 shows the similarity of the two for a 1205 segment. The effect of the thrust termination ports upon surface history was previously stated to be minimal. That effect is illustrated in figure 9.

Examination of the above equations discloses the need for adjusting the basic propellant burning rate whenever the propellant geometry or nozzle throat

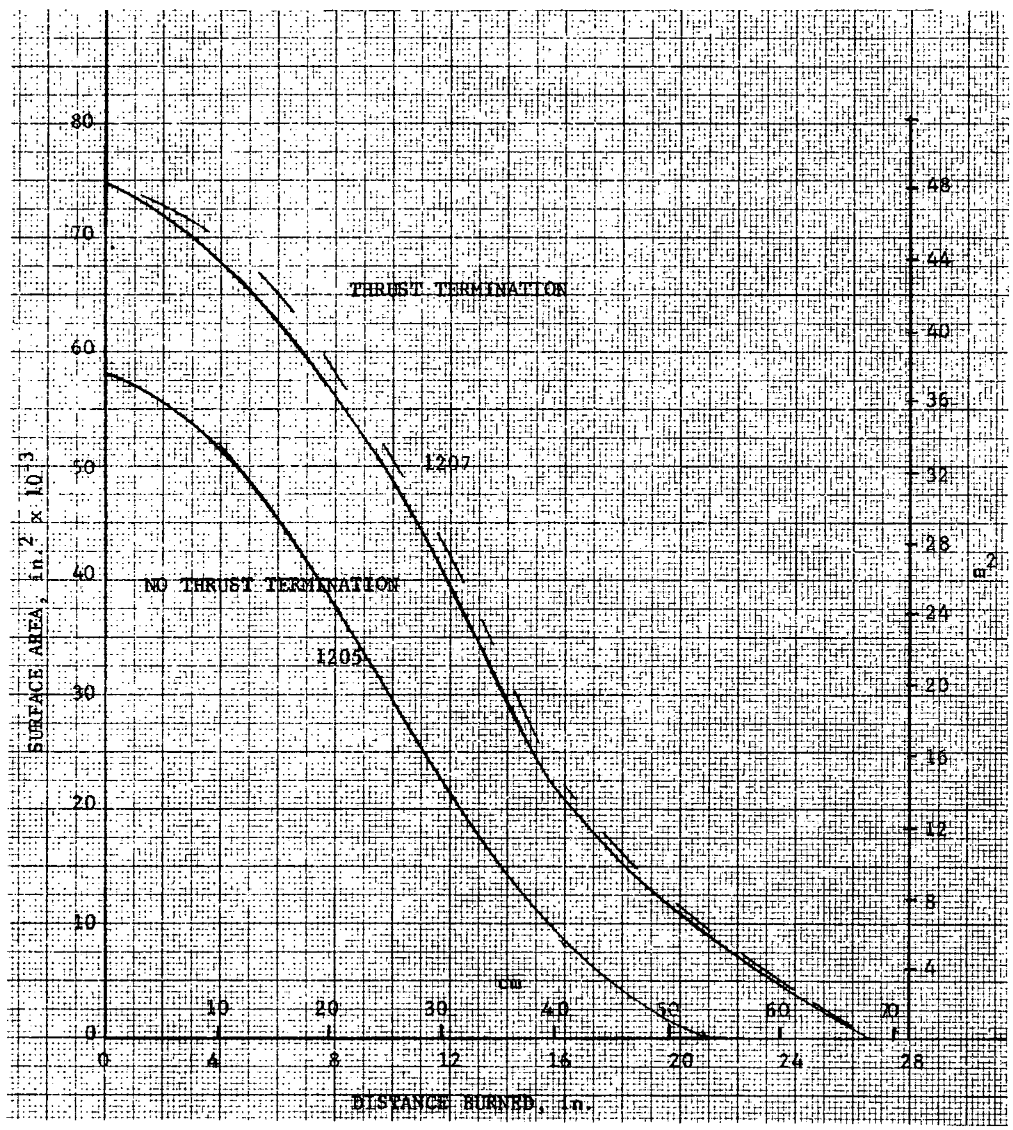


Figure 9. Contribution of Forward Closure to Total Surface Area

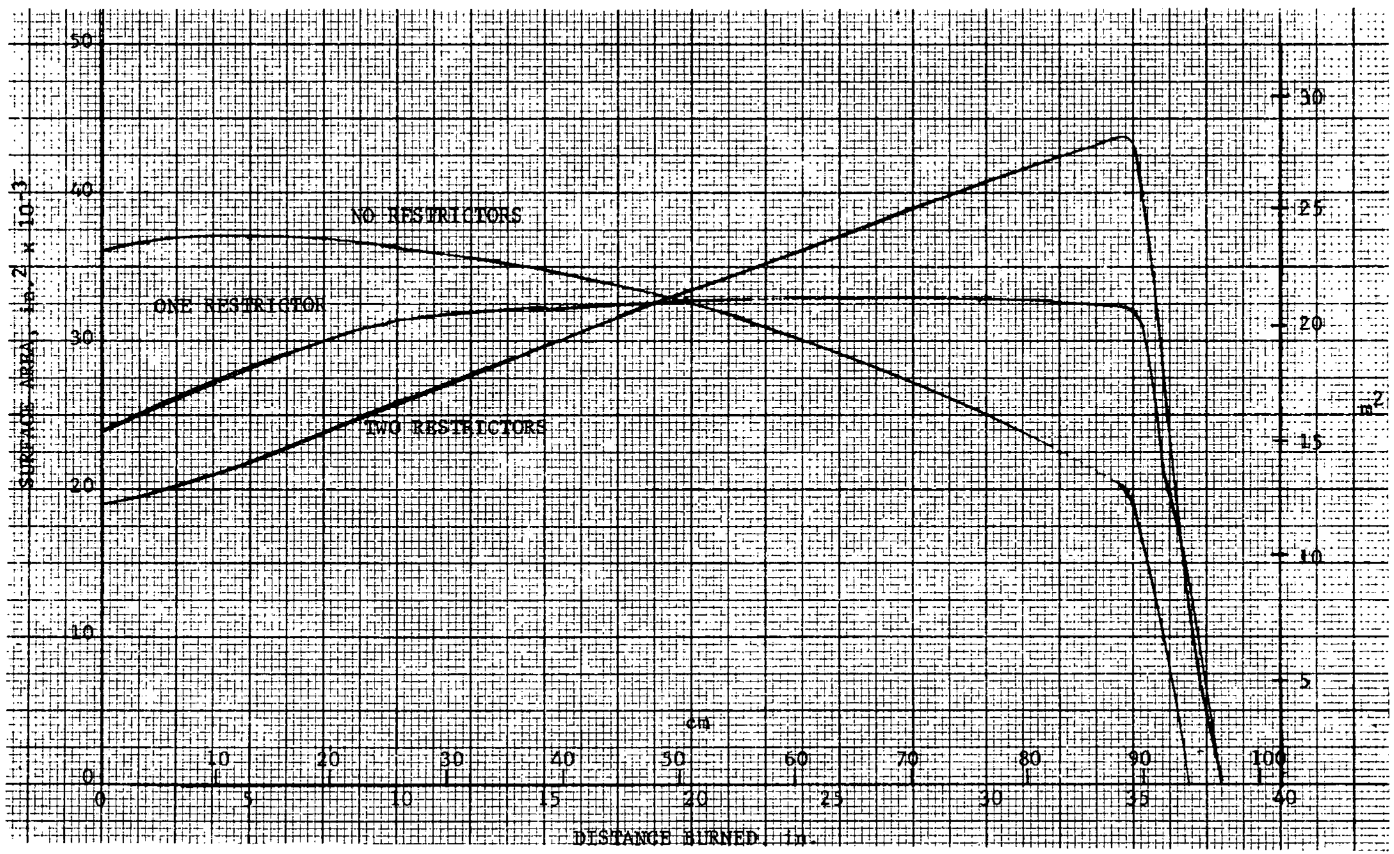


Figure 10. Effect of Segment Restriction on Burning Surface Area, UA 1207

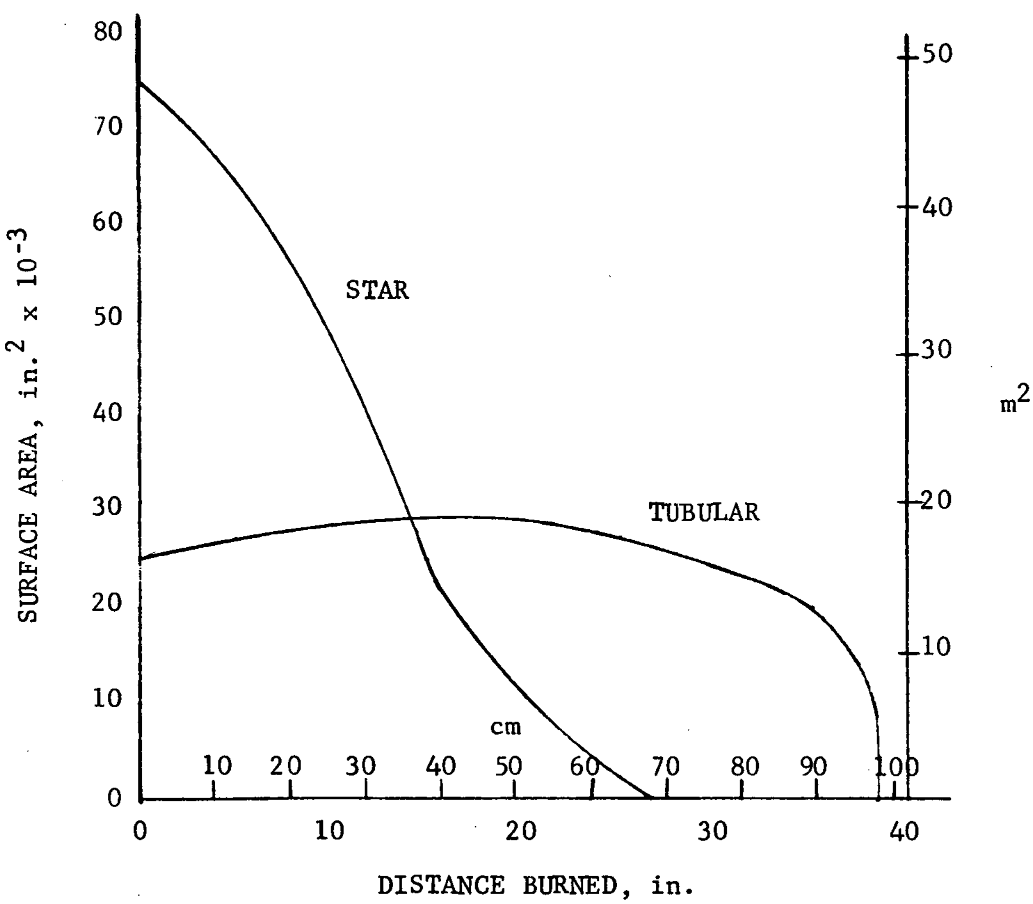


Figure 11. Effect of Forward Closure Perforation on Burning Surface Area

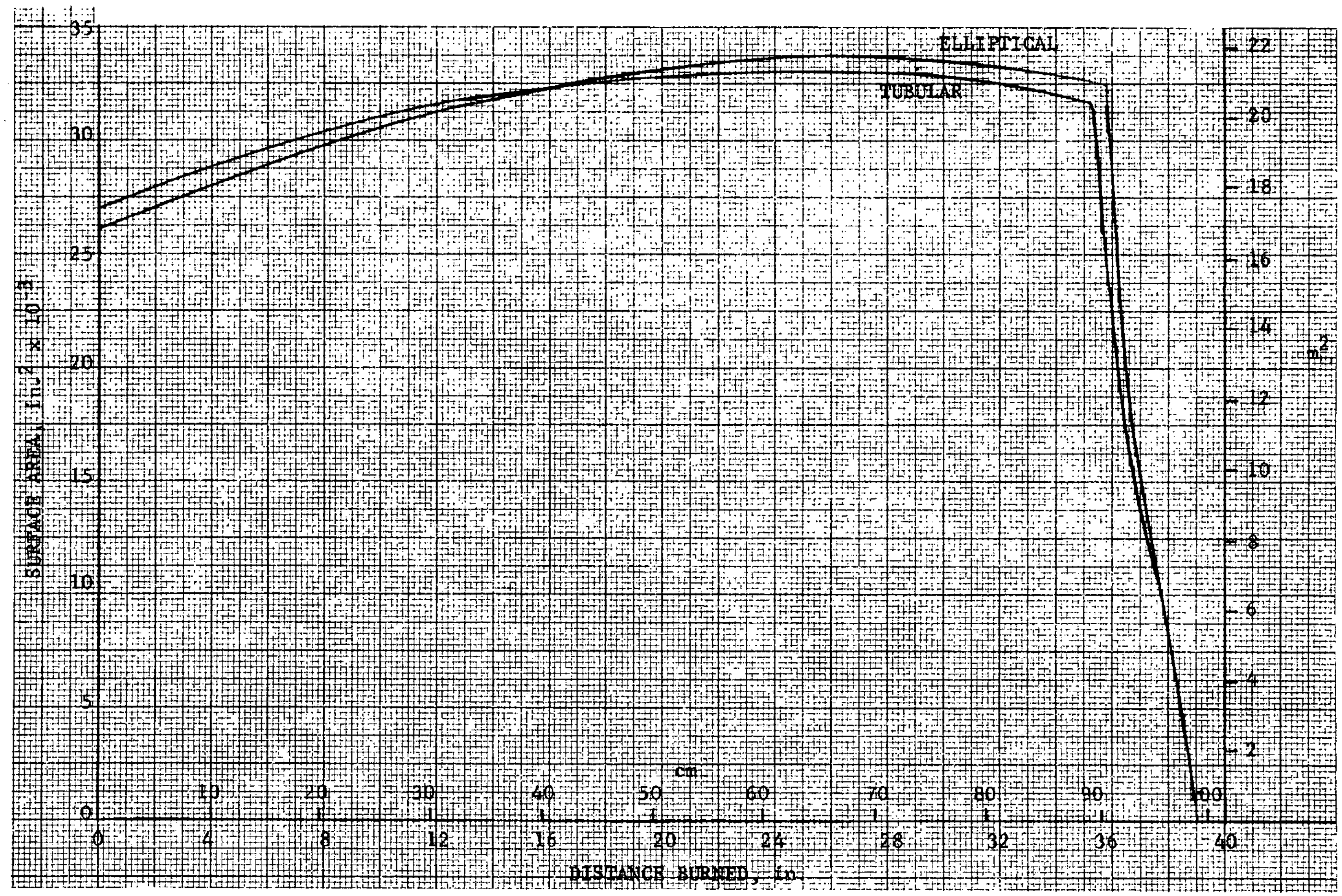


Figure 12. Comparison of Elliptical and Tubular Segment Bores, UA 1205

size are changed. The factors of burning rate, surface area, and throat area must all be balanced to maintain the desired 920 psig (6.32 MN/m^2) MEOP. The more rigorous factors of internal gas dynamics also enter into this relationship and affect the MEOP as will be seen in the results of Section 2.4.

2.3 DESIGN MODIFICATIONS

Study of the ballistic changes which could be made to the baseline 120-inch (3.05 m) diameter solid rocket motor was begun with a listing of the specific parameters to be investigated. These parameters were selected on the basis of minimizing impact upon demonstration or qualification testing requirements. The intent of the analysis is to show the flexibility of design and performance of the existing SRMs which can be achieved with relatively minor modification and minimum testing. Figure 2 presents the parameters to be investigated in a flow diagram style. Selecting a path from the top to the bottom of figure 2 will completely define a unique ballistic design. A complete analysis of all of these possible combinations would yield 576 configurations. This number was reduced to 24 by judicial limitation of application of some of the alternatives. Boundaries or limits were established for each of the parameters based upon the ballistic, physical and geometric limitations of the design. A discussion of the potential modifications is contained in this section. The ballistic effects of these changes are presented in Section 2.4.

2.3.1 Forward and Aft Closure Length

Motor size or length is the primary ballistic parameter as motor length directly affects the total impulse to be packaged. Closure length is the sole choice available having once selected between five- and seven-segment motors. Use of both the 1205 and 1207 forward closures was investigated in this study.

The 1205 forward closure was not applied to seven-segment motors as the reduced propellant capacity was not judged to be a desirable feature. These two unique lengths were used in the study whereas any reasonable length could be implemented should a further more detailed study warrant it. The standard length segments and aft closure were utilized throughout the study. While these lengths could readily be changed, such changes would have massive impact on manufacturing, transportation and assembly methods and equipment.

2.3.2 Segment Restrictors

The second most significant parameter affecting ballistic performance is the selection of propellant surfaces to be restricted from burning. The baseline 1205 and 1207 segments, figures 13 and 14, have one end surface restricted through application of a rubber restrictor on the forward face. Segment without restrictors and segments restricted at both ends have been included in this analysis. Layouts of these segments are shown in figures 15 and 16 as applied to a 1205 grain. The doubly restricted segment was tested successfully on the initial 120-inch (3.05 m) diameter single segment static test. The unrestricted case, involving burning of opposed end surfaces, is standard practice and occurs between the last segment and unrestricted aft closure face in both the current 1205 and 1207 SRMs.

The detail changes required in motor case insulation as the segment restrictors change should be noted as they effect the motor inert weight. An increase in propellant weight of about 600 (272 kg) pounds per segment can be achieved when both ends of the segment are allowed to burn. This propellant weight increase is obtained by replacing the present restrictor with propellant. The same propellant weight increase is maintained for the doubly restricted

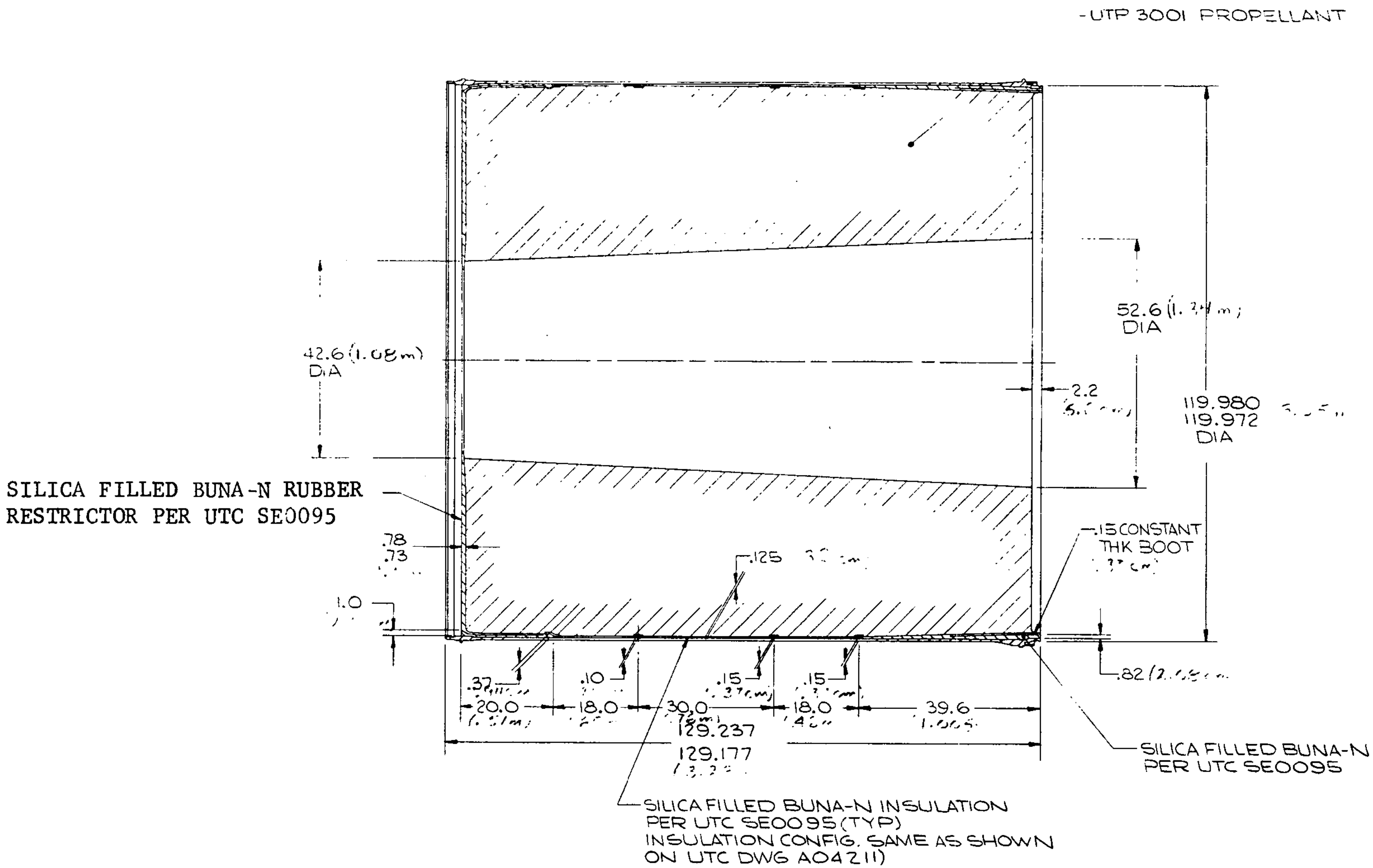


Figure 13. Baseline UA 1205 Segment With One Restrictor

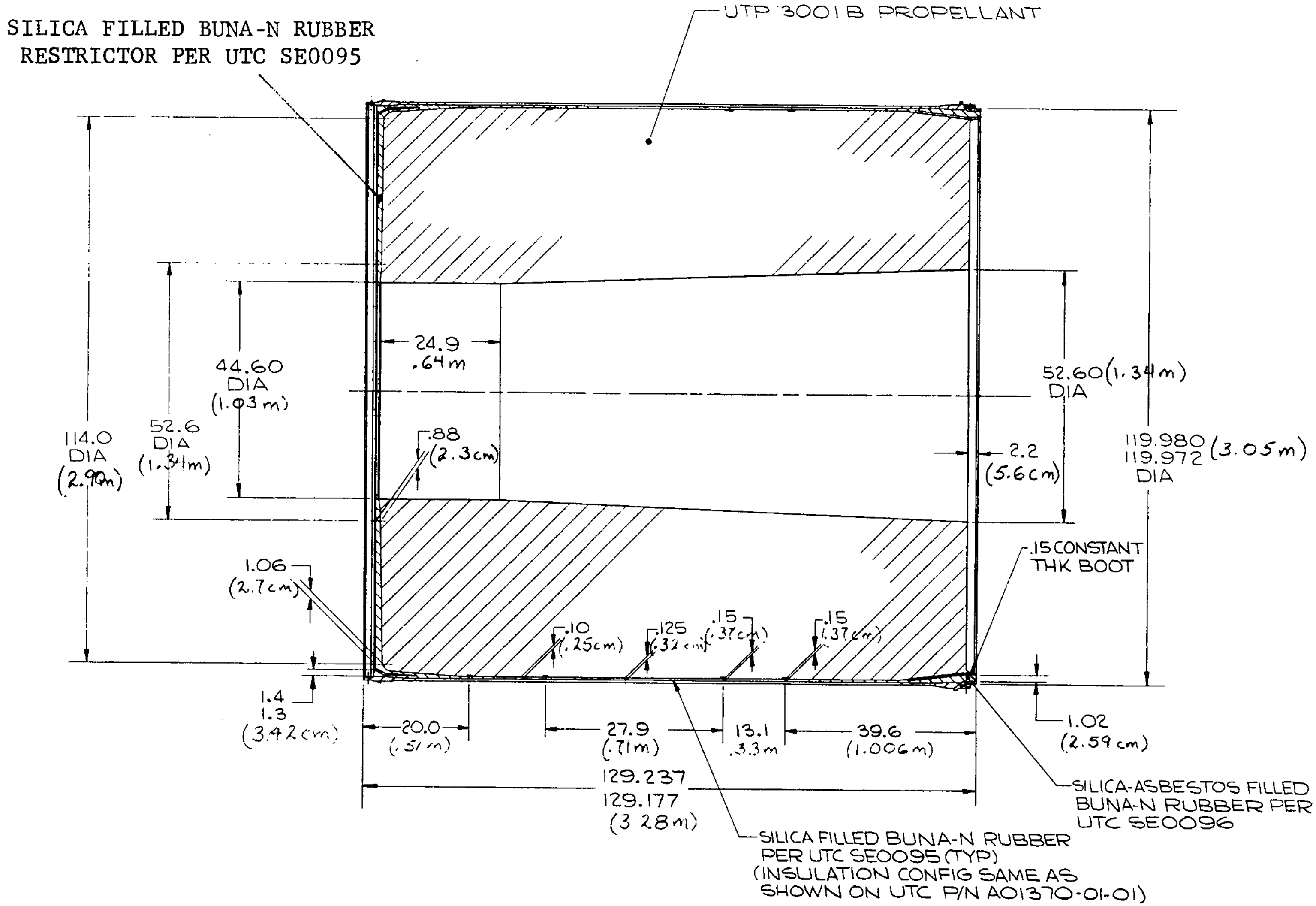


Figure 14. Baseline UA 1207 Segment With One Restrictor

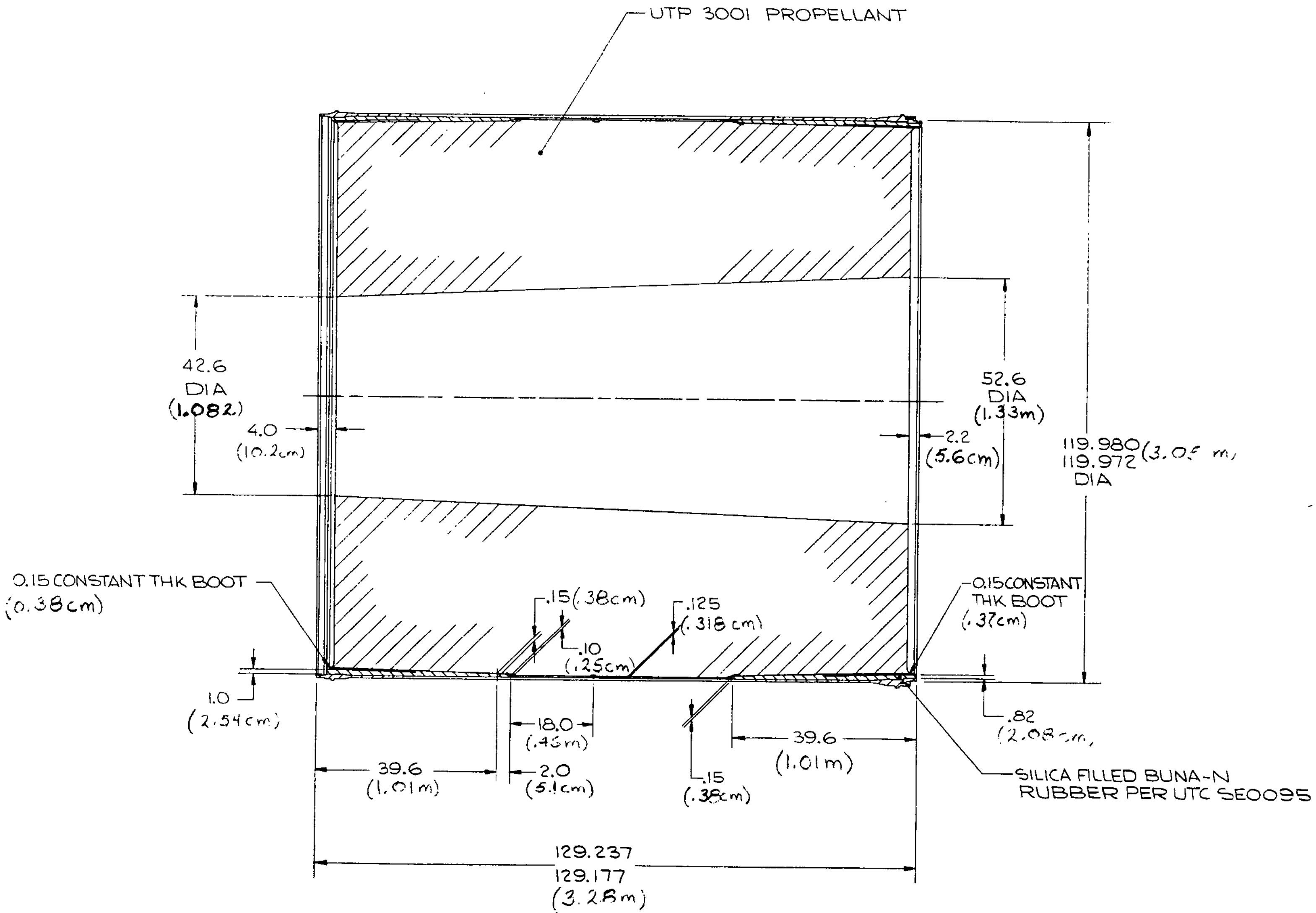


Figure 15. UA 1205 Segment Without Restrictors

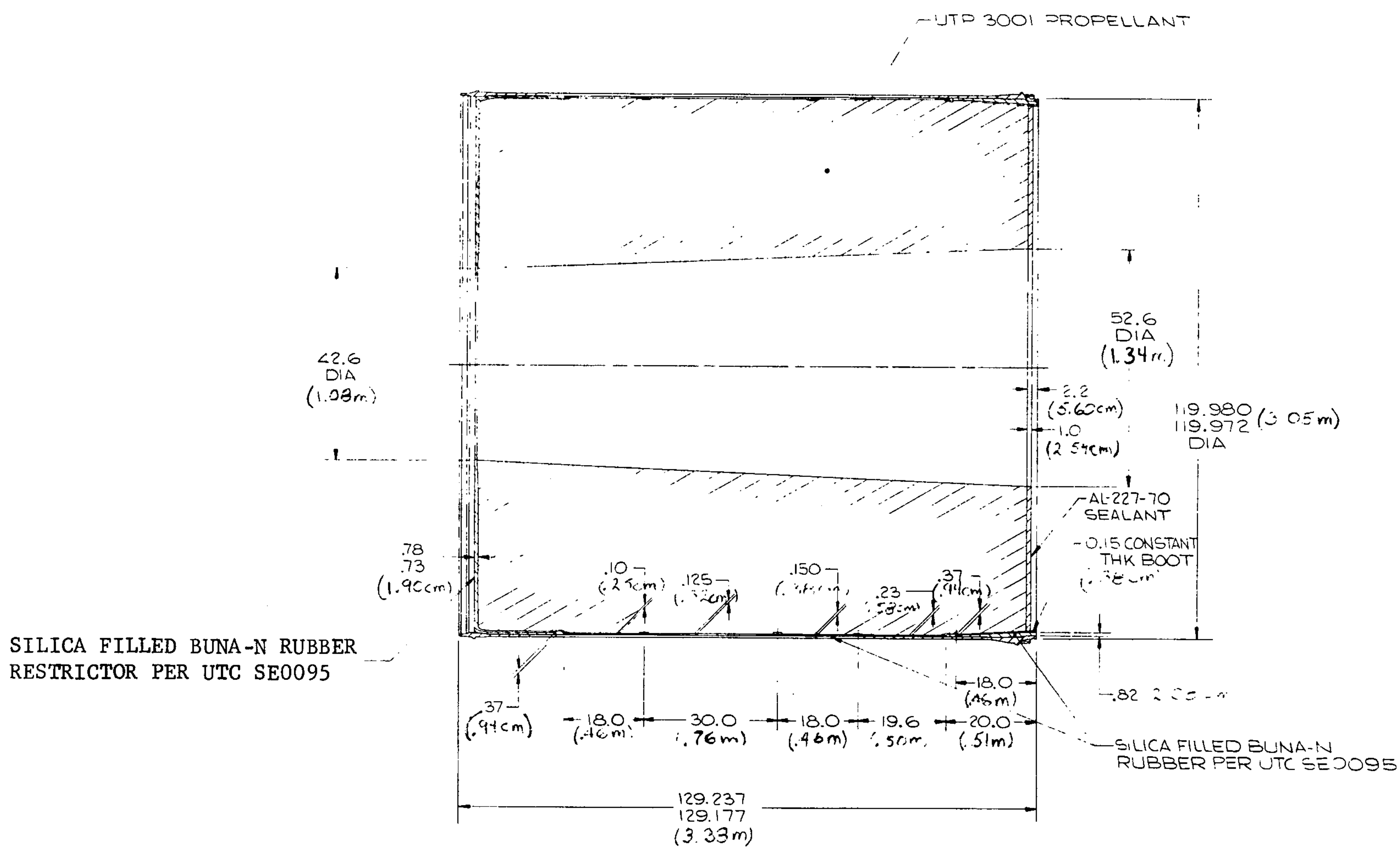


Figure 16. UA 1205 Segment With Two Restrictors

segment since the absence of burning permits reduction of the existing gap between segments by lengthening of the propellant grain.

The effects of restrictor changes upon ballistic performance is to change the general shape of the thrust-time history. A segment with no restrictors would have a regressive history, with one restrictor a neutral or humped history, and restriction of both ends provides a progressive history. Other combinations of surface restriction can be devised to provide other performance but these three will define the basic characteristics. Selection of an SRM design for a specific launch vehicle application can lead to further refined studies of other restrictor design refinements.

2.3.3 Forward Closure Grain

The forward closure grain design provides a useful opportunity to refine the ballistic performance provided by the chosen segment restrictor design. A simple tubular internal perforation, as in figure 17, can be used to provide simplicity and maximum propellant loading. The resultant ballistics would tend to repeat the neutral or humped histories of the baseline segments. Addition of a star grain perforation as in the baseline configurations, figures 18 and 19, serves to increase the initial burning area and hence the initial thrust level. Use of the star reduces the propellant web dimension so that the forward closure propellant is totally consumed at 30 to 50 percent of the motor duration. Replacement of the present star configuration with a tube will provide a propellant weight increase of 1,825 pounds (826 kg) for the 1205 and 2,688 pounds (1,220 kg) for the 1207.

The basic shapes of the baseline closures and the simple tube have been

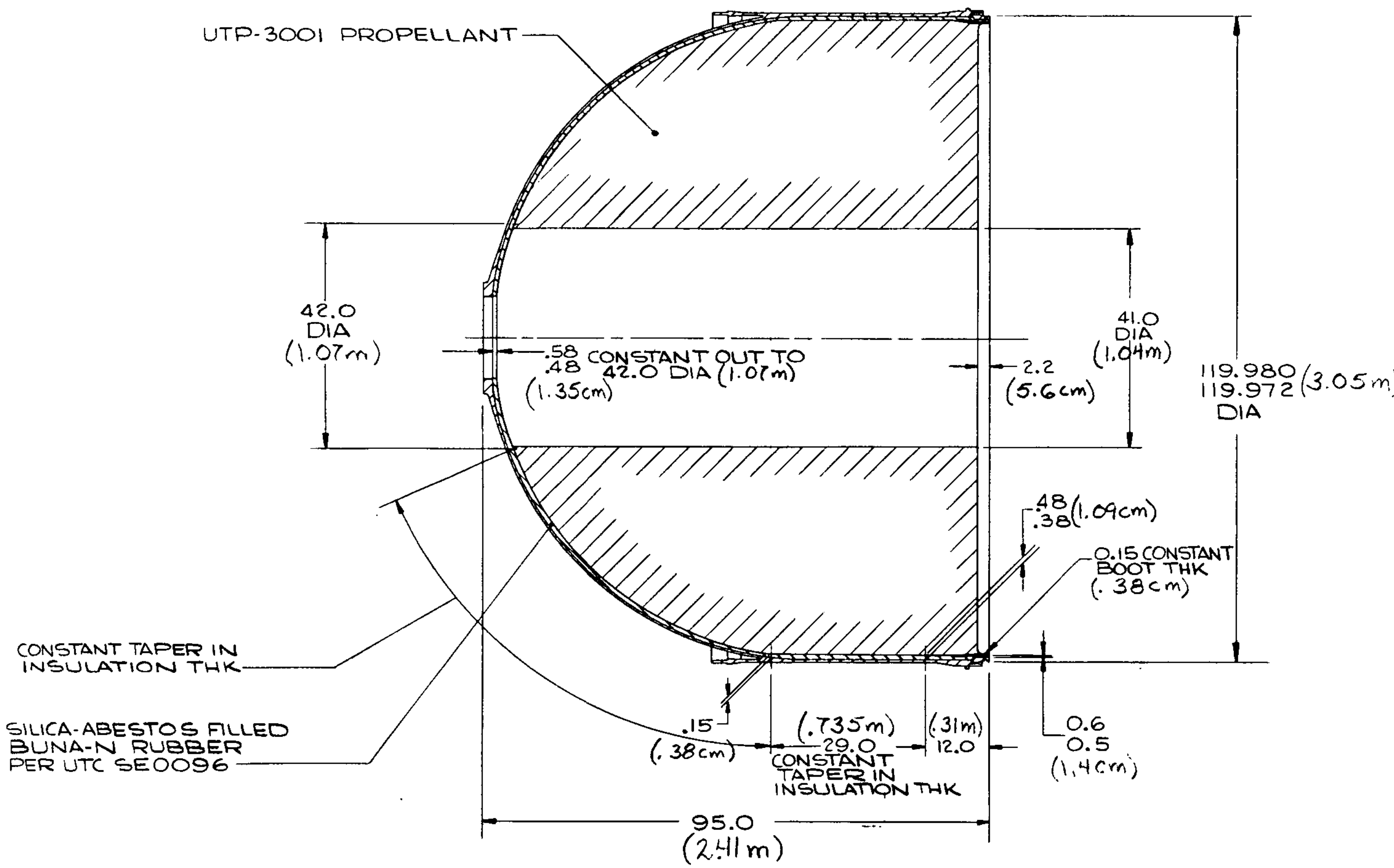


Figure 17. UA 1205 Forward Closure With Tubular Grain

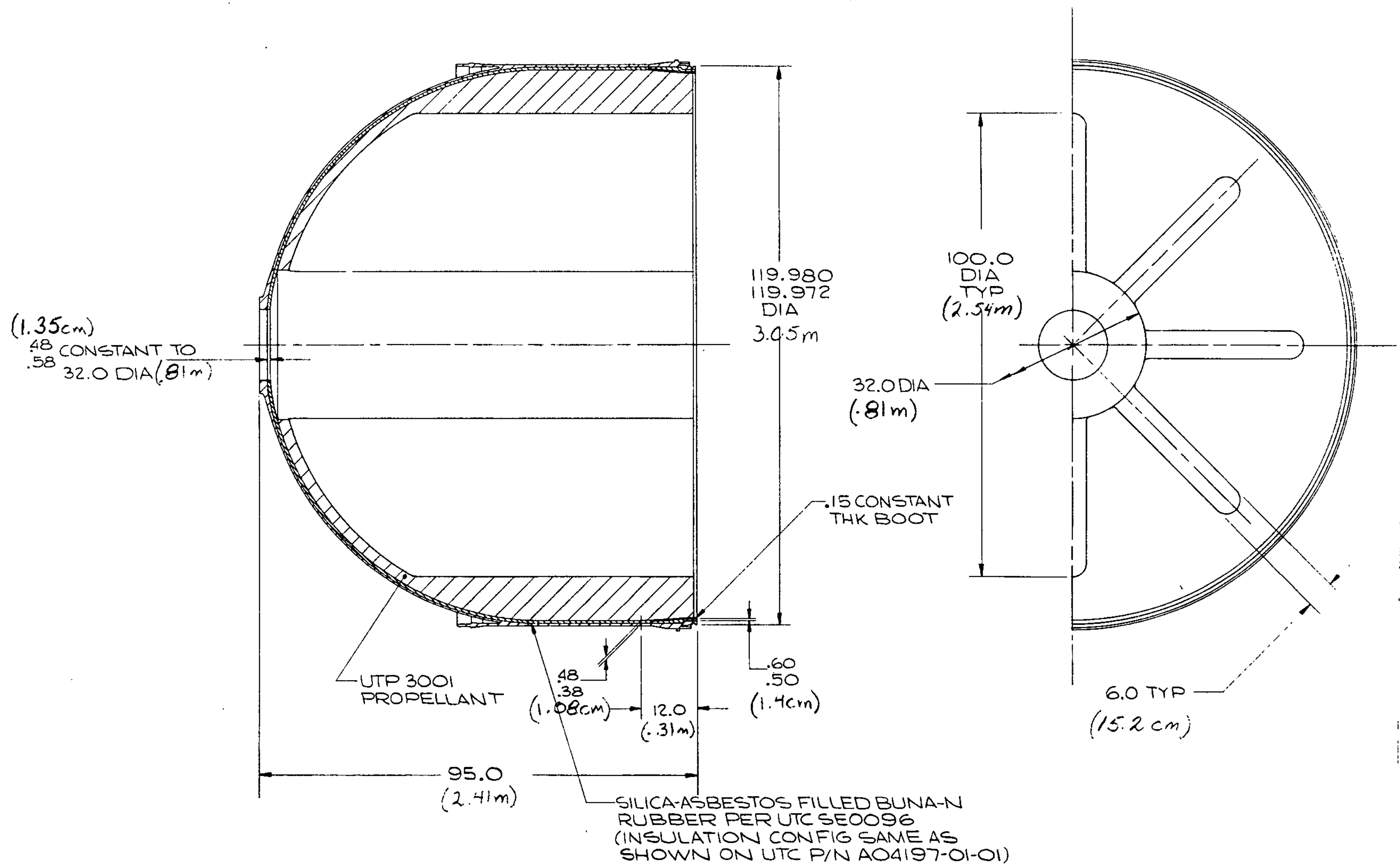


Figure 18. Baseline UA 1205 Forward Closure

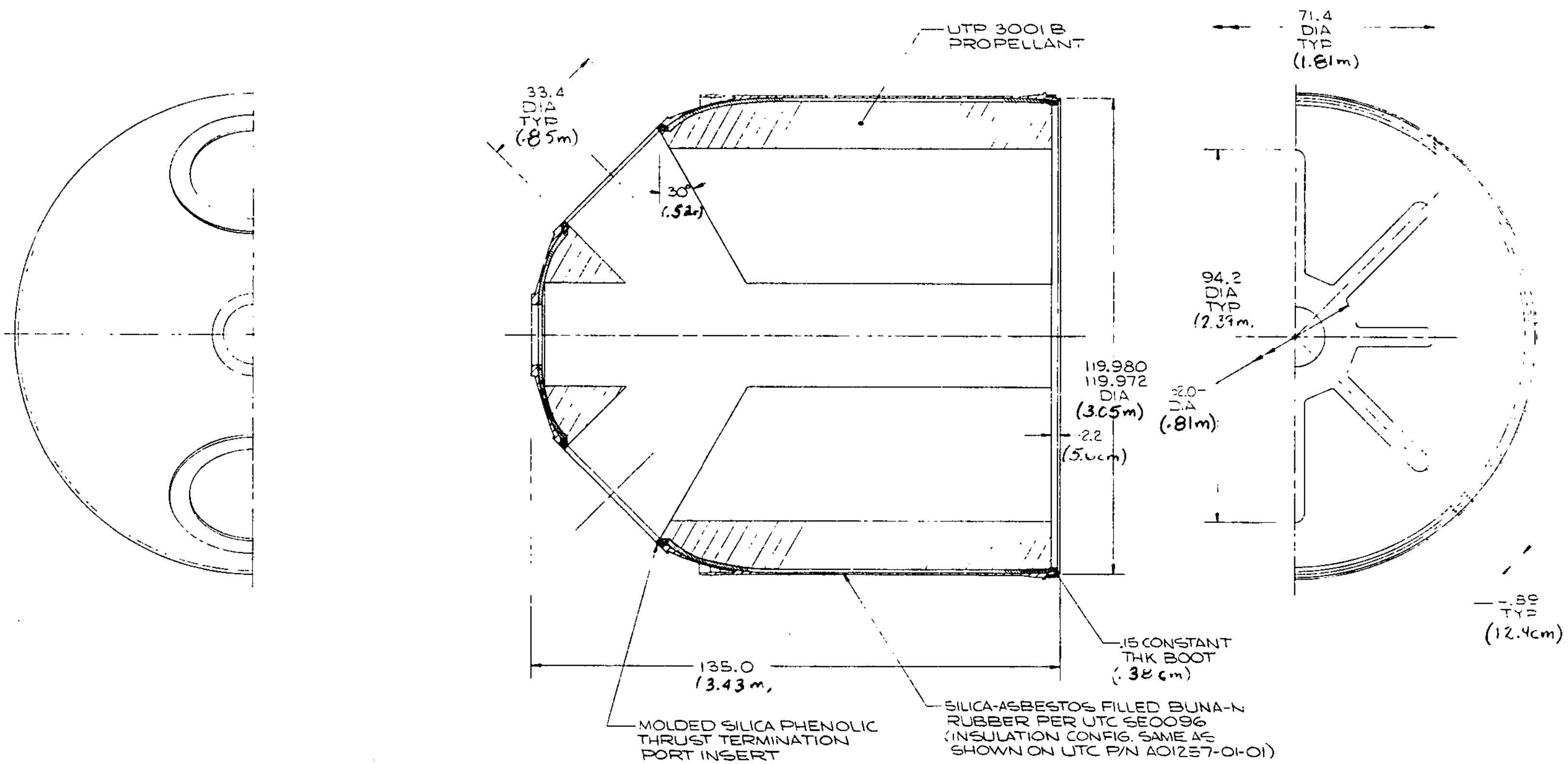


Figure 19. Baseline UA 1207 Forward Closure

used in the analysis to demonstrate the results obtainable. Further refinement of the results to be shown can be made using any of a variety of other available grain perforations.

2.3.4 Propellants

Propellant selections used in the ballistic analysis are based upon UTC's proven PBAN formulations UTP 3001, 3096 and 1090. These propellants, with suitable adjustments of oxidizer particle size and catalyst concentration can provide a burning rate range of 0.2 in./sec. (.507 cm/sec) to 0.7 in./sec. (1.78 cm/sec) which is adequate for the applications of this study. Selection of propellant burning rate for a specific motor configuration was based on maintaining a maximum expected operating pressure (MEOP) of 920 psig (6.34 MN/m^2) @ 90^oF (306^o k). This MEOP is consistent with the pressure load capabilities and safety factors as demonstrated by qualification testing of the D6aC steel motor case during the Titan programs. Fixing the propellant burning rate in accordance with the MEOP leaves the motor duration to be fixed by the size of the nozzle throat and the average chamber pressure of the specific thrust-time (pressure-time) history.

The motor chamber pressure is, of course, a basic ballistic parameter which could be varied at the expense of a new motor case qualification test. The MEOP of the current design was selected as being near the optimum during the design definition phase of the original Titan III-C program. Increasing the MEOP could lead to higher thrust levels and increased specific impulse but at the expense of increased motor case (assuming present strength levels and safety factors), insulation and nozzle weights. Increases in motor thrust would be approximately proportional to chamber pressure increases for a fixed exhaust nozzle.

Conversely, the specific impulse could be increased through a reduction in throat size with a constant thrust level. A 10% increase in chamber pressure would yield about a 1.0% increase in vacuum Isp while the effect on inert weight would be about a 10,000-pound (4530 kg), or 2%, increase. Evaluation of these factors would have to be carried out for specific configuration/ mission requirements to determine optimum conditions.

A single propellant formulation is loaded in all components of most of the motor configurations analyzed. However, it is possible to tailor the motor ballistics by utilizing propellants of more than one burning rate in a single motor. This effect was investigated by placing a higher burning rate propellant in the forward closure of five of the configurations analyzed (configurations 3, 7, 10, 12 and 14). Use of increased burning rate propellant in the forward closure produces a similar effect as a change from a cylindrical to a star grain perforation. Both factors lead to higher initial gas generation and higher thrust with early burnout of the forward closure. The star perforated closure has a high initial surface area decaying to zero at burnout. The high burning rate tube closure has a near uniform surface area with a step reduction at burnout.

There are an infinite variety of burning rate combinations which can be utilized in a given design. The five analyzed were chosen to demonstrate the ballistic effects which can be achieved. Selection of a unique design for a given application can lead to further refinement or tailoring of mixed burning rate propellants.

2.3.5 Nozzle Limits

Selection of an SRM nozzle size is normally based upon the maximum thrust desired. The throat size also serves to regulate motor burning duration as throat size, propellant burning rate, grain geometry, propellant quantity and duration are all carefully balanced interacting parameters. A given motor design will have a unique set of values for these parameters. For a fixed value of MEOP, an increase in the throat size will require an increase in propellant burning rate and cause a reduction in duration while maintaining total impulse. Similarly, a reduction in throat size will have the opposite effect. Thus, a given thrust-time history shape will be maintained but the maximum thrust will change directly with the throat size and the duration will vary inversely with throat size.

There are realistic bounds upon the range of throat sizes which may be employed in a given design. The 1207 nozzle with its 41-inch (1.04 m) throat is the practical upper limit for the 120-inch (3.05 m) diameter motor. For larger throats, the increasing mass flux within the motor bore causes undesirable internal pressure drop, defeating the increased throat size, and leads to more extreme ablation effects within the aft end of the motor. A larger throat could be used only if propellant were removed from the motor to create an appropriately larger internal port. Reduction of throat size leading to longer durations would be limited by the lowest practical vehicle thrust-to-weight ratio or the necessary increase of internal insulation weight and nozzle liner thickness to protect against long duration thermal exposure.

A brief discussion of the effects of nozzle size on performance is contained at the end of Section 2.4.1.

2.3.6 Segment Grains

The ballistic analysis has been limited to the use of tapered tubular segment grains as shown in figures 13 and 14. Other cross sections could, of course, be used. The tubular grain was the basis for the study as this grain is capable of delivering the basic ballistic performance profiles which might be required. There is one variation of the tubular grain which offers a performance advantage. This variation is the offset circular arc or elliptical cross section perforation as shown in figure 20. In this grain the tailoff propellant is provided by the varying web thickness rather than the longitudinal taper. Thus, the motor port is a constant size from end-to-end. This constant size eliminates the internal pressure drop associated with the step change in diameter at the segment ends of current motors. Reduction of internal pressure drop allows greater initial thrust through higher aft end stagnation pressures and provides a shorter duration through use of a faster burning rate permitted by greater internal mass flow. A side benefit of this elliptical grain is that it is possible to place about 2,000 pounds (905 kg) more propellant in each segment. The 10,000 (4,530 kg) to 14,000 pound (6,350 kg) propellant weight increase for the 1205 and 1207 motors corresponds to approximately 1.9% and 2.4% total impulse increases, respectively.

2.3.7 Thrust Termination

Application of the 120-inch (3.05 m) diameter SRMs to a manned payload launch vehicle will probably result in a requirement for thrust termination of the SRMs. Such capability was provided for in the original 1205 and 1207 designs but has been deleted from the current unmanned 1205s. Thrust termination can be easily handled as a block change addition or deletion. Figures 21 and 22 show how thrust termination would be added to a 1205 motor with either a star or tubular forward closure. The same modification would apply to a 1207 motor. Addition of thrust termination creates a small change in the resultant motor thrust-time and pressure-time characteristics and represents

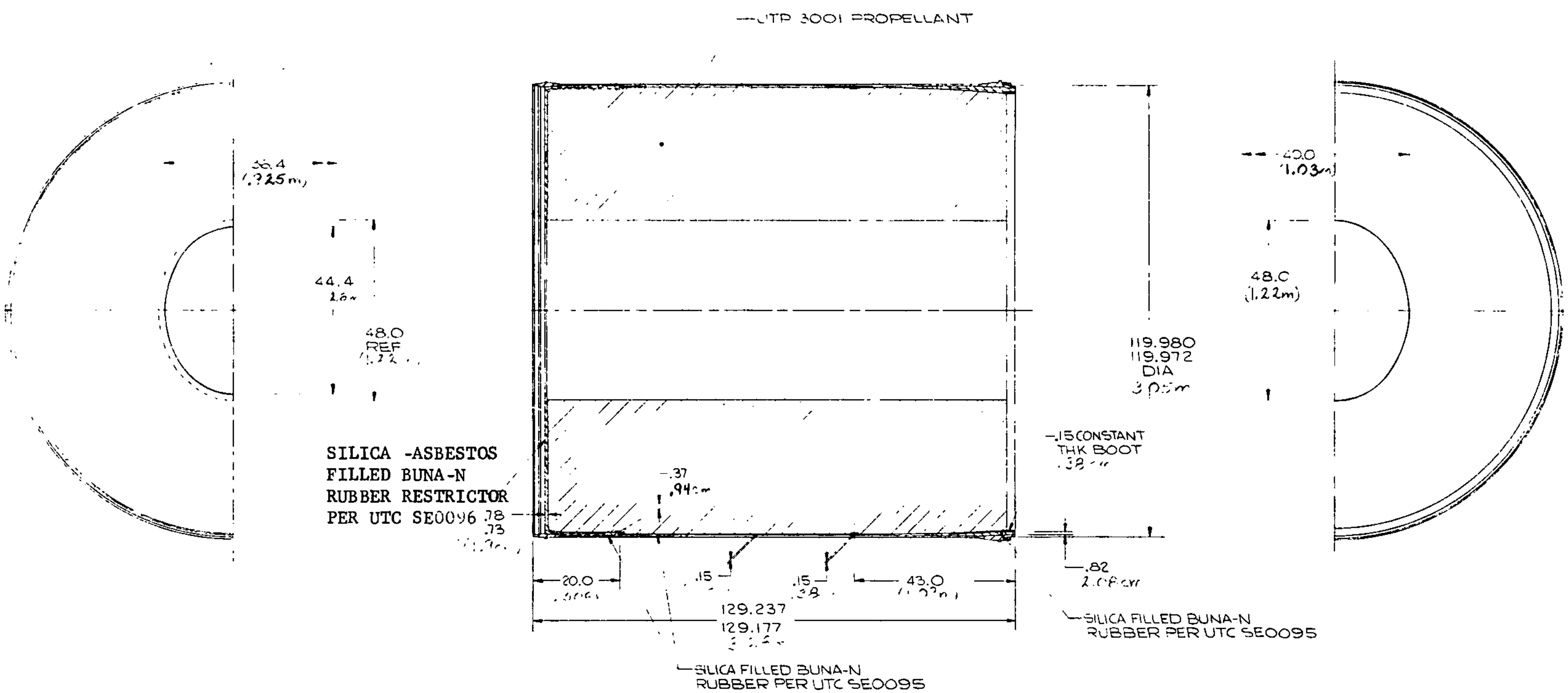


Figure 20. UA 1205 Segment With Elliptical Grain

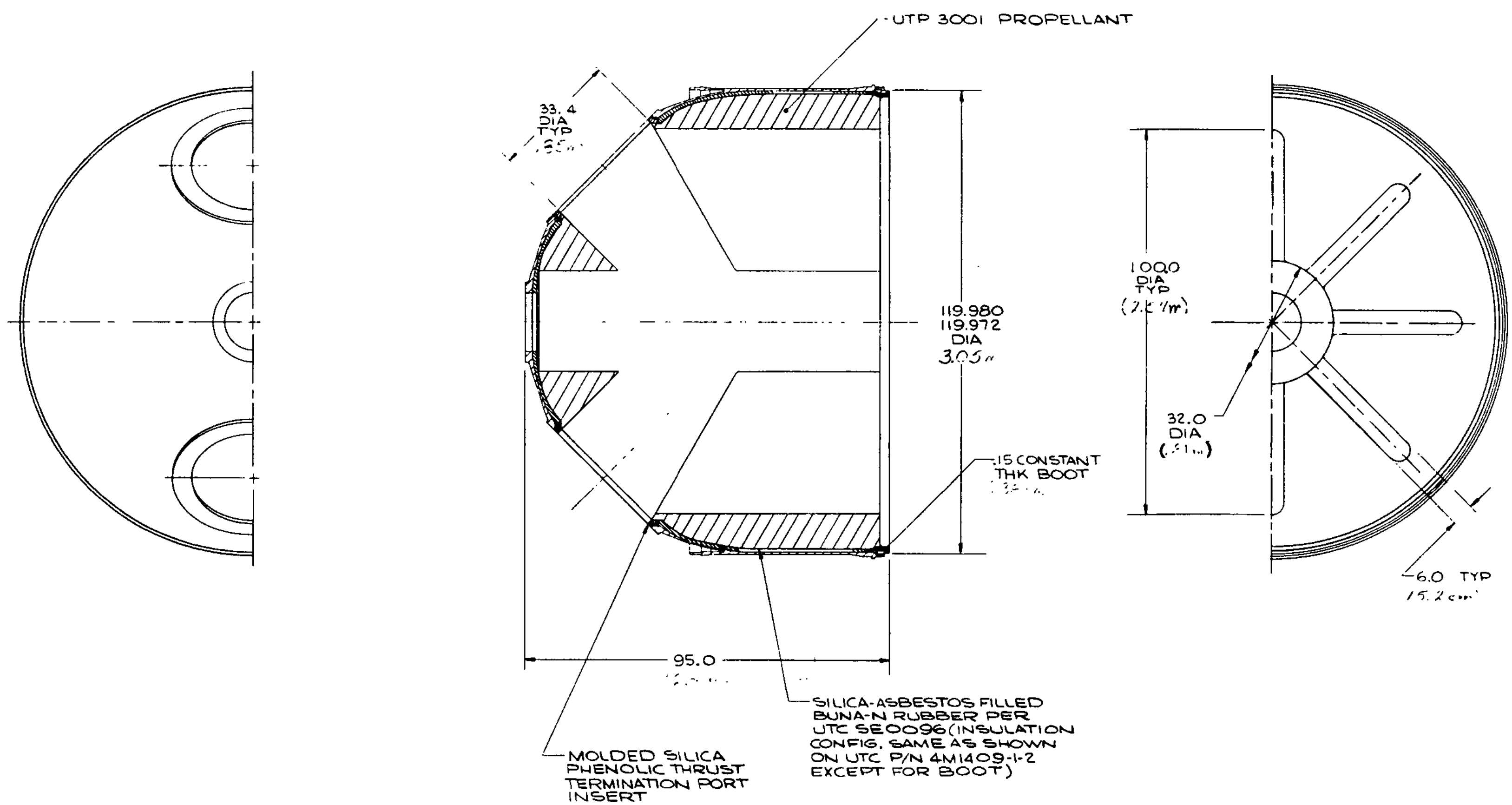


Figure 21. UA 1205 Forward Closure With Star Grain and Thrust Termination

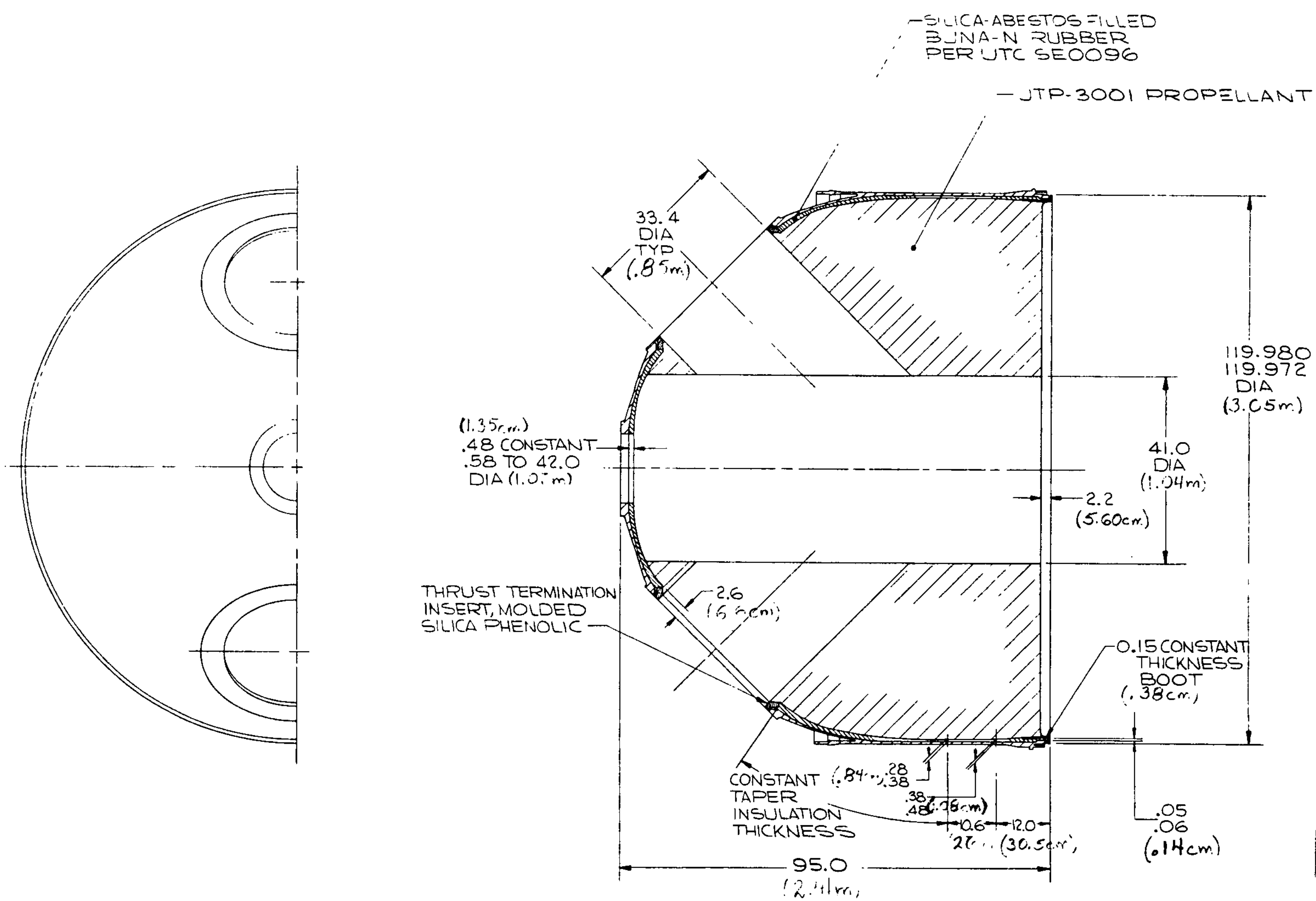


Figure 22. UA 1205 Forward Closure With Tubular Grain and Thrust Termination

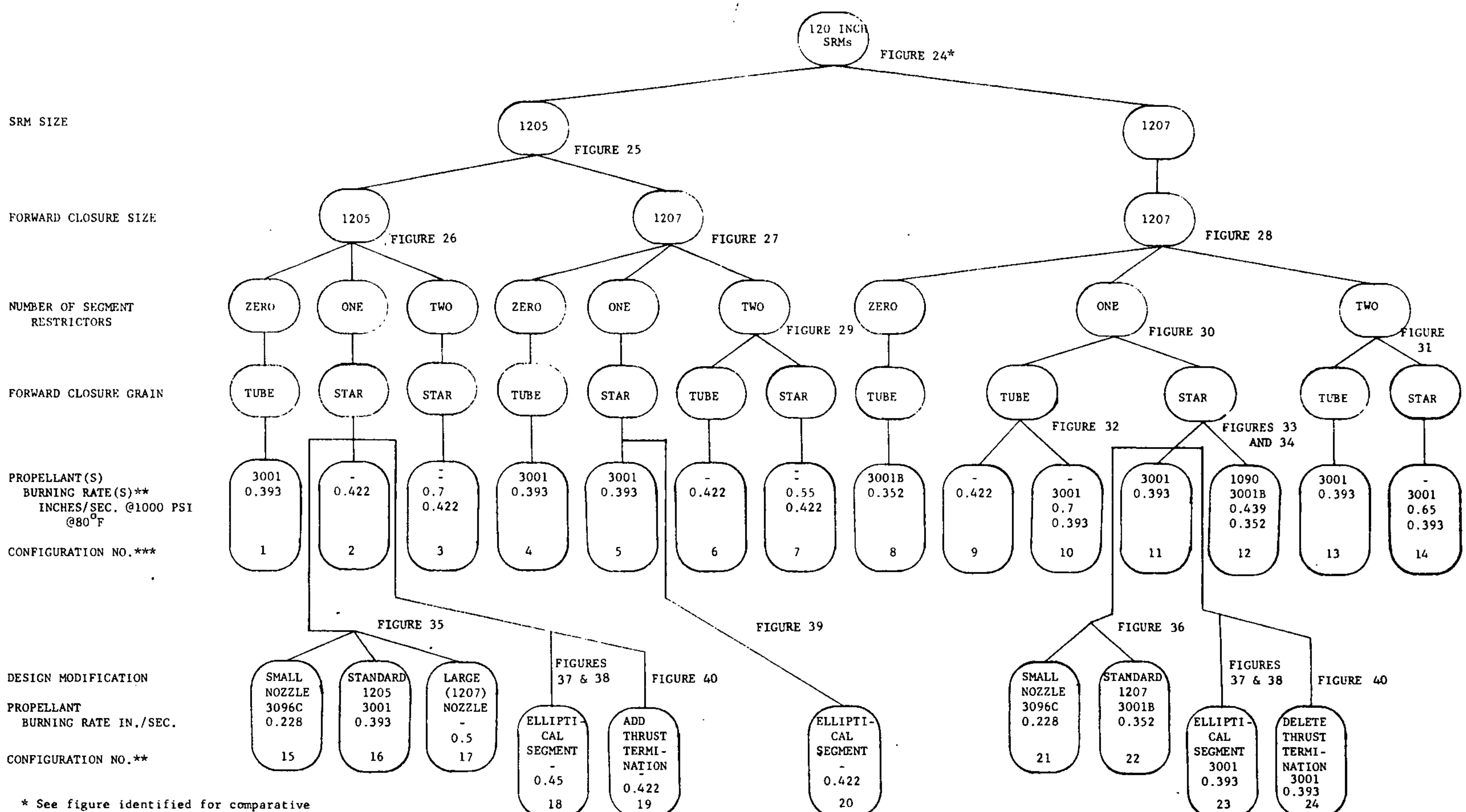
a decrease of about 0.4% and 0.3% in total impulse for the 1205 and 1207, respectively. About 2,000 pounds (905 kg) of propellant are removed to provide ports and 1,350 pounds (610 kg) of inerts are added to provide exhaust stacks.

2.4 MATRIX OF ANALYSIS

Twenty-four unique combinations of the design parameters discussed in section 2.2 were selected for detailed analysis. These 24 configurations are shown in figure 23. Figure 23 was designed to follow a logical progression of design selection and includes most of the options discussed in section 2.2. Some of the options were not analyzed as they were judged not to offer any desirable performance advantages over those selected. The ballistic performance data of these 24 designs is presented below in a comparative manner to show the flexibility of the basic 120-in. (3.05 m) SRM design and to allow evaluation of the effects of specific modifications.

2.4.1 Single Point Design Comparison

Evaluation of the effects of the ballistic design parameters will be accomplished by passing from the top to the bottom of figure 23. Configuration numbers refer to the identification numbers given in the bottom levels of figure 23 and their placement in the appendix. A comparison will be made at each junction for the motors defined at the next level below. The figure numbers adjacent to the junctions of figure 23 reference these comparisons. Starting at the top of figure 23, figure 24 illustrates the difference in thrust, duration and total impulse between the baseline 1205 and 1207 designs (configurations 16 and 22). The first design choice given for a 1205 motor is that of forward closure length. Figure 25 compares the effects of the two closures on a standard 1205 thrust, duration and total impulse (configurations 2 and 5).



* See figure identified for comparative illustrations of ballistic performance.

** Double entries indicate forward closure and segment burning rates, respectively.

*** Specific SRM ballistic data in section 3.2 and the appendix relate to these numbers.

Figure 23. Ballistic Design Matrix

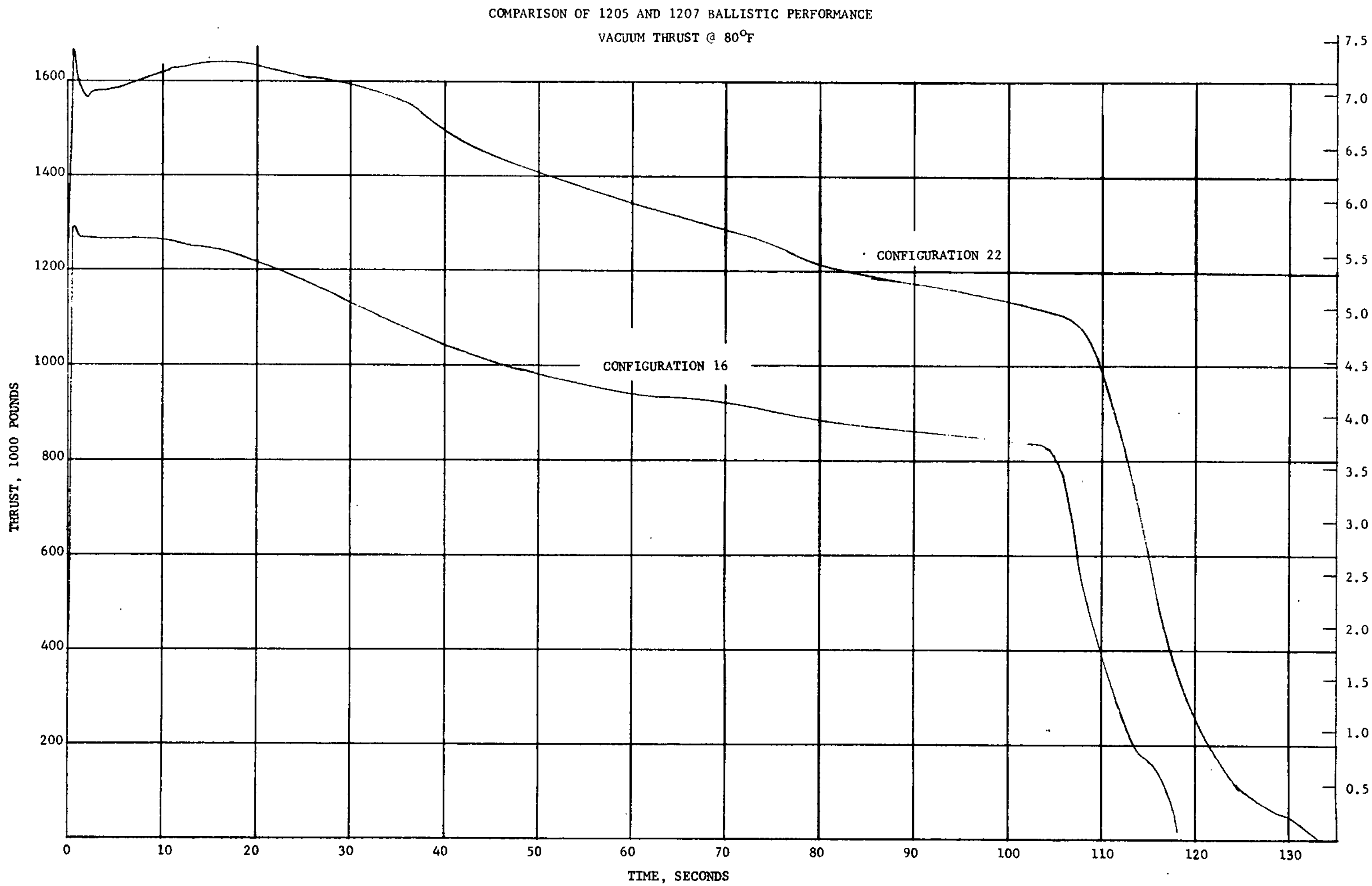


Figure 24. Comparison of UA 1205 and UA 1207 Thrust-Time History

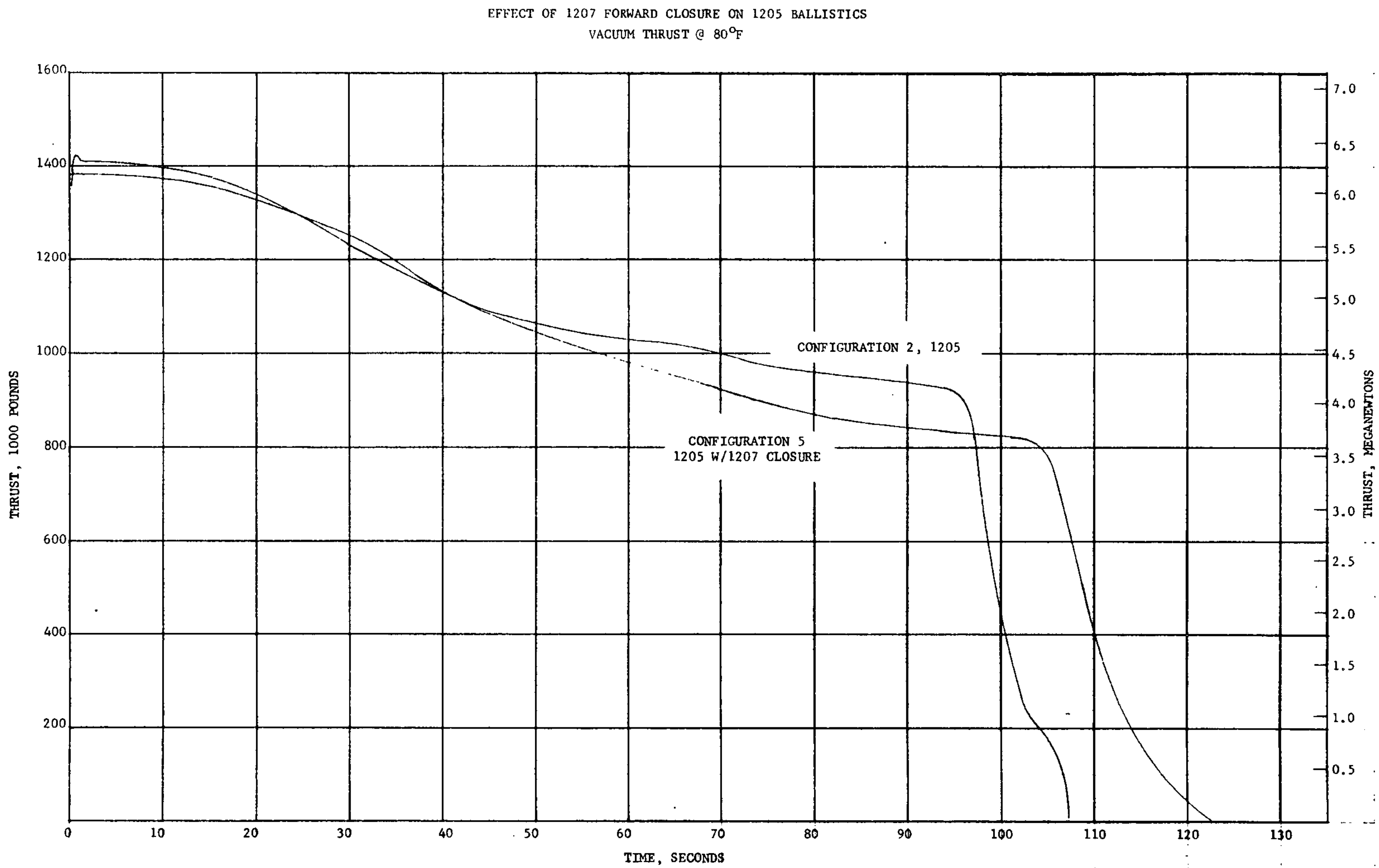


Figure 25. Effect of Forward Closure Length on UA 1205 Ballistic Performance

The effects of inhibiting segment ends from burning are typically depicted in figures 26 (configurations 1, 2, and 3), 27 (configurations 4, 5 and 6), and 28 (configurations 8, 11 and 13) for the five- and seven-segment motors. The segment restrictors are thus shown to be an effective device for shaping the regressive, neutral or progressive ballistic performance that is desired.

Star grain perforations in the forward closure are useful for raising the initial thrust levels as was discussed in Section 2.3. Figure 29 (configurations 6 and 7) shows this effect on long closured, doubly restricted 1205 ballistics. Figure 30 (configurations 9 and 11) shows this effect on a normal 1207 motor. Figure 31 (configurations 13 and 14) shows the effect on a doubly restricted 1207. These figures show how increased initial thrust is obtained and with the double restrictors illustrate how a saddle shape may be obtained. Saddle shaped curves have been shown to be useful in reducing vehicle maximum dynamic pressure while maintaining a minimum duration to minimize gravity losses.

Increased initial thrust can also be produced by using higher burning rate propellant in the forward closure. This effect is shown for a 1207 SRM with a tubular forward closure in figure 32 (configurations 9 and 10). The burn-out time of the forward closure is graphically portrayed by the step decrease in thrust. Of course any number of burning rate combinations could be developed to give slightly different results. High burning rate forward closures are included in the star forward closures of figures 29 and 31 serving to reinforce the increase in initial thrust. Unexpected results are obtained when higher burning rate propellant is placed in the normal 1207 star forward closure as shown in figure 33 (configurations 11 and 12), a slight decrease in thrust

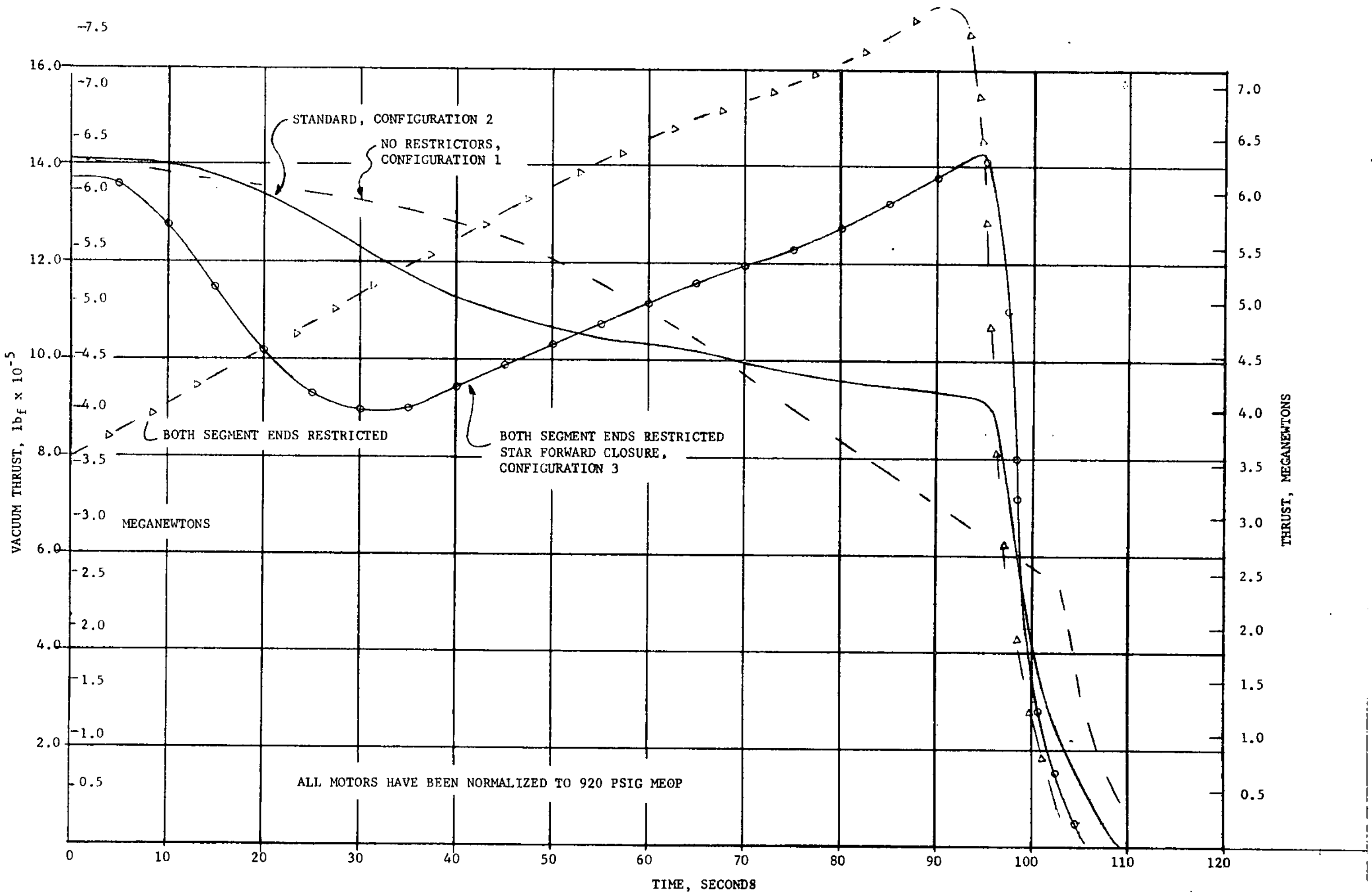


Figure 26. Effect of Segment Restrictors on UA 1205 Ballistic Performance

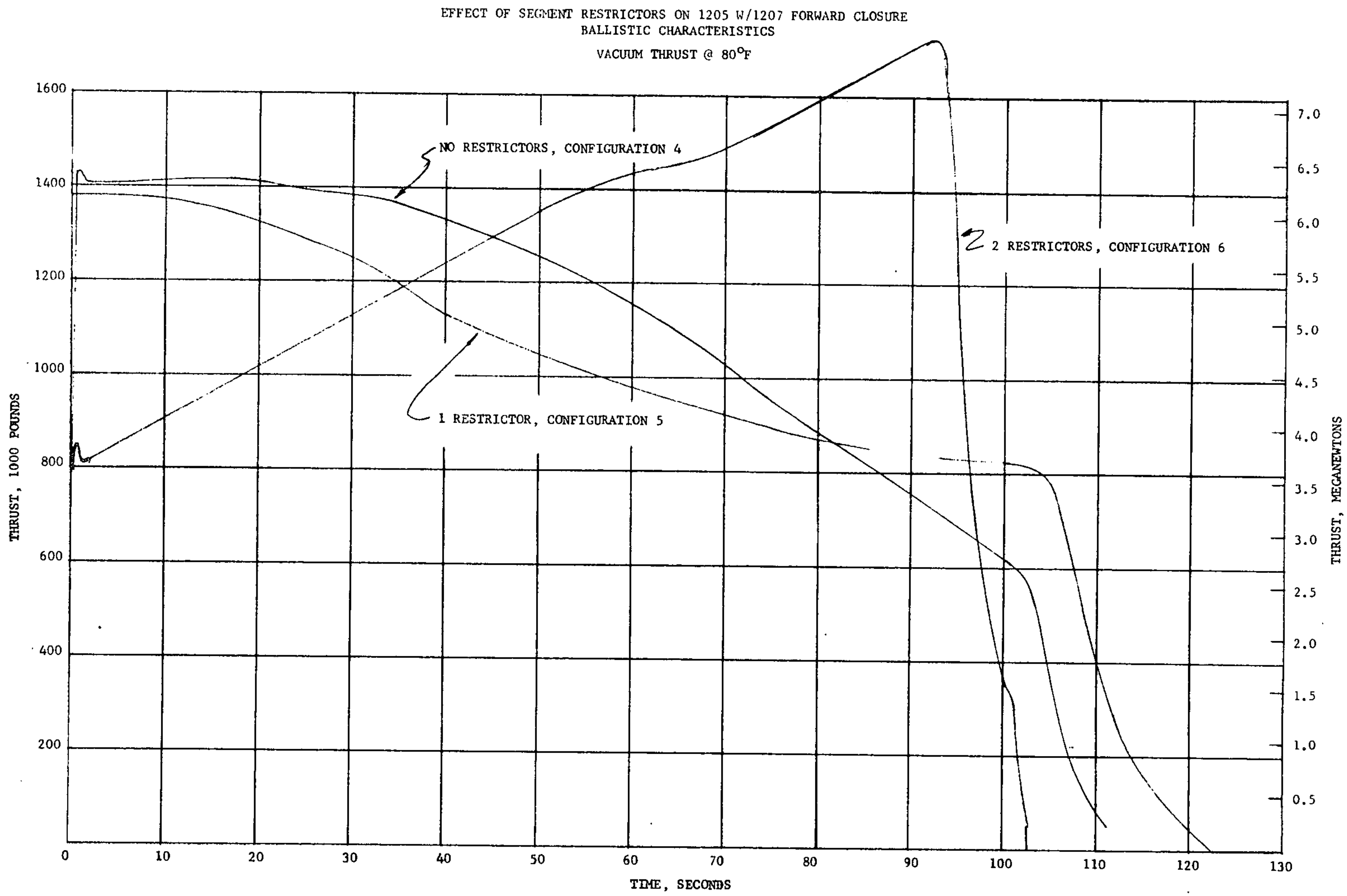


Figure 27. Effect of Segment Restriction on Ballistic Performance of UA 1205 With Long Forward Closure

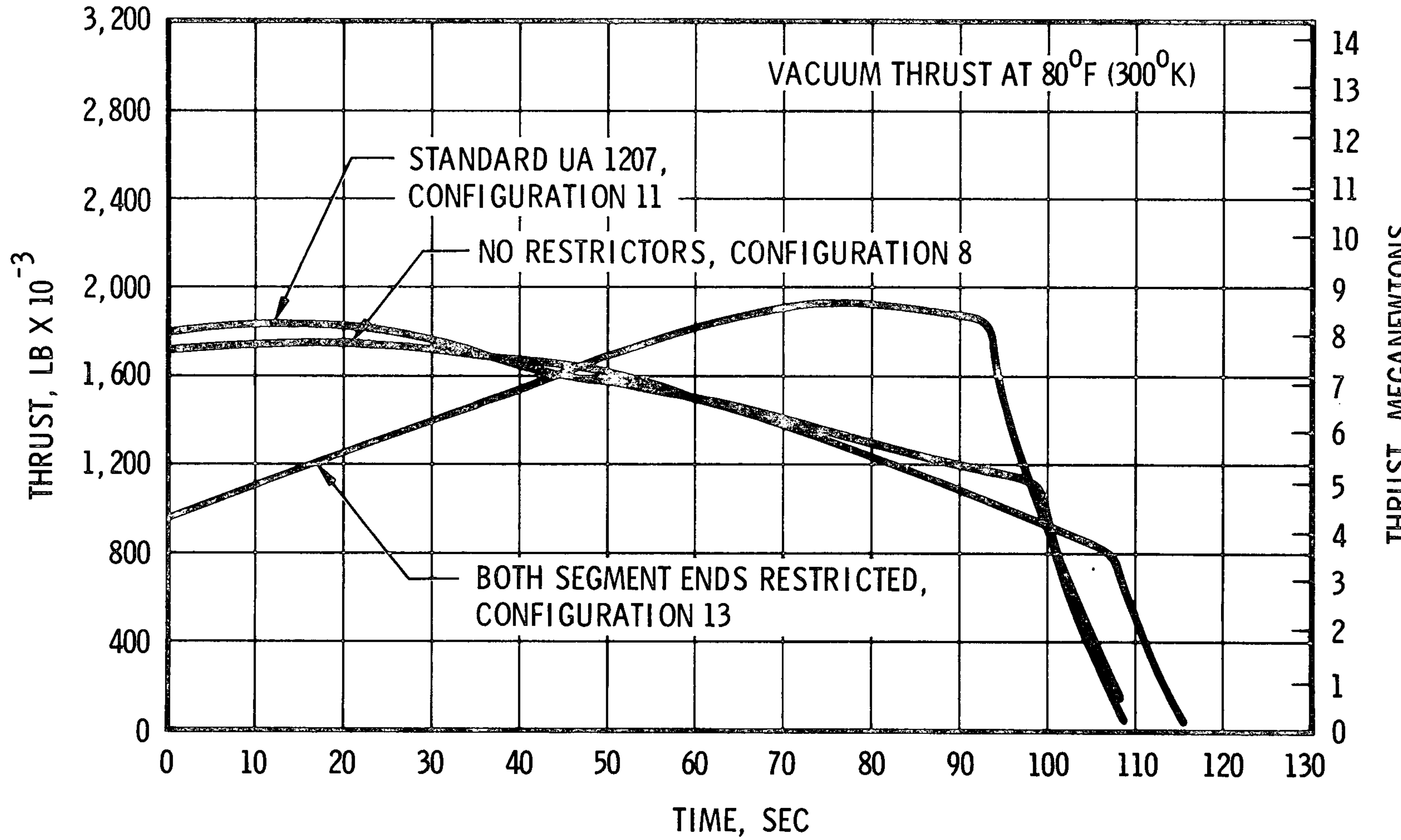


Figure 28. Effect of Segment Restriction on Ballistic Performance of UA 1207

02042

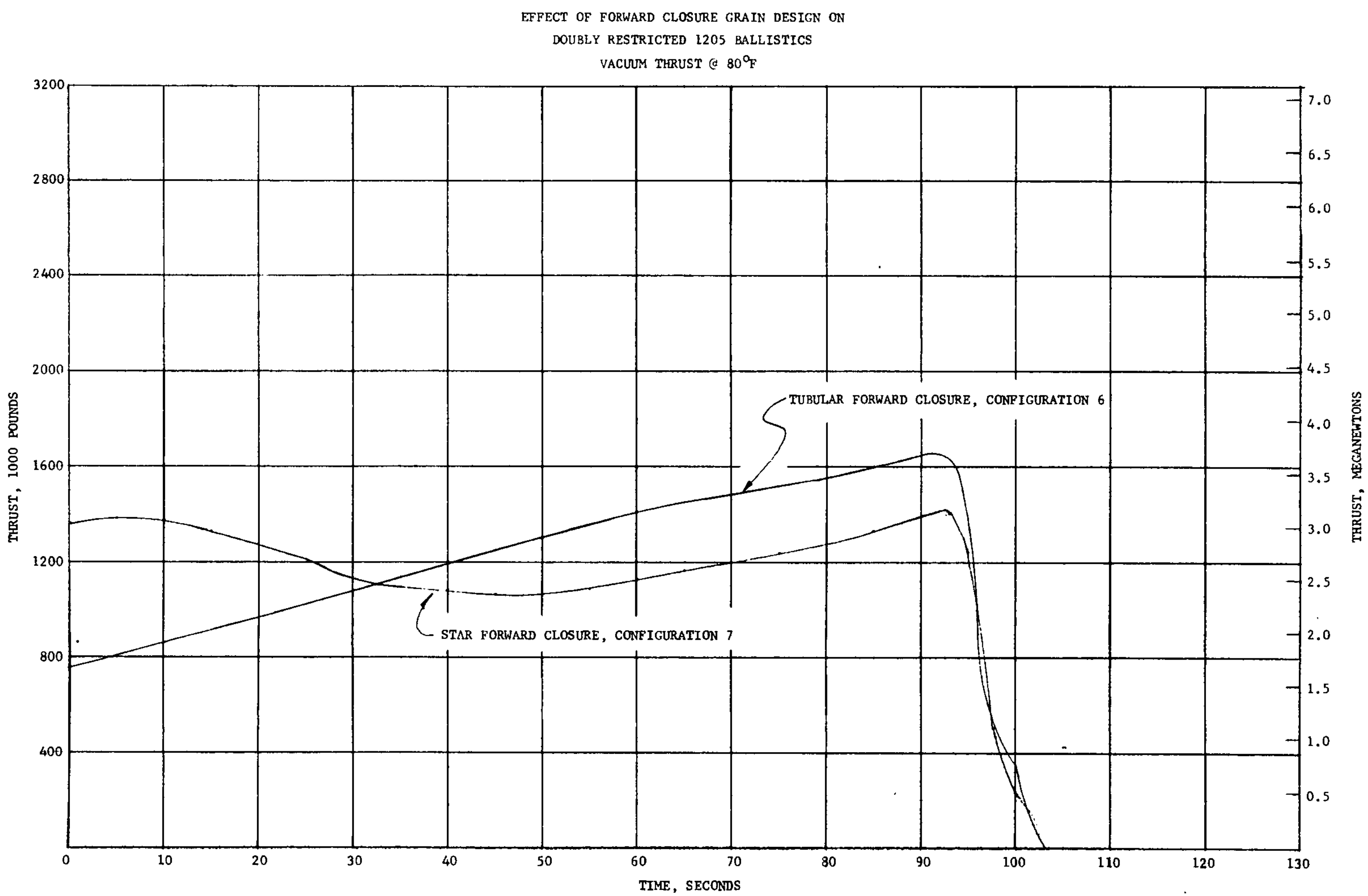


Figure 29. Effect of Forward Closure Grain on
Ballistic Performance of Doubly Restricted UA 1205

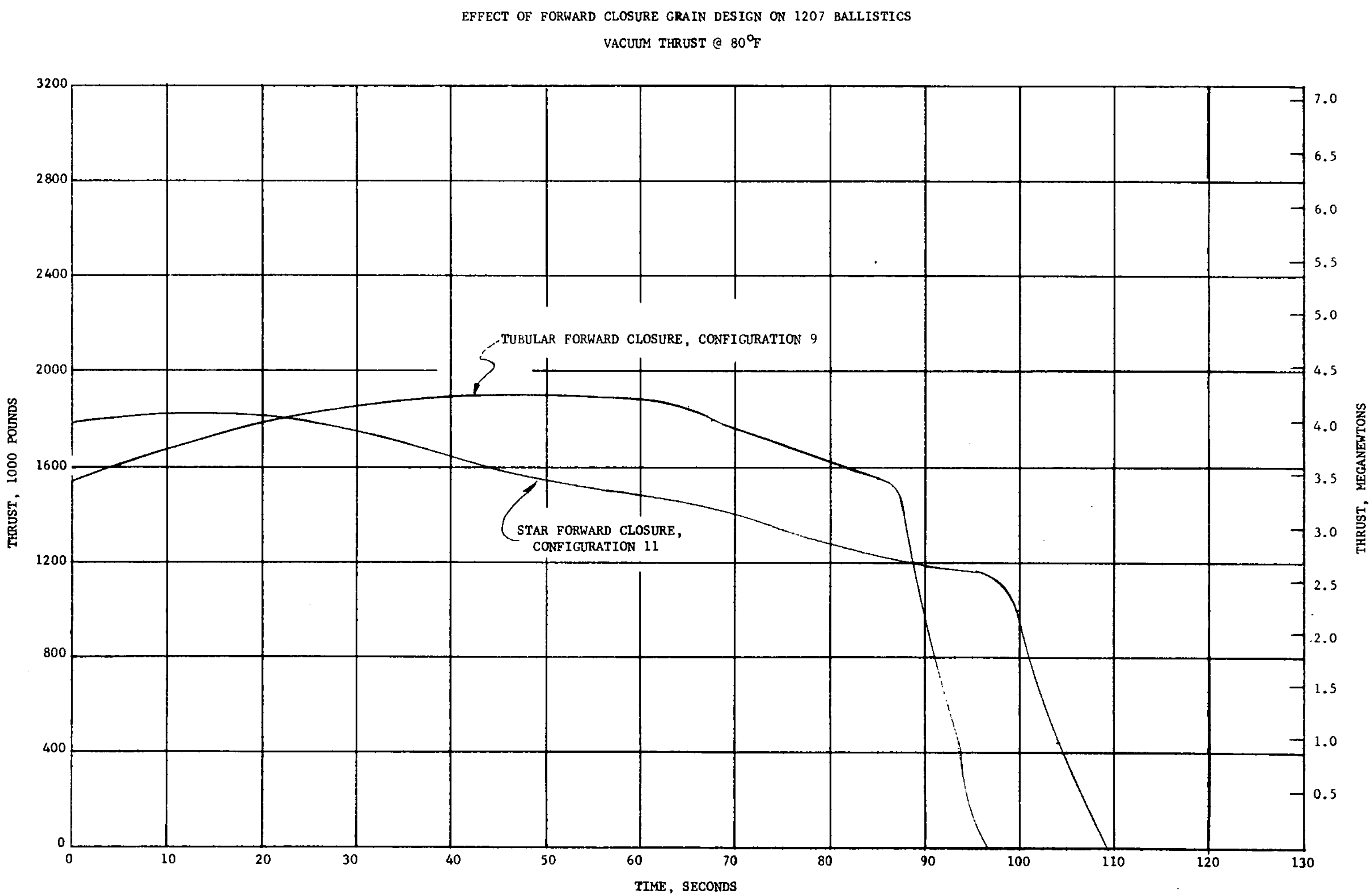


Figure 30. Effect of Forward Closure Grain Design on Ballistic Performance of UA 1207

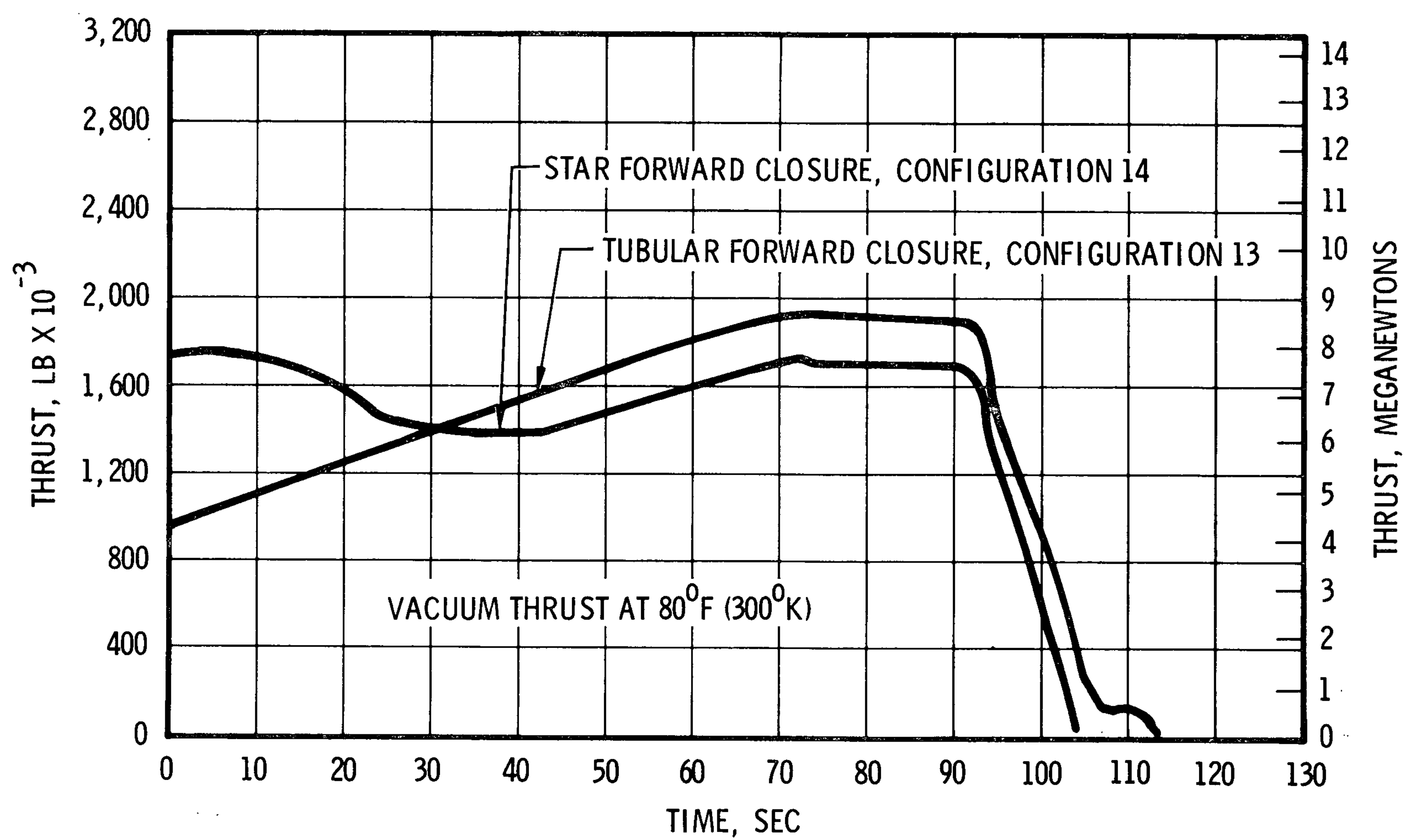


Figure 31. Effect of Forward Closure Grain on Ballistic Performance of Doubly Restricted UA 1207

02043

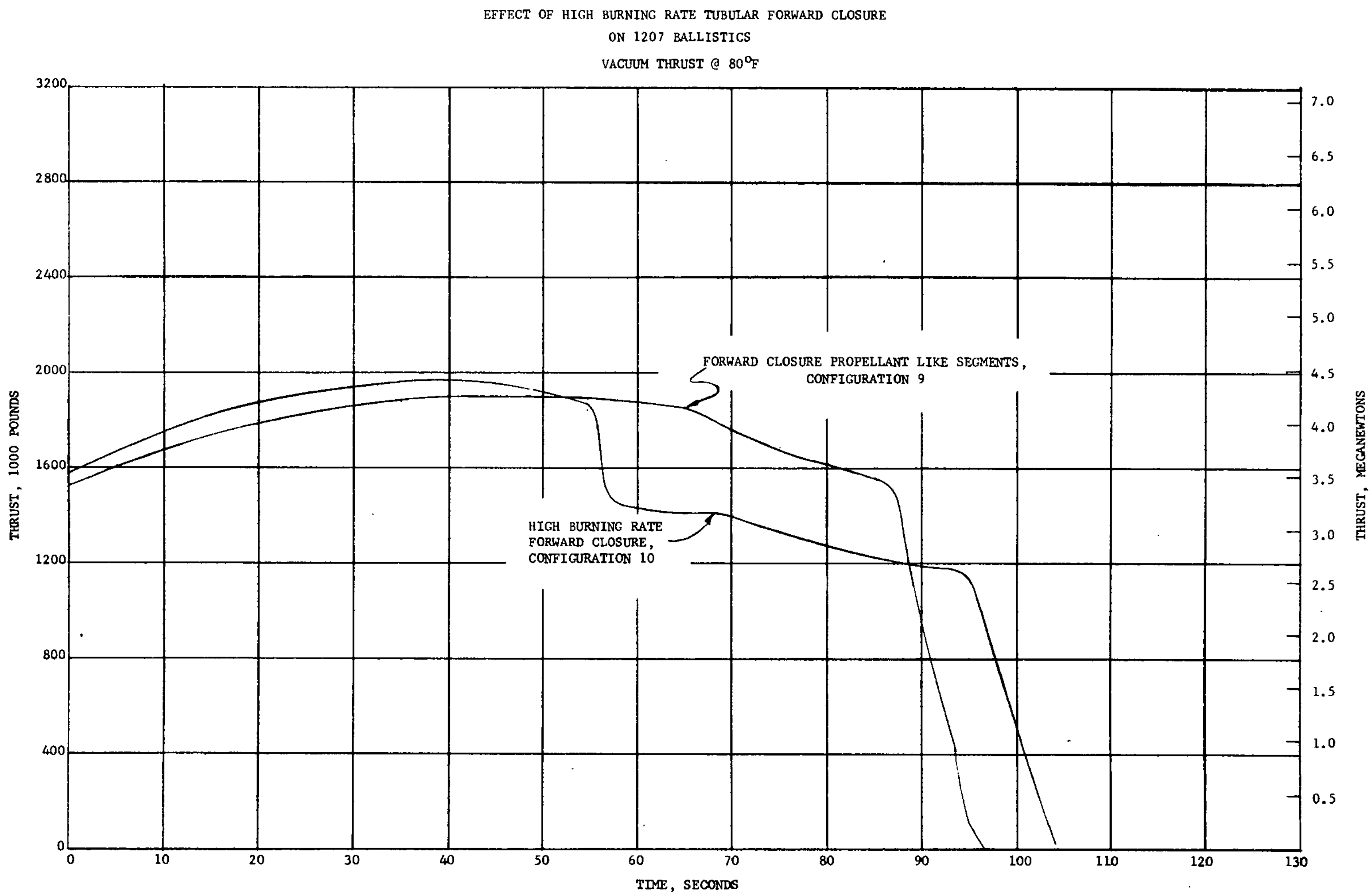


Figure 32. UA 1207 Ballistic Performance,
Forward Closure With Tubular Grain and High Burning Rate Propellant

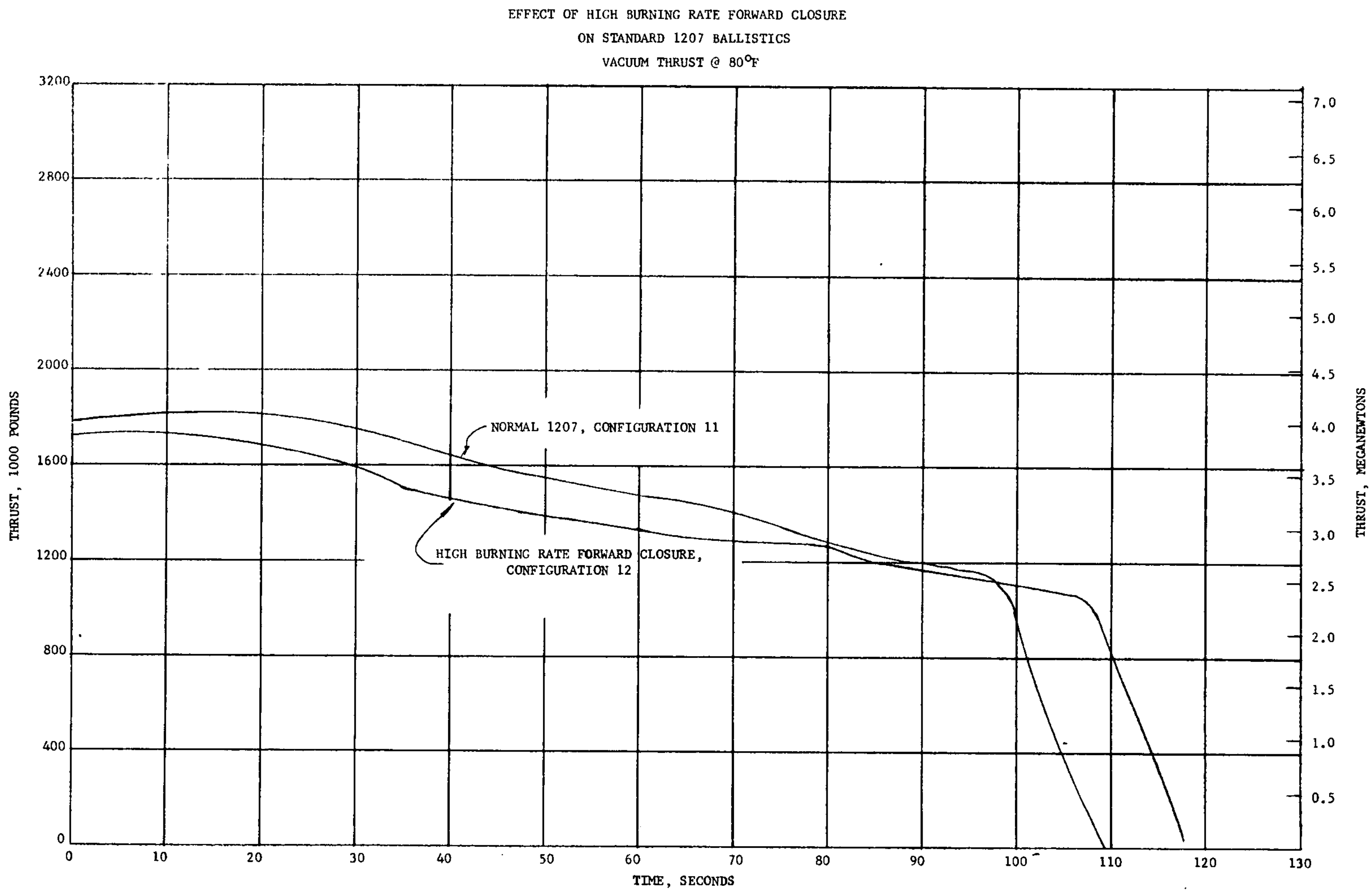


Figure 33. Effect of High Burning Rate Forward Closure on Ballistic Performance of Standard UA 1207, Forward Closure With High Burning Rate Propellant

is realized whereas an increase was expected. This effect is explained by an increase of pressure drop inside of the motor. The standard 1207 produces maximum thrust close to ignition. Maximum head end chamber pressure, leading to the MEOP, is simultaneous. Addition of higher burning rate propellant at the forward end increases the mass flow down the motor internal bore producing a greater pressure drop. Adjusting the burning rates to maintain the 920 psig (6.33 MN/m^2) MEOP yields a reduced aft end pressure and hence reduced thrust. This phenomenon may be deduced from the head end chamber pressure of these designs as shown in figure 34. The fast drop of pressure in the first few seconds indicates high internal pressure drop. The longer duration reflects the reduced burning rate necessary to maintain the MEOP with the internal pressure drop.

An investigation of the attainable variations in motor duration or maximum thrust produced the results of figures 35 and 36. Figure 35 (configurations 15, 16, 2 and 17) demonstrates achievable action times for the 1205 design. The shortest duration, 81 seconds (maximum thrust 1,680,000 pounds (7.47 MN), is achieved utilizing a 1207 nozzle throat of 41.6-inch (1.06 m) diameter. The longest duration, 168 seconds (maximum thrust 815,000 pounds (3.63 MN)), is an arbitrary selection using UTC's slowest burning standard propellant and a 26.6-inch (.675 m) throat. The standard 1205 design could be modified to perform anywhere within this range. The standard 1205 design with its 853 psig (5.87 MN/m^2) MEOP has a duration of 105 seconds. Adjusting its propellant burning rate to produce a 920 psig (6.33 MN/m^2) MEOP reduces the duration to 95 seconds. Figure 36 (configurations 21, 22, and 11) shows similar results for the 1207 design. The 1207 throat size was judged to be the largest practical size for application to the 120-inch (3.05 m) motor so there is no

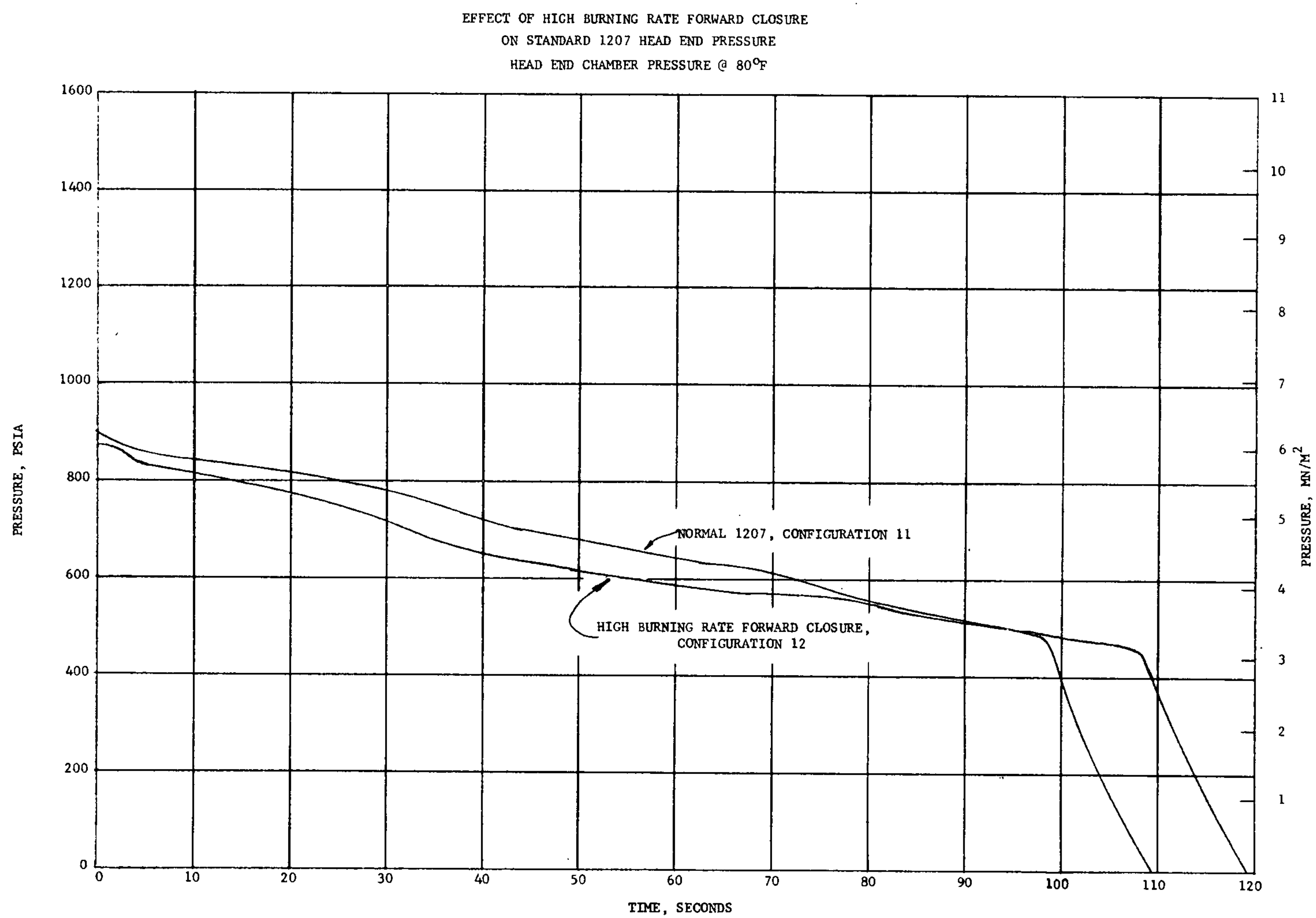


Figure 34. Effect of Forward Closure With High Burning Rate Propellant on Head End Chamber Pressure of Standard UA 1207

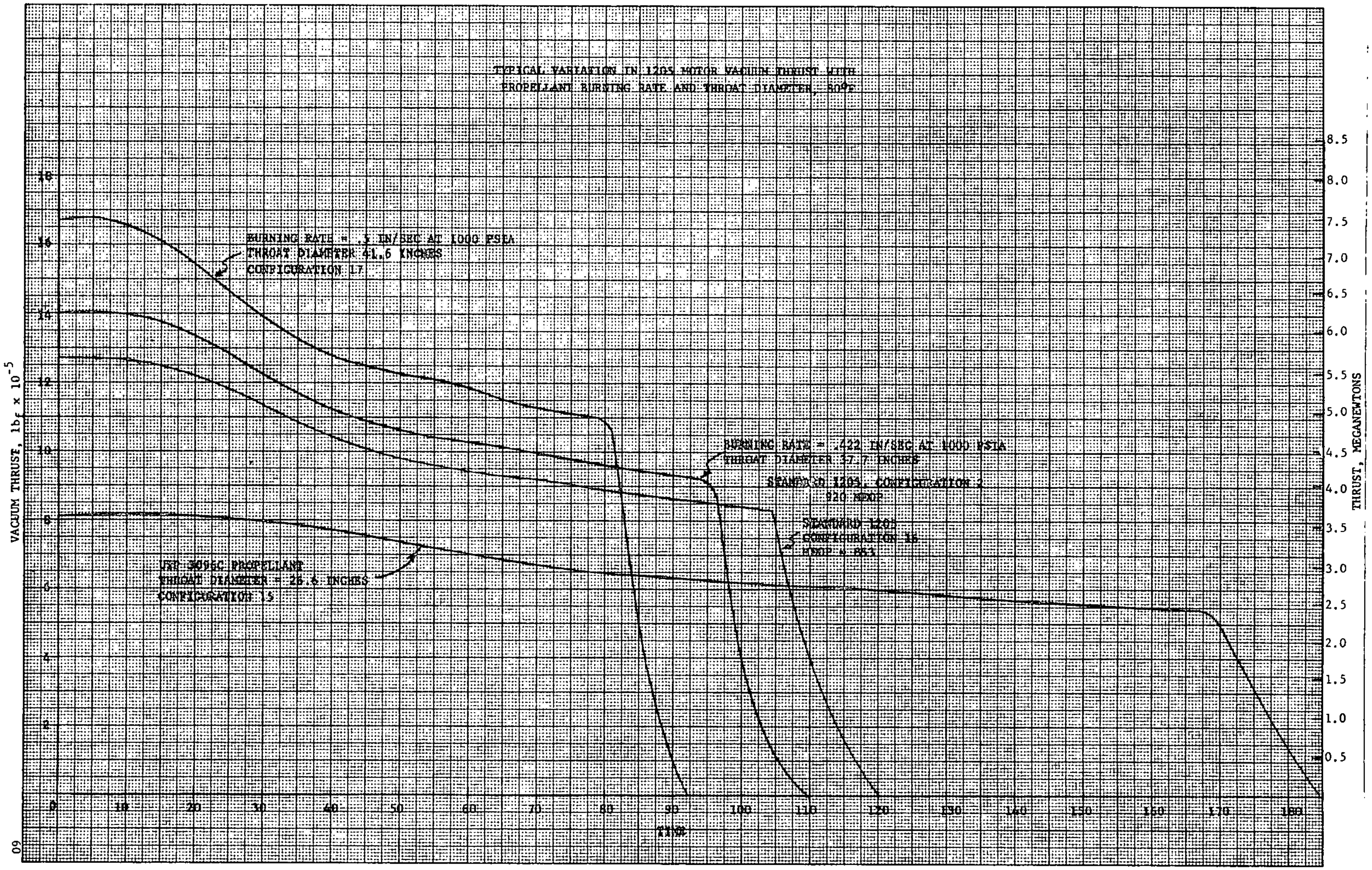


Figure 35. Action Time Limits of the UA 1205

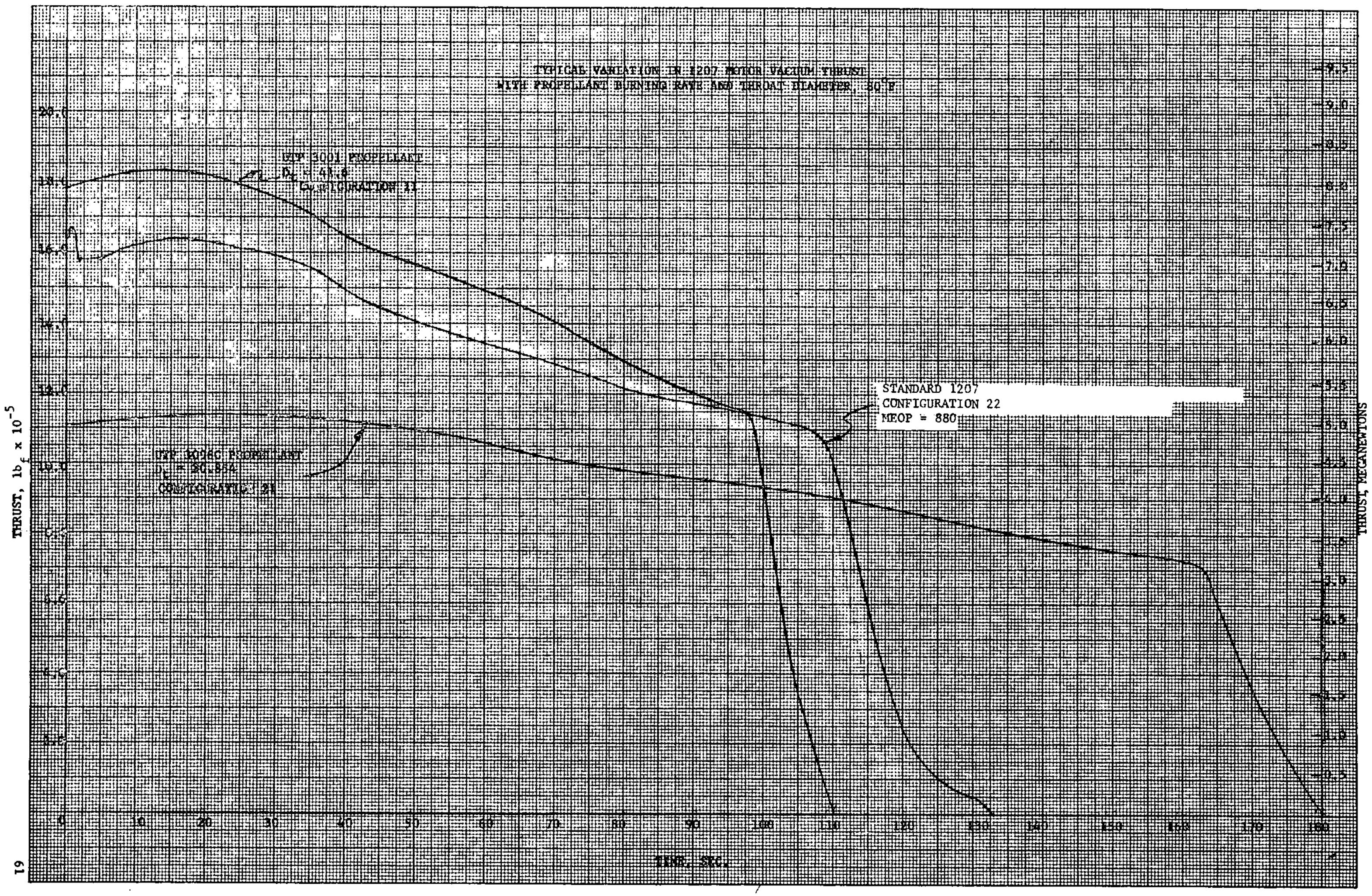


Figure 36. Action Time Limits of the UA 1207

configuration with a greatly reduced duration. The standard 1207 design does not produce a 920 psig (6.33 MN/m^2) MEOP due to certain ballistic safety margins allowed in the initial design phase. Adjusting the burning rate to deliver a true 920 psig (6.33 MN/m^2) MEOP reduces the duration from 108 seconds to 98 seconds.

The elliptical bore segment was investigated to evaluate its performance improvement potential. Changing from the tubular to the elliptical design does not revise the thrust-time characteristics but offers advantages of increased propellant loading and reduced internal pressure drop. Figure 37 (configurations 2, 18, 11 and 23) illustrates the thrust impact of this modification on the 1205 and 1207 design. The expected thrust improvement is apparent for the 1205 design. Examination of the pressure traces as shown in figure 38 reveals the reduction in internal pressure drop. No significant difference is seen in the case of the 1207 design. There is an increase in total impulse due to the increased propellant loading, but no improvement was shown in initial thrust level. This result is due to the increased pressure drop caused by a smaller bore offsetting the pressure drop decrease of eliminating the steps between segments. The seven-segment motor is more critical than the five in this regard because of its higher mass flux. Figure 39 (configurations 5 and 20) illustrates the successful application of the elliptical bore segment to the long forward closured 1205 SRM.

The effects of adding or deleting thrust termination are shown in figure 40 (configurations 2, 19, 11 and 24) for both the 1205 and 1207 designs. It is seen that the effects upon the ballistic profile are negligible. There are associated changes in propellant and inert weights which are listed in the next section.

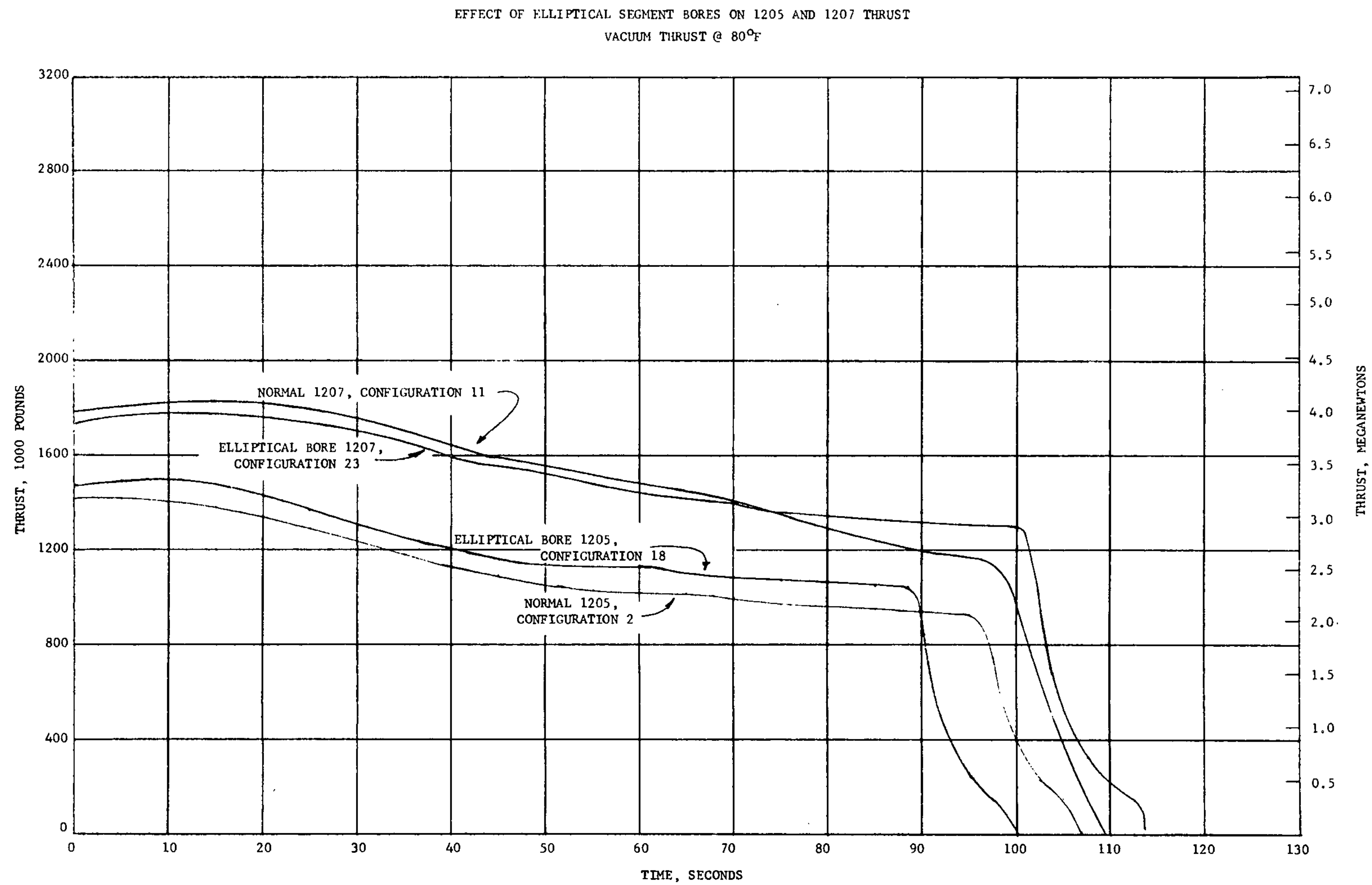


Figure 37. Effect of Elliptical Segment Bores on UA 1205 and UA 1207 Thrust

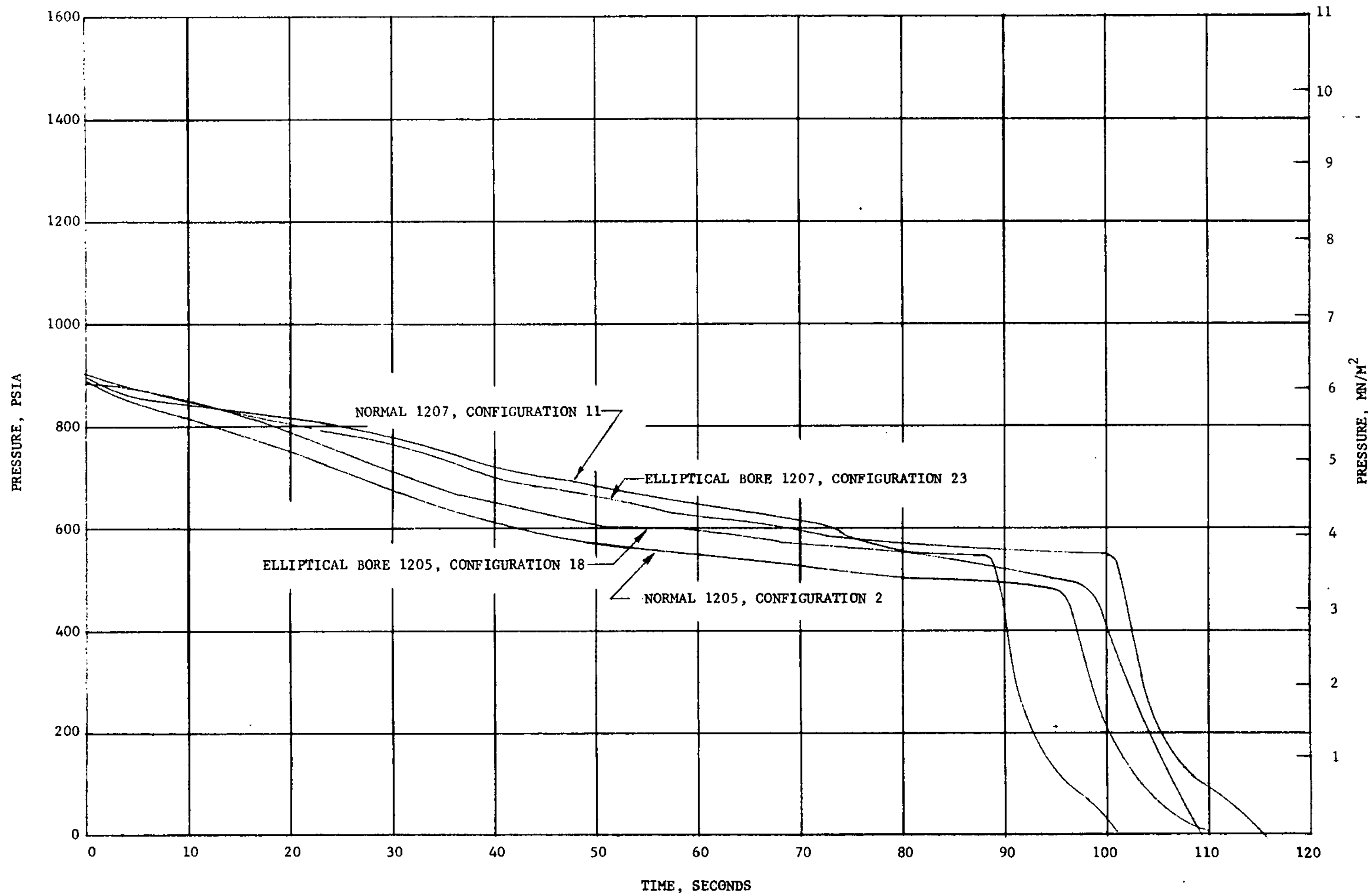


Figure 38. Effect of Elliptical Segment Bores on UA 1205 and UA 1207

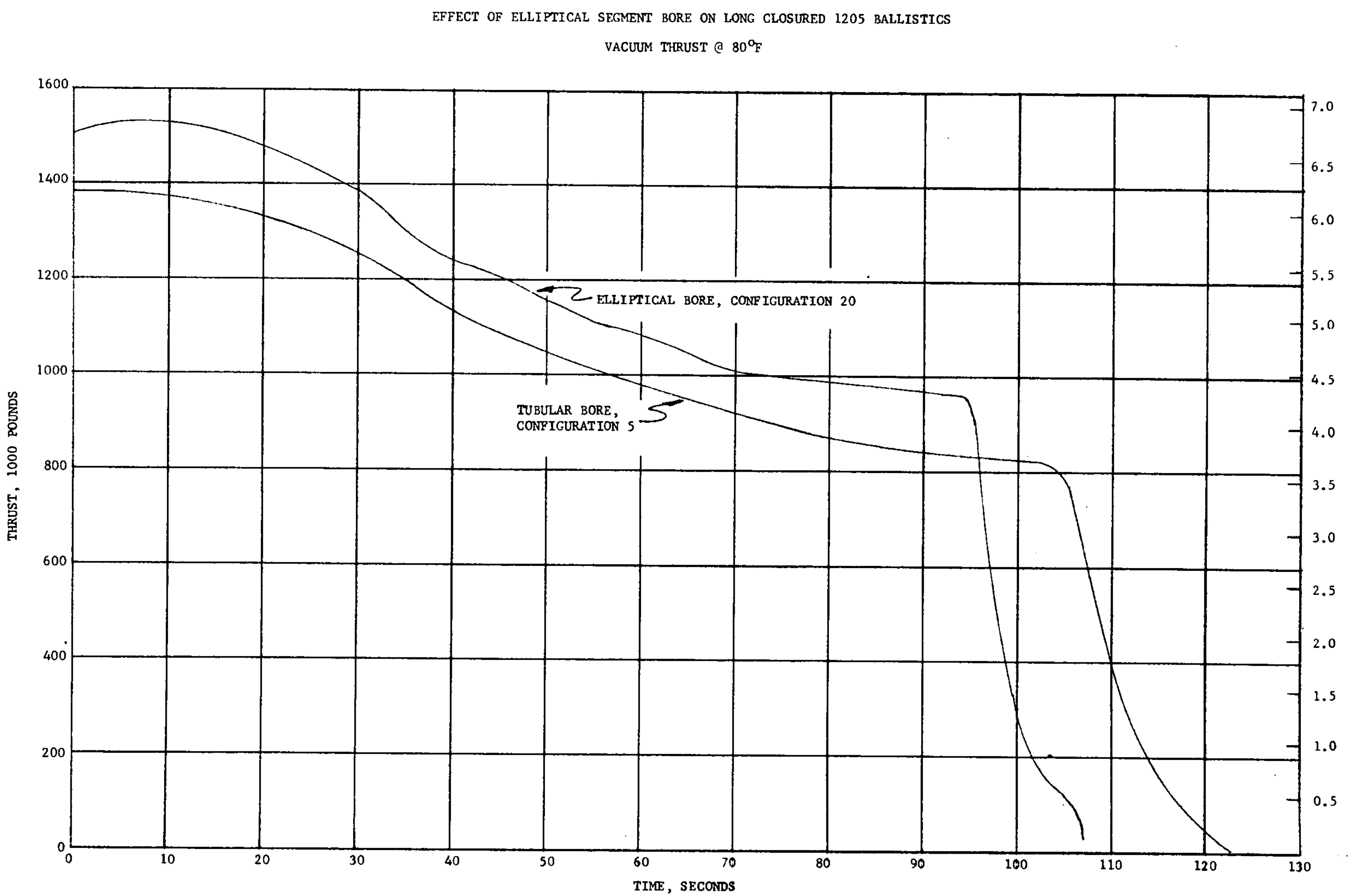


Figure 39. Effect of Elliptical Segment Bores on Ballistic Performance of UA 1205 With Long Forward Closure

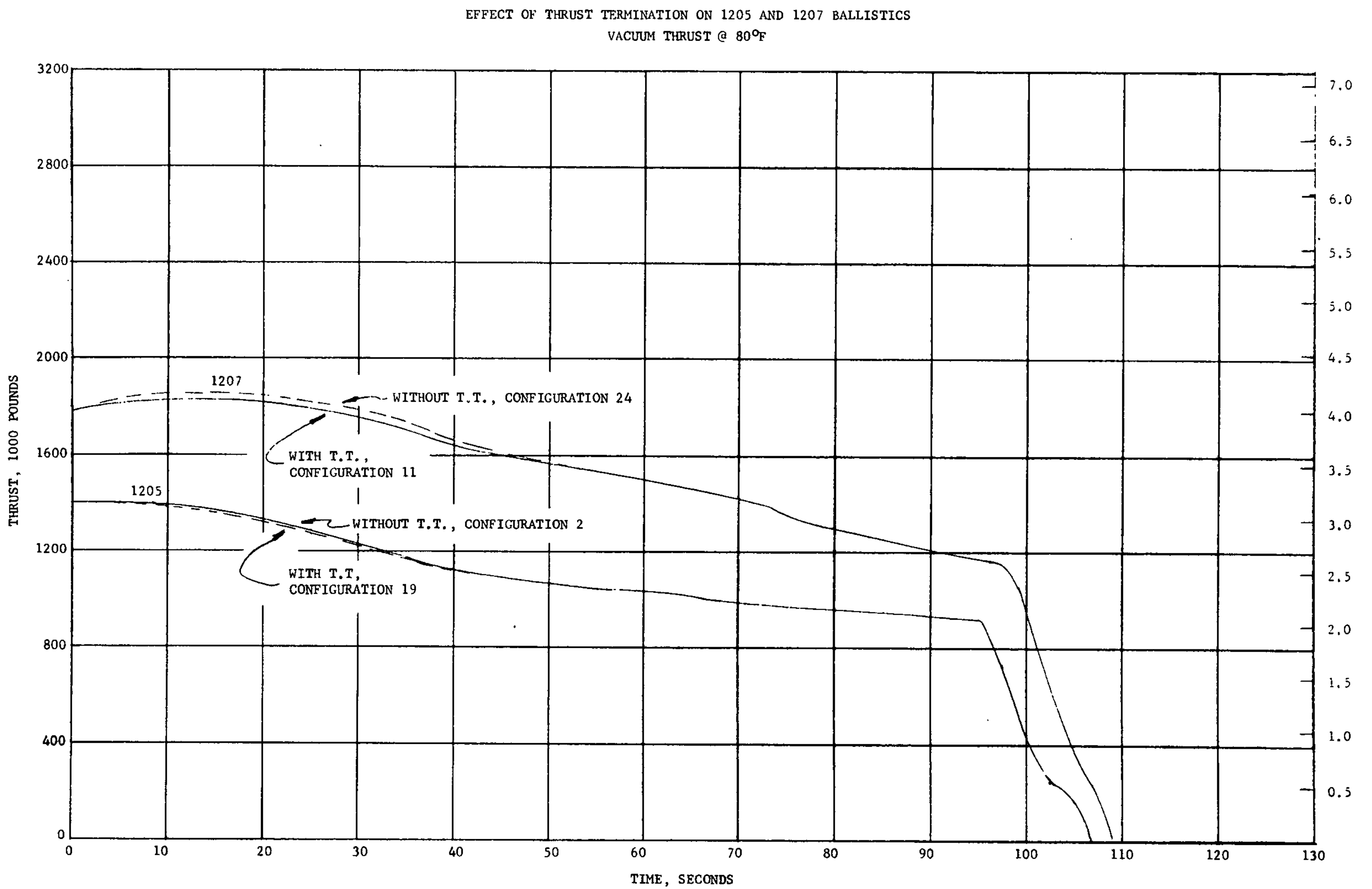


Figure 40. Effect of Thrust Termination on UA 1205 and UA 1207 Ballistics

SRM performance can always be changed by changing the nozzle expansion ratio. Such a modification would be most desirable in a second stage application. Figure 41 illustrates the performance changes which can be realized with such modification. However, increasing expansion ratio means physical growth of an already large nozzle. This growth may interfere with ground support requirements or clustering layouts. The growth to be expected is also illustrated in figure 41.

2.4.2 Derived Ballistic Data

A complete ballistic analysis was performed of the twenty-four configurations discussed above. This analysis included development of all pertinent ballistic data and preparation of thrust-time and pressure-time data plots. A compilation of the pertinent ballistic data for the configurations identified on figure 23 is given in table IV. Individual thrust and chamber pressure plots for the configurations are contained in the appendix.

Mass property data of the basic SRM without stage accessories is also given in table IV to properly relate any changes in propellant weight or inert weight to the ballistic changes.

2.5 INSULATION AND NOZZLE DESIGN

Internal insulation design changes must accompany the ballistic parameter changes of section 2.3. The changes necessary to accommodate the building blocks used in this analysis are all based on available technology and are variations of current practice or have already been demonstrated in previous UTC testing.

The various forward closure designs of figures 17, 18, 19, 21 and 22 relate to the same basic design. The star grain designs with and without

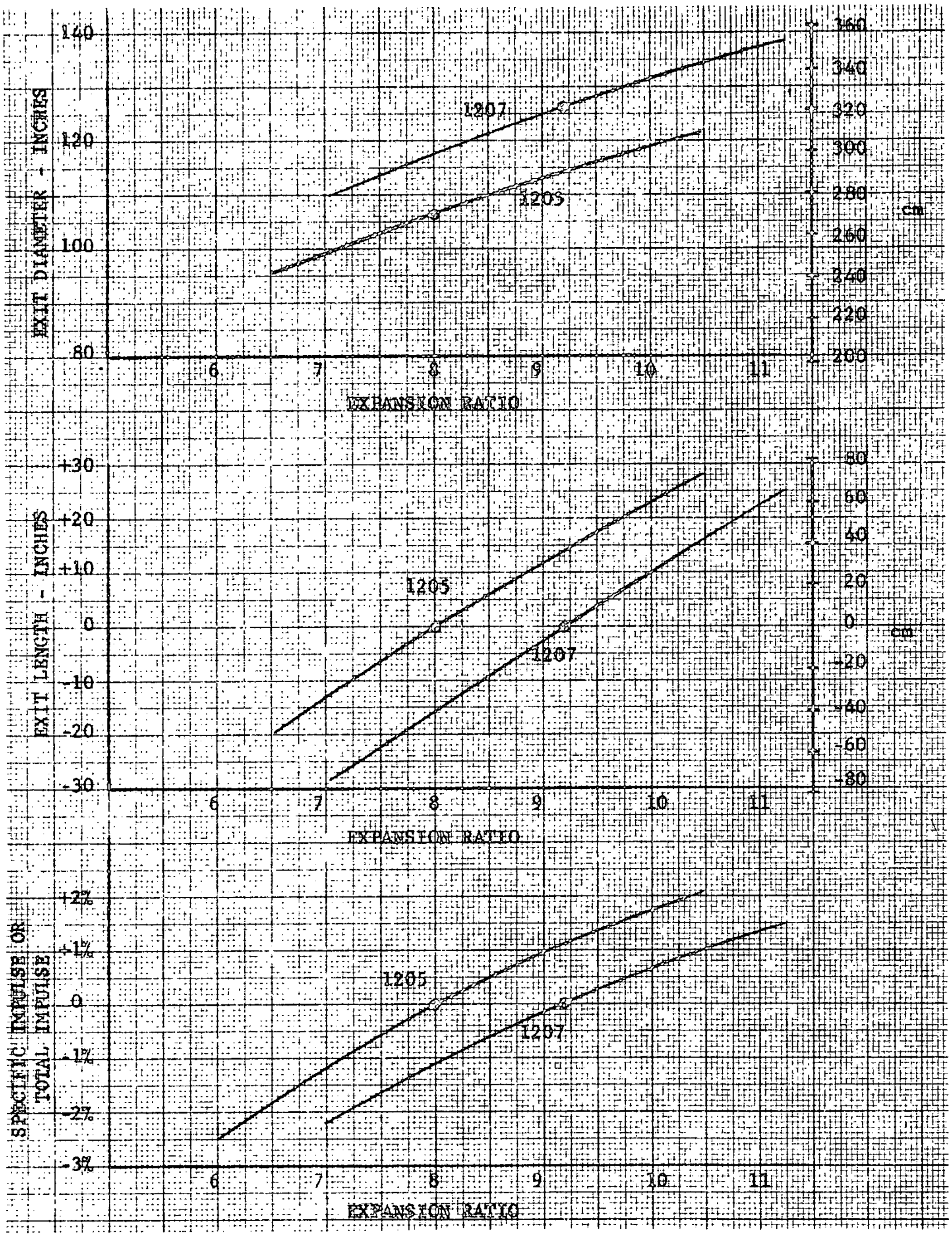


Figure 41. Effect of Nozzle Expansion Ratio on SRM Performance and Nozzle Exit Size

TABLE IV

120-INCH BALLISTIC PERFORMANCE DATA SUMMARY

UNAUGMENTED NOZZLE CENTERLINE, 80°F

	Configuration*		Web Action Time Total Impulse x 10^{-8} lb_f sec (N-sec) Vacuum	Web Action Time Total Impulse Sea Level	Action Time Total Impulse x 10^{-8} lb_f sec (N-sec) Vacuum	Action Time Total Impulse Sea Level	Web Action Time, sec	Action Time, sec	Web Action Time Delivered Specific Impulse lb_f-sec./lb_m Vacuum	Web Action Time Delivered Specific Impulse Sea Level	Initial Thrust, lb_f (N) Vacuum	Initial Thrust Sea Level	Propellant Weight lb_m (kg)	Inert† Weight lb_m (kg)	Basic† SRM Weight lb_m (kg)
	1		1.11566 (4.96245)	0.98815 (4.39529)	1.13676 (5.05630)	1.00432 (4.46721)	102.	108	266.0	235.6	1,424,300 (6,335,286)	1,293,000 (5,751,264)	429,142 (194,658)	53,088 (24,080)	482,230 (218,739)
	2		1.07596 (4.78587)	0.95138 (4.23173)	1.12635 (5.01000)	0.98991 (4.40311)	95.	105.4	266.0	235.2	1,431,600 (6,367,756)	1,300,400 (5,784,179)	424,317 (192,470)	53,505 (24,269)	477,822 (216,740)
	3		1.07596 (4.78587)	0.95138 (4.23173)	1.12635 (5.01000)	0.98991 (4.40311)	94.6	104.4	266.0	235.2	1,367,800 (6,083,974)	1,236,500 (5,499,952)	424,317 (192,470)	54,820 (24,866)	479,137 (217,336)
1205	4		1.17134 (5.21012)	1.04611 (4.65309)	1.19843 (5.33061)	1.06544 (4.73907)	100.1	107.1	266.0	237.5	1,467,300 (6,526,550)	1,336,000 (5,942,528)	452,787 (205,384)	55,742 (25,284)	508,518 (230,663)
	5	1207 Forward Closure	1.13841 ([illegible]360)	0.99932 (4.44497)	1.18665 (5.2[illegible])	1.03343 (4.59[illegible])	104.9	115.5	266.0	233.5	1,385,000 (6,160,480)	1,253,800 (5,576,902)	447,093 (202,801)	57,453 (26,060)	504,636 (228,902)
	6		1.11336 (4.95133)	1.00017 (4.44875)	1.19428 (5.31215)	1.07033 (4.76082)	97.6	100.9	266.0	239.0	853,300 (3,795,478)	722,100 (3,211,900)	449,787 (204,023)	57,515 (26,088)	507,302 (230,112)
	7		1.11824 (4.97415)	0.99806 (4.43937)	1.18701 ([illegible])	1.05608 (4.69744)	92.7	102.4	266.0	237.4	1,375,700 (6,119,113)	1,244,500 (5,535,536)	447,099 (202,804)	58,768 (26,657)	505,867 (229,461)
	8		1.57184 (6.99154)	1.38112 (6.14322)	[illegible] (7.15945)	1.40815 (6.26345)	106.9	114.1	269.5	236.8	1,774,800 (7,894,310)	1,591,200 (7,077,657)	599,745 (272,044)	70,300 (31,888)	670,045 (303,932)
	9		1.53145 (6.81188)	1.37745 (6.12689)	1.60226 (7.12685)	1.43539 (6.38461)	86.4	94.1	269.5	242.4	1,590,700 (7.075,433)	1,407,100 (6,258,780)	595,545 (270,139)	72,316 (32,802)	667,861 (302,941)
	10		1.54878 (6.88897)	1.38040 (6.14001)	1.60382 (7.13379)	1.42271 (6.32821)	94.5	102.6	269.5	240.2	1,642,100 (7,304060)	1,458,500 (6,487,408)	595,545 (270,139)	72,316 (32,802)	667,861 (302,941)
1207	11		1.54007 (6.85023)	1.35835 (6.04194)	1.59636 (7.10060)	1.40037 (6.22884)	98.4	107.3	269.5	237.7	1,785,500 (7,941,904)	1,601,900 (7,125,251)	592,857 (268,919)	73,672 (33,417)	666,529 (302,337)
	12		1.53990 (6.84947)	1.33941 (5.95991)	1.59658 (7.10158)	1.38159 (6.14531)	108.0	117.2	269.5	234.5	1,741,100 (7,744,412)	1,557,600 (6,928,204)	592,857 (268,919)	73,672 (33,417)	666,529 (302,337)
	13		1.52901 (6.80103)	1.35596 (6.03131)	1.59536 (7.09616)	1.40795 (6.26256)	96.8	105.5	269.5	239.0	1,063,500 (4,730,448)	879,900 (3,913,795)	595,545 (270,139)	74,141 (33,630)	669,686 (303,769)
	14		1.53832 (6.84244)	1.36080 (6.05283)	1.59686 (7.10283)	1.40495 (6.24921)	95.5	103.8	269.5	238.4	1,744,000 (7,757,312)	1,560,000 (6,938,880)	592,857 (268,919)	75,394 (34,198)	668,251 (303,118)
	15		1.11078 (4.94074)	0.89317 (3.97282)	1.16113 (5.16470)	0.92724 (4.12436)	168.1	186.4	278.2	223.7	809,800 (3,595,512)	678,500 (3,039,680)	417,417 (189,340)	58,934 (26,732)	476,351 (216,072)
	16‡		1.08430 (4.82296)	0.94720 (4.21314)	1.12520 (5.00488)	0.97443 (4.33426)	104.1	113.8	266.0	232.2	1,330,600 (5,918,508)	1,199,300 (5,334,486)	424,317 (192,470)	53,505 (24,269)	477,822 (216,740)
1205	17		1.09856 (4.88639)	0.95966 (4.26856)	1.14000 (5.07072)	0.98724 (4.39124)	80.4	89.3	269.5	235.3	1,671,700 (7,435,721)	1,488,100 (6,619,068)	424,317 (192,470)	54,069 (24,525)	478,386 (216,995)
	18		1.11065 (4.94017)	0.99333 (4.41833)	1.15715 (5.14700)	1.02946 (4.57903)	88.3	97.2	266.0	237.9	1,479,600 (6,581,260)	1,348,300 (5,997,238)	436,352 (197,929)	53.505 (24,269)	489,957 (222,244)
	19		1.06842 (4.75233)	0.94472 (4.20211)	1.11846 (4.97491)	0.98298 (4.37229)	95.0	105.4	266.0	235.2	1,431,600 (6,367,756)	1,300,400 (5,784,179)	421,367 (191,132)	54,948 (24,924)	476,315 (216,056)
	20	1207 Forward Closure	1.17361 (5.22021)	1.04743 (4.65896)	1.21635 (5.41032)	1.08050 (4.80606)	94.7	103.2	266.0	237.4	1,505,500 (6,696,464)	1,374,200 (6.112,441)	459,134 (208,263)	57,453 (26,060)	516,587 (234,323)
	21		1.57902 (7.02348)	1.28190 (5.70189)	1.63810 (7.28626)	1.32181 (5.87941)	162.3	176.6	279.0	226.5	1,104,300 (4,911,926)	920,700 (4,095,273)	584,563 (265,157)	80,096 (36,331)	664,659 (301,489)
1207	22§		1.53134 (6.81140)	1.32961 (5.91410)	1.58797 (7.06329)	1.37138 (6.09989)	110.6	121.3	269.5	234.1	1,642,600 (7,306,284)	1,460,300 (6,495,414)	592,857 (268,919)	73,672 (33,417)	666,529 (302,337)
	23		1.58267 (7.03971)	1.39359 (6.19868)	1.64004 (7.29489)	1.43569 (6.38594)	100.9	111.1	269.5	237.3	1,735,200 (7,718169)	1,551,800 (6,902,406)	610,371 (276,864)	73,994 (33,563)	684,365 (310,427)
	24		1.54761 (6.88376)	1.3835 (6.06484)	1.60418 (7.13539)	1.40723 (6.25935)	98.4	107.3	269.5	237.7	1,785,500 (7,941,904)	1,601,900 (7,025,251)	595,807 (270,258)	72,403 (32,842)	668,210 (303,100)

* Refer to figure 23.
† Motor case, insulation, nozzles and igniter only, stage accessories are not included.
‡ Standard 1205
§ Standard 1207

thrust termination have been produced and flown on previous Titan III-C flights. A change to a tubular grain reduces heating of the forward closure. Thus maintenance of the existing insulation would be more than adequate and require no demonstration. A reduction of insulation thickness would be effective from both a performance and production cost viewpoint. Relations and requirements for the 1207 motor are similar with the only differences being closure length and motor duration.

The various segment designs used in the analysis trade upon current production with the exception of the double restrictor. The one restrictor design, figure 13, is currently in production. The zero restrictor design, figure 15, merely uses two of the segment ends without restrictors and as discussed earlier is duplicated at the last segment aft closure juncture. The double restrictor design would be totally different but will utilize a design successfully demonstrated early in the Titan III-C development testing. Objective of the design is to allow no exposure of the restrictor surface or the side wall insulation until motor tailoff. Thus, the end restrictor can be thin and will be bonded to the propellant surfaces to prevent flame propagation. The gap currently existing between segments would be reduced in size and filled with foam for thermal protection. The most stringent requirement of the design will be to provide sufficient axial flexibility to allow for production variations in the segment-to-segment separation. Side wall insulation will be limited to that necessary to install shrinkage boots at the segment ends with a thin, less than 0.100 inch (2.54 mm), layer on the balance for tailoff protection. Such a design would also allow 1500 pounds (680 kg) additional propellant per segment. All of these objectives could not be met in practice and figure 16 was developed as a compromise design to provide protection of the forward end of the forward segment and the aft end of the aft segment. Additional design work could develop a more attractive implementation of this concept. The elliptical bore segment insulation would be identical to current production except for the side wall protection. Current segments utilize an axially stepped thickness side wall. With an elliptical bore, circumferential variation in thickness or a uniform thickness insulator could be used.

Insulation and propellant weight data are given in table V for the above building blocks. The data can be used in an add or delete manner to provide a thorough vehicle evaluation of the ballistic changes.

Modification of the nozzle to revise the throat diameter could be readily accomplished. The current 1205 and 1207 designs use identical outer steel shells and aft closure openings. A change of throat diameter can thus be accomplished by revising the internal contour and perhaps the throat billet detail arrangements.

Drastic changes to the motor duration, such as an increase to 170 seconds, would, of course, require increasing the thickness of the internal insulation and nozzle liners. An approximate measure of this change is included in the weights in table IV.

TABLE V

BUILDING BLOCK WEIGHT SUMMARY

Configuration	Component Inert Weight lb	(kg)	Propellant Weight lb	(kg)	Gross Weight lb	(kg)
1205 Forward Closure (Star)						
Case	4,135	(1,876)				
Insulation	891	(404)				
Paint, liner & potting	78	(35)				
	5,104	(2,315)	38,150	(17,304)	43,254	(19,620)
1205 Forward Closure (Star with TT)						
Case	4,238	(1,922)				
Insulation	875	(397)				
Paint, liner & potting	78	(35)				
Thrust termination	1,356	(615)				
	6,547	(2,969)	35,200	(15,966)	41,747	(18,936)
1205 Forward Closure (Tube with TT)						
Case	4,238	(1,922)				
Insulation	726	(330)				
Paint, liner & potting	78	(35)				
Thrust termination	1,356	(615)				
	6,398	(2,902)	39,975	(18,132)	45,017	(20,419)
1205 Forward Closure (Tube)						
Case	4,135	(1,876)				
Insulation	711	(323)				
Paint, liner & potting	78	(35)				
	4,924	(2,233)	41,975	(19,039)	48,255	(21,888)
1207 Forward Closure (Star with TT)						
Case	5,928	(2,689)				
Insulation	1,701	(772)				
Paint, liner & potting	67	(30)				
Thrust termination	1,356	(615)				
	9,052	(4,106)	60,932	(27,638)	69,984	(31,744)

TABLE V

BUILDING BLOCK WEIGHT SUMMARY (Continued)

Configuration	Component Inert Weight lb	(kg)	Propellant Weight lb	(kg)	Gross Weight lb	(kg)
1207 Forward Closure (Star)						
Case	6,031	(2,736)				
Insulation	1,685	(764)				
Paint, liner & potting	67	(30)				
	7,783	(3,530)	63,882	(28,977)	71,665	(32,507)
1207 Forward Closure (Tube)						
Case	6,031	(2,736)				
Insulation	1,701	(772)				
Paint, liner & potting	67	(30)				
	7,799	(3,538)	63,620	(28,858)	71,316	(32,349)
1205 Segment (One Restrictor)						
Case	5,648	(2,562)				
Insulation	966	(438)				
Paint, liner & potting	228	(103)				
	6,842	(3,103)	73,250	(33,226)	80,092	(36,330)
1205 Segment (No Restrictors)						
Case	5,648	(2,562)				
Insulation	895	(406)				
Paint, liner & potting	228	(103)				
	6,771	(3,071)	73,850	(33,498)	80,621	(36,570)
1205 Segment (Two Restrictors)						
Case	5,648	(2,562)				
Insulation	1,229	(557)				
Paint, liner & potting	228	(103)				
	7,105	(3,222)	73,250	(33,226)	80,355	(36,449)

TABLE V

BUILDING BLOCK WEIGHT SUMMARY (Continued)

Configuration	Component Inert Weight lb	(kg)	Propellant Weight lb	(kg)	Gross Weight lb	(kg)
1207 Segment (One Restrictor)						
Case	5,648	(2,562)				
Insulation	1,183	(537)				
Paint, liner & potting	228	(103)				
	7,059	(3,202)	73,155	(33,183)	80,214	(36,385)
1207 Segment (Two Restrictors)						
Case	5,648	(2,562)				
Insulation	1,429	(648)				
Paint, liner & potting	228	(103)				
	7,305	(3,313)	73,155	(33,183)	80,460	(36,497)
1207 Segment (No Restrictors)						
Case	5,648	(2,562)				
Insulation	1,051	(477)				
Paint, liner & potting	228	(103)				
	6,927	(3,142)	73,755	(33,455)	80,682	(36,598)
1205 Aft Closure						
Case	3,193	(1,449)				
Insulation	2,375	(1,077)				
Paint, liner & potting	45	(20)				
	5,613	(2,546)	19,917	(9,034)	25,530	(11,580)
1207 Aft Closure						
Case	3,139	(1,424)				
Insulation	2,801	(1,271)				
Paint, liner & potting	45	(20)				
	5,985	(2,715)	19,840	(8,999)	25,825	(11,714)

3.0 TECHROLL SEAL IMPLEMENTATION

Application of the TECHROLL Seal movable nozzle to the seven-segment 120-inch (3.05m) diameter solid rocket motor (SRM) was first reported by UTC in an internal Technical Memorandum TM-15-70-U4, December 1970. That TM concentrated upon the technical design aspects of the TECHROLL seal and its actuation requirements. This study applies the seal and actuator data from the TM to TECHROLL seal installation into a 1207 rocket motor. Specifics of the aft closure insulation and propellant grain have been examined. The nozzle design has been refined to accept actuator loads and reduce liner thickness. Two methods of providing nozzle cant have been investigated using the 6° (.105 rad) Titan cant requirements as a baseline. The current baseline 1207 liquid injection thrust vector control (LITVC) system is also described (Section 3.5) to facilitate comparison of the merits of each system.

The TECHROLL seal nozzle assembly offers three principal advantages over the LITVC system currently used. The first of these is 9% reduction in total hardware cost. The second is a 10,000-pound (4540 kg) decrease in SRM inert weight. The final advantage is a capability to provide steering control far in excess of LITVC system capabilities.

3.1 TECHROLL SEAL NOZZLE ASSEMBLY

The application of a TECHROLL seal nozzle assembly to a seven-segment 120-inch (3.05m) diameter SRM was based on the technology and actuator loads data of UTC technical memorandum TM-15-70-U4. Technology provided by this study emphasizes the areas of nozzle design, aft closure insulation design, propellant grain effects, and TECHROLL seal installation. The designs developed are based upon the baseline 1207 design, technology and steering requirements. Modifications to the basic 1207 design to attach the TECHROLL seal, delete those design features required by the liquid injection TVC system and improve the design to reduce cost or weight.

Three design modifications of the TECHROLL seal nozzle-aft closure installations were evaluated. Two of these modifications were designed to provide the Titan vehicle maximum steering requirement of 3° (.052 rad) but provided alternate solutions to the additional 6° (0.105 rad) steering requirement expected at tailoff of the clustered stage. This steering requirement originates in the differential thrust created by nonuniformities in motor performance during tailoff. Nozzle deflection requirements can probably be reduced if the 1207 SRMs are utilized on larger vehicles with an increased number of SRMs per stage. However, application of the SRMs to a vehicle with a winged payload or upper stage can cause the deflection requirements to increase. For example, requirements from 10° (.174 rad) to 15° (.262 rad) have been indicated in recent booster studies for winged payloads. Therefore, the third TECHROLL seal design modification shown in figure 44 was made to provide a large deflection angle of 11° (.192 rad) and satisfy some of these possible future requirements.

The first design uses a non-canted nozzle but contains a TECHROLL seal possessing a $\pm 9^{\circ}$ (.157 rad) omniaxial movement capability equal to the sum of the required 6° (.105 rad) cant angle plus maximum 3° (.052 rad) deflection angle for the Titan application. This means that the nozzle could remain in the null position during most of the motor firing (with excursions only as required to provide steering corrections) but could be vectored as much as 9° (.157 rad) during tailoff to eliminate overturning moments due to possible thrust differentials when the motor is used in a clustered configuration. This design offers advantages of reduced external air loads, or actuator forces, during most of the motor firing,

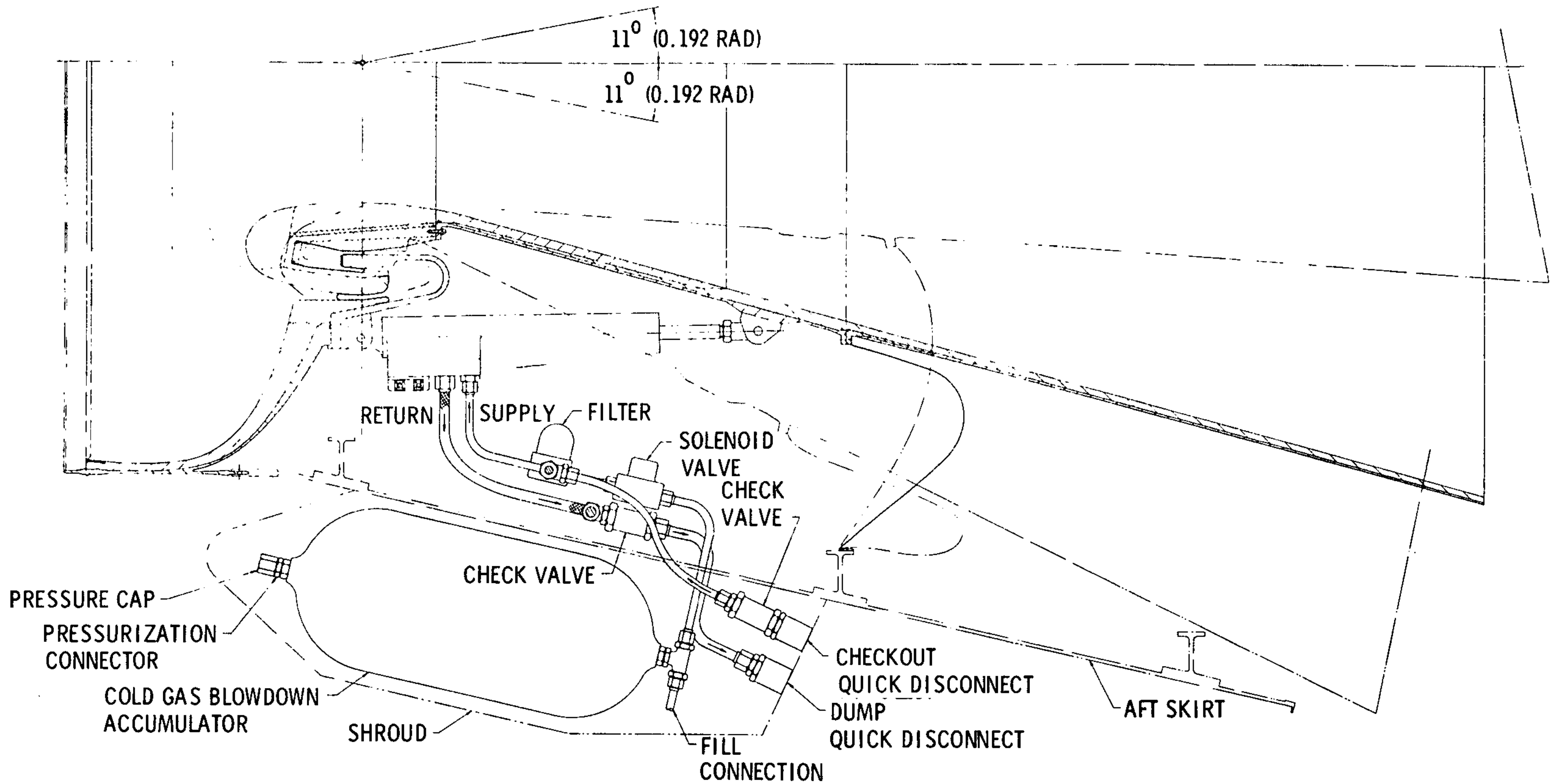


Figure 44. TECHROLL Seal Movable Nozzle Assembly

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symmetrical nozzle and aft closure insulation components, lower overall system weight (TRS/nozzle assembly, insulated aft closure), and increased propellant loading. (See detailed weight breakdown in section 3.6.)

The second design contains the same initial 6° (.105 rad) cant as does the baseline nozzle. This results in nonsymmetrical nozzle structural shell components and nonsymmetrical aft closure insulation. The TECHROLL seal is smaller, however, as its deflection capability requirement is now only ±3° (.052 rad). The overall system weight is again lower than the baseline 1207 system but higher than that for the "straight" TECHROLL seal nozzle assembly. Propellant loading is reduced from the baseline design.

The third design provides for an 11° (.192 rad) omniaxial deflection. A symmetrical aft closure, entrance section and mounting shell have been retained. System weight is slightly greater than the 9° (.157 rad) design above due to the greater size of the seal housing components. The increased propellant loading advantages of the 9° (.157 rad) design have been retained. A flared aft skirt design has been included to reduce the actuator system size controlling factor of external aerodynamic torque.

3.1.1 "Straight" TECHROLL Seal/Nozzle Assembly

The straight nozzle configuration is shown in figure 42. The cant has been eliminated resulting in totally symmetrical nozzle structural and ablative components. The nozzle has been submerged to allow the Titan required ±9° (.157 rad) movement.

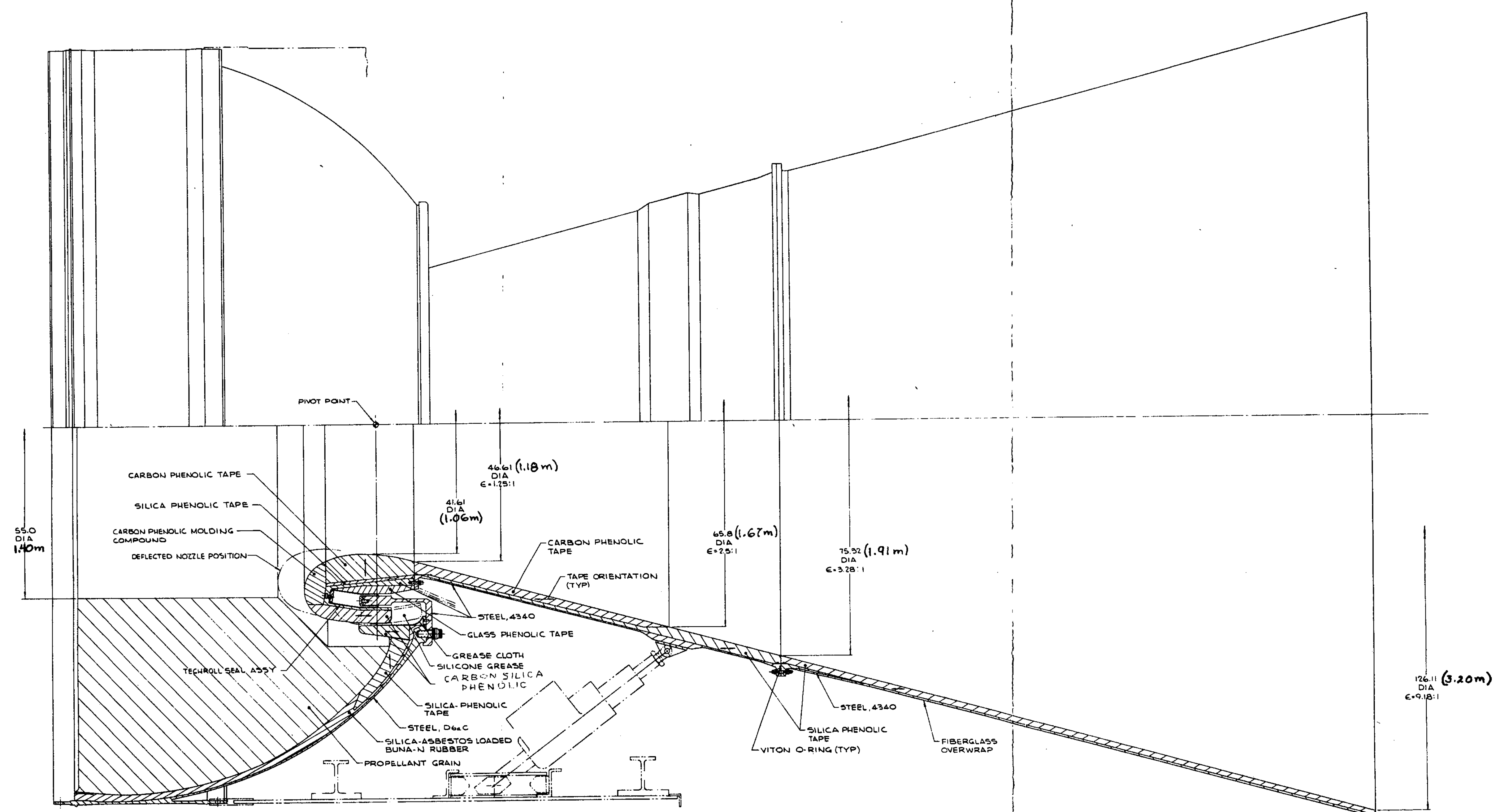

Figure 42. Straight TECHROLL Seal/Nozzle Assembly

FOLDOUT FRAME 1

FOLDOUT FRAME 2

A new structural member has been added to attach the TRS to the motor aft closure. This component will be fabricated of hardened and tempered 4340 steel. It is designed to resist the combined load effects of axial, nozzle ejection loads and internal pressure transmitted through the silicone grease filled cavity. An additional structural member of the same material surrounds the TRS and also provides support for the nozzle throat. The aft end of this new structural member contains threaded holes for attachment of the exit cone. The outer diameter of this component is protected by tape-wrapped carbon-silica phenolic. This ablative component is bonded to the housing with EA 913 adhesive. This component and all other ablative/insulative components have been designed to withstand predicted ablation and include sufficient additional material to maintain all structural bondline temperatures to ambient throughout the firing. The nozzle nose cap is fabricated of elastomeric, carbon-phenolic molding compound. The nose cap is bonded to the forward end of the throat insert and the TRS housing and additional radial support is provided by the tape-wrapped carbon-silica phenolic insulator. The throat insert is fabricated of carbon-phenolic, tape-wrapped at 90° (1.57 rad) to the nozzle centerline. This is an improvement over the baseline 1207 design as it employs a less expensive material and the tape-wrapped configuration allows the part to be made in one piece eliminating many intermediate machining and bonding operations. The throat insert is insulated with tape-wrapped silica-phenolic and the assembly is bonded to the TRS housing on a 5° (.087 rad) half-angle ramp.

The exit cone shell is fabricated of the same material (4340 steel) as the 1207 nozzle but the shell thickness has been reduced as the structural loading severity has been reduced with the elimination of the liquid injection TVC (LITVC) system. A local stiffening ring running a full 360° (2π rad) has been added, however, at the point of actuator attachment to limit shell deflection and prevent cracking of the liner under the 27,000 lbs (12,200 kg) actuator loads. Exit cone liner ablation has been reduced by elimination of the LITVC system, so the liner thicknesses have been reduced accordingly.

The extension contains an attach flange (4340 steel) for bolting the extension to the exit cone. The extension liner has remained the same length as the 1207 nozzle extension due to hydroclave vessel size limitations. The liner thicknesses have been reduced as noted above. Consideration could be given to using tape-wrapped glass-phenolic in place of the silica-phenolic extension liner in order to effect additional cost savings. The aluminum honeycomb structure has been replaced by a fiberglass overwrap since the requirement for high structure stiffness has been eliminated with the removal of the LITVC system. This change results in a weight reduction of 207 (94 kg) pounds and an expected improvement in manufacturing simplicity.

3.1.2 "Canted" TECHROLL Seal/Nozzle Assembly

The canted configuration is shown in figure 43. The essential design features discussed in section 3.1.1 are applicable to this design. The primary difference lies in the metallic structure used to attach the TRS/nozzle assembly to the motor aft closure. This member becomes non-axisymmetrical because of the permanent 6° (.105 rad) cant. The aft closure insulation design is also complicated by this assymetry.

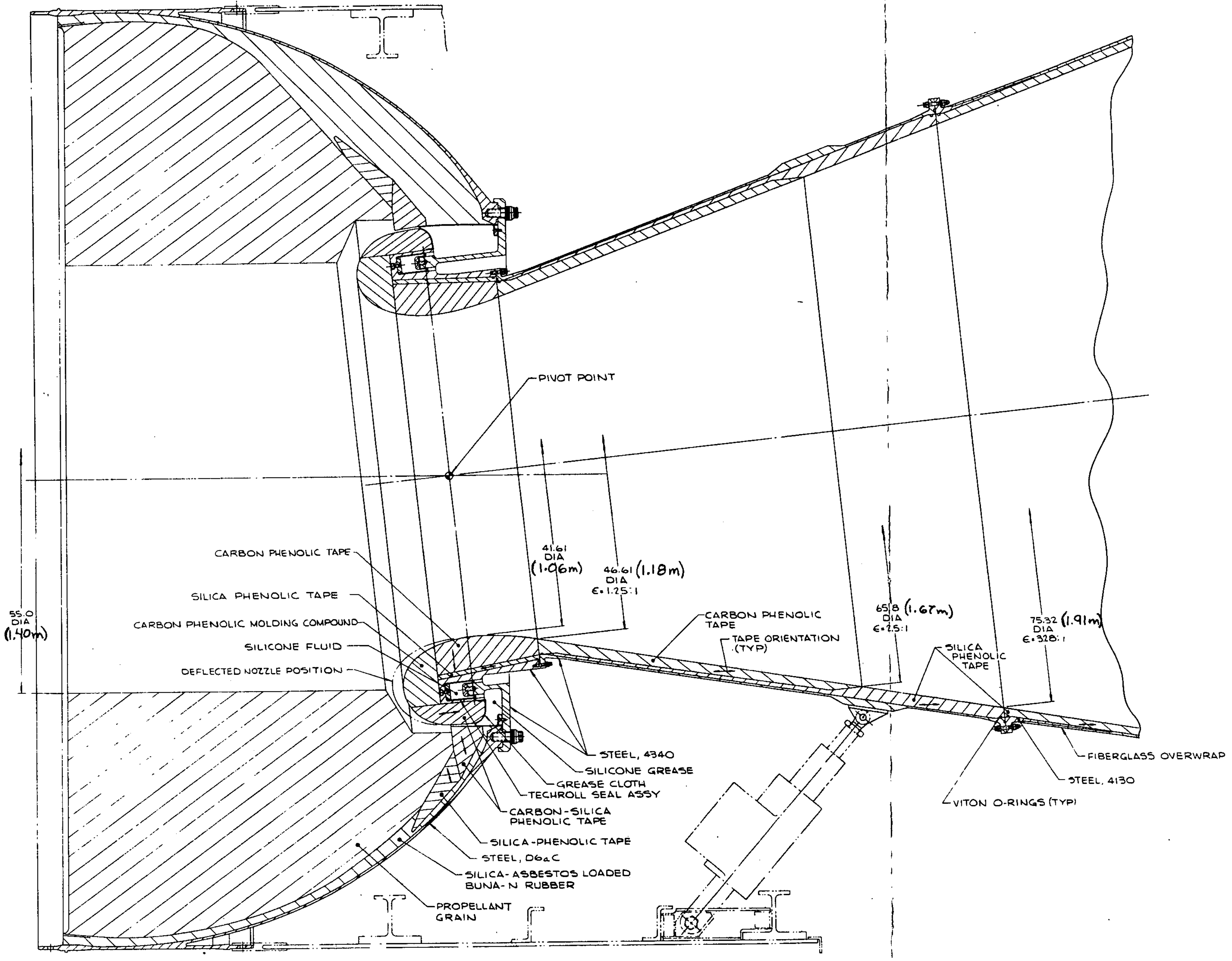

Figure 43. Canted TECHROLL Seal/Nozzle Assembly

FOLDOUT FRAME 1

FOLDOUT FRAME 2

3.1.3 11° (.192 rad) Winged Payload Design

A design layout projected for large steering deflections with winged payloads is shown in figure 44. The primary difference from the design of 3.1.1 is the larger deflection capability, the extended mounting adapter and the flared support skirt. The extended adapter improves the design of the aft closure insulation components which serves to improve the reliability of the TRS hot side thermal protection. The flared skirt serves to shield the nozzle extension from external air drag which reduces the resultant actuator loads.

3.1.4 Design Selection

The straight nozzle TECHROLL seal design would be recommended for application to the 1207 SRM. This recommendation is based upon its minimum weight, its maximum propellant loading (see section 3.6) improved aft closure insulation and internal aerodynamics and its expected ease and lower cost of production derived from its symmetry. Its sole negative point is the large seal deflection required. This deflection results in greater weight from longer seal and throat assembly parts and increased stroke required of the actuators. The selection of precise mounting technique should be dependent upon the specific steering requirements of a given application.

3.2 AFT CLOSURE INSULATION

The application of the TECHROLL seal nozzle assembly to the 1207 SRMs is expected to provide an improved solution to the aft closure insulation problem. Use of the TECHROLL seal causes the nozzle assembly to be moved forward slightly. The result is a semi-submerged nozzle entrance section. This configuration is expected to relieve the internal environment of aft closure/ nozzle entrance ablation which has caused difficulties on the 1207 development program. This improvement is expected as the aft closure insulation is removed from the nozzle entrance flow field and the 1207 peculiar entrance contour is eliminated.

The aft closure insulation design for a "straight" nozzle configuration is shown in figures 42 and 44. These designs provide an improvement over the baseline 1207 design through their symmetry and the elimination of the humped nozzle entrance countour. Two large plastic inserts are used. The first, which protects the seal and provides a rolling surface for the grease retention cloth, is fabricated of tape-wrapped carbon-silica phenolic. The design of figure 44 offers superior support to this member. At the higher area ratios, a tape-wrapped silica-phenolic component is used. Use of these plastic components eliminates the need for extreme rubber thicknesses, reduces closure weight, and maximizes the propellant loading. The rubber used in the closure is the same silica-asbestos loaded Buna-N material used in the baseline design.

The aft closure insulation design for the "canted" nozzle configuration is shown in figure 43. This design requires the non-symmetrical insulation design typical of the baseline design. The two-piece insert is also used but must be slightly thicker due to less nozzle submergence than for the straight nozzle and the resultant higher ablation. The rubber used in this closure is also the same silica-asbestos loaded Buna-N material used in the baseline design.

3.3 AFT CLOSURE GRAIN AND BALLISTICS

Modification of the aft closure propellant grain to the TECHROLL seal configuration is a simple matter accomplished by removing propellant to provide clearance to the moving nozzle throat assembly. The baseline internal port is retained except for the nozzle relief at the aft end. This relief is shown in figures 42, 43 and 44 for the designs presented. Any effect upon the SRM ballistics is negligible. Propellant loading is effected by the amount of aft closure insulation used. The straight TECHROLL seal installation provides a slight propellant loading advantage through its minimum insulation thickness. Precise weight data is presented in Section 3.6.

3.4 ACCESSORY SYSTEMS

Implementation of the TECHROLL seal nozzle TVC system to the 1207 can affect the arrangement and complexity of other SRM accessory systems. The most obvious change is the addition of a hydraulic power supply. Less obvious are the simplifications which can be made to the electrical components.

A basic description and sizing of a hydraulic system for control of the TECHROLL seal nozzle to satisfy Titan requirements was given in the original TM-15-70-U4. The basic design parameters of the system are repeated in table VI.

TABLE VI

TITAN HYDRAULIC SYSTEM PERFORMANCE PARAMETERS

Parameter	Value
Number of actuators	2
Maximum actuator load, lb (N)	27,000 (120,096)
Actuator stroke, in. (m)	
Normal control	$\pm$3.8 (0.0965)
Tailoff control in yaw	+10 (0.254)
Hydraulic supply pressure, psi (MN/m^2)	2,800 (19.0)
Hydraulic flow rate (maximum), gpm (m^3/min)	27.5 (0.12111)
Accumulator volume, in.^{3} (m^3)	1,680 (0.02753)
Accumulator active oil volume, gal. (m^3)	0.4 (0.0017616)
Accumulator precharge pressure, psi (MN/m^2)	2,000 (13.8)
Hydraulic pump size, gpm (m^3/min)	8.0 (0.035232)

The hydraulic supply requirements can be satisfied by two of the previous Titan III-C pump motor units operating in parallel with a common accumulator. Other proprietary units utilizing schemes such as gas generator turbine drives are available. The actuator requirements may be satisfied by Saturn developed units or modifications thereof to accommodate the peculiar stroke requirements. Proprietary majority vote units have been introduced which could serve to accommodate potential crew safety requirements.

Design requirements for a 11° deflection angle application are as given in table VII. A battery powered system to satisfy these demands would be much larger than in table VI but could be developed to required power ratings. Lightweight gas generator-turbine drive units as used on the Zeus rocket could be developed. The major drawbacks of the gas generator system would be turbine drive reliability and the expected relatively high cost of development and production. An alternate scheme which offers promise is the blowdown system. This system is shown in figure 44. A precharged high pressure reservoir of hydraulic fluid is fed through the actuators and dumped overboard as consumed. The critical parameter for this system is the expected flight duty cycle. Final decision on hydraulic system selection should await a specific vehicle application with attendant defined duty cycles.

Resources have not been expended in the further analysis and definition of nozzle control system requirements. It is recommended that further examination of this area await application to a specific launch vehicle. Detailed realistic minimum control system requirements can then be established.

Electrical system distribution requirements are simplified by the introduction of the TECHROLL seal nozzle. The current electro-mechanical valves require electrical power and control commands to be distributed to each valve. Instrumentation signals are also collected from each of the 24 valves. The TECHROLL seal will require power to the hydraulic system, and control signals direct to the two actuators and instrumentation signals from each. The current TVC distribution box can be eliminated. The instrumentation distribution box functions would be simplified and all remaining electrical

TABLE VII

TECHROLL SEAL SYSTEM HYDRAULIC SYSTEM PARAMETERS - $\pm 11^{\circ}$ SYSTEM

	Battery/ Motor/Pump (2 units)		G.G./Turbine/ Pump (1 unit)		Blowdown (1 unit)	
Number of actuators	2		2		2	
Maximum torque						
in.-lb	1.3×10^6		1.3×10^6		1.3×10^6	
(N-m)	(146,873)		(146,873)		(146,873)	
Supply pressure						
psi	3,000		3,000		3,000 to 2,000	
(MN/m^2)	(20.7)		(20.7		(20.7 to 30.8)	
Actuator area						
$in.^2$	10.85		10.85		16.25	
(m^2)	(0.00699)		(0.00699)		(0.01048)	
Actuator stroke						
in.	7.8		7.8		7.8	
(m)	(0.19812)		(0.19812)		(0.19812)	
Maximum flow (10°/sec any plane)						
gpm	20		20		30	
(m^3/min)	(0.08808)		(0.08808)		(0.13212)	
Accumulator active oil volume						
gal	1		0.1		25	
(m^2)	(0.0044)		(0.0044)		(0.11010)	
Weight, lb (kg)						
Power source	720	(326)	150	(68)	760	(345)
Actuators	300	(136)	300	(136)	320	(145)
Hydraulic oil	50	(23)	40	(18)	180	(82)
Gas, lines, and fittings	30	(14)	20	(9)	40	(18)
Total	1,100	(499)	510	(231)	1,300	(590)

functions could be combined into a single aft distribution box. Aft end functional components would then consist of the ground power umbilical, distribution box, battery, hydraulic power supply, hydraulic actuators, hydraulic fluid lines and required connecting cabling.

All of the functional components are currently mounted upon the nozzle shell. This location was dictated by the location of the LITVC injectant valves and the desire for an assembly which could undergo system testing at the factory. Introduction of the TECHROLL seal allows placement of all accessory items on the aft skirt interior. Ground and airborne cabling can now pass directly to the components without the need to bridge over to the nozzle and return. All bonded component mounting pads and studs can be removed from the nozzle reducing its cost and weight. A reduction in vibration environment is achieved by locating components on the skirt rather than the nozzle. Handling of the nozzle will be minimized as it will not be required in subassembly operations and will not take part in system testing.

Application of the moving TECHROLL seal nozzle prohibits continued use of the rigid heat shield. It may be possible to eliminate the heat shield with the attendant reduction in cabling and components and their removal from the nozzle. The use of minimum surface protection of the electrical and hydraulic components would be investigated. An alternate approach would be to apply a local heat shield cocoon around the sensitive components.

3.5 BASELINE 1207 LITVC SYSTEM

The current solid rocket motor (SRM) TVC system consists of an injectant storage tank, transfer tube and distribution manifold, flow control valves, pre-injection seals, and an electrical control and power distribution system. The TVC system function is to provide a steering capability during flight operation of the SRM. Prior to SRM ignition, a completely sealed system is maintained. The fluid supply system operates on the ullage blowdown principle; fluid injection into the SRM nozzle is controlled by electromechanical valves (EMV). With this system the nozzle remains rigidly mounted to the SRM, and injection of liquid N_2O_4 into the nozzle exit cone produces a disturbance causing an oblique shock wave. This shock wave produces an asymmetric or unbalanced nozzle pressure field within the nozzle and deflection of the rocket motor exhaust with resultant deflection of the thrust vector.

3.5.1 Feed System Description

The feed system pressurized components are shown by the shading in figure 45. They consist of a 201 ft.^{3} (5.70 m^3) injectant tank which supplies pressurized injectant through an adapter spool, injectant transfer tube, and a toroidal injectant manifold to 24 equally spaced injectant valve housings mounted on the nozzle exit cone. The EMV installed in each valve housing provides the function of injectant flow control. A pyroseal is connected to each EMV outlet to accomplish system sealing until the pyroseal is burned off at motor ignition.

The functional components of the ullage blowdown TVC system are also shown in figure 45. They consist of a TVC distribution box, TVC battery, and TVC power transfer switch; three system servicing-connections (the GN_2 fill and vent valve, the N_2O_4 fill and drain quick disconnect, and a manifold drain quick disconnect); and the electromechanical injectant valves.

3.5.2 Baseline Nozzle-Aft Closure Configuration

The baseline 1207 nozzle-aft closure configuration is shown in figure 46. The design satisfies the basic requirements of table VIII. The fluid usage and nozzle cant requirements are unique to the two-motor Titan stage zero strap-on design but are believed to be more than adequate for larger clustered vehicles with the possible exception of the shuttle booster designs.

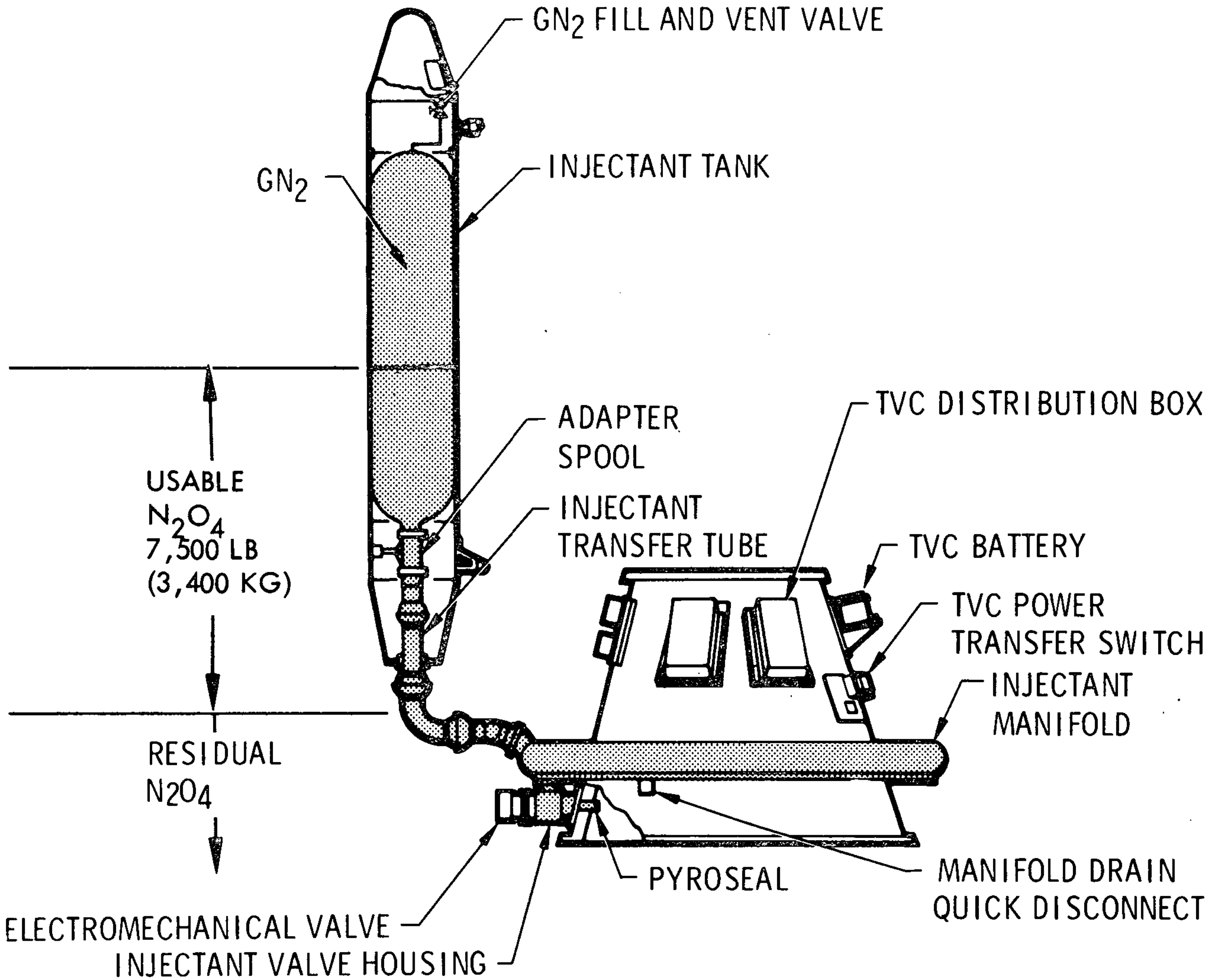

Figure 45. Components of TVC System

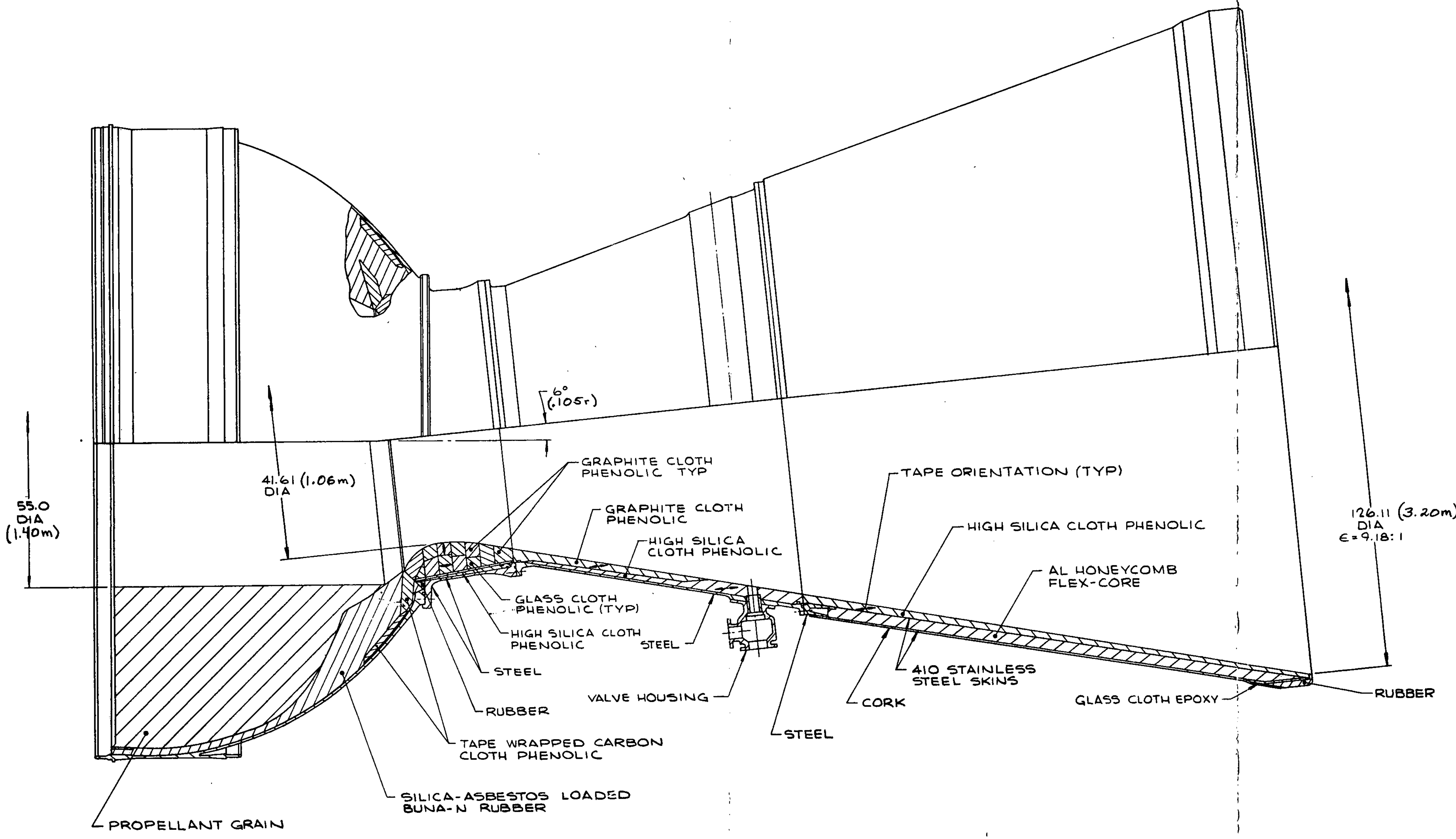

Figure 46. Design for UA 1207
Baseline Nozzle/Aft Closure

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE VIII

UA 1207 NOZZLE DESIGN REQUIREMENTS

Parameter	Value
Nominal operating temperature, °F (°K)	60 (288.70)
Average pressure, Pca, psia (MN/m^2)	552 (3.80)
Action time, t_a, sec	123.9
Flame temperature, °F (°K)	5,700 (3,422)
TVC system	N_2O_4 fluid injection
Fluid usage, lb (kg)	7,500 (3,402)
Nozzle cant, degrees (rad)	6 (0.1047)

3.5.2.1 Baseline 1207 Nozzle

The nozzle has a throat diameter of 41.61 inches (1.06 m). The diameter at the exit plane is 126.11 inches (3.2 m) resulting in an overall expansion ratio of 9.18:1. The maximum nozzle outside diameter is 130.528 inches (3.32 m). Exit cone and extension half-angles are 15° (.262 rad) and 15°3' (.2625 rad) respectively. Twenty-four thrust vector control valve housings bolt to the exit cone structural shell at an expansion ratio of 2.86. A manufacturing joint is provided between the exit cone and extension at an expansion ratio of 3.28.

The throat is fabricated of molded graphite cloth-phenolic rosette rings. The throat subassembly is supported by a conical [5° (.087 rad) half-angle] annealed 4340 steel ring. The exit cone liner is a tape-wrapped, hydroclave cured composite of graphite-phenolic and silica-phenolic. The ablative liner is bonded to the normalized and tempered 4340 steel structural shell with EA 913. The TVC and flight instrumentation system units are mounted on the external surfaces of the nozzle exit cone shell with rubber pads to which are bonded aluminum plates. The nozzle extension consists of a high silica-phenolic tape-wrapped ablative liner and a honeycomb support structure.

3.5.2.2 Insulated Aft Closure

The baseline 1207 aft closure design is based on the nominal operating conditions of table VIII and the particular aft closure grain design used in the 1207 motor.

The aft closure insulation is fabricated of silica-asbestos loaded Buna-N rubber. A tape-wrapped, hydroclave cured, carbon-phenolic insulation insert is installed in the rubber immediately upstream of the throat. An additional tape-wrapped carbon-phenolic "shingle" is placed immediately upstream of the insert. These ablative components provide additional ablation resistance in the low area ratio, high heat flux regions of the aft closure. Due to the nozzle cant, the insulation insert also must be canted at 6° (.105 rad) relative to the closure centerline. This requires a nonuniform insulation thickness configuration at various circumferential locations. The "shingle" is not canted, however, and is installed adjacent to the aft closure wall for 360° (2π rad).

3.6 MASS PROPERTY EFFECTS

Replacement of the 1207 LITVC system with the Techroll seal nozzle assembly will provide a 10,342 pound (4680 kg) decrease in inert weight. A summary of this weight change is provided in table IX. 7,500 pounds (3400 kg) of N_2O_4 injectant are also eliminated although the N_2O_4 would carry its own weight through LITVC thrust augmentation effects. Table IX also provides an insight into the overall system simplification which can be achieved through use of the Techroll seal nozzle.

A weight comparison of the 1207 baseline design and the Techroll seal designs of 2.0 is presented in table X. The weight advantage, both in decreased inerts and increased propellant, of the straight seal design is evident.

TABLE IX

SUMMARY OF COMPONENT WEIGHTS AFFECTED BY TVC DESIGN

	Baseline UA 1207 with LITVC		TECHROLL Seal TVC Options					
			Straight Nozzle Design		6° (0.105 rad) Canted Nozzle Design		11° (0.192 rad) Shuttle Booster Design	
	lb	(kg)	lb	(kg)	lb	(kg)	lb	(kg)
Nozzle assembly	8,995	(4,080)	8,467*	(3,841)	8,110*	(3,679)	12,519	(5,678)
Aft closure inerts	5,994	(2,719)	4,767	(2,162)	6,016	(2,729)	4,594	(2,084)
Injectant feed system	6,472	(2,936)	NA	NA	NA	NA	NA	NA
Control system (valves, actuators, etc.)	532	(241)	800	(363)	800	(362)	1,300	(590)†
Structural, mechanical, thermal components	1,802	(817)	100	(45)	100	(45)	100	(45)
Electrical components	473	(215)	271	(123)	271	(123)	271	(123)
Ordnance components‡	57	(26)	NA	NA	NA	NA	NA	NA
	24,325	(11,034)	14,405	(6,534)	15,297	(6,910)	18,784	(8,520)
Total inerts weight change	–	–	-9,920	(-4,499)	-9,028	(-4,090)	-8,587	(-3,895)
Usable NTO injectant change	–	–	-7,500	(-3,402)	-7,500	(-3,402)	-7,500	(-3,402)
Aft closure propellant change	–	–	+402	(182)	-1,151	(-522)	-1,600	(-725)
Total gross weight change	–	–	-17,018	(-7,719)	-17,679	(-8,000)	-17,687	(-8,023)

* Includes TECHROLL seal assembly

† Additional structural weight of up to 4,000 lb (1,820 kg) would be incurred with the flared support skirt

‡ Destruct system for TVC tank

TABLE X

NOZZLE - AFT CLOSURE WEIGHT DATA

	"Straight" Design 0^o Cant $\pm 9^o$ (0.157 rad) Deflection		"Canted" Design 6^o (0.105 rad) Cant $\pm 3^o$ (0.052 rad) Deflection		11^o (0.192 rad) Shuttle Booster Design		1207 Baseline	
	lb	kg	lb	kg	lb	kg	lb	kg
Nozzle	(8,467)	(3,841)	(8,110)	(3,679)	(12,519)	(5,679)	(8,995)	(4,080)
Attach shell	903	410	746	338	2,662	1,207	–	–
Seal housing	1,056	479	986	447	2,521	1,144	–	–
Throat & entrance	1,017	461	887	402	1,145	519	2,085	946
Exit cone	2,442	1,108	2,442	1,108	2,542	1,153	3,041	1,379
Extension	2,592	1,176	2,592	1,176	2,592	1,176	3,412	1,548
Assembly hardware	124	56	124	56	124	56	124	56
External insulation	333	151	333	151	333	151	333	151
Aft closure	(4,767)	(2,162)	(6,016)	(2,729)	(4,594)	(2,084)	(5,994)	(2,719)
Case	3,172	1,439	3,172	1,439	3,064	1,390	3,193	1,448
Insulation	1,564	709	2,813	1,276	1,500	680	2,770	1,256
Liner	31	14	31	14	30	14	31	14
Total inerts	13,234	6,003	14,126	6,408	17,113	7,762	14,989	6,799
Aft closure propellant loading	20,242	9,182	18,689	8,477	18,240	8,274	19,840	8,999

4.0 TECHROLL SEAL/LITVC TRADE STUDIES

Selection of a steering system for the five- and seven-segment 120-in. (3.05 m) diameter solid rocket motors should be based upon all pertinent factors such as performance, weight, complexity, service requirements, adaptability to the application, and cost. A partially qualitative and partially quantitative evaluation of these factors has been made with regard to replacement of the current 120-in. (3.05 m) SRM LITVC system with the TECHROLL seal nozzle.

4.1 STEERING PERFORMANCE

Current Titan steering requirements for the five- and seven-segment 120-in. (3.05 m) diameter SRMs are specified as 55,000 (244,000 N) and 77,000 pounds (342,000 N) of side force, respectively, at T+55 seconds. This time corresponds approximately to the period of maximum dynamic pressure. This requirement equates to an equivalent jet deflection of about 3° (.052 rad). It is expected that this requirement would be reduced with application of the SRMs to larger vehicles. One exception to this is the shuttle booster application where deflections of 10° (.174 rad) to 15° (.262 rad) may be required. The current Titan LITVC design provides a jet deflection capability of approximately 5° (.087 rad). A growth LITVC system could produce a maximum of about 7° (.122 rad) deflection. Although greater deflections are practical and one 1207 application has been designed with an 11° capability, the TECHROLL seal designs would be guided by a basic 3° deflection capability. Tactical rocket designs have already been built and tested with a 15° capability. As seen, either system is capable of the deflections required in large boost vehicle applications with normal cylindrical payloads.

Consideration of duty cycle requirements shows a significant difference between the two systems. The LITVC duty cycle is presented in terms of usable secondary injection fluid which must be carried. This requirement is 7,500 pounds (4150 kg) of N_2O_4 on the current 1205 and 1207 SRMs. While the system is capable of the expected required duty cycle, the needed fluid and tankage weight represent a vehicle performance penalty. The TECHROLL seal utilizes hydraulic actuation with either a recirculation or blowdown system. The system selection would be based on duty cycle demands. A recirculating system would have effectively limitless capability

The 120-inch (3.05m) diameter SRM LITVC system has other performance parameters imposed upon it such as side force variation, linearity, hysteresis, dead band and frequency response. It is recognized that final selection of the TECHROLL seal for a specific vehicle application will require extensive examination of true control system response requirements. Design studies of the TECHROLL seal nozzle assembly have carried over the current Titan III LITVC performance requirements. This has been done to economize on current resources. Detailed evaluations of these parameters have not been performed with regard to the TECHROLL seal nozzle and actuators. It is presumed that adequate performance can be obtained on the basis of similarity to gimballed liquid rocket engine installations. A preliminary evaluation has been performed of the TECHROLL seal nozzle capability to achieve current Titan frequency response requirements. This was done to arrive at size requirements for the hydraulic system. While the Titan requirements are achievable, they are believed to be more stringent than is necessary. Eventual definition of minimum required performance levels would lead to economies in the sizing of the actuation system.

4.2 PHYSICAL ARRANGEMENT

The LITVC and TECHROLL seal nozzle systems have two basic physical design features which affect their application to clustered SRMs. These features are the TVC tank of the LITVC system and the movable nozzle exit of the TECHROLL seal nozzle.

The LITVC tankage presents an additional body to be packaged in layout of clustered stages. The tankage is readily accommodated on the 2+1 and 3+1 configurations studied. On the 4+1 the tankage begins to affect the dense clustering arrangements desired for structural reasons. The tank of the center motor begins to interfere with one of the outer tanks at a centerline to centerline separation of 145 inches (3.68m). This dimension could be reduced ten (.254m) to fifteen inches (.381m) by rotation of the center motor of about 6° (.105 rad). The center motor tankage dictates a 150-inch (3.81m) centerline separation for the 5+1 configuration. The only way to alleviate this condition would be to relocate the tank for one of the outboard motors to an outboard position. Such relocation would require a new configuration of transfer tube, heat shield, aft skirt tank mounts and possible flange relocation on the injectant manifold. Tank packaging does not present a problem for the 4+2 configuration. The seven-segment motor ground support longerons dictate the limiting separation distance in this case. Use of five-segment motors would allow the two sets of three motors to be brought closer together so that tank interference would be a consideration. It would be possible to relocate the tank to the opposite side (symmetrically to the current Titan yaw plane) at minimum effort. The tanks do not present packaging problems to the 5+2 configuration although it may be desirable to switch some of the tanks to opposite sides for balance purposes.

A nozzle clearance envelope must be provided when the TECHROLL seal nozzle is applied to clustered stages. The exit plane of a seven-segment motor will translate 8.3 inches (.21 m) with steering deflections up to 3^{o} (.05 rad). Use of the zero cant nozzle, described earlier in section 3.0, with a 9^{o} (.157 rad) steering requirement for tailoff will cause lateral motions of 25 inches (.635 m). A null position static clearance of the full 25-in. (.635 m) tailoff deflection is not required as all nozzles would move in unison at that time. A motor-to-motor centerline distance of at least 140 inches (3.55 m) is required for nozzle clearance when seven-segment motors are clustered with all motors at the same elevation. The 2+1 configuration is the only one with equal elevation motors and the centerline distance is a safe 163 inches (4.14 m). The five other cluster configurations have the center motors at a higher elevation such that nozzle interference is not a concern. However, there are potential hazards of exhaust jet interactions which may aggravate base heating conditions or cause impingement of center motor exhaust on the outer motor nozzles during phased ignition or staging.

Launch mount clearance has been a continuing concern with the large solid motor exhaust nozzles of the Titan family. The five-segment motors with their fixed LITVC have only five inches of lateral clearance from the nozzle exit to the launch mount. This criteria was raised to ten inches with the larger nozzles of the seven-segment motor. The greater clearance was obtained by extending the outboard ground supports. Obtaining increased clearance in this manner causes extensive skirt and longeron design and analysis to cope with the increased loading applied to the structure. A requirement for steering to compensate for guidance system offsets during launch mount clearance serves to complicate the matter. Steering will cause no nozzle movement with the LITVC system. Use of the TECHROLL seal nozzle will result in nozzle movements at this critical time. It is expected that the required movements would be less than one inch laterally. Requirements for prelaunch steering checks of a TECHROLL seal nozzle system may be compromised by the clearance allowed in the launch stand design. An alternative would be to provide cantilevered ground support jacks such that the nozzle could swing freely below them.

4.3 WEIGHT AND VEHICLE PERFORMANCE

Replacement of the 120-inch (3.05m) rocket motor LITVC system with the TECHROLL seal nozzle provides three benefits to vehicle performance. SRM inert weight is decreased 10,300 pounds (4550 kg); 7,500 pounds (3400 kg) of usable LITVC fluid are eliminated and 402 pounds (182 kg) of additional propellant are loaded in the aft closure. These weight changes would equate approximately to a 5% change in vehicle payload. Thus use of the TECHROLL seal in both stages of the SRM-SIVB launch vehicles by McDonnell Douglas Company would show a 5% payload advantage over the LITVC system. In a 3+1 cluster, this effect is distributed approximately 2% for the first stage and 3% for the second stage. Detailed weight changes have been presented in section 3.6.

4.4 SERVICE AND CHECKOUT

Service and checkout requirements of a control system can strongly affect the manpower and equipment needed to support a launch system. The current 120-inch (3.05m) diameter SRM LITVC system represents a significant

3

reduction in service requirements from the original Titan III-C design. Further reductions in service requirements are possible with the TECHROLL seal nozzle. These benefits are derived primarily from the elimination of the LITVC fluid system.

The LITVC fluid system currently represents a significant portion of manufacturing, assembly and service operations. The subcontract operations of tank, transfer tube, spool, manifold, valve housings, nozzle connection provisions and tank attach structure can all be eliminated. Major launch base assembly operations of tank and transfer tube installation are removed. The service and checkout requirements for the entire fluid system for leaks, tank filling and pressurizing, hold requirements, etc. are eliminated. Engineering support in terms of loading predictions and tank monitoring as well as inflight performance evaluation are no longer required.

The current LITVC system utilizes 24 electrically operated valves to perform the control function. This control function would be accomplished by two linear actuators operating with the TECHROLL seal nozzle. To date the electrically operated valves have proven to be trouble free in the field. Failure of one of the valves following tank loading can require several days for replacement. The two TECHROLL seal actuators should be readily replaceable and more trouble free than the valves.

The TECHROLL seal has one significant set of service and checkout requirements associated with the hydraulic system presently envisioned to power the nozzle actuators. But, such a hydraulic system would be state-of-the-art and comparable to systems flying on liquid rocket engines today. However, hydraulic systems do have extensive service requirements for cleanliness, filling, pressurizing, leakage and performance monitoring.

4.5 RELIABILITY

A numerical comparison of the current LITVC system and the TECHROLL Seal System must necessarily reflect the current state of development of TECHROLL Seal. Consideration must also be given to the effect of the specific duty cycle requirements since failures due to inadequate performance form a major portion of the evaluation criteria.

A preliminary examination of the TECHROLL seal TVC system reliability potential shows two areas which cannot be defined without additional test history as well as system performance definition. These areas are primary seal leakage and the interaction between the actuators and the seal. The remainder of the TVC system - actuators, servovalves, fluid distribution unit - is almost totally dependent upon the particular system requirements with considerable latitude in the possible design options for a given set of conditions. An example of this is the fluid distribution unit where three alternative unit types are being considered. These are:

1. a gas generator powered hydraulic pump system
2. an electric motor powered hydraulic pump system
3. a blowdown system

The reliability of options 2 and 3 are both dependent upon duty cycle whereas that of option 1 remains essentially constant across all duty cycles.

The TECHROLL seal system, assuming the estimated seal and interaction effects are correct, can be designed in a manner which will not increase the probability of losing total TVC capability from that presently achieved with the Titan LITVC system.

In addition, the capability to design failsafe mechanisms similar to those used in the present Titan system to allow continued performance at degraded levels after a failure occurs or to assure a failed null condition in the event of complete seal failure exists.

A detailed design study with failure modes and effects analysis should be performed prior to serious reliability evaluations.

4.6 COST

A principal advantage of the TECHROLL seal nozzle is its greatly reduced cost compared to the current Titan LITVC system. This cost reduction results from the elimination of the entire injectant feed system, simplification of the nozzle design and reduction of the control system from twenty-four electro-mechanical valves to a hydraulic supply with two actuators. The cost advantage of the TECHROLL seal system is estimated at 9% of total SRM cost. Thus substantial system cost savings can be realized where quantity usage will offset the original development costs. Sections 7.1.2 and 7.2 provide further cost data.

4.7 NOZZLE TRADEOFFS

Nozzle tradeoffs can be performed to select an optimum nozzle configuration. Optimum values for parameters such as nozzle cant angle and expansion ratio will vary depending upon the size motor selected, the stage in which the motor is to be used and the choice of SRM thrust vector control system.

The requirements for nozzle canting are derived from the overturning moments produced by motor-to-motor thrust differentials in clustered stages. The effect of the nozzle cant is to reduce the overturning moment by causing the thrust vectors to be directed closer to or through the vehicle center-of-gravity. These motor-to-motor thrust differentials would be a maximum during SRM tailoff due to the slight differences in motor action time. Thus the nozzle cant angle would be selected on the basis of this overturning moment and the clustered stage steering forces available to counteract it. The scope of this study does not allow conducting the necessary statistical evaluation of this overturning moment such that a recommendation of optimum values could be made. The current six degree (.105 rad) cant angle may have to be retained to provide clearance for the center motor exhaust.

The use of a TECHROLL seal nozzle steering system in the first clustered stage of SRMs would not require nozzle canting for control purposes. The zero cant angle design presented in another section will provide for expected tailoff steering requirements. Continued use of the LITVC system would require an undetermined cant angle. A maximum of about 6° (.105 rad) would be expected in the case of the 2+1 configuration. Use of the 6° (.105 rad) cant angle causes a 0.55% reduction in vehicle axial impulse.

Canted nozzles would not be required in the second stage of any of the clustered vehicles under study. A zero cant TECHROLL seal nozzle would be readily interchangeable from first to second stage. Use of an LITVC steering system would require a unique nozzle aft closure design for the second stage. Such a design has been prepared for a seven-segment motor and a layout drawing is presented in figure 47. The current design is shown in figure 46. This design was prepared to provide maximum interchangeability and flexibility with the current 1207 LITVC design. Different configurations

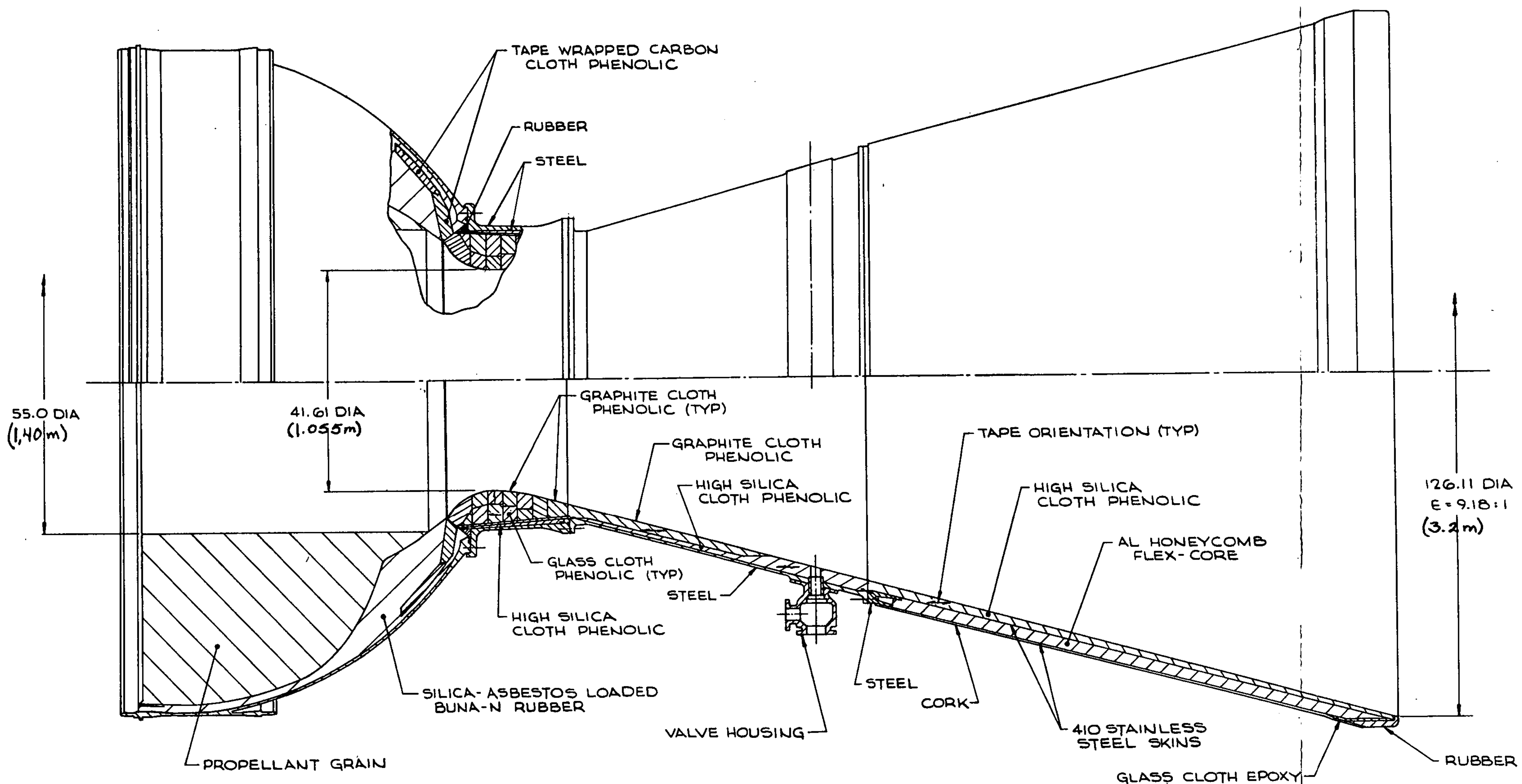

Figure 47. Design for UA 1207 Straight Nozzle/Aft Closure

FOLDOUT FRAME 1

FOLDOUT FRAME 2

must be used for the nozzle throat shell and the aft closure insulation contour. Nozzle internal parts, the aft closure insulation insert and insert extension would be identical to current production. The zero cant design should be less expensive and easier to produce. A slight propellant weight gain is also achieved from elimination of filler insulation on one side of the closure.

Stage performance can be improved by increasing the SRM nozzle expansion ratio. However, increases in the expansion ratio cause the nozzle exit to be larger and tends to aggravate problems of nozzle clearance within the cluster, nozzle launch clearance, and manufacturing and transport. Figure 41 of section 2.0 presented data on expected performance improvement with given nozzle sizes. The second stage application would be most promising for increased expansion ratio nozzles. An expansion ratio of 15 is about the largest size which can be accommodated without interference of the nozzle exits. Such nozzles would serve to reduce base heating and heating of the outboard nozzle as the exit plane is moved aft. Expansion ratios of 17 or 18 could be accommodated if a 6° (.105 rad) cant is maintained on the outboard or first stage motors. Nozzles with expansion ratios greater than 18 would protrude into the first stage exhaust stream. An expansion ratio of 15 would provide a payload increase of about 4 percent with the seven-segment motors. The use of larger expansion ratios on the first stage SRMs is impractical because of motor-to-motor interference, the extended ground support longerons required and the increased loads fed into the aft skirt from the ground supports. Further, the outer motor nozzles cannot be extended without protruding directly into the exhaust jet of the center motor.

Manufacturing and transportation capabilities must be considered when increasing the nozzle expansion ratio. Selection of the current 1207 nozzle extension size, expansion ratio of 9.2, was influenced by the then available hydroclave size. The hydroclave has been required for curing of the nozzle ablative plastic liner at high pressures 1,000 psig (6.89 MN/m^2) . Recent experience has shown that autoclave cured parts, at pressures of 180-200 psig (1.24-1.36 MN/m^2), are adequate for use at high area ratio locations in nozzle extensions. Autoclaves are available up to 32 feet (9.75m) in diameter. Increasing the expansion ratio to 15 would mean an increase in diameter of 34 inches (.865m) to about 165 inches (4.2m) and an increase in length of about 45 inches (1.14m). The exit cones for the Aerojet 260-inch (6.6m) diameter test motors were 118 inches (3.0m) long and 180 inches (4.57m) in diameter. These exit cones were autoclave-cured at 190 psi (1.31 MN/m^2) and performed acceptably. The 165-inch (4.2m) diameter exceeds the 156-inch (3.96m) size which has been considered to be the largest size which is rail transportable. A rail route might be found to accept this oversize nozzle. The alternate modes of shipping would be by truck with oversize permits required or by air with aircraft such as the Super-Guppy.

4.8 DESIGN RECOMMENDATIONS

The above discussions of the relative merits of the TECHROLL seal and LITVC systems can be summarized in an advantage-disadvantage style of matrix. Such a matrix is presented in table XI to aid in recommendation of an optimum system. Consideration of these criteria leads to selection of the TECHROLL seal nozzle TVC system. Evaluation of the nozzle tradeoff discussion of Section 4.7 leads to the following recommendations: (1) A nozzle expansion ratio of 15 should be used on the second stage SRMs as allowed by manufacturing limitations: (2) The first stage SRMs should maintain the current 1207 expansion

TABLE XI

LITVC/TECHROLL SEAL NOZZLE TRADEOFF MATRIX

Parameter	LITVC System	TECHROLL Seal Nozzle	Comments
Steering performance	+	+	Both systems have adequate capability for Titan requirements. Shuttle booster application may demand TECHROLL seal capability.
Physical arrangement cluster packaging		+	Problem with LITVC packaging only on 4 + 1 and 5 + 1 configurations
Nozzle clearance	+		LITVC system is simpler to analyze. Either system is workable.
Weight and vehicle performance		+	5% increase in vehicle payload with TECHROLL seal nozzle.
Service and checkout		+	
Reliability	+		A detailed design and failure mode analysis of the TECHROLL seal design should be developed prior to serious reliability evaluation
Cost		+	9% reduction in recurring cost as reported in section 7.0.

ratio of 9.2. (3) A zero cant angle should be utilized on all stages as allowed by nozzle clearance restraints. (4) Stage one nozzles should be canted outboard the minimum amount to provide clearance under deflected conditions when cluster geometry creates nozzle interference because of the zero cant angle. (5) The zero cant angle TECHROLL seal design with large deflection angle as reported in Section 3.1.1 or 3.1.3 is recommended for use. (6) Actuator null settings would be selected to provide the appropriate cant angle. Thus, the TECHROLL seal could operate at a deflected position as the null position.

5.0 CLUSTERED STAGE STUDIES

Six configurations of parallel staged 120-inch (3.05 m) solid rocket motor boosters were examined as stages one and two of a 3 stage launch vehicle. An "optimum" clustering arrangement and structure were conceived to take maximum advantage of existing design Titan attach structure and SRM motor case strength. Six combinations of first and second SRM stages were examined. The combinations studied, listed here,

First Stage	Second Stage
2 SRMs	1 SRM
3 "	1 "
4 "	1 "
5 "	1 "
4 "	2 SRMs
5 "	2 "

can be assembled into vehicles with an S-IVB third stage with payload capabilities of about 50,000 (22,600 kg) to 110,000 (50,000 kg) pounds into a low earth orbit.

Attach structure concepts were developed for each of the clustered arrangements utilizing the central or second stage SRMs as a load bearing core. An objective of the study was to provide a structural concept which maximized the commonality of structural components between all vehicle configurations. The first stage SRMs are attached to the sides of the core SRMs in the manner of the current Titan stage 0. Thrust and ground loads are transmitted from the base of stage one to the base of stage two and up through stage two to the upper stages. Adapter sections or payload above stage two were not included in this study. The attach structures conceived have weight penalties ranging from 0 to 5,000 pounds (2,260 kg) above standard 1205 or 1207 SRM structure weights.

Examination of the base heating environment of the most severe 5+1 configuration reveals heating rates significantly greater than on the Titan. An estimated 0.6 inches (1.5 cm) of Dow Corning silicone insulation would be required for protection. The added weight of insulation would be in the range of 300 pounds (136 kg) per SRM. The analysis performed was of a simplified nature and utilized conservative assumptions. Conduct of a detailed analysis with more precise data offers the promise of reduced insulation requirements. The requirements would, of course, be less severe for other configurations.

Cursory examination of staging, thrust termination, separation motor and ordnance requirements indicate workable techniques with current Titan designs. The implementation of a successful thrust termination system would require careful attention to debris and exhaust removal and will create a penalty to the upper interstage structure design.

5.1 CURRENT 1205 AND 1207 ATTACH METHOD

Cluster configuration for a Titan III vehicle is the "strap-on" where the solid rocket motors forming the first stage are mounted on the side of the second stage rather than behind it. All thrust and ground loads are transmitted to the bottom of the core section. The Titan III-C general arrangement drawing of figure 48 illustrates the interrelation of the SRM and core and the various load paths. The various Titan SRM structural components were depicted in figure 1 (section 2.0).

The SRM attachment structure consists of an aft support skirt, a forward

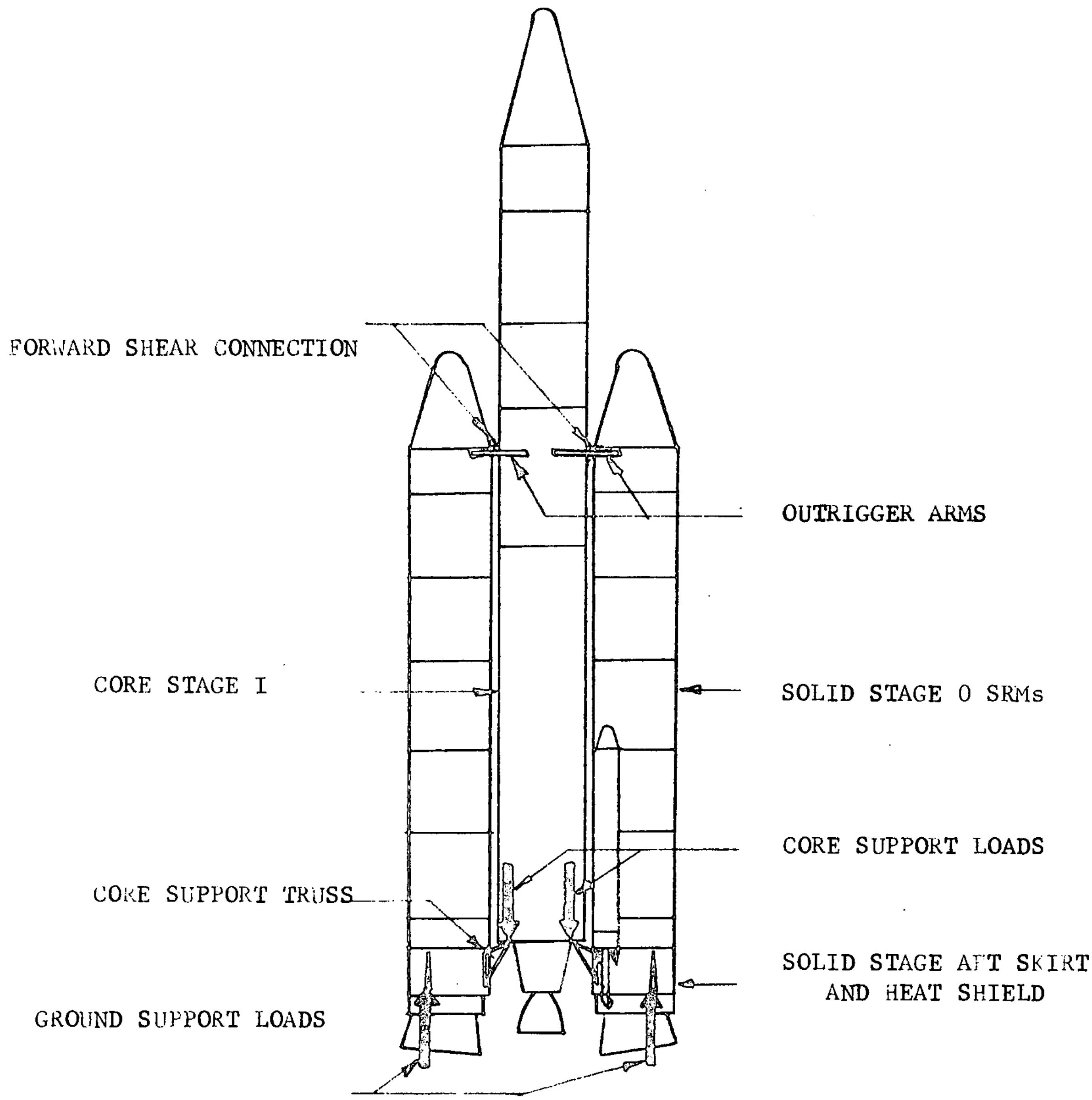

Figure 48. General Arrangement of the Titan III-C

attach ring and forward attach fittings and outrigger arms. The primary functions of the aft support skirt are to support the SRM prior to attachment to the vehicle, to support the vehicle on the ground, to transmit the propulsive thrust and other axial loads from the SRM to the second stage, to provide the aft reaction for second stage lateral loads and moments, and to provide correct flexibilities between SRM and second stage to insure vehicle structural integrity under load. Secondary functions of the aft support skirt are to provide support and/or environmental protection for some subsystem components.

The aft support skirt consists of a ring stiffened, semi-monocoque, cylindrical shell to which truss structures are attached extending from the side of the shell. At the apex of each truss is a ball fitting which mates with a socket on the second stage to provide the aft interface between the stages. The ball and socket are held together by an explosive bolt which is fired during staging. This bolt is mounted in an oversize hole to allow relative rotation of the ball and socket. The aft support skirt also employs three forged longerons with a ball and socket for its ground interface. There are three ground support points used during erection and two (per SRM) after the vehicle is assembled. The aft support skirt interfaces with the motor case by means of a clevis ring which mates with the aft closure and is attached with shoulder bolts.

The aft support skirt is designed not only to have sufficient strength to insure its structural integrity under load, but also to have flexibility and load distribution characteristics that preclude it from causing failure of structures with which it interfaces.

The reactions between the forward end of the first stage* SRMs and the second stage are taken out by the forward attach ring, fittings and outrigger arms. The forward attachment transmits lateral loads only (all axial loads are transmitted through the aft attachment). The forward attachment provides for relative axial motion between SRM and second stage to accommodate manufacturing tolerances and growth of the SRM resulting from pressurization.

The attachment fittings consist of a shear fitting and outrigger arms and clevis fittings. Spherical bearings are employed where the outrigger arms attach to the clevis fittings so that rotation is possible about two mutually perpendicular axes with the joints functioning as universal joints. The outrigger arms react inboard and outboard radial loads (i.e., loads acting toward or away from the second stage) and torques about any axis parallel to the vehicle longitudinal axis. The outrigger arms rotate up or down on their universal joints to accommodate the relative axial movement between SRM and second stage. These arms are attached to the second stage with explosive bolts which are fired during staging. After the explosive bolts are fired, the arms are swung out of the way (toward the SRM) by means of spring-loaded actuators.

The other lateral reaction (tangential) is transmitted by a shear fitting. The shear fitting consists of a block which slides between two plates. The block is mounted on a ball and socket joint to accommodate angular misalignment. This fitting allows relative motion of SRM and second stage in the

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* In the Titan family applications the SRMs are designated as the zero stage since the two core stages retain their first and second stage designations applicable to their original roles in Titan I and II vehicles.

axial and radial directions. The radial motion feature is necessary because the outrigger arms provide for relative axial motion by swinging through an arc, which results in changing the radial distance between SRM and second stage. During staging the block merely slips out from between the plates as there is no radial restraint.

The shear fitting, the clevis fittings for the outrigger arms, and the spring-loaded actuator attach brackets are bolted to the forward attach ring. The forward attach ring transmits these loads to the SRM forward closure and also distributes these concentrated loads in a manner that does not jeopardize the structural integrity of the motor case. The forward attach ring is a clevis ring which slips over the mating clevis on the forward closure of the SRM, and the two are attached with shoulder bolts. The forward end of the forward attach ring mates with the SRM nose cone, and the ring provides a load path between nose cone and SRM.

5.2 ALTERNATE STRUCTURAL DESIGN APPROACHES

5.2.1 Arrangement of SRMs for Configurations under Study

The clustered stage configurations studied are those listed in the work statement and are as follows:

SRMs in Stage I	SRMs in Stage II
2	1
3	1
4	1
5	1
4	2
5	2

For the configurations using a single SRM for the second stage, the cluster arrangement selection appears straightforward. The Stage I SRMs are merely arranged in an axisymmetrical fashion about the Stage II SRM. This arrangement appears to be the optimum for compactness, symmetry of mass and thrust distribution, ease of attachment and staging.

The 4+2 configuration uses a rectangular cluster arrangement with 3 rows and 2 columns. This arrangement is compact, provides symmetry of mass and thrust distribution, simplifies attachment design and facilitates staging. (The 2 SRMs in the center row are the Stage II SRMs.)

The arrangement selected for the 5+2 configuration clusters the five Stage I SRMs around the 2 Stage II SRMs in a manner that is geometrically symmetrical about one axis only but provides symmetry of mass and thrust distribution. This yields a compact cluster arrangement and results in a simplified attachment design. An alternate arrangement was considered for the 5+2 configuration which consisted of clustering the 5 Stage I SRMs around the 2 Stage II SRMs so that the entire arrangement is axisymmetrical. This eliminates the disadvantages of the selected method and provides symmetry of mass and thrust distribution but provides a large diameter vehicle and requires a complicated attachment design to transmit the loads over the relatively long distances involved.

5.2.2 Alternate Structural Design Approaches for the Selected Cluster Arrangements

At the outset of this study the philosophy adopted was to minimize non-recurring expenditures. This philosophy is believed to be consistent with the overall goal of an interim program which is to assemble existing hardware into new vehicle configurations in order to fill a gap in payload capabilities, and to accomplish this with minimum development costs.

The design approaches investigated use as much of the existing attach structure as possible. Following this approach, the Titan III aft support skirt design was considered for use on Stage I SRMs with modification only as required to transmit the possibly higher structural loads. This skirt design was investigated also for possible use on the Stage II SRM. To achieve adequate distribution of concentrated axial loads of large magnitudes, it is necessary to utilize nearly the full length of the skirt. Thus, the concentrated axial loads must be introduced near the aft end of the support skirt. Two concepts satisfying this requirement were investigated.

The first concept employed a Titan type aft support skirt for the Stage II SRM(s) with one set of truss arms for each Stage I SRM which attaches to it. The Stage I and Stage II SRMs would then interface truss to truss with the existing ball fittings on the Stage I trusses and new socket fittings on the Stage II trusses. The trusses alluded to are existing Titan hardware (strengthened as required) and have the members oriented so that most of the axial load is introduced near the aft end of the support skirt. It was found that there is sufficient room to attach only two Stage I SRMs to a Stage II SRM. This attachment method also has the undesirable effect of separating the Stage I SRMs from Stage II by a rather large distance (as compared to the Titan vehicle).

The second concept employs longitudinal displacement between the first and second stages with the second stage moved forward relative to the first. This allows the aft end of Stage II to line up with the ball fittings on the Stage I support skirt. This method also lends itself to the use of a thrust collector structure which picks up the ball fittings on each Stage I SRM and introduces these loads to the aft end of the Stage II support skirt(s). The thrust collector concept permits more compact clustering of SRMs and does not limit the number of Stage I SRMs which can be clustered around a Stage II SRM.

The longitudinal displacement between Stage I and Stage II SRMs that results when the thrust collector concept is used has both advantages and disadvantages.

On the positive side, it simplifies the problem of designing an interstage structure to go between Stages II and III because the displacement has moved this interstage farther forward from the Stage I SRM nose cones which it must clear. This is helpful also during thrust termination of Stage I when thrust termination port covers and exhaust plume must clear the interstage structure.

Disadvantages are that the Stage I aft support skirts must support the entire vehicle weight (the Stage II SRM aft support skirts cannot be used for ground support) and phased ignition creates serious exhaust plume impingement problems.

If the thrust collector concept is employed, the Stage II aft support skirt can use much of the Titan III hardware. The existing ring frames are used, the chemically milled skins are replaced with constant thickness skins, and the only longitudinals employed are inboard ground support longerons and stringers. One inboard ground support longeron with its set of two stringers is required for each Stage I SRM that attaches to the Stage II support skirt.

Rather than blindly pursue the philosophy of utilizing existing hardware, an investigation was made into simplifying the design of the Stage II aft support skirt. It was believed that such an investigation has merit because the Stage II support skirt mounted on a well designed thrust collector structure does not see the eccentricity of loading to which a Titan support skirt was designed. Such a design would consist of a constant thickness skin with light internal rings and extruded or formed hat section external stringers. Eliminated are the heavy and expensive longeron, ground support and H ring frame forgings. The feasibility of this approach depends on how evenly the thrust collector structure distributes loads from Stage I to the Stage II support skirt(s).

The forward attachments must allow relative axial movement between the stages but must transmit lateral loads. Various methods for accomplishing this have been employed by UTC. On small motors, dovetail fittings or clamps with elastomers between them and the motor case have been successful. These methods do not appear feasible on 120-inch (3.05 m) SRMs, however. These motors require a three-point support such as used on the Titan. The Titan forward attachment utilizing two outrigger arms and a shear fitting for each SRM has proven to be very successful on the 120-inch (3.05 m) SRM.

5.3 PRELIMINARY STRUCTURAL DESIGN CONCEPT

The arrangement of SRMs for the various cluster configurations was discussed in section 5.2.1. Design layouts were prepared to determine the spacing that would be required for the SRMs and their subsystems. It was decided to cluster the SRMs as close together as possible to reduce the size, weight, complexity and cost of attach structures and to reduce the pad size requirements.

Additionally, reducing the size of the cluster probably results in a reduction of aerodynamic drag. On the other hand, close spacing aggravates aerothermodynamic problems. Thermal insulation will be employed as required to circumvent these problems.

The attach structure required was roughed in starting with the various arrangements of known components. It is not within the scope of this phase of the study to provide detail design of the attach hardware, although preliminary sizing of major structural components was performed to demonstrate the feasibility of the concepts. Sizing of components requires load information so the problem of determining loads was examined to determine the extent of information that would be obtainable in the manhours available for this phase of the study. Using the weight information and known thrust versus time curves for the 1207* motor, it was found that the static ground loads, the loads at launch, and the loads at maximum acceleration were readily obtainable. It was also determined that accurate estimates could not be made of bending moments resulting from thrust vector control or lateral aerodynamic loads.

To establish the upper limit of bending moment resulting from thrust vector control application, maximum TVC side force for five SRMs was applied to the 5+1 configuration using as a moment arm the approximate distance from the TVC line of action to the center of gravity of the cluster. It was found that if the running normal load resulting from the bending moment is added to that from maximum acceleration, the design allowable for the Stage II motor case is

* This study assumes that 1207 motors are used. 1205 motors may also be substituted. 1207 motors were used in the study because of their higher attach structure design loads.

exceeded. However, the magnitude of the excess is within the range that would be anticipated from inertia load relief. No major problems are anticipated in this area inasmuch as relatively minor modifications to the Stage II motor case can result in significant increases in the magnitude of external loads that it is capable of withstanding. On Stage I, the bending moment problems are less severe and no problems are anticipated.

Some tentative sizing of members was performed on the Stage II aft support skirt. A design criteria selected for this skirt was that it have axial load and bending moment capability equal to or greater than the unmodified Stage II SRM motor case.

Another significant load condition occurs when ground wind loads are superposed on static ground loads. The Titan vehicle uses the outboard ground supports on the Stage I SRMs to react these loads but the configurations presented in this study are not designed to react wind loads in this manner. Because of the large size of the vehicles considered which results in large bending moments generated by the wind, use of the Titan system of reacting ground wind loads would result in an excessive inert weight penalty. Therefore, the designs presented require that the vehicles be sheltered from the wind while on the ground or that they have some sort of forward lateral restraint. The later technique is currently employed on the Saturn vehicle.

A preliminary loads analysis was completed and yielded the following results:

If the Titan aft support skirt is used on the Stage I SRMs, all configurations require strengthening of the core support trusses. Accomplishing this should not cause a significant price increase as compared to Titan hardware.

The distribution of loads from the Titan support skirt to the Stage I SRM motor case causes failure of the latter for the static ground condition for all configurations except the 5+1. All configurations examined are adequate for flight loads although the 2+1 is marginal for the maximum acceleration condition. Failure due to ground loads is based on using only the outboard ground supports to support the vehicle on the ground. If the existing inboard ground support longeron is used in addition, the problem is greatly reduced, although minor modifications to the skirt or motor case might be required. The exception to this is the 2+1 configuration which requires at least eight ground support pick up points.

A general description of the structural design of each of the configurations follows.

2+1 Configuration

This configuration, figure 49, uses standard Titan hardware on the first stage except that the core support trusses on the support skirts are strengthened. The second stage uses an SRM with a straight nozzle and a modified Titan support skirt. This skirt has an extra set of core support trusses. The ball fittings at the apexes of the trusses are replaced with socket fittings which mate with the ball fittings on the Stage I support skirt trusses. This arrangement does not use a thrust collector structure and has the advantage that vehicle stations for the Stage II SRM correspond with those on the Stage I SRMs. This facilitates the addition of ground support longerons because all ground support points will be in the same plane. This arrangement also allows phased ignition.

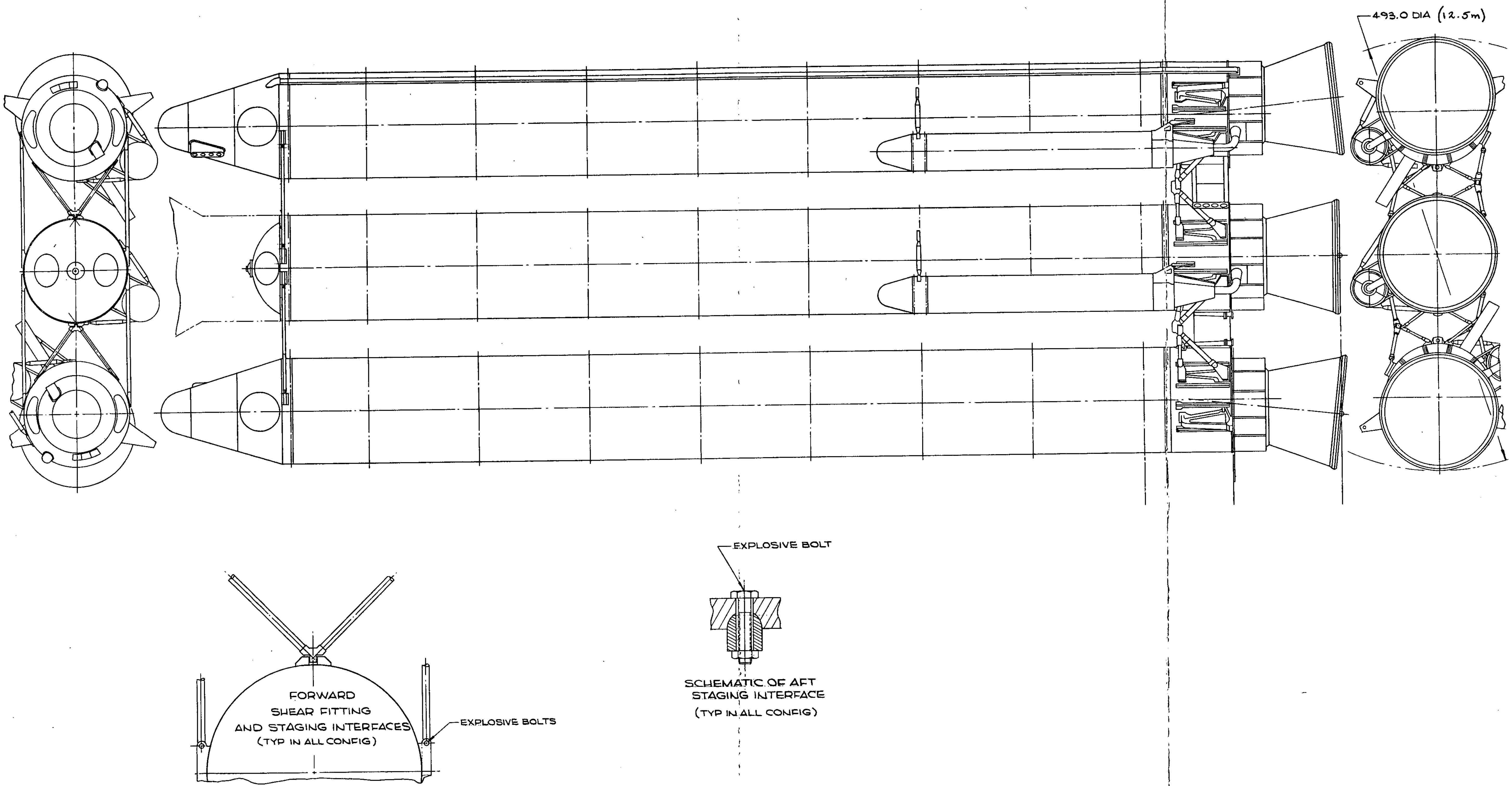

Figure 49. Configuration of 2 + 1 SRM Cluster

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Two ground support longerons are used on the Stage II SRM. These two ground support points, together with the three existing ones on each Stage I SRM, give the required eight ground support points.

Forward attachment uses the Titan concept which provides a three-point support consisting of two outrigger arms and a shear fitting. Stage I uses the Titan nose cone, Titan forward attach ring and forward outrigger brackets. Stage II uses the Titan forward attach ring and outrigger brackets. The outrigger arms between the stages are tangential to the SRMs. Stage II uses the Titan female shear fitting while Stage I has a new male shear fitting mounted at the apex of two struts whose other ends are attached to the Stage I SRMs' forward attach ring. The SRMs could be mounted so the Titan geometry is maintained at the forward end. Stage I/Stage II aft staging interfaces are the ball and socket joints at the apexes of the trusses on the support skirts while the forward staging interfaces are between the male and female halves of the shear fittings and between the outrigger arms and the outrigger attach brackets on the Stage II SRM. (See figure 49.)

<u>3+1 Configuration</u>

This configuration, figure 50, uses the thrust collector concept with the Stage II SRM staggered forward of Stage I. The amount of the stagger is such that the forward attach rings of the Stage I SRMs are at the same vehicle station as the joint between the forward closure and the first segment of the Stage II SRM. An external ring is added to Stage II at this segment joint to serve as a forward attach ring. The forward attachment is similar to that used on the two and one.

The thrust collector structure is merely a network of beams which picks up

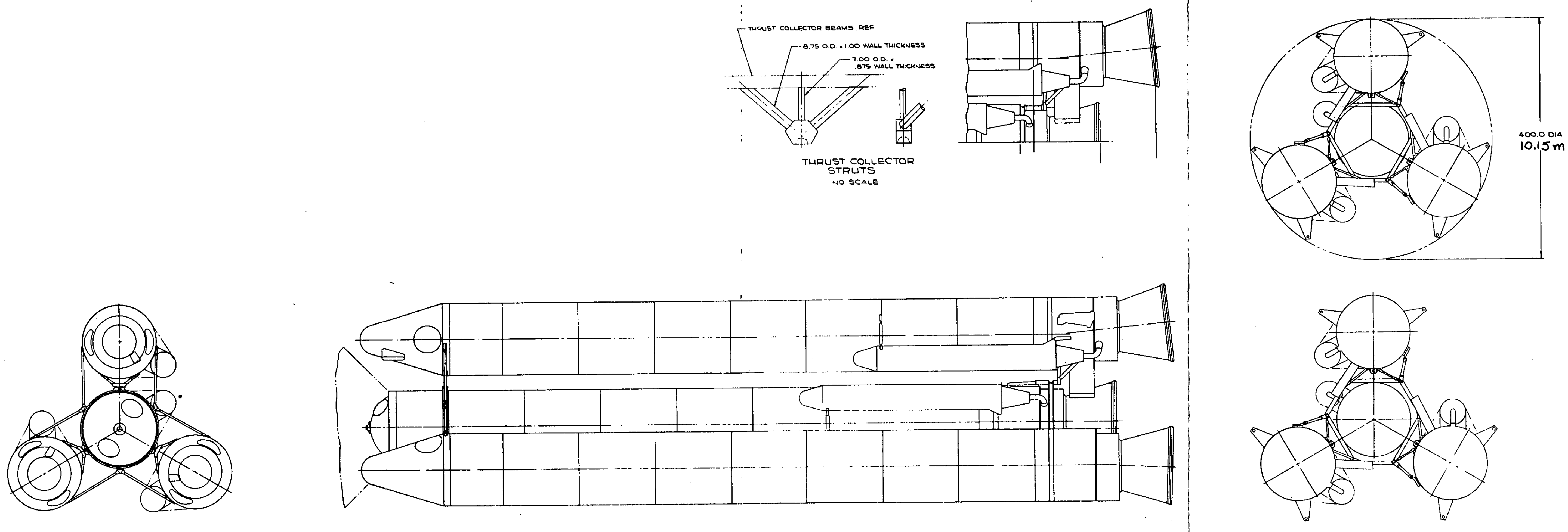

Figure 50. Configuration of
3 + 1 SRM Cluster

FOLDOUT FRAME

FOLDOUT FRAME 1

FOLDOUT FRAME 2

thrust loads from the ball fittings of the Stage I SRM support skirts and transfers these loads to the Stage II support skirt. Preliminary sizing indicated that a section modulus of about 200 inches cubed ($3.28 \times 10^{-3} m^3$) is required if the beams are high strength steel. This size was not calculated specifically for the 3+1 but was selected to work for all configurations. Thus, further studies might show that considerable weight reduction in the thrust collector structure is possible for some configurations. It is expected that the weight of the beams in the thrust collector structure will be approximately 100 pounds (45 kg) per linear foot.

The thrust collector structure for the 3+1 configuration has a rather large contact area with the Stage II support skirt. Therefore, a simplified support skirt as described in section 5.2.2 is used. For further details of this support skirt, see figure 51. Forward staging interfaces are the same as the 2+1 configuration. Aft staging interfaces are between the Stage I SRM ball fittings and the thrust collector structure. The latter flies with Stage II.

<u>4+1 Configuration</u>

This configuration, figure 52, is similar to the 3+1 except that the contact area between the thrust collector structure and the Stage II support skirt is reduced. This necessitates the use of a modified Titan Stage II support skirt. This skirt uses the Titan inboard ground support longerons to pick up the load from the thrust collector structure at each point of contact. The punch loads from these longerons are reacted by the large H section Titan support skirt main ring frames. These punch loads are characteristic of the Titan support skirt which introduces axial loads to these longerons outboard of the skin centerline, thus giving rise to bending moments.

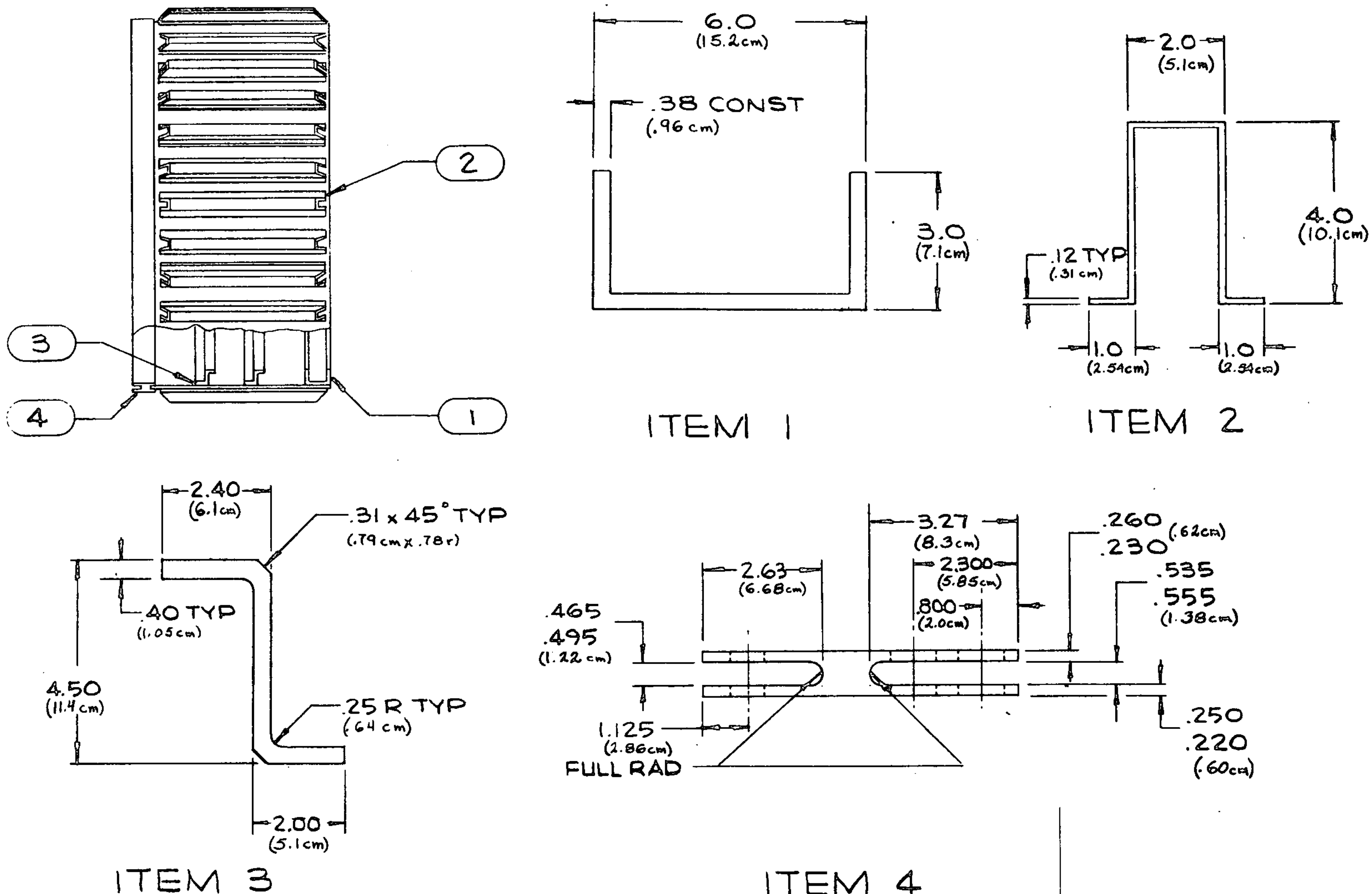

Figure 51. Simplified Aft Support Skirt for Stage II

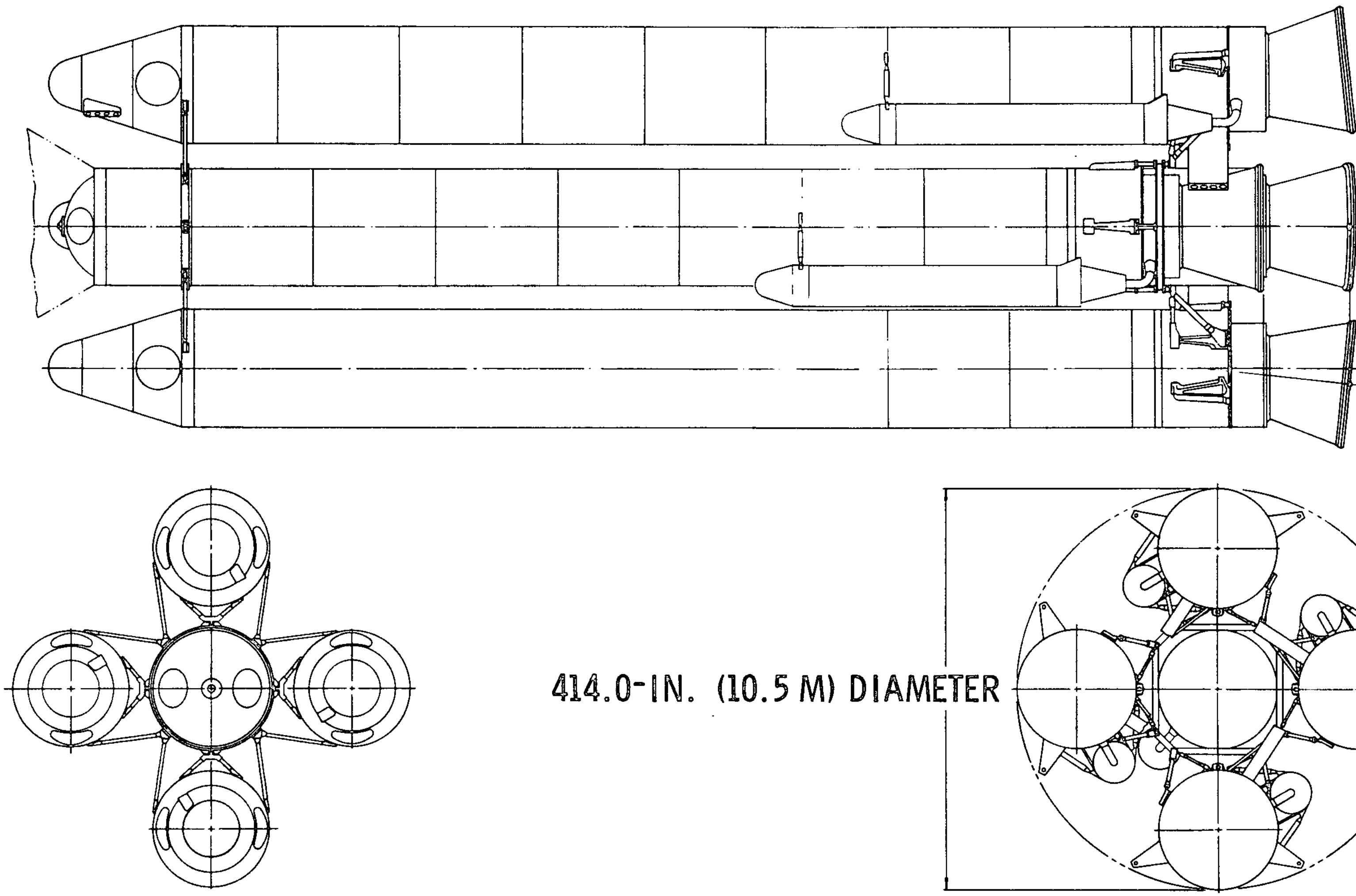

Figure 52. Configuration of 4 + 1 SRM Cluster

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5+1 Configuration

This configuration, figure 53, is essentially similar to the 4+1 in structural design concept.

4+2 Configuration

This configuration, figure 54, is somewhat like the 3+1 in structural design concept and uses simplified Stage II aft support skirts and thrust collector structures which provide excellent load distribution to these skirts. The Stage II-III interstage structure is used to collect the longitudinal loads from the two Stage II motors and maintain their longitudinal alignment. The 4+2 configuration has the largest contact area between the thrust collector structures and the Stage II support skirts. One thrust collector structure is built around each Stage II SRM and the two structures are linked together to transfer lateral loads. Each thrust collector structure has two Stage I SRMs connected to it and adjacent Stage I SRMs have spreader struts fore and aft to prevent them from colliding during staging. Stage I and II SRMs are close enough together so that struts are not required on the forward shear fitting.

5+2 Configuration

This configuration, figure 55, uses the structural design concepts of the 4+2 configuration although the thrust collector structure acts more like a single unit than as two independent units as on the 4+2 configuration. Independent thrust collectors connected with pin jointed links permit relative axial travel between the two Stage II SRMs which is useful for accommodating manufacturing tolerances. However, this can also be accomplished by shimming. Since the Stage II SRMs are pressurized simultaneously, it is not necessary to allow for relative axial growth due to pressurization of the Stage II SRMs. Therefore, a single piece rigid thrust collector structure is employed for this configuration.

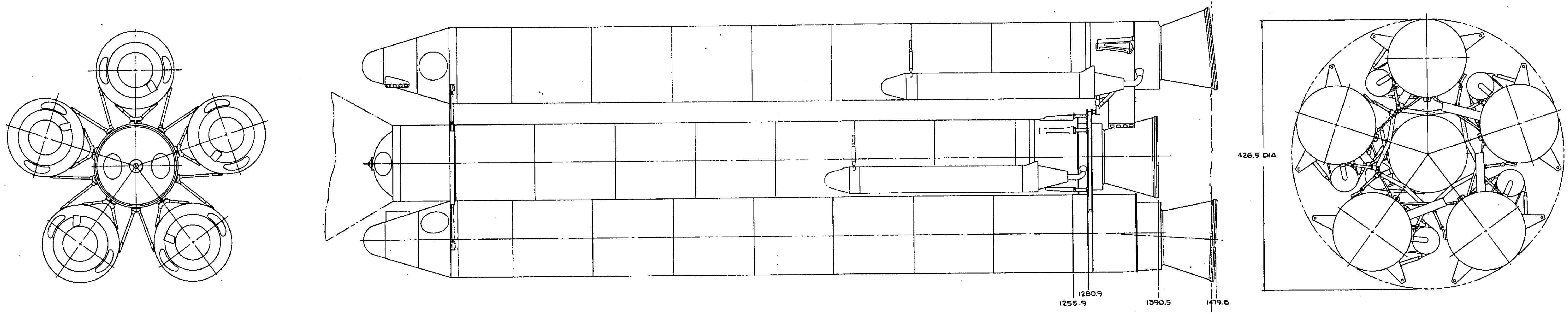


Figure 53. Configuration of
5 + 1 SRM Cluster

FOLDOUT FRAME 1

FOLDOUT FRAME 2

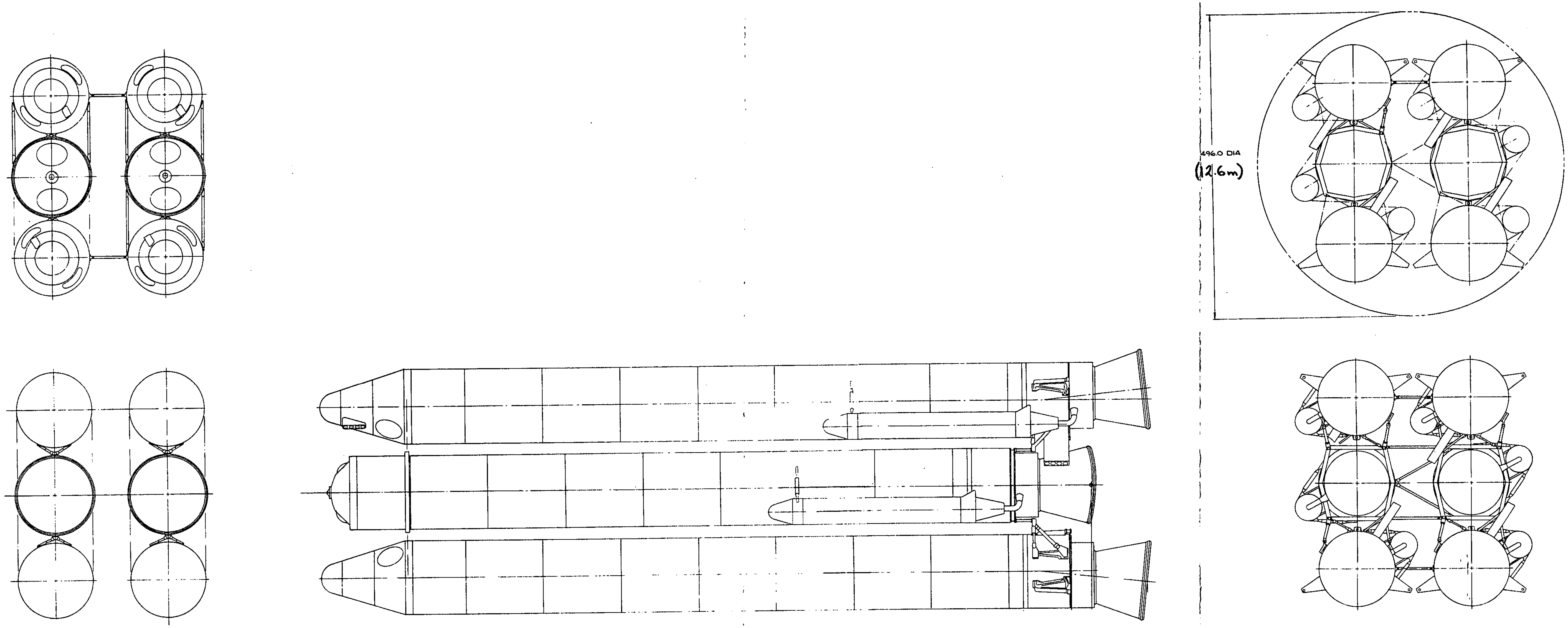


Figure 54. Configuration of
4 + 2 SRM Cluster

FOLDOUT FRAME 1

FOLDOUT FRAME 2

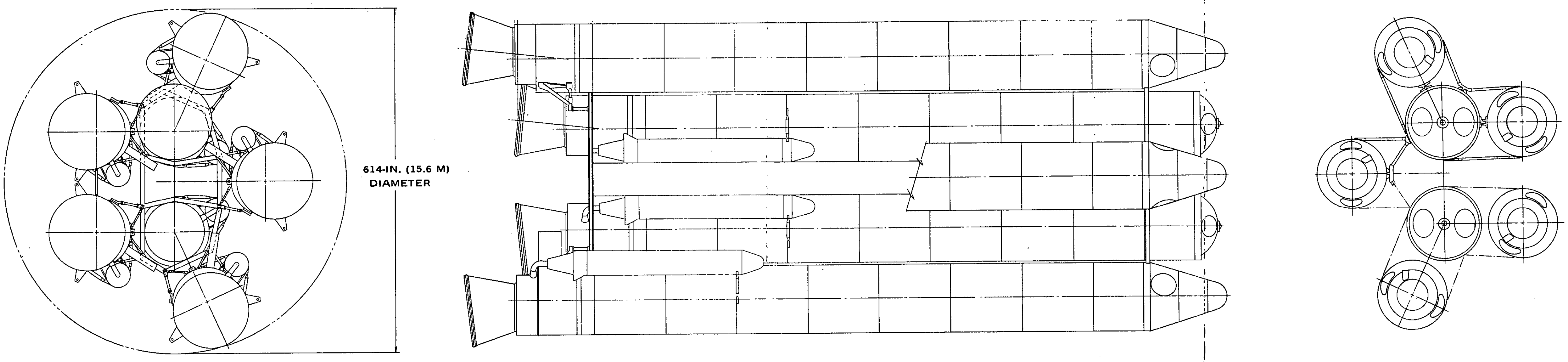


Figure 55. Configuration of 5 + 2 SRM Cluster

FOLDOUT FRAME 1

FOLDOUT FRAME 2

5.4 BASE HEATING ANALYSIS

A preliminary analysis was performed to determine the amount of thermal insulation necessary to protect the base region of a cluster of six UTC 1207 solid rocket motors (shown in figure 55) from recirculation and radiative heating resulting from the interaction of their aluminum-oxide laden exhaust plumes. The cluster of six motors was judged to be the most severe arrangement of those studied because the distances between nozzles are minimum, and the plumes can interact seriously even at low altitudes. Of the six motors in the cluster, the five circumferentially positioned motors were assumed to fire in unison and the center motor was assumed to fire after staging of the first five motors.

5.4.1 General Qualitative Description of Problem

The base flow phenomena causing recirculation heating is attributable to the turbulent mixing occurring between the free-stream air and the exhaust plumes. If the plumes do not intersect, the plumes pull free-stream air into the base region. Plume intersection, however, causes a pressure rise due to shock waves resulting from the intersection. A portion of the gas in the turbulent mixing zone cannot overcome the increased pressure and is turned toward the base region where it is turned and accelerated to ambient pressure. The back flow may be of such a magnitude so that choking results at the smallest flow area. The recirculation gases have a recovery temperature dependent on the amounts of free-stream air and exhaust gas mixed and cause significant convective heating of the base region. The magnitude of the convective heating is strongly dependent on vehicle trajectory and geometry.

Besides recirculation heating the base region is also subjected to radiation heating from the exhaust plumes. The aluminum-oxide in the plumes is the primary contributor, while the gaseous components are of negligible importance. It has been UTC's experience that the emissive power of a plume can be found by using the static temperature at the nozzle exit and the Beer's Law emissivity of the aluminum-oxide particles. However, for plumes which have been affected by N_2O_4 liquid thrust vector control, the emissive power is considerably greater because of the increased plume temperature. Reference 1* gives the emissive power of a 1207 plume as a function of time based on 1205 flight data. The magnitude of radiative heating at a particular point in the base region is strongly dependent on view factor which is in turn dependent on vehicle trajectory and geometry.

Therefore, since both convective and radiative heating are both strongly dependent on vehicle trajectory and geometry (both of which have not been strictly defined) and because of the analytical difficulties involved, this analysis must be considered preliminary. The cluster of six motors with five firing simultaneously was analyzed because it appeared to be the most severe.

5.4.2 Radiation Heating Analysis

Reference 1 was used to establish the emissive power at the exhaust plumes. A constant value of 0.278 Btu/in.^{2}sec. (455 kW/m^2) for the entire 130 second firing was chosen even though the reference suggests that for the last 65 seconds the emissive power drops linearly to 0.139 Btu/in.^{2}sec. (227 kW/m^2). This drop is probably due to plume expansion with resultant lessened emissivity at higher altitudes. The constant 0.278 Btu/in.^{2}sec. (455 kW/m^2) value was chosen because it was felt that plume expansion would not result in lessened emissivity because of the intersection of the five plumes resulting in an

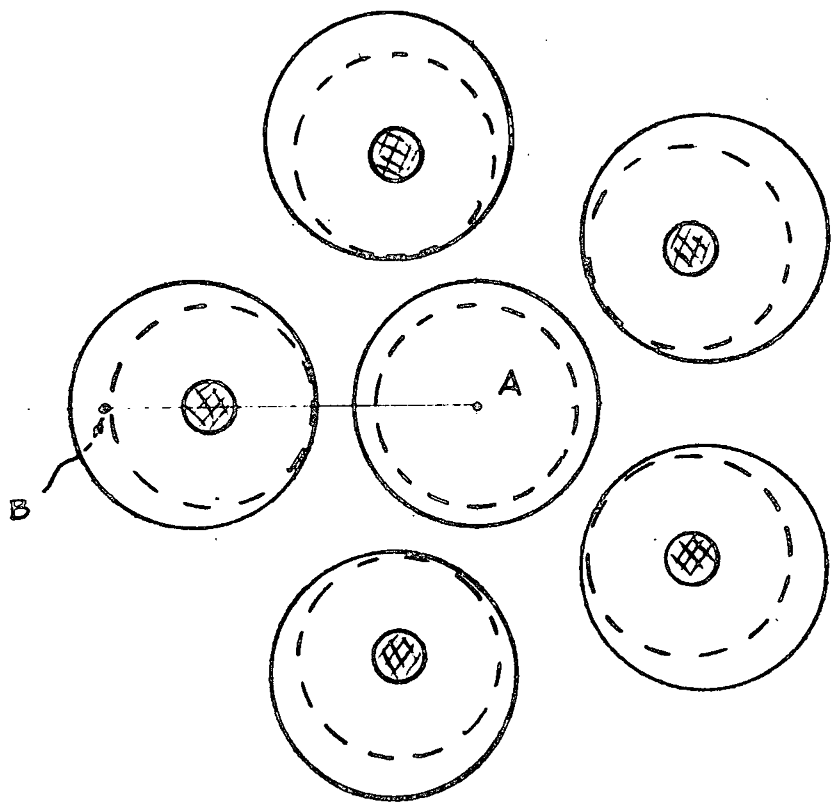
*1. Gee, C., "Determination of Base Heating Thermal Criteria for Titan III/M," UTC Analysis Report 632A-25 increased concentration of aluminum oxide. A view factor of 0.73 for point A shown in figure 56 was calculated assuming conical-shaped plumes with an apex angle equal to the nozzle apex angle. Such an assumption results in an overall combined plume shape having five triangular "daylight windows." The view factor was calculated by integrating over the windows and the other non-plume areas and then subtracting that result from the total spherical field factor of 1. Plume expansion was not accounted for in determining the shape of the windows. The error, however, is small judging from the numbers involved in the calculation. Point B shown in figure 56 has a view factor of 0 and was chosen to represent an extreme relative to point A, which has the maximum view factor.

5.4.3 Recirculation Heating Determination

A worst case stagnation point heating heat transfer coefficient 1×10^{-4} Btu./in.^{2}sec.$^\circ$F (91 W/m^2 $^\circ$k), and recirculation gas temperature, 2500°F (1640°k), were calculated from the experimental data presented in reference 2.* The data are from a subscale model with four nozzles on the end of a cylindrical body. As such, the six motor cluster is not exactly modeled. However, it is felt that the data are conservative because the cluster geometry allows more free-stream air to enter the base region and both probably lower the recirculation gas temperature and amount of recirculated gas (lowering the heat transfer coefficient). Furthermore, the large flow area between the clustered motors prevents choking of the recirculated gas and resultant increased heat transfer. The calculated heat transfer coefficient was corrected for the difference between model and actual cluster sizes, about 1:30, using the factor $(1/30)^{1/3}$ as recommended in reference 3.* Using the 1/3 exponent

*2. Musial, N. T. and J. J. Ward, "Base Flow Characteristics for Several Four-Clustered Rocket Configurations at Mach Numbers from 2.0 to 3.5," NASA TN-D-1093, 1961

3. Payne, R. G. and I. P. Jones, "Summary of Saturn I Base Thermal Environment," J. Spacecraft, 1966



AFT VIEW

NOTE: CENTER NOZZLE
HAS HEAT SHIELD
IN PLACE.

Figure 56. UA 1207 SRM Cluster (5 + 1) Showing Points of Thermal Insulation Requirements Analysis

is conservative relative to use of a 1/2 exponent as is indicated in stagnation point heating relationships.

In order to verify the calculated heat transfer coefficient, the method given in reference 4* was used to calculate a recirculation mass flux for the six motor cluster. The mass flux was then used to calculate a heat transfer coefficient for turbulent flow on a flat plate using the method described in reference 4. The resultant heat transfer coefficient 8×10^{-5} Btu/in.^{2}sec.$^{\circ}$F (73 W/m^2 $^{\circ}$k) is comparable to the experimental stagnation heat transfer coefficient, 1×10^{-4} Btu/in.^{2}sec.$^{\circ}$F (91 W/m^2 $^{\circ}$k). It was assumed that this latter coefficient is applicable over the calculated recirculation gas temperature entire base region for the entire firing time of 130 seconds. It is felt that this assumption is conservative.

5.4.4 Insulation Thickness Determination

A one-dimensional heat conduction computer program was used to determine the thermal profile through a one-inch thickness of Dow Corning 93027 insulation material. Cork was found to ablate prohibitively in the environment defined previously. Reference 5* shows that Dow Corning ablates at an insignificant rate in the environment. The Dow Corning was assumed to have an absorptivity of 1 and an emissivity of 0.9.

*4. Rosler, R. S., "Recirculation and Heat Transfer in the Base Region of the Titan III," UTC TM-14-62-U31, 1962

5. Overmier, D. K., "Development of Airframe Heat Protection for a High Performance Sounding Rocket," AIAA

5.4.5 Results

The results of this base heating analysis are shown in figures 57 and 58, plots of the thermal profiles through a one-inch (2.54 cm) thickness of Dow Corning at points A and B are shown in figure 56. It may be seen from the profiles that approximately 0.6 inch (1.52 cm) of Dow Corning insulation results in a backside temperature within about 20^{o}F (10^{o}k) of the initial temperature of 100^{o}F (310^{o}k) regardless of location on the base region. An additional study was made at location A to determine the effects of an increased recirculation gas temperature, 3000^{o}F (1920^{o}k). Again, from figure 59, it is seen than 0.6 inch (1.52 cm) of Dow Corning is adequate. Therefore, it is concluded that 0.6 inch (1.52 cm) of Dow Corning insulation represents a maximum amount of insulation required since it will most probably be possible to allow backside temperatures in excess of 100^{o}F (310^{o}k).

5.5 SUBSYSTEM EFFECTS

5.5.1 Thrust Vector Control System

A discussion of the advantages of LITVC versus movable nozzle TVC using the UTC TECHROLL seal is located in section 3.0 of this report. The structural configuations shown are all based on using the current Titan baseline LITVC. Use of the TECHROLL seal would permit clustering the SRMs closer together for some of the configurations because clearance would not have to be provided for the TVC tanks. Also the thrust collector structure could be simplified because it would no longer have to be designed to clear the injectant transfer tubes(s). Use of the TECHROLL seal would require only minor modifications to the aft support skirts to enable them to react the nozzle actuator loads.

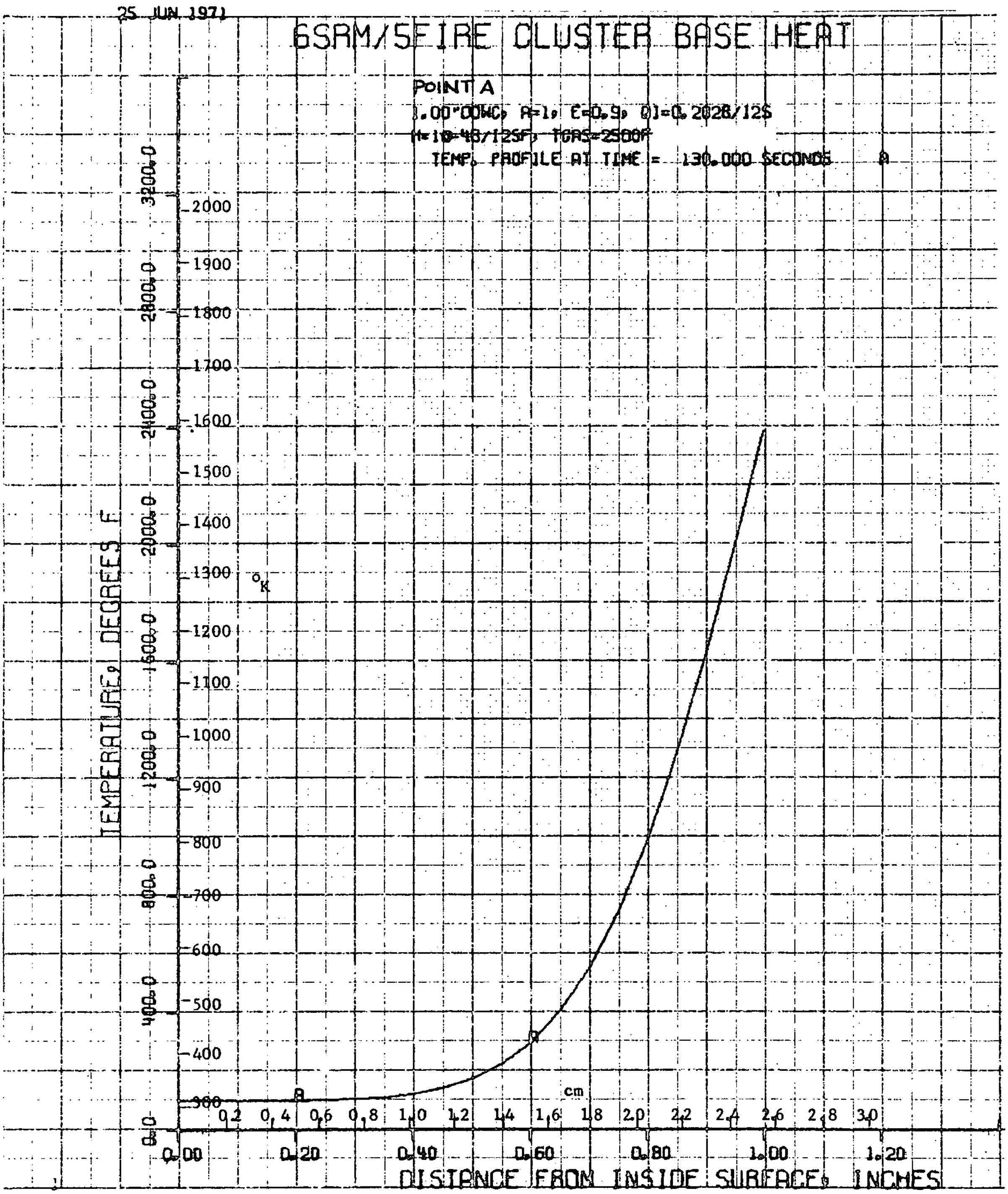


Figure 57. Cluster Insulation Backside Temperature, Central

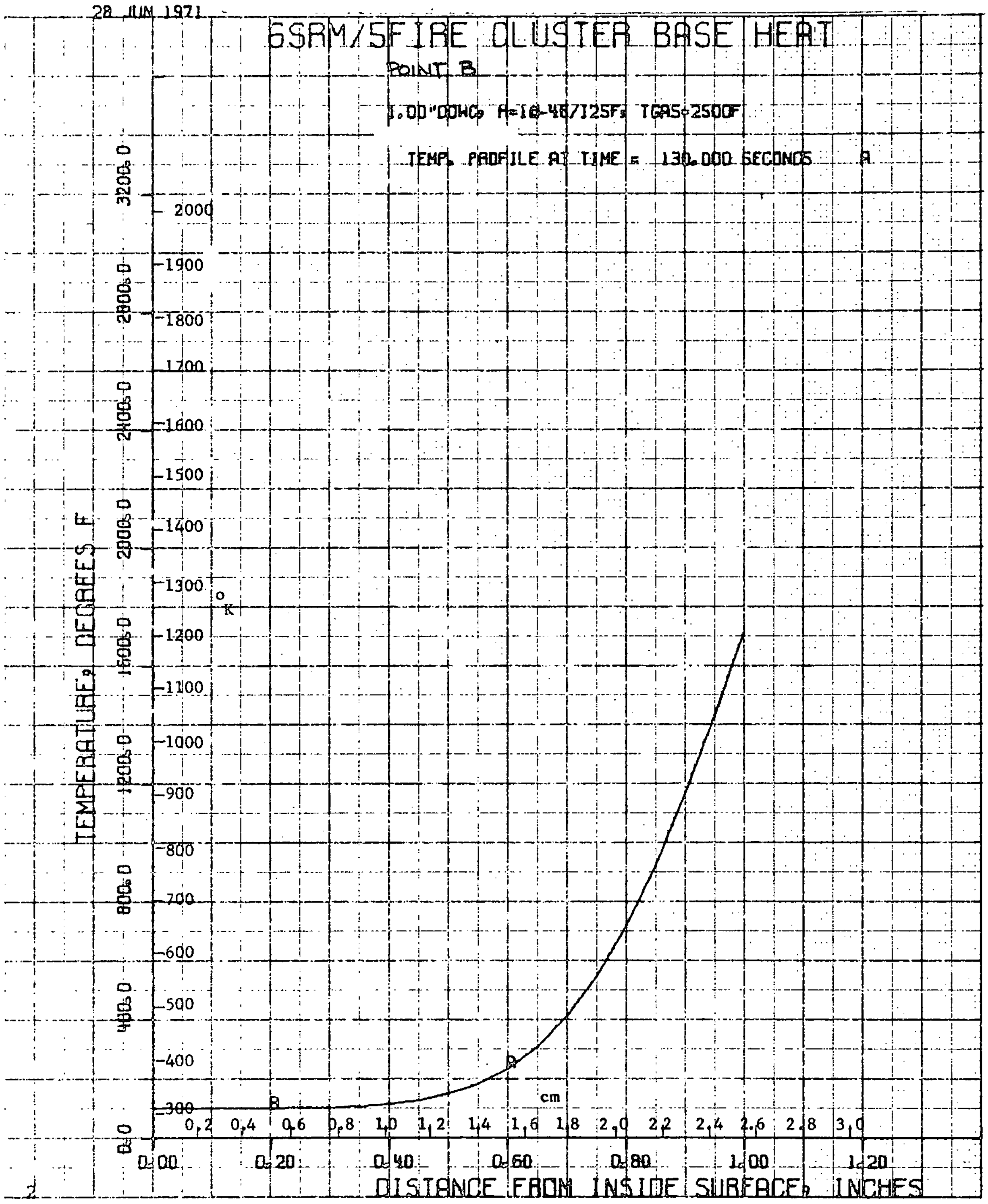


Figure 58. Cluster Insulation Backside Temperature, Outer

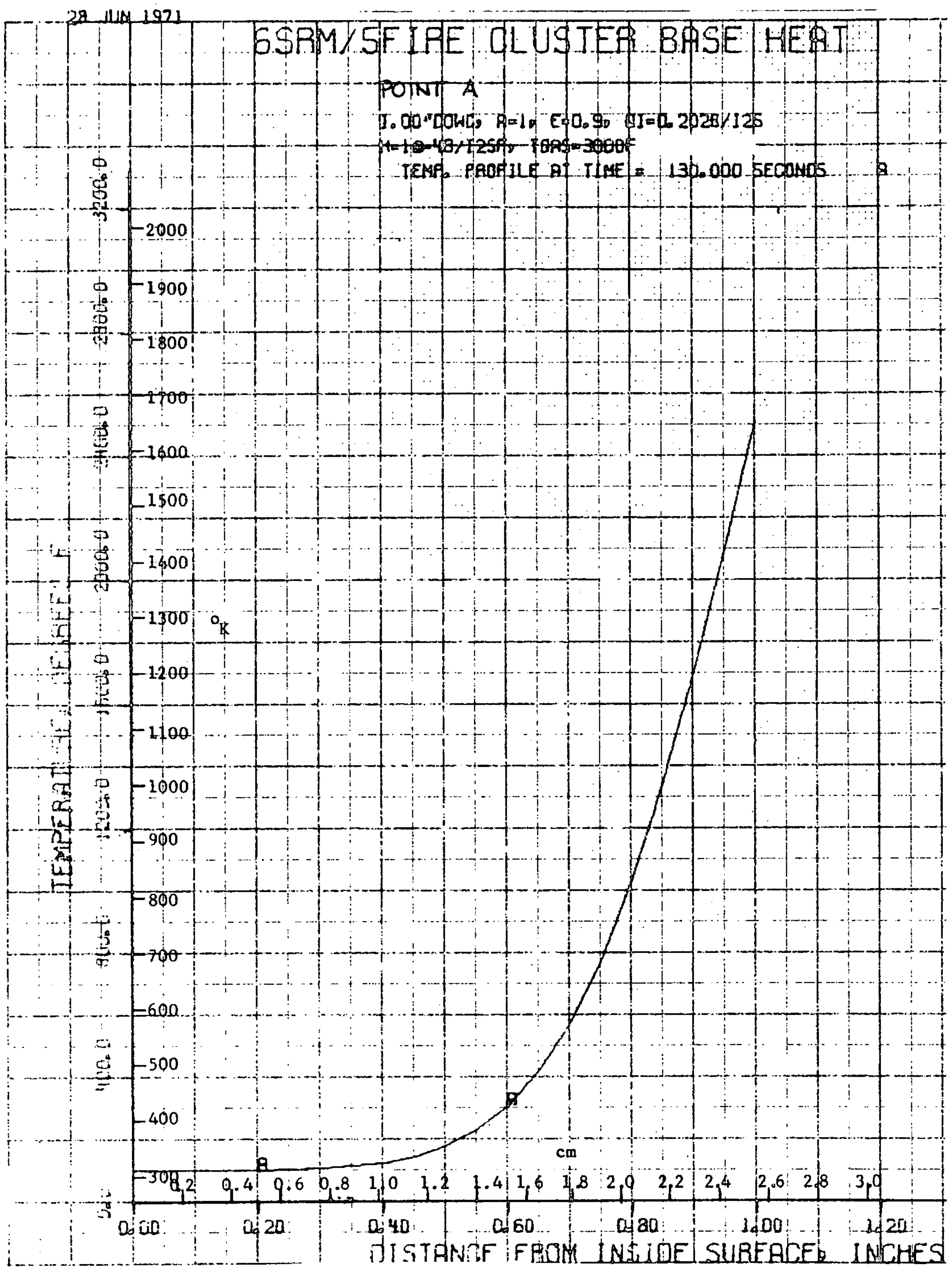


Figure 59. Cluster Insulation Backside Temperature, Central With Recirculation

5.5.2 Nozzle Configuration

A standard 1207 nozzle is used on all Stage I SRMs and Stage II SRMs where two motors form the second stage. For those configurations where a single SRM is used for Stage II propulsion a straight nozzle is substituted for the canted one. Further studies might indicate that the cant angle of the nozzle (where this feature is retained) should be different from that used on the Titan or that the expansion ratio for a second stage nozzle should differ from that of a first stage nozzle. Any of the changes mentioned above would have an effect on the attach structures design and in particular on the heat shield which closes the gap between the open ended aft support skirt and the nozzle.

5.5.3 Staging

It is assumed that the current Titan staging motor design concept is adequate for the vehicles studied. Separation is by means of explosive bolts at the interfaces described in section 5.3 and in figure 49. The SRMs are staged in a lateral direction away from the second stage with the staging impulse supplied by 8 staging rocket motors per SRM, four mounted forward and four aft. Stage II SRMs are staged in the aft direction. Staging motors are not shown on Stage II as their location would be based on specific dynamic studies. They could be located on the aft skirt, the interstage adapter, or the motor case as necessary.

5.5.4 Thrust Termination

An off the shelf Titan thrust termination system is assumed. The only modification considered was the rotation of the forward closures to keep adjacent components outside of the trajectories of the port covers and exhaust gases. Changing the angular orientation of the thrust termination ports can be accomplished without affecting the orientation of the forward staging motors as the entire thrust termination system is located aft of the forward staging motors. The thrust termination system will exert a large influence on the Stage II/Stage III interstage structure design because of the need for clearance of the thrust termination debris and gases.

5.5.5 Destruct System

The standard Titan destruct system employing linear-shaped charges is assumed. The attach structures specified in this study provide for the incorporation of this system.

5.6 MASS PROPERTY DATA

Preliminary estimates of the weight of the attach structures required to accomplish the studied cluster configurations are given in table XII. Weight penalties of zero to 5,000 pounds (2260 kg) above standard SRM structure weights are required per specific SRM. Specific weight data are provided for 1207-based designs. Standard 1205 data are provided so that the equivalent 1205-based vehicle weights may be determined.

TABLE XII

STRUCTURE WEIGHT DATA

	CONFIGURATION											
	2+1		3+1		4+1		5+1		4+2		5+2	
	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Total cluster weight	2,092,369	949,099	2,790,757	1,265,887	3,489,230	1,582,715	4,180,626	1,896,332	4,176,707	1,894,554	4,874,936	2,211,271
Total stage I	1,395,222	632,873	2,092,833	949,309	2,790,444	1,265,745	3,488,055	1,582,182	2,790,644	1,265,836	3,488,055	1,582,182
Stage I total/SRM	697,611	316,436	697,611	316,436	697,611	316,436	697,611	316,436	697,661	316,459	697,611	316,436
Stage I SRM*	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933
Stage I SRM structure	14,338	6,504	14,338	6,504	14,338	6,504	14,338	6,504	14,388	6,526	14,338	6,504
Aft support skirt	9,486	4,303	9,486	4,303	9,486	4,303	9,486	4,303	9,536	4,326	9,486	4,303
Heat shield	820	372	820	372	820	372	820	372	820	372	820	372
Nose cone	1,280	581	1,280	581	1,280	581	1,280	581	1,280	581	1,280	581
Forward attach ring	1,050	476	1,050	476	1,050	476	1,050	476	1,050	476	1,050	476
TVC tank attachments and fairings	881	400	881	400	881	400	881	400	881	400	881	400
Aft staging rocket fairing	521	236	521	236	521	236	521	236	521	236	521	236
Forward collector	300	136	300	136	300	136	300	136	300	136	300	136
Total Stage II	697,147	316,226	697,924	316,578	698,786	316,969	701,571	318,233	1,386,063	628,718	1,386,881	629,089
Thrust collector	–	–	8,400	3,810	6,300	2,858	9,000	4,082	13,266	6,017	14,084	6,389
Stage II total/SRM	697,147	316,226	689,524	312,768	692,486	314,112	692,571	314,150	689,524	312,768	689,524	312,768
Stage II SRM*	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933	683,273	309,933
Stage II SRM structure	13,874	6,293	6,251	2,835	9,213	4,179	9,298	4,218	6,251	2,835	6,251	2,835
Aft support skirt	11,123	5,045	3,500	1,588	6,462	2,931	6,547	2,970	3,500	1,588	3,500	1,588
Heat shield	820	372	820	372	820	372	820	372	820	372	820	372
Forward attach ring	1,050	476	1,050	476	1,050	476	1,050	476	1,050	476	1,050	476
TVC tank attachments and fairings	881	400	881	400	881	400	881	400	881	400	881	400

* Standard UA 1207 SRM

	lb	kg
SRM weight	683,273	309,933
Attach structure	14,072	6,383
Total weight	697,345	316,316
Expendable weight	607,435	275,533

Standard UA 1205 SRM

	lb	kg
SRM weight	495,074	224,566
Attach structure	12,740	5,779
Total weight	507,814	230,345
Expendable weight	436,279	197,896

6.0 PROGRAM DEFINITION

Sections 2.0 through 5.0 of this report presented technical data for design modifications to the 120-inch (3.05 m) solid rocket motors which offer performance and possibly cost-improvement potential for the SRMs or for the launch vehicle system of which they are a part. A full evaluation of the modifications must include a thorough review of the developmental and production programs required before the concepts are employed in operational hardware. Developmental programs include development testing to obtain data for confirmation or completion of design features as well as qualification testing to demonstrate the adequacy of the designs to meet the operational requirements. Production programs involve manufacturing processes, tools and facilities which may require modification or expansion to produce the modified design in the desired quantity. In addition, launch operations require a thorough review to adequately define any new equipment, facility or techniques required to support the new designs at planned launch rates.

These three areas - development, manufacturing and launch operations - have been examined relative to implementing the SRM modifications and stage configurations described in sections 2.0 through 5.0. Developmental programs have been defined for each of the design modifications. Manufacturing requirements for tooling and facilities to produce the new designs at increased rates have been estimated. New requirements for launch operations, AGE, procedures and support have also been designated.

The three areas above were investigated in order to determine schedule requirements for the clustered solid booster portion of 120-in. (3.05 m) SRM launch vehicles as well as to provide a basis for the non-recurring and recurring cost estimates presented in section 7.0.

The program schedules presented in section 6.4 have been prepared to illustrate the time spans and interrelation of program tasks to carry each of the design concepts to flight-test ready or operational status. The schedules may be integrated with those for development of the upper stage, payload, overall system integration, launch facilities implementation and other necessary factors, to arrive at a total program schedule.

6.1 DEVELOPMENT TASKS

Conversion of the design concepts presented in sections 2.0 through 5.0 into qualified flight-ready hardware will require completion of a design, development and qualification test sequences. The recommended test sequences are based upon the prior development and operational experience of current 120-in. (3.05 m) rocket motor designs. The test sequences were designed to include developmental testing to provide data for confirmation or completion of design features, demonstration testing to confirm satisfactory performance of the concept and qualification testing of production articles to prove readiness of the design for full operational use.

Test requirements associated with the SRM ballistic modifications, the TECHROLL seal TVC system, the straight high-altitude nozzle for the stage 2 SRMs and the clustering structure are identified and presented below.

6.1.1 Development Tasks for Ballistic Modifications

Booster configurations based on the current standard production 1205 design may be test flown without further SRM ground ballistic testing. Selection of boosters based on the standard 1207 SRM, which to date has been subjected to four development static firings, would require four PFRT static tests. Incorporation of any of the ballistic modifications described will increase the testing required as discussed below.

Each of the individual design changes for the 24 motor configurations defined in figure 23 was evaluated and a judgment made of the scope of testing required. Table XIII presents a set of recommended tests developed in this manner. Further discussion is provided below based on the individual changes. A summary of all developmental testing by motor configuration is presented later in Section 6.4.

Designs which involve a revision of the standard propellant burning rates will require tailoring of the propellant formulation. Such tailoring should be verified by subscale testing to demonstrate the burning rate characteristics of the revised propellant and to provide confidence in achieving the desired full-scale results. The testing would be comprised of small-scale formulation tests with attendant TM-1 [5-pound (2.3 kg) propellant charge] motor firings to determine resultant propellant burning rate. Finally, normal production scale batches [500 gallons (2.3 m^3)] of the new formulations would be processed for firing in additional TM-1 and TM-3 [nominal 300-lb. (135 kg) propellant charge] test motors. These motors would be fired at various initial temperatures and chamber pressures to provide a full characterization and confirmation of specific propellant formulation burning

TABLE XIII

TEST REQUIREMENTS FOR INDIVIDUAL BALLISTIC DESIGN CHANGES

Design Change	Required Tests 1205	Required Tests 1207
None	0	4 static tests (completion of PFRT)
Propellant burning rate	Subscale propellant characterization	Subscale propellant characterization + 4 PFRT static tests
Long forward closure instead of short	0	N/A
No forward restrictors on segments	2 full-scale static tests	1 full-scale + 4 PFRT static tests
Both ends of segments restricted	Process demonstration & subscale + 3 full-scale static tests	Process demonstration & subscale + 1 full-scale + 4 PFRT static tests
Tubular forward closure instead of star	0 - 1 full-scale static tests	0 - 1 full-scale + 4 PFRT static tests
Thrust termination	0	0 + 4 PFRT static tests
Substitute 1207 nozzle for 1205 nozzle	3 full-scale static tests	N/A
Reduce standard nozzle throat size	1 full-scale static test	1 full-scale + 4 PFRT static tests
Elliptical bore segments	1 - 2 full-scale static tests	0 + 4 PFRT static tests

rate. This recommendation is based on similar experience in the Titan Program in which the PBAN propellant of the 1205 was tailored to achieve a 10% burning rate reduction for the 1207 and was fully characterized prior to full-scale motor testing.

Substitution of the longer 1207 forward closure for the 1205 motor forward closure could be accomplished without demonstration static testing. However, any attendant revisions to the burning rate of the closure or segment propellants will require subscale characterization testing as described above.

Deletion of the segment restrictor in a five-segment motor would require two static tests to demonstrate the ballistic performance and to verify the modified insulation design. Incorporation of this change to a 1207 SRM would increase the basic 1207 PFRT requirements by only one development motor since the remaining 4 PFRT motors would provide ample additional verification. Application of a doubly restricted segment is the design change requiring greatest effort including a subscale program of process demonstration and motor firing. This subscale program would begin with laboratory testing of castable restrictors to confirm processing techniques and physical and thermal properties of the resulting restrictor. Processing tests would also be conducted to develop methods for installing foam rubber fillers bonded between segment surfaces during motor assembly. Subscale motors would also be fired to confirm the thermal adequacy of the selected design. Some data do exist on this concept since it was utilized on an initial 120-inch (3.05 m) single segment development motor firing. However, three full-scale static tests are estimated to be required in a 1205 modification program. For a 1207 program, this requirement could be reduced to one development firing in addition to the four PFRT firings.

The single change from a star to a tubular forward closure grain could probably be implemented without a static test. Most likely however, this change would be coupled with reduction of insulation and perhaps a segment change which in total would justify a single full-scale demonstration static test.

Addition or deletion of thrust termination provisions would require no testing since this option has already been implemented in the Titan III-C program.

Modification of a 1205 motor to include a 1207 nozzle is judged to require three PFRT static tests since use of the larger nozzle would create a more severe gas flow environment within the aft end of the 1205 motor. On the other hand, reduction of throat size on either the 1205 or 1207 motor would reduce the severity of the environment within the aft closure and a single full-scale demonstration static firing would then be required only to verify adequacy of the new nozzle throat and insulation design.

Use of grain designs with elliptical bore cross sections would require one or two static tests to confirm the ballistic predictions. This additional test requirement could be waived on a 1207 motor as the change could be accommodated within the PFRT requirements for the basic design.

6.1.2 Development Tasks for Adoption of TECHROLL Seal TVC

Replacement of the current LITVC system by the TECHROLL Seal movable nozzle system would require a four-phase development/PFRT program including full-scale motor static tests. It is estimated that for the major changes involved in a new TVC/nozzle/aft closure system it would be necessary to accumulate full-scale static testing on at least seven (7) motors to achieve the levels of confidence before any flights are made. For the 1205 SRM or its ballistic modifications, which when using LITVC, require only from 0 to 3 full-scale tests, the adoption of the TECHROLL Seal system would necessitate additional static tests to accumulate the total of seven (2 development and 5 PFRT) tests before committing the SRM to flight. The 1207 SRM, whose development is not complete, requires 4 to 5 full-scale static firing (0 to 1 development and 4 PFRT) for any of the ballistic modifications described using LITVC. As with the 1205, the adoption of TECHROLL Seal TVC on the 1207 would require accumulation of a total of seven full-scale tests for flight readiness. Thus, for the 1207, only 2 to 3 additional static firings and their associated costs would be chargeable to the TECHROLL Seal system. In either case, the adoption of TECHROLL Seal TVC would represent a dominant factor in determining the scope of the test program and would entail the four program phases described below.

Phase I of the recommended four-phase TVC development will have three subtasks. Task 1, system design studies, will include definition of performance characteristics for vehicles and missions of interest to NASA and preparation of responsive design layouts. Alternative actuation techniques will be evaluated to define optimum methods. The cost, weight, reliability and maintainability aspects of the TECHROLL Seal system will be investigated in detail. A system design will be selected and associated development plans and costs will be identified. Task 2 will be directed at component evaluation. Candidate TECHROLL Seal bladder materials and fabrication techniques will be evaluated in terms of burst, fatigue, compatibility and temperature sensitivity. Manufacturing methods and inspection and NDT techniques applicable to low-cost production of large diameter seals will be investigated. Task 3, development of system parameters, will involve subscale hardware and static test firings. The TECHROLL Seal operating characteristics including actuation torque, hysteresis and other non-linearities will be evaluated during bench and motor firing tests. Simplified hot side heat barrier systems will be evaluated. Scale-up relationships used to predict large motor seal torques and displacements will be verified through testing of seals for 2.5-inch (6.35 cm) and 5.0-inch (12.7 cm) throat size nozzles.

Some of the activities of Phase I are presently underway at UTC as part of in-house programs and under contracts from the Air Force Rocket Propulsion Laboratory, Thiokol Chemical Company and Army Missile Command. Development is currently underway leading up to a hot firing demonstration on a Minuteman motor with a 17.5-inch (44.5 cm) diameter seal and a Poseidon motor with a 23.5-inch (59.6 cm) diameter seal. Additional seals will be tested on the AFRPL high pressure test motor. Appropriate definition of the TECHROLL Seal program for any future solid vehicle application would, of course, be based on evaluation of results obtained on the above programs to avoid unnecessary duplication of effort.

The primary objective of the Phase II testing is the demonstration of the TECHROLL Seal with a significant scale-up in motor size. Two Algol III 45-inch (114 cm) diameter motors with a 12-inch (30.5 cm) throat and 47-second duration will be tested. Completion of this effort would allow entry into full-scale testing at minimum cost, schedule and risk.

Phase III testing will accomplish preliminary development of a full-scale TECHROLL Seal system for the 120-inch (3.05 M) diameter SRM. The phase will be divided into three subtasks. Task 1 will finalize design and analysis of the full-scale TECHROLL Seal, nozzle structure and actuation system. Task 2 will accomplish procurement and testing of individual nozzle and controls components. Complete control system development and qualification would be included in this phase. Only structural components involved with the control mechanism will be utilized. Ablative materials and non-functional parts will be omitted to reduce costs. Task 3 will accomplish assembled system testing of prototype structural, TECHROLL Seal and controls components. The dynamic response and other operating characteristics of the system will be determined under conditions of full-scale prelaunch and launch operating loads.

Phase IV will include the procurement of additional TECHROLL Seal assemblies based on the results of testing and analysis of the prototype components of Phase III. Assemblies will be subjected to component and subsystem checkout and will be then used on two development static tests and five PFRT static tests of the full-scale SRMs. Successful completion of Phase IV will constitute qualification of the TECHROLL Seal nozzle TVC system for use on a flight system.

6.1.3 Development Tasks for Straight Nozzle

A straight or uncanted LITVC exhaust nozzle for stage 2 SRMs was discussed in section 4.3.7. This nozzle would probably utilize a high altitude expansion ratio of 15 or 18 to one. Qualification requirements for this design are minimal since maximum utilization would be made of the existing body of data on current design, assemblies and processes. Subscale testing would be required to confirm LITVC performance projections at the larger area ratio of injection. The qualification requirements would be limited to a single demonstration test firing of the specific installation. It is believed that

4

the straight design produces a less severe environmental test than the canted design. Thus, it is planned that a single static test utilizing the straight nozzle would be sufficient and this could be included as one of the static tests required for ballistic qualification.

6.1.4 Development Tasks for Clustered Stage Concepts

Final design and structural testing of the clustering structure components and assemblies described in section 5.0 for an SRM launch vehicle represents major developmental tasks requiring a long-time span. The design process involves a series of operations, often iterative in nature. These operations start with launch vehicle definition and a preliminary description of attach structure. The vehicle integrating contractor then proceeds to model the vehicle and evaluate its ground and flight behavior to determine the external and internal loads applied to and within the vehicle assembly. This process may be preceded by extensive wind tunnel testing to determine external vehicle airloads. Detail design of the attachment structure can proceed following a determination of the attachment loads. Release for procurement of long-production time items such as forgings can occur when the design is sufficiently advanced to size these members. Final design release will occur on a continuous basis as design and analysis of various components and assemblies are completed.

A structural test series would be required to demonstrate the adequacy of the design to withstand the projected ground and flight loads. Thus, the first production set of structure would be allocated to static test. The attachment structure would be mounted in a fixture and the projected limit and ultimate loads would be applied to it. The success criteria would allow no plastic deformation under limit load conditions and no failure under ultimate load conditions. Successful completion of the structural test will accomplish qualification of the units for flight use.

6.1.5 Summary of Development Tests

The rationale described above for the various design modifications was applied as appropriate to each of the 24 SRM configurations defined in figure 23. Since full-scale tests are capable of fulfilling multiple test objectives, the requirements for such tests are not directly additive when more than one change is involved. These test requirements are summarized in table XIV.

Although not shown, in table XIV, the design and structural tests of clustering structure components would be a common requirement for all configurations intended for application with the solid launch vehicles. Static testing of clustered SRM stages is not recommended nor considered necessary. Static testing of the single SRMs and their component qualification tests serve to qualify the SRMs for flight. Structural testing of the clustering structure test the structure for the most rigorous and severe loading conditions. Stage static testing will not reproduce the expected flight loading conditions with the possible exception of vibration and noise spectra. Component testing will already have verified performance under environmental loading conditions.

6.2 MANUFACTURING

Manufacturing considerations for the 120-inch (3.05 m) solid rocket motors of interest in this study primarily concern the planning for acquisition of additional equipment and tooling to support the intended rate of production. The UTC manufacuring facility at Coyote, California, is currently operating at

TABLE XIV

DEVELOPMENT AND PFRT REQUIREMENTS FOR 120-INCH (3.05 m) MOTORS INCORPORATING VARIOUS BALLISTIC MODIFICATIONS

Configuration*	Propellant Characterization	Process Demonstration & Subscale Tests	Full-scale Static Tests** number
1			2
2	X		-
3	XX	X	3
4			2
5			-
6	X	X	3
7	XX	X	3
8			5 (4 PFRT)†
9	X		5 (4 PFRT)
10	X		5 (4 PFRT)
11			4 (4 PFRT)
12			5 (4 PFRT)
13		X	5 (4 PFRT)
14	X	X	5 (4 PFRT)
15			2
16			-
17	X		2
18	X		2
19	X		-
20	X		2
21			5 (4 PFRT)
22			4 (4 PFRT)
23			4 (4 PFRT)
24			4 (4 PFRT)

* Configuration descriptions are given in figure 23.
** For incorporation of TECHROLL Seal TVC, all numbers become 7(5 PFRT).
† Indicates a total of 5 tests of which 4 are PFRT

a nominal level of fourteen motors per year. The UTC subcontractors are also tooled and operating at this rate. An increase of production rates to more than 14/year would require various levels of increase in production equipment and tooling. Incorporation of the SRM modifications discussed in sections 2.0 and 3.0 will have only a secondary effect upon the tooling which would be required.

Production rates discussed in this study result from a summation of Air Force-NASA basic Titan III system utilization plus the additional requirements for SRM vehicles as described in this study. The current Titan production rate is 14 motors per year. Projections of future Air Force and NASA procurement of Titan IIIC, Titan IIID and other vehicles could raise this production rate to 20 to 25 SRMs per year. Rates of up to 35 motors per year above the basic Titan production rate of 25 motors have been considered for SRM vehicles in estimating manufacturing program requirements. Thus, total SRM production in the range of 14 to 60 SRMs per year is considered. The maximum production rate would support SRM vehicle launch rates of up to twelve 2+1 configurations, five 5+2 configurations, or some mixture of any of the six vehicle configurations described.

In estimating additional manufacturing support items which would be common to Titan and SRM launch vehicle production, it has been assumed that pooling of resources would be permitted to achieve lowest cost to the government regardless of the specific program for which manufacturing is carried out.

UTC's basic propellant processing facility at Coyote has the capability in most areas of processing 60 to 80 SRMs per year and hence can accommodate the maximum rates used in this study. These facilities are wholly owned by

United Aircraft Corporation. Secondary facilities for manufacture of attach structures and electronic components, receiving inspection, and various subassembly operations are designed for lower rates and would require expansion. United Aircraft would build these additional facilities as required to economically produce SRMs at the higher rates.

Manufacturing tooling required for fabrication and assembly of SRM components at both UTC and its subcontractors is capable of production rates in the 14 to 20 SRM per year range. Increases in this rate, up to the total of 60 per year, will require the procurement of additional contractor tooling. Estimates of additional tooling requirements have been obtained from UTC's case insulation and nozzle contractor which account for about 75% of the tooling required. Remaining contractor requirements have been estimated by UTC.

Initial tooling requirements for introduction of the SRM modifications described in sections 2.0 through 5.0 will be provided for in the associated developmental programs of section 6.1. Quantity requirements for higher production rates will be a recurring cost item as discussed above.

6.3 LAUNCH OPERATIONS

Launch operations encompass all of the SRM support equipment and launch site activities following factory assembly. Items to be considered here are AGE, transportation, launch facilities, launch services and administrative support.

6.3.1 AGE

Aerospace ground equipment, AGE, falls into two principal categories on current Titan programs. The first category is transportation AGE used to transport the solid propellant loaded SRM components from the factory to the launch site. The amount of AGE required for this purpose is directly related to production rates. Thus, quantities of AGE required for transportation can be scaled directly from current rates and usage.

The second category of AGE is that used to handle, assemble and test the SRMs at the launch sites. Certain operational modes must be determined or assumed before these requirements can be fully defined. Thus, the following modes are assumed for SRM launch operations:

1. All SRMs and vehicles will be assembled on the launch stand using facility cranes.
2. Commercial heavy-duty low-bed trailers will be used to transport SRM components from the SRM receiving area to the launch stand.
3. The launch complex will be self-sufficient in terms of AGE. No sharing of AGE with other nearby SRM programs is assumed.
4. Launch vehicle checkout and major maintenance reverification will be accomplished by use of vehicle or system contractor AGE or computer. SRM AGE will provide for buffer equipment, SRM servicing and necessary on pad electrical distribution systems.

AGE requirements for support of the study vehicles can be estimated based on current Titan SRM techniques and experience and the above assumptions. Potential savings do exist where current Titan programs may be able to share facilities, AGE and launch personnel but such savings have not been evaluated.

6.3.2 Transportation

Transportation of SRM components from the UTC factory to the launch site would follow current Titan practice. The major propellant-loaded SRM components travel from the factory to a nearby railhead by means of commercial low-bed trailers. Transportation is then by rail direct to a SRM receiving area at the launch base. Transportation AGE as discussed in 6.3.1 is used to support the components during these modes. Other SRM components are crated and shipped by a convenient commercial carrier. Transportation costs are normally covered by government bills of lading and hence are not contract expenses.

6.3.3 Launch Site Facilities

Solid rocket motors present relatively simple requirements for facilities at the launch base. An inert receiving area, propellant-loaded component receiving and subassembly area and a storage area are all that are required if build up on the launch stand is employed, as assumed.

SRM support facilities requirements are normally presented by UTC to an integrating contractor. These requirements are combined with other requirements and considerations given to the intended launch site and evaluations made of the availability of existing facilities on a shared or dedicated basis. Any required new facilities would then be designed.

The inert receiving area would be a warehouse type of building suitable for inspection and storage of inert SRM components. Building size would be predicated on the intended vehicle launch schedule and the quantity of inprocess storage judged necessary. Propellant-loaded component receiving inspection and subassembly will require an area separated by the appropriate quantity-distance requirements. A facility crane would be required for train unloading and on-site truck loading. Environmentally protected areas are desired for the inspection and subassembly operations.

Storage of SRM propellant-loaded components can be accomplished in warehouse buildings or in open areas when passive protective covers are provided for the components. Both methods are currently in use at the Air Force VAFB and CKAFS. Storage facility size would again be determined on the amount of inprocess storage required by production rates and launch schedules.

The launch pad facilities requirements for various intermediate payload boosters, including 120-inch (3.05 m) SRMs/SIVB, have been studied previously by Chrysler Corporation under NASA contract.* However, launch pad requirements are fairly straight forward. Physical support must be provided for the selected launch vehicle configuration. Ducting must be provided for exhaust flow at ignition. Access must be provided to the vehicle for assembly and servicing. A crane must be provided for vehicle assembly.

Implementation of these facilities could be accomplished by take over of an existing suitable facility, sharing of an existing facility such as the Titan or Saturn complexes or construction of a new dedicated single purpose facility. Selection of the method would depend upon expected launch rates, expected service life, suitability of existing facilities, availability of existing facilities and availability of funding.

*"Comparative Economic Study of Launch Facilities, Launch Operations and Support for a 120-in. SRM Tri-Cluster Launch Vehicle at the Kennedy Space Center and Kennedy Air Force Station" Chrysler Corporation, Addendum report dated 18 June 1970, Contract NAS 10-6776.

6.3.4 Launch Services

Launch services normally cover all of the activities at the launch base and the UTC, Sunnyvale, California, offices which are associated with the assembly, inspection, test, launch and evaluation of flight vehicles. Two additional items are added here to cover the initial activation of the launch base SRM facilities and compatibility and electromagnetic interference testing which is normally conducted on initial flight vehicles.

Normal launch services are provided by a fixed labor base at the test site which accomplishes assembly and test of the SRM. Manning requirements and schedules for this activity can be projected from UTC's current experience at VAFB and CKAFS on similar motors with similar operational schemes. It is assumed that primary electrical testing will continue to occur at the factory as is current Titan practice. Launch base SRM testing will be limited to continuity and integrity checks and participation in vehicle integrated testing. Additional launch services are provided at UTC's Sunnyvale plant where the prelaunch support and post-launch evaluation are performed.

Initial program startup of a new launch base will require an activation task. This task will accomplish facility planning, construction surveillance, equipment installation, and initial utilization. Projections of this task related to the SRMs can be made from UTC experience with Titan activation at VAFB and CKAFS.

Initial launch vehicles of a new design normally undergo a battery of special one-time only testing prior to their first launch. This testing will demonstrate the overall compatibility of the vehicle following the initial assembly of all system components. The prime test of this category is the electromagnetic interference test. Projections for this test can also be based upon previous UTC Titan experience.

6.3.5 Administrative Support

Program administrative support includes all of the program management, control disciplines of cost/schedule control, configuration management, procedural data support, systems engineering, and reporting. These items are normally referred to as software. They are not limited to launch operations tasks but cover all aspects of program development, engineering, production, and test. Projections of software requirements for the SRMs and vehicles in this study can be made from current UTC Air Force and NASA programs.

6.4 PROGRAM SCHEDULES

Program schedules have been prepared to show the time span required to complete the development of clustered SRM stages based on the modifications described in sections 2.0 through 5.0. The schedules have been prepared for selected groups of the ballistic modifications as well as for the Techroll Seal nozzle development. Two basic schedules were prepared.

The first schedule, figure 60, illustrates activity spans for the five-segment motor configurations. The schedule illustrates the relative phasing and concurrences of development which are permitted. Three sets of possibilities are provided for the static test requirements. Zero, two or three static tests are shown corresponding to the test requirements of section 6.1.1 which are predicated on certain ballistic modifications. Thus, the total time span to the completion of static tests ranges from 28 months to 32 months depending on

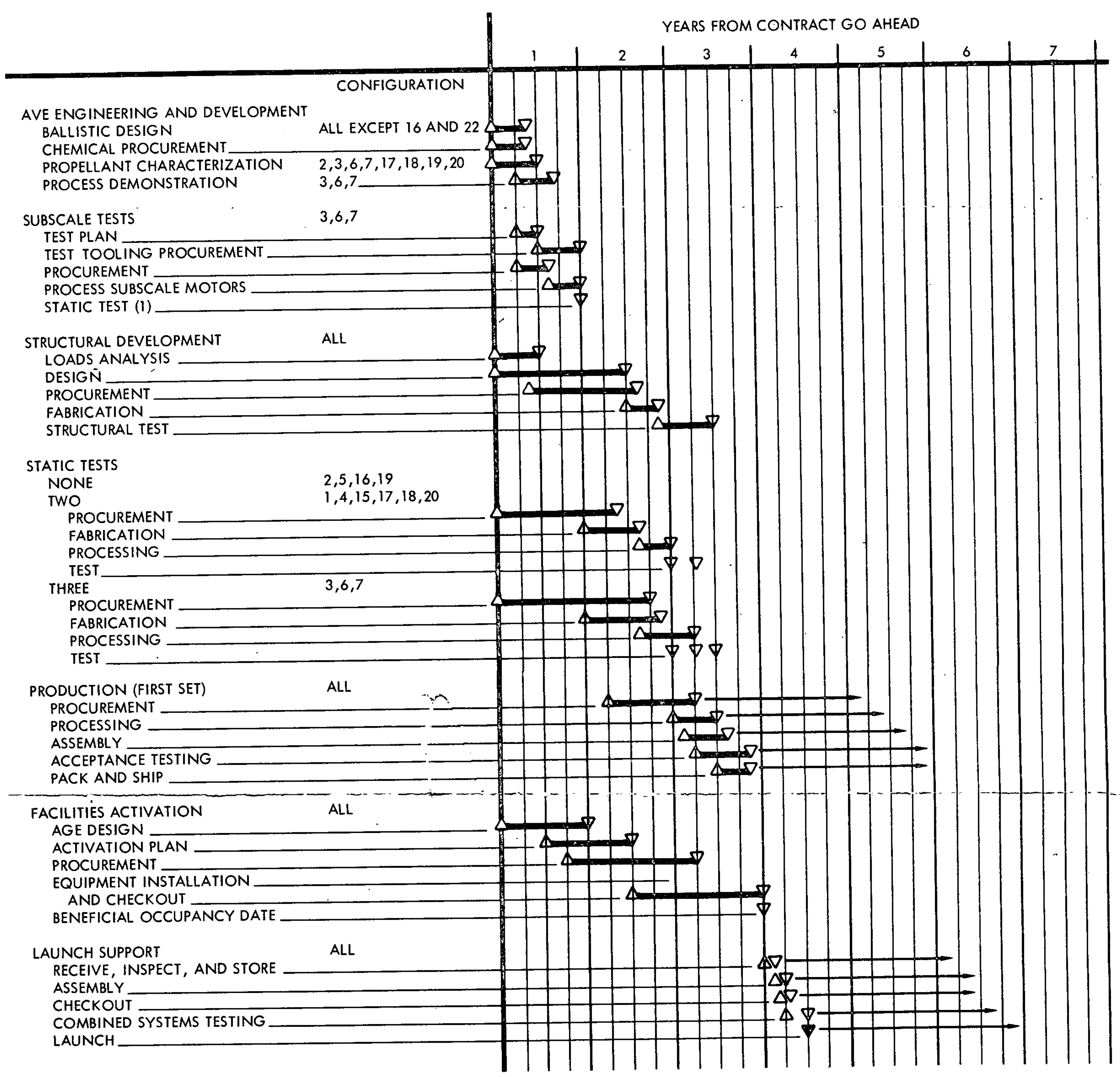


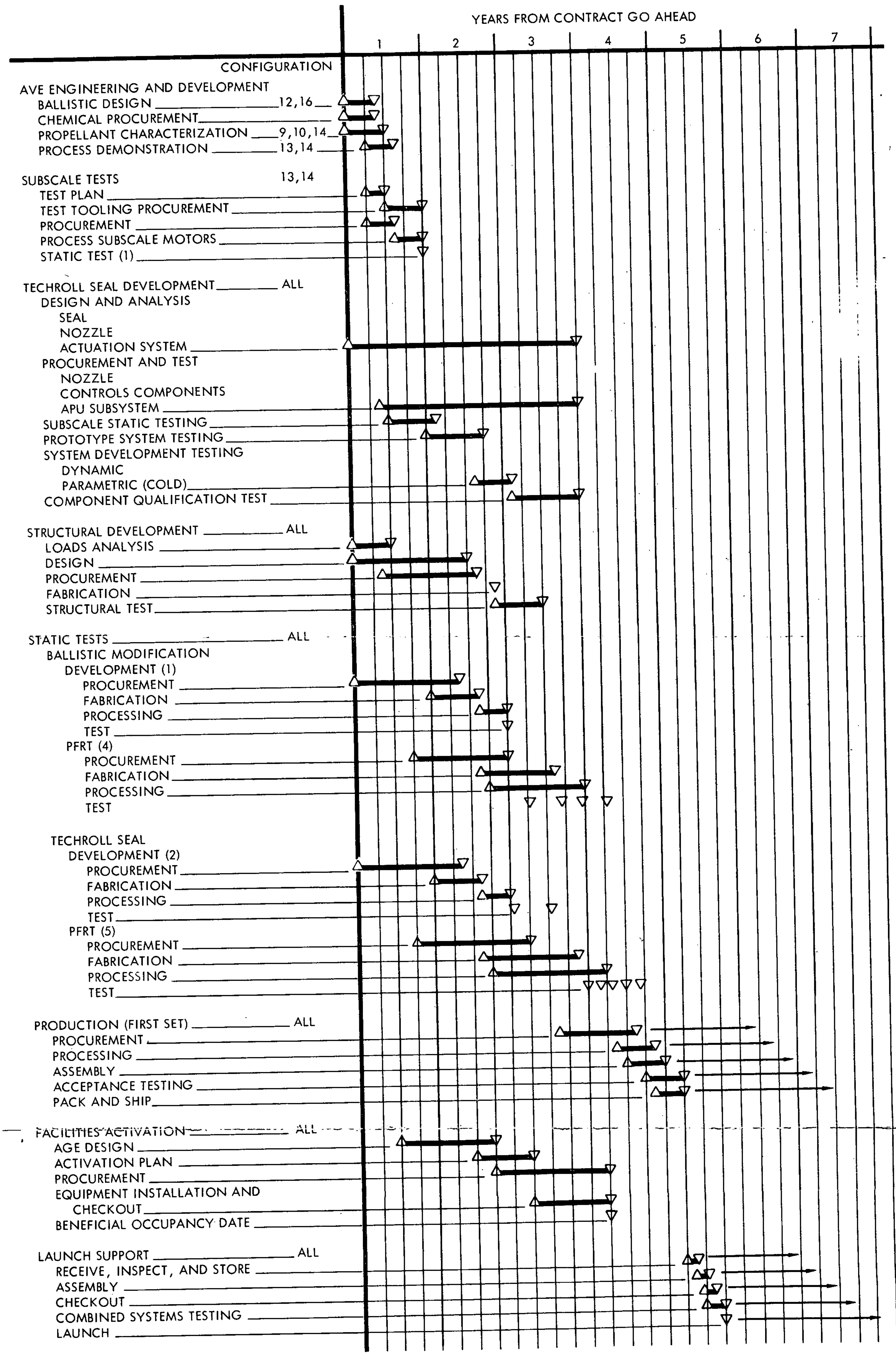
Figure 60. UA 1205 Milestone Schedule, Ballistic Modification and Structural Design

the ballistic design change selected. Implementation of TECHROLL Seal nozzle development would follow the schedule shown on the seven-segment schedule of figure 61 and increase the program duration to 44 months for completion of PFRT. The structural design and test task is also a controlling factor in achieving a qualified stage design. About 30 months would be required to complete the cycle of loads definition, design, fabrication and test. This time span should be relatively independent of the particular structural configuration selected. Thus, regardless of which 1205 SRM configuration using LITVC is chosen, from 30-32 months are required before flight ready components can be shipped for the first test flight.

Production of flight articles can occur during the static test and structural test phases and released for shipment upon satisfactory test completion so that the initial flight could occur approximately 42 months from program start. The initial launch capability would not be at the full highest production of 35 motors of this program per year. Fabrication facilities and tooling at UTC and its subcontractors will require approximately one additional year to build up to the full rate. Thus, the full capability could be achieved about one year into the flight program, or 52 months from program start. Any time restraints of launch facility activation have not been considered in this schedule.

The seven-segment schedule, figure 61, is generally similar to the five-segment version. The significant difference is the added four PFRT tests. A maximum of four or five static tests are shown as based on the selected ballistic design. The first launch capability is extended eight months with these added tests and occurs after 50 program months.

FOLDOUT FRAME 1



FOLDOUT FRAME 2

Figure 61. UA 1207 Milestone Schedule, Ballistic Modification or TECHROLL Seal

The TECHROLL Seal nozzle development program is also shown on the seven-segment schedule. A total of seven static tests are illustrated. Implementation of the TECHROLL Seal nozzle will accommodate and supersede any test requirements for the ballistic modifications. A schedule for a five-segment motor development with a TECHROLL Seal nozzle is also illustrated by this seven-segment schedule. It is seen that the time span to the completion of PFRT is now extended to 44 months.

The schedules shown in figures 60 and 61 represent a desirable phasing of series dependent tasks to minimize the risks associated with beginning a subsequent phase prior to confirmation of a successful design on a previous phase. These schedules could, of course, be reduced in time by accepting a greater risk and compressing the sequential tasks, reducing turn around time in repetitive tasks and by the application of premium labor. In this manner the five-segment motor program could be shortened 4 to 6 months in time to first launch. The seven-segment program could be shortened 6-8 months and the TECHROLL Seal program could be shortened by 12 months.

7.0 PROGRAM COSTS

Program cost estimates have been developed for the programs defined in section 6.0 to allow preliminary planning and budgeting for any combination of modified 120-inch (3.05 m) SRM design and cluster configuration. Once an appropriate 120-inch (3.05 m) SRM launch vehicle has been selected and a mission plan established, the tabulated data presented in this section will allow an estimate to be made of non-recurring and recurring costs associated with the SRM stage. Combination of these data with estimates of costs for the upper stages, payloads, and other program elements would result in total costs for use in program evaluation.

The cost data presented herein for the SRM stage are estimates of selling price to the government. Where the effects of production rate were studied, projections were made of the effects of total business volume on burden rates and the appropriate rate estimates were then applied. The estimates are based on 1971 dollars, and no provisions for price escalation due to inflation are included.

The cost data to be presented are based on engineering estimates of the defined programs. The quality of these engineering estimates is greatly enhanced by UTC's Titan III program experience, current production data and recent seven-segment 120-inch (3.05 m) solid rocket motor development test history. Costs for the basic clustered booster stages include hardware and labor for each complete structural configuration. Supporting cost estimates for major hardware components were obtained from Rohr Aircraft, the present subcontractor for motor cases, motor case insulation and nozzles for Titan SRMs. Other subcontract costs were estimated from current purchases.

Costs of hardware components currently manufactured by UTC as well as propellant processing, assembly and test costs were estimated from current cost data. In-house manufactured components currently include the attach structures, electrical distribution boxes, electromechanical liquid injectant valves, igniter rocket motors and staging rocket motors. The basic booster stage is costed as a man-rated system with all associated redundancies except that thrust termination is priced separately as an option under the ballistic variations.

Propellant ingredient costs were estimated on median weights for the 1205 and 1207 motors since the weight differences of the various ballistic configurations within each of the two basic models were not considered to significantly affect overall cost. Slight decreases over current costs per pound for propellant ingredients were envisioned, based on the increased production rates.

7.1 NON-RECURRING COSTS

Cost estimates were developed for each of the development programs and other non-recurring program activities discussed in section 6.0. These program costs represent the cost of implementation of any of the design concepts of sections 2.0 through 5.0.

7.1.1 Costs of Ballistic Modifications

The design concepts of each of the ballistic modifications of section 2.0 were reviewed with their program definitions of section 6.1.1. Engineering estimates were made of the propellant characterization programs, process demonstration and subscale testing, design and analyses efforts associated with each of the ballistic variations. Tooling costs peculiar to the ballistic variations, such as mandrels for elliptical segment grain casting, were also included where applicable. These costs represent acquisition of tooling to support the development programs and low levels of follow-on production. Static test hardware costs were obtained as discussed above. Static test labor and tooling costs were derived from the cost experience of the four 1207 static tests conducted between April 1969 and September 1970.

The cost categories of design, propellant characterization, process demonstration, static test and tooling applicable to qualification of the ballistic modifications were included in the costs presented in table XV. The static test costs are the overwhelming cost factor; thus, cost of implementation of the modifications varies almost directly with the number of static tests required. The development costs range from zero for the standard 1205 motor, currently in production, to approximately 15 million dollars for a modified 1207 design.

7.1.2 <u>Cost of TECHROLL Seal Implementation</u>

The TECHROLL Seal (TRS) nozzle development effort was estimated in two categories. The first is an engineering estimate covering design, manufacturing tooling necessary for TRS production, component qualification testing and system testing. Included here is the development and qualification of the control system components. The estimate was based upon selection of a gas generator-turbine drive hydraulic system which represents the highest cost power system. The second TRS cost category covers incremental static test costs. It was assumed that the TRS requires 7 static tests regardless of the ballistic configuration and the costs, therefore, represent the costs of static tests in addition to those accounted for in section 7.1.1. The estimated total costs of TECHROLL Seal implementation are listed in table XVI.

TABLE XV

ESTIMATED BALLISTIC MODIFICATION DEVELOPMENT COSTS
(1971 dollars x 10^6)

Configuration	Total Cost
1	4.6
2	0.3
3	7.6
4	4.6
5	0.4
6	7.9
7	8.9
8	13.7
9	14.1
10	14.1
11	12.1
12	14.7
13	13.9
14	15.0
15	4.6
16	-
17	7.0
18	5.1
19	0.7
20	6.4
21	14.1
22	12.1
23	12.4
24	11.4

TABLE XVI

ESTIMATED DEVELOPMENT COSTS FOR TECHROLL SEAL

(1971 dollars x 10^6)

SRM Configuration	Quantity of Additional Tests*	Total Development Cost
2, 5, 16, 19	7	21.1
1, 4, 15, 18, 20	5	16.5
3, 6, 7, 17	4	14.1
11, 22, 23, 24	3	13.3
8, 9, 10, 12, 13, 14, 21	2	10.5

* In addition to static tests dictated by ballistic modifications so that the total static tests will total 7 in all cases.

Total implementation costs for the TECHROLL Seal nozzle added to a ballistic modification program range from $10,500,000 for a modified 1207 motor to $21,100,000 for a current production 1205 motor.

7.1.3 Costs of Straight Nozzle Design and Development

Estimated costs are $300,000 for design of the large expansion ratio uncanted nozzle and performing subscale testing to confirm the LITVC performance at large expansion ratios. As discussed earlier, for configurations which require full-scale static tests to meet other objectives, the straight nozzle could be incorporated with no significant cost increase. For any of the 1205 motors which otherwise require no tests, a single test costing approximately $2,500,000 would be required.

7.1.4 Cost of Structural Design and Test

Cost estimates for accomplishment of the design and test programs discussed in section 6.1.4 vary from about $2.0 million for the 2+1 booster configuration with 1205 SRMs to about $4.2 million for the 4+2 or 5+2 configurations using the 1207 SRM. These costs are based on engineering estimates of the design and test costs with test hardware costs being derived from current production data. Table XVII presents the total cost for each of the designs studied.

7.1.5 Costs of Production Tooling

Production tooling costs, both at UTC and its subcontractors are rate dependent as discussed in section 6.2. Tooling cost estimates chargeable to SRM launch vehicle programs at rates of 15 SRMs per year and 35 SRMs per year are $4,600,000 and $8,900,000, respectively. For rates of up to 3-7 SRMs/year, tooling required for development activities would be adequate for production.

TABLE XVII

ESTIMATED STRUCTURAL DESIGN AND TEST COSTS

(1971 Dollars x 10^6)

Configuration		Total Cost
2+1	1205	2.0
	1207	2.3
3+1	1205	2.1
	1207	2.8
4+1	1205	2.1
	1207	2.8
5+1	1205	2.1
	1207	2.8
4+2	1205	4.1
	1207	4.2
5+2	1205	4.1
	1207	4.2

Neglecting minor differences between the 1205 and 1207, the production tooling costs for intermediate rates above 35 per year may be approximated on the basis of an additional $220,000 per SRM per year.

7.1.6 Costs for AGE

The aerospace ground equipment (AGE) required to support a launch program is dependent both upon launch rates for the transportation phase and upon configuration for the assembly and test phase. Cost estimates based on the six selected booster configurations using either 1205 or 1207 motors are shown in table XVIII for SRM rates of 15 per year and 35 per year. These two SRM rates assume total SRM production rates of 35 per year and 60 per year when AF/NASA Titan requirements are included. (Also see section 6.2).

7.1.7 Other Non-Recurring Costs

Costs for additional non-recurring cost items total $1,600,000 for completion of the following tasks:

A. Program Definition

   Provide software services in the area of program definition such as preparation of program plans and schedules and preliminary design support prior to initiation of hardware development.

B. Base Activation

   Activation of launch facilities and equipment in which SRMs will be involved will require initial operations, equipment installation and checkout chargeable to the SRM booster stage.

C. Compatibility Testing

   Conduct of a one-time EMI test. Since all SRMs are expected to be electrically identical, the variation of cost for clusters of 3 to 7 SRMs is a negligible effect on this estimate.

TABLE XVIII

ESTIMATED SRM STAGE AGE COSTS

(1971 Dollars x 10^6)

Vehicle Configuration	Production Rate*- SRMs/Year 15		35	
	1205	1207	1205	1207
2+1	3.8	4.3	6.3	7.4
3+1	4.1	4.6	4.6	7.7
4+1	4.4	4.9	6.9	8.0
5+1	4.8	5.3	7.2	8.3
4+2	4.8	5.3	7.2	8.3
5+2	5.2	5.7	7.7	8.8

* In addition to AF/NASA Titan requirements of 20 and 25 SRMs per year

7.2 RECURRING COSTS

Recurring or production cost data for the various configurations and design options were prepared in a multistep process. Production costs were first established for SRMs at varying production rates. The baseline motors are the current 1205 design, configuration 16, and the 1207 design without thrust termination, configuration 24. Various production cost increments were then determined for each of the ballistic modifications, the TECHROLL Seal nozzle, and the straight nozzle option.

The recurring cost data presented include all costs necessary for fabrication, assembly, test, SRM and booster stage assembly, and launch support of the flight vehicle. Administrative support of manufacture and launch services by the SRM stage contractor are included. Launch services are included based on current Titan activities.

7.2.1 Baseline SRM Production and Launch Costs

Production unit cost estimates for the baseline motors as a function of annual production rate were made on the basis of Titan Program cost data and inputs from major subcontractors to cover rates as high as 60 SRMs per year. This rate encompasses the minimum and maximum requirements expected for a program involving a 120-inch SRM launch vehicle as well as those which could result from expanded Titan use by the Air Force and NASA.

In accordance with the current practice of the Titan Program, UTC has assumed that recurring launch operations and support will be conducted by the SRM contractor and, therefore, has included the associated costs in the baseline unit prices. Since these costs are largely the result of operations on individual SRMs and SRM components, the costs are mainly dependent on the rate and number of SRMs launched rather than the number of booster assemblies launched.

Estimation of SRM and stage attach structure costs was undertaken using a rigorous configuration-oriented approach. The design data of section 5.0 were used to derive a description of the type, size and quantity of structural components, most of which were derived from the Titan SRM components. Costs based on this description were then estimated using UTC's current Titan manufacturing cost data.

It should be noted that the attach structural members used to form the 2-stage clustered solid assembly do not include the interstage between the center SRM(s) and the upper stage. It has been assumed that this component would be furnished as part of the upper stage.

As in the Titan Program, transportation costs for loaded and inert end items (segments, closures, TVC systems, etc.,) are assumed to be provided under Government Bills of Lading. Hence, no costs are included in this study for transportation of these end items between UTC facilities and the launch facility. Transportation costs for materials and components shipped to UTC are included in their unit prices.

7.2.2 Incremental Costs for Ballistic Modifications and TECHROLL Seal TVC

Detailed estimation of the recurring costs for the various ballistic variations was performed on the same basis as the baseline costs. The only variations shown to have cost significance at the level of detail of this study were the addition of thrust termination, use of the long forward closure, and changes in the number of restrictors.

Incorporation of the TECHROLL Seal nozzle was estimated to result in approximately a 9% decrease in baseline recurring costs over the range of production rates examined. LITVC system components such as valves, TVC manifold, TVC fluid storage tank, etc., would be eliminated as discussed in section 3.0. Changes in aft closure and nozzle costs plus costs of added TRS and hydraulic actuating equipment were estimated. If TRS were used, the current two electrical distribution boxes (TVC and instrumentation) would be combined into one box. The reduced cost of the D-box combination is an engineering estimate.

Evaluation of the straight nozzle option indicates no significant cost change. The increase caused by the larger expansion ratio, length, and weight is approximately balanced by reductions due to the symmetrical nozzle flange design and aft closure insulation. Any slight inequality of these effects is further minimized on a vehicle average basis since the ratio of outer motors to center motors is at least 2 to 1, thereby allowing this convenient simplification with negligible error.

7.2.3 Summary of Clustered Stage Recurring Costs

Recurring unit costs for cluster configurations comprised of various numbers of the 1205 and 1207 SRMs are listed in table XIX for selected launch rates. The cost variations of the ballistic options were found to lie within the accuracy of the estimates and, thus, an average price of the SRM clusters is presented on the basis of the use of either a 1205 or 1207 SRM and with either LITVC or TRS thrust vector control.

TABLE XIX

ESTIMATED SRM CLUSTER COSTS AS LAUNCHED

(1971 Dollars x 10^6)

Vehicle Configuration		15 SRMs/year LITVC	15 SRMs/year TECHROLL Seal	35 SRMs/year LITVC	35 SRMs/year TECHROLL Seal
2+1	1205	7.4	6.7	6.6	6.0
	1207	8.4	7.6	7.6	6.9
3+1	1205	9.5	8.6	8.7	7.9
	1207	11.1	10.1	10.1	9.2
4+1	1205	12.1	11.0	10.9	9.9
	1207	14.0	12.7	12.7	11.6
5+1	1205	14.5	13.2	13.2	12.0
	1207	16.7	15.2	15.3	13.8
4+2	1205	14.3	13.0	13.0	11.7
	1207	16.6	15.0	14.1	12.7
5+2	1205	16.8	15.3	15.3	13.8
	1207	19.4	17.7	17.8	16.1

7.3 ESTIMATION OF PROGRAM COSTS

The data presented in sections 7.1 and 7.2 may be used to prepare budgetary estimates of the SRM-stage related costs for a wide variety of booster stages. These stages represent clustered 120-inch, 2-stage boosters comprised of any one of the 24 SRM configurations identified in figure 23 and arranged in any of the six cluster configurations identified in section 5.0.

Because the large number of possible combinations makes graphical presentation of the results impractical, a tabular format is suggested for use in arriving at program cost estimates. For restricted variables, plotted data can be considered and may offer a more convenient approach.

A general tabular format illustrating the required cost elements and their source in this report is given in table XX.

TABLE XX

ESTIMATING FORMAT FOR BUDGETARY COSTS RELATED TO
CLUSTERED 120-INCH SRM BOOSTER STAGES

A. Obtain required input data:

1. Desired 1205 or 1207 ballistic performance and design features to allow selection of one of configurations 1-24 as discussed in section 2.0
2. Choice of LITVC or TECHROLL Seal TVC
3. Selection of desired cluster configuration per section 5.0
4. Estimated quantity and rate data for vehicle flight program - vehicle quantities and average annual launch rates, average annual SRM production rate to support flights and concurrent SRM production rate for AF/NASA Titan Programs.

B. Estimate non-recurring cost:

1. Ballistic modification cost - per A.1 and table XV
2. TECHROLL Seal TVC implementation cost (if selected per A.2) Development increment - per A.1 and table XVI
3. Straight nozzle design and development - $300,000 plus $2,500,000 if configuration is 2, 5, 16 or 19
4. Attach structure design and test - per A.3 and table XVII
5. Production tooling - $4,600,000 for 15 SRMs/yr. or $8,900,000 for 35 SRMs/yr.
6. AGE costs - per A.4 and table XVIII
7. Other non-recurring costs - $1,600,000
8. Total non-recurring cost - sum of 1-7 above

TABLE XX (continued)

C. Estimate recurring cost:

  1. Clustered stage baseline launched cost - per A.1, A.2, A.3, A.4 and table XIX

  2. Total recurring cost - quantity per A.4 times C.1 above

D. Estimate total program cost:

  1. Total non-recurring cost - per B.8

  2. Total recurring cost - per C.2

  3. Total program cost - sum of D.1 and D.2 above.

8.0 RESULTS AND CONCLUSIONS

Investigation of low-cost ballistic design changes to current UA-1205 and UA-1207 solid rocket motors demonstrates the flexibility of ballistic performance. Relatively simple changes in propellant burning rate, internal port perforation of segments and closures and segment inhibitors were shown to produce significant changes in the SRM thrust-time characteristics at low non-recurring cost and little or no increase in recurring cost. All of the basic ballistic shapes of progressive, regressive, neutral and saddle thrust histories were produced. Selection of optimum UA-1205 or UA-1207 characteristics for a particular vehicle application must be determined from analyses of flight performance. The study indicates the relative ease in achieving these characteristics once specified.

Comparison of the TECHROLL Seal movable nozzle and LITVC control systems leads to a preference for the TECHROLL Seal design based on its advantages of a 5 percent vehicle payload increase, a 9 percent recurring cost saving, reduced system and operating complexity, and greater steering deflection capability. Further detailed design definition is required to define the precise actuation and power system and resultant reliability. Final economic justification for the TECHROLL Seal would, however, require a knowledge of the mission model to determine the total recurring cost savings compared to the required non-recurring cost investment.

Evaluation of nozzle size and cant angle relationships for the clustered stages studied suggests the use of current nozzle expansion ratio of 8.0 and 9.2 on the first stage SRMs and an expansion ratio of 15 in the second stage SRMs. These values are near optimum for physical arrangement, base heating, and vehicle performance criteria. The cant angle of the first stage nozzles should be the minimum required to provide adequate nozzle clearance. This cant will be less than the current 6 degree Titan value. Center or second stage nozzles should be uncanted.

Investigation of clustered, parallel-staged 120-inch solid rocket motors as the boost stages of a launch vehicle shows the feasibility of the concept. Structural components of similar design to the current Titan SRM structural component can be used to assemble SRMs into first and second stages of the vehicle booster. The current Titan structure will require modification to withstand the higher loadings of the new vehicle and new thrust collection and forward attach linkage must be designed. Weights of the required new structures vary with the cluster configuration and result in average stage structural weight fractions of about 2 percent.

Examination of the cluster arrangement having the most severe base heating environment indicates that application of approximately 0.6 inches of Dow Corning silicone insulation is required to give adequate thermal protection. This addition represents an inert weight increase of only about 300 pounds per SRM over current insulation.

Examination of development schedules indicates that a period of 42 months is required for incorporation of desired ballistic modifications in the UA-1205 SRM, completion of stage structural testing and other activities up to launch of the first flight vehicle. If the UA-1207 SRM is used this time period increases to about 52 months because of the added static test requirements to complete PFRT. If TECHROLL Seal movable nozzle is incorporated into either the UA-1205 or UA-1207, the associated development and full-scale static test requirements result in a program duration of about 57 months from initiation to first test flight. Analysis of the program schedules above indicates that slight acceleration amounting to 4-12 month duration in time spans could be achieved if required.

Estimates were developed for non-recurring and recurring costs associated with the development and production of clustered SRM, 2-stage boosters comprised of any of 24 defined 120-inch SRM modifications arranged in any of six cluster configurations. The data and procedures presented allow the program planner to determine SRM-related budgetary costs for programs using the 120-inch SRM launch vehicle. Data are presented for various vehicle launch rates corresponding to total annual SRM production rates as high as 60 per year. The configurations studied involve non-recurring stage costs ranging from as little as $12,000,000 to as much as $44,600,000, depending on the selection of SRM and its design modifications from the current standard design and the size of the cluster. The recurring launched costs for various configurations also vary widely as a function of launch rate, number of SRMs per vehicle and design features of the SRM. Table XXI presents a summary of the range which may be expected in the costs of the various non-recurring and recurring program elements.

TABLE XXI

ESTIMATED SRM STAGE SUMMARY COSTS

(1971 Dollars x 10^6)

	1205 SRMs	1207 SRMs
NON-RECURRING COSTS		
Ballistic modifications	$ 0*-8.9	$11.4*-15.0
TECHROLL Seal nozzle	14.1-21.0	10.4-13.2
Straight nozzle development	0.3	0.3
Attach structure design & test	2.0*-4.2	2.6*-4.2
Tooling for 15 SRMs/year	4.6*	4.6*
AGE for 15 SRMs/year	3.8*-5.2	4.3*-5.7
Program costs	1.6*	1.6*
	12.0*-45.8	24.5-44.6
RECURRING COSTS @ 15 SRMs/YEAR WITH AN ASSUMED BASE OF 20 SRMs/YEAR		
SRM and cluster hardware (9% reduction with TECHROLL Seal nozzle)	2.4/SRM	2.7/SRM

* Minimum program cost items

APPENDIX

PERFORMANCE DATA

This appendix presents the thrust- and pressure-time histories for configurations 1 through 24. The figure numbers of the appendix are coded to the configuration number shown on figure 23 of the main text. Thus, figures 9A and 9B relate to configuration 9. The A figure contains the head end chamber pressure data, and the B figure contains the vacuum thrust data.

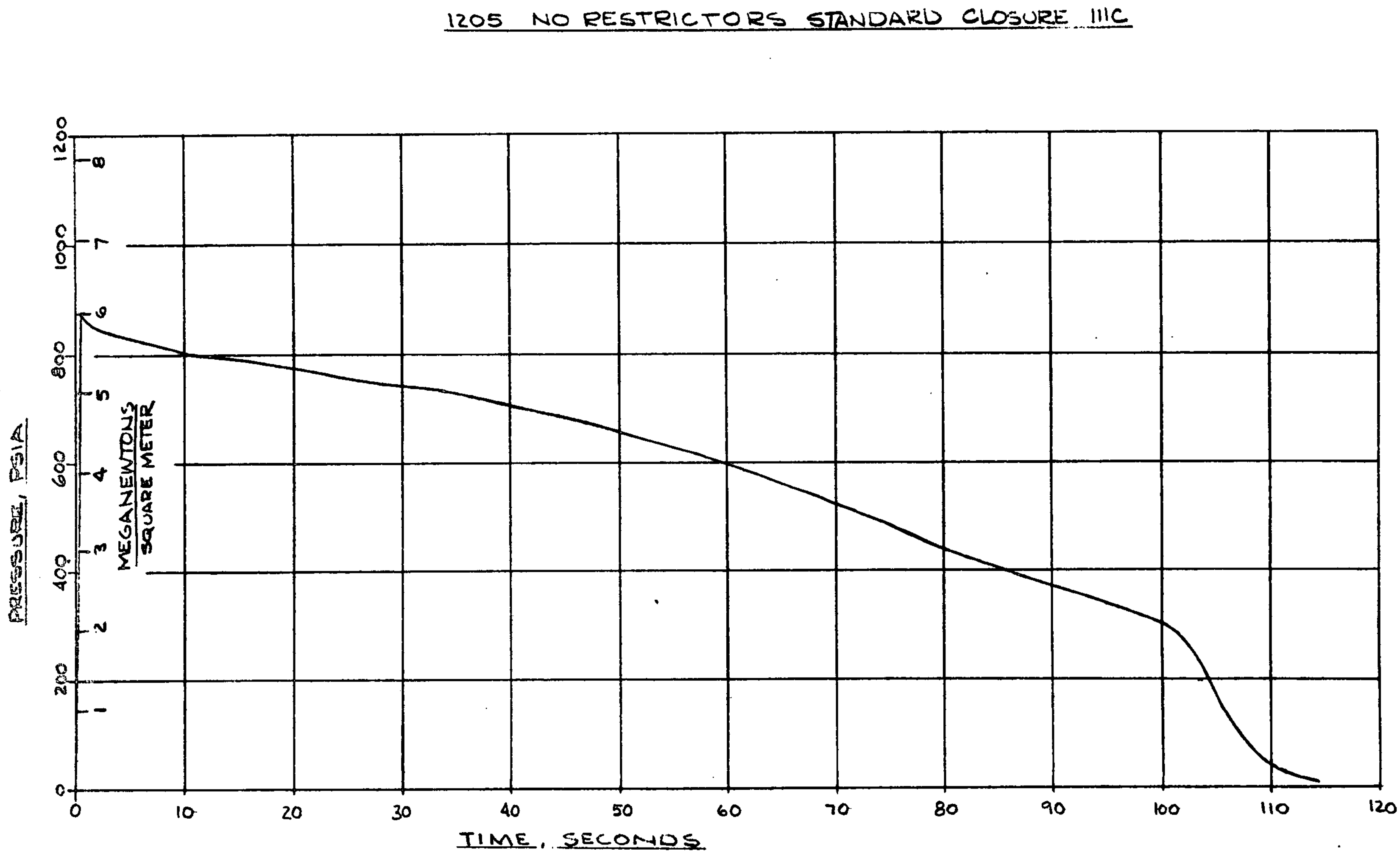


Figure 1A. Configuration 1, Pressure vs Time

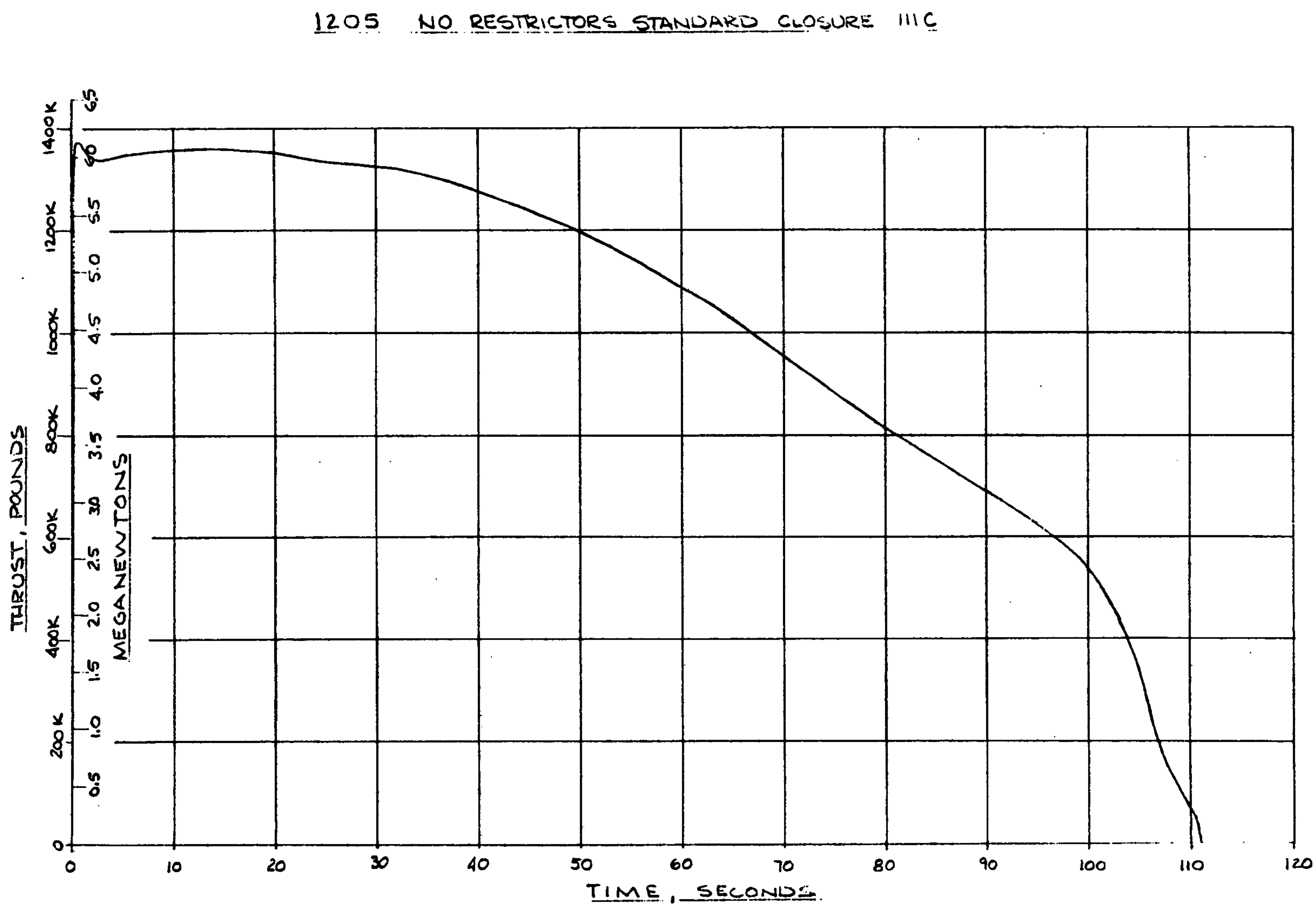


Figure 1B. Configuration 1, Thrust vs Time

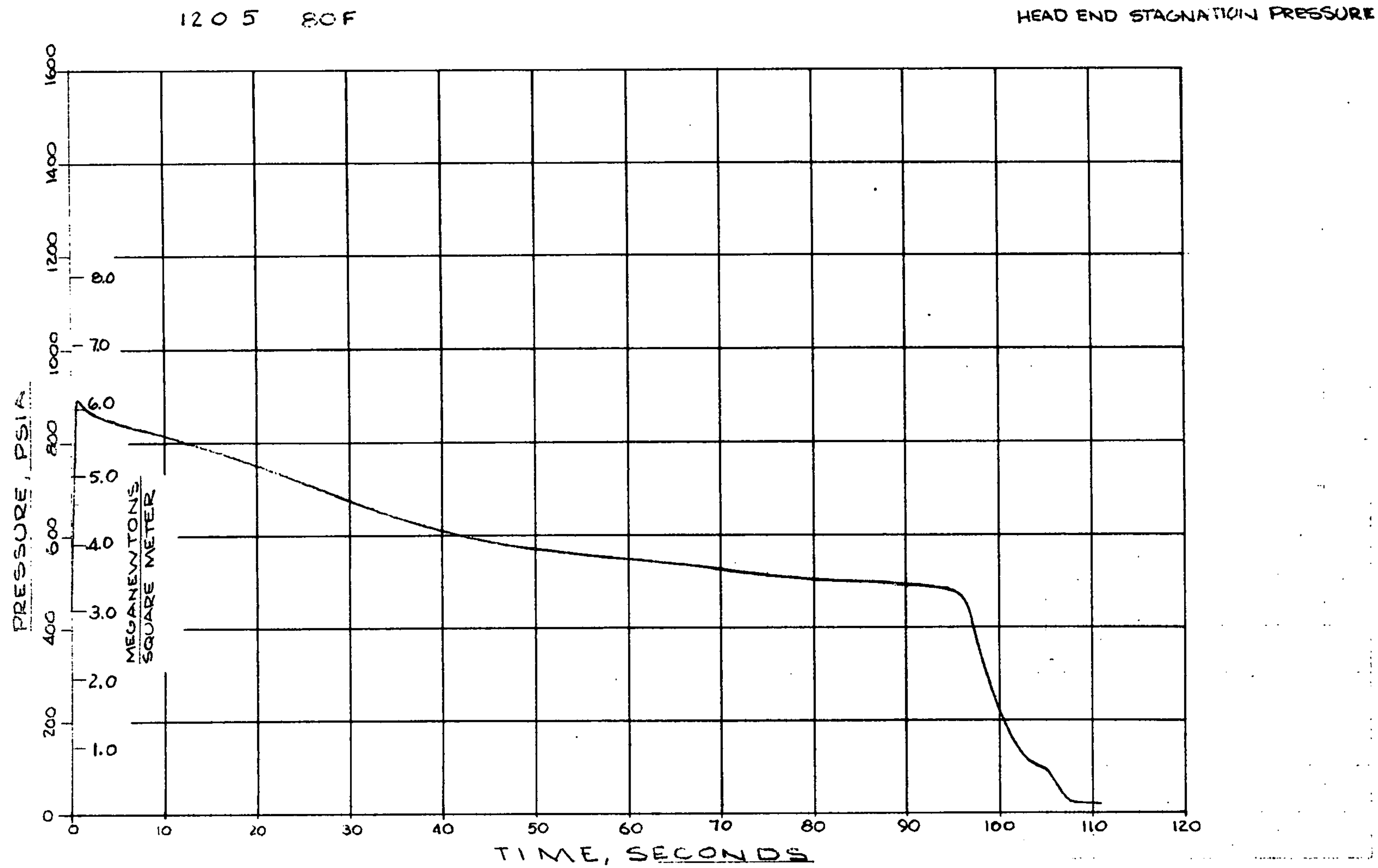


Figure 2A. Configuration 2, Pressure vs. Time

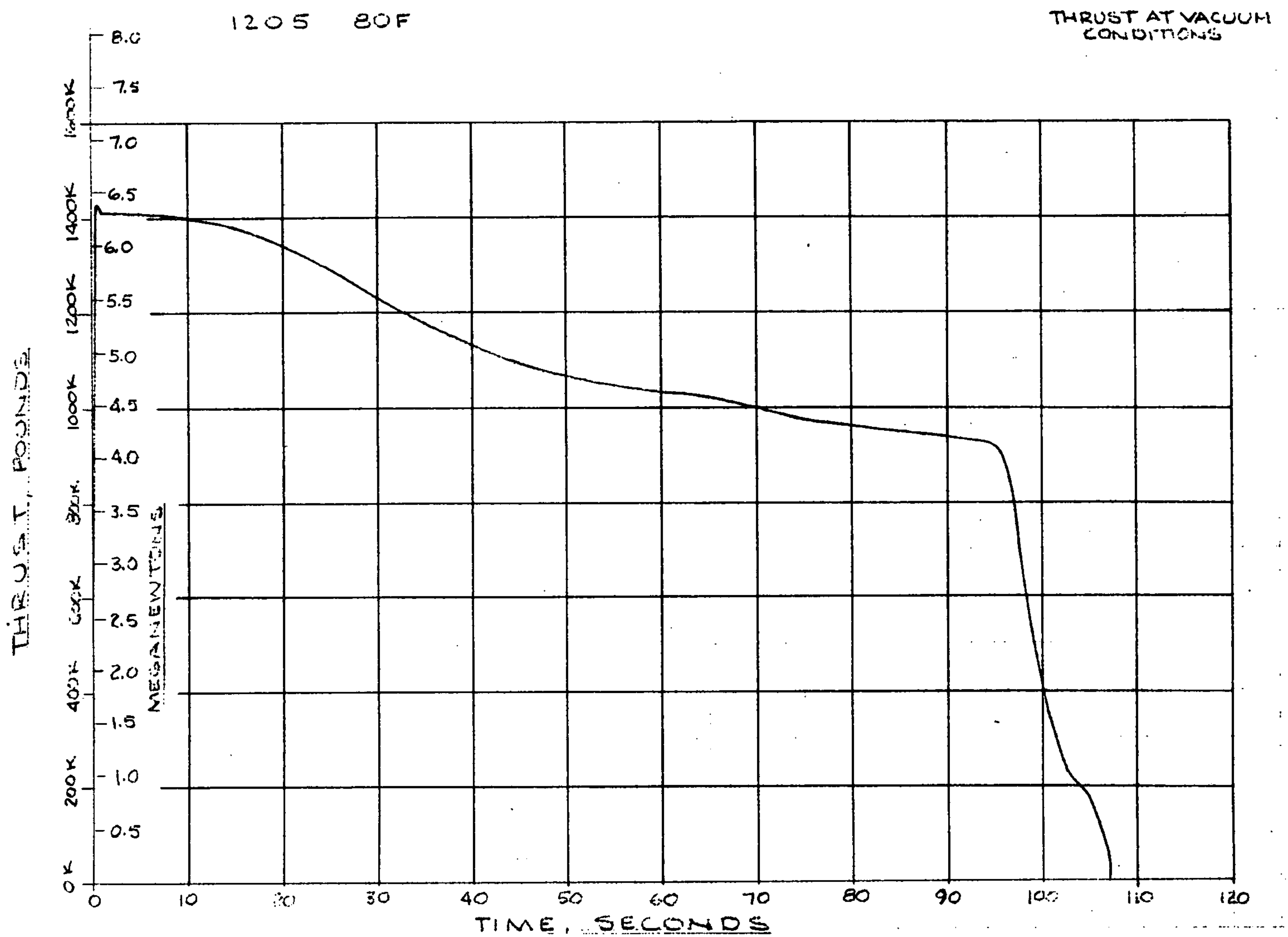


Figure 2B. Configuration 2, Thrust vs Time

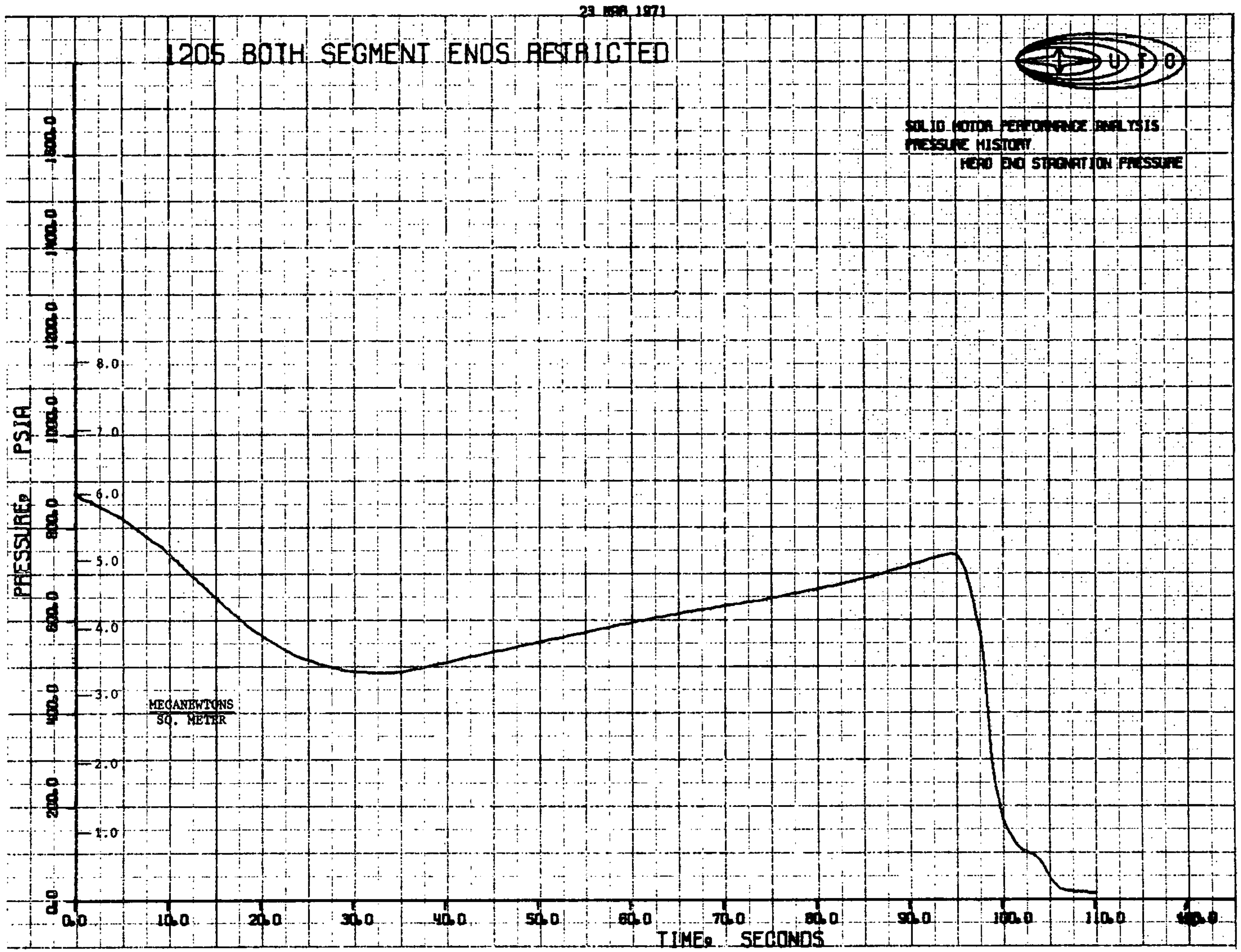


Figure 3A. Configuration 3, Pressure vs Time

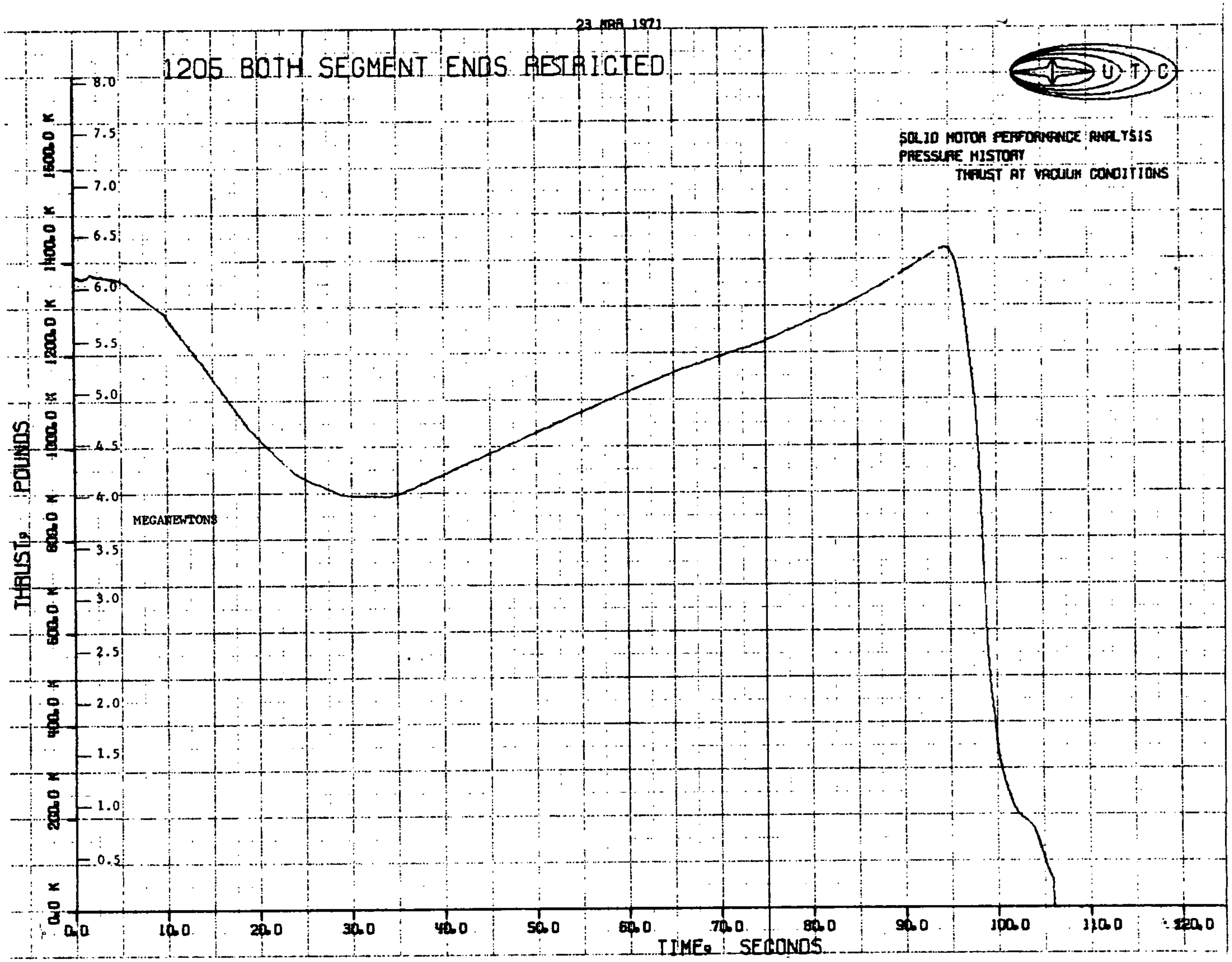


Figure 3B. Configuration 3, Thrust vs Time

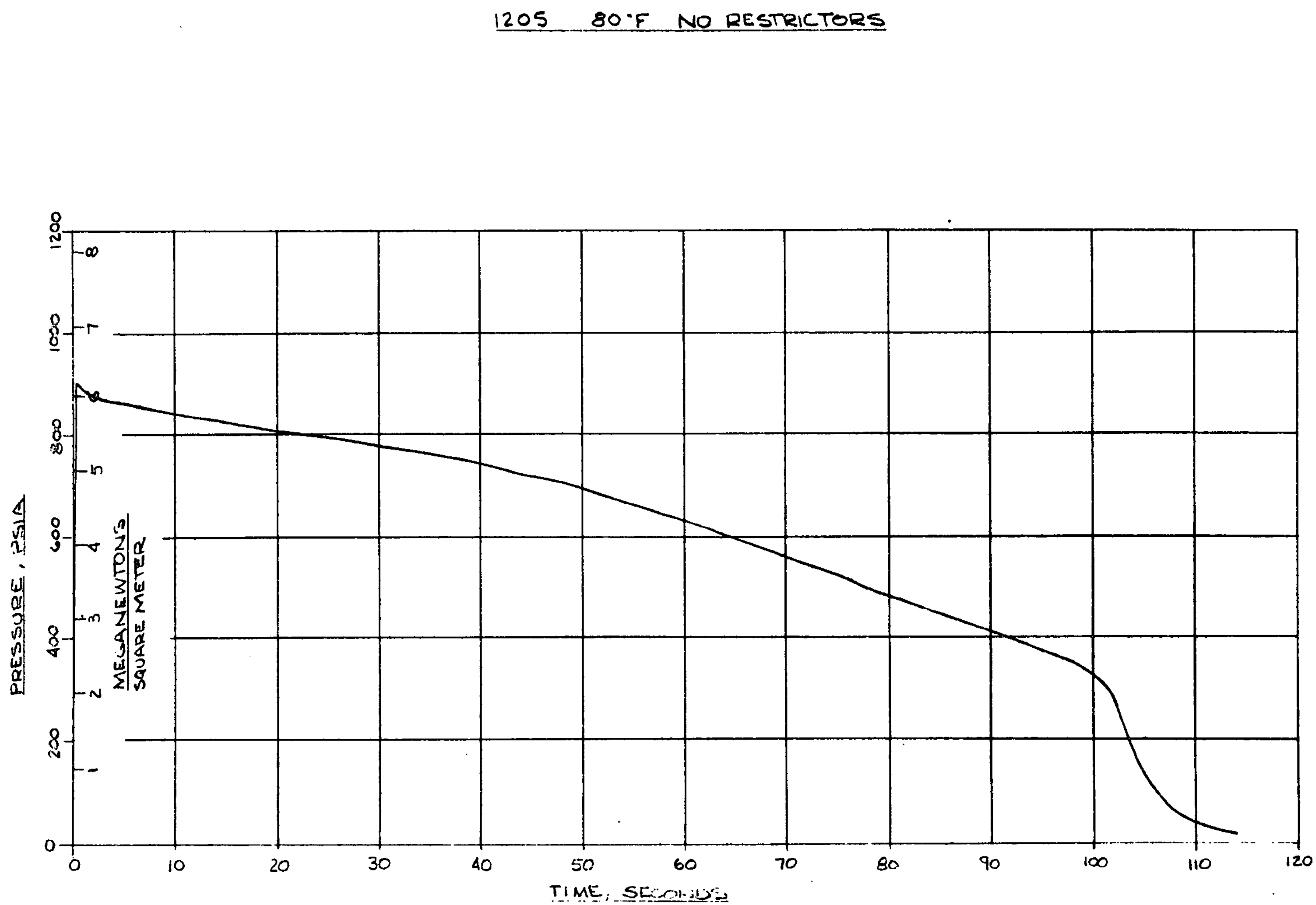


Figure 4A. Configuration 4, Pressure vs Time

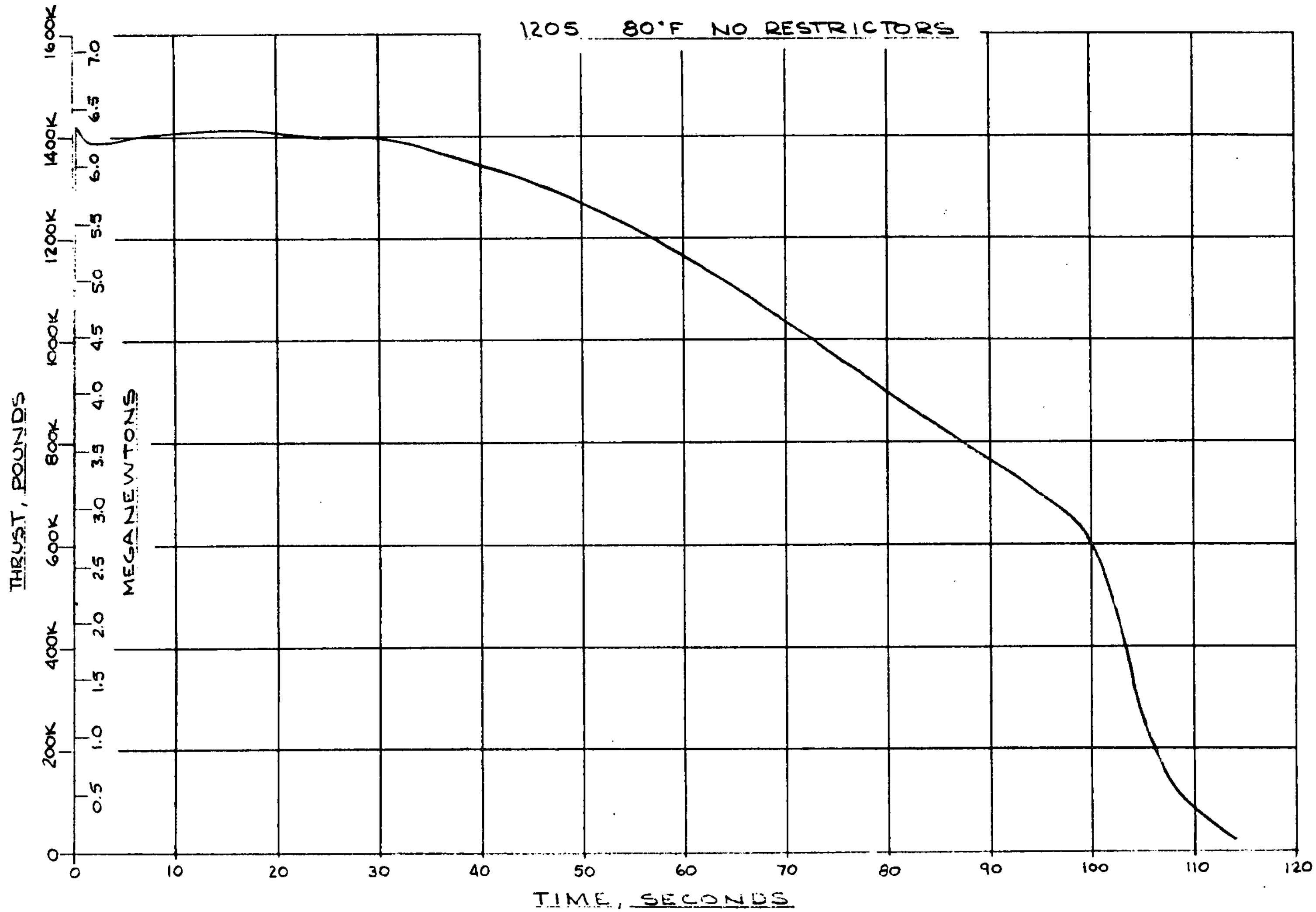


Figure 4B. Configuration 4, Thrust vs Time

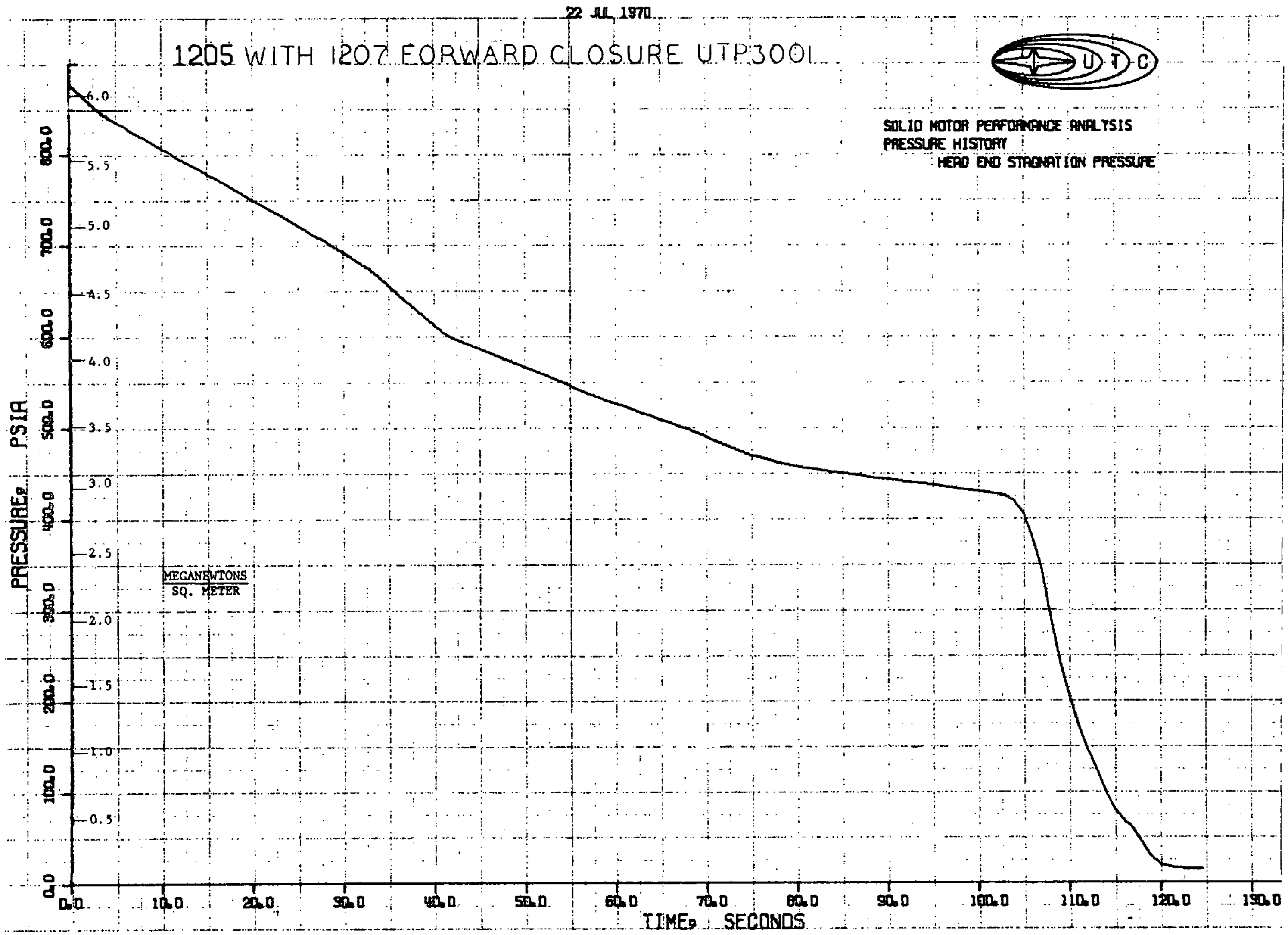


Figure 5A. Configuration 5, Pressure vs Time

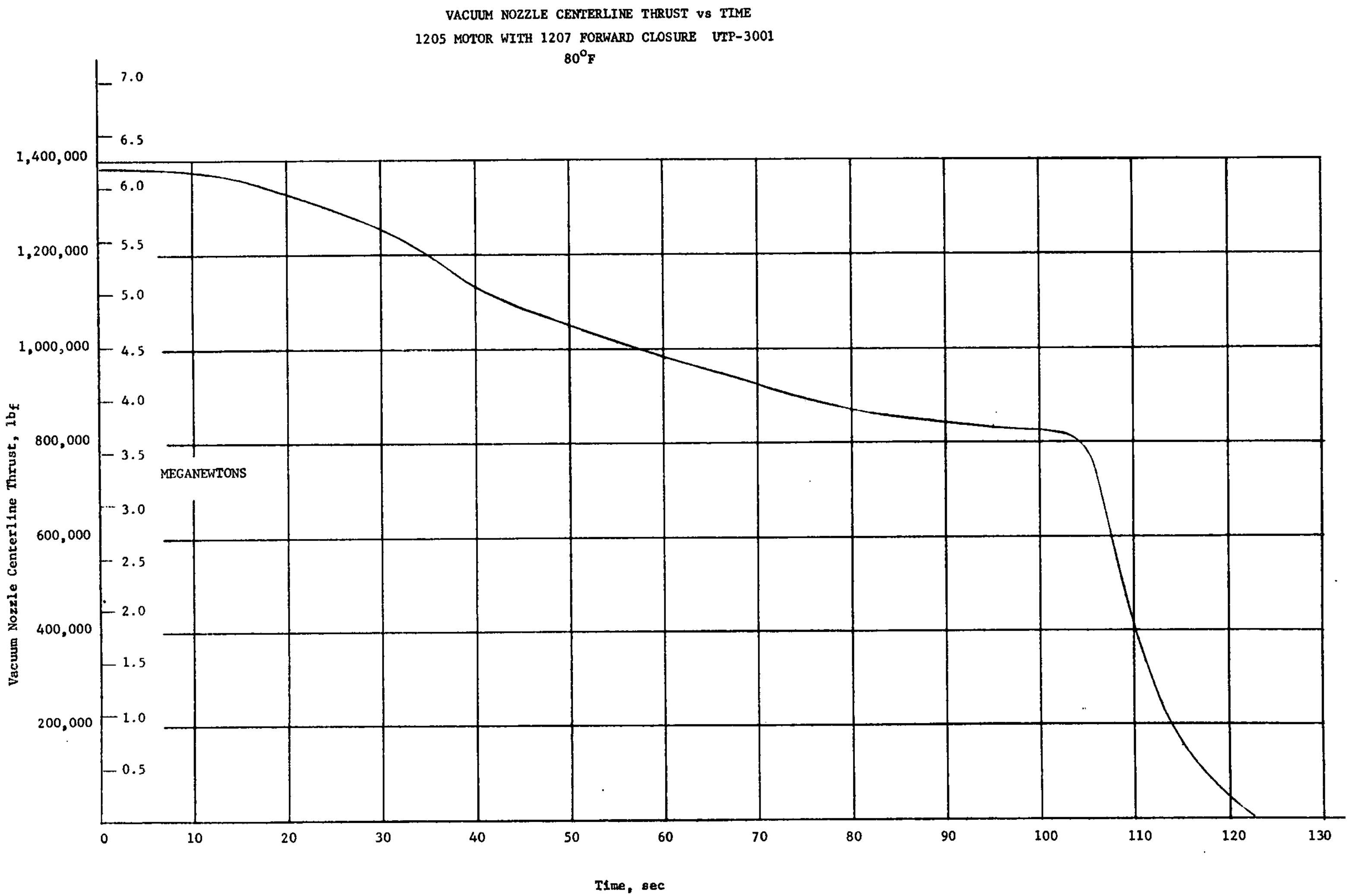


Figure 5B. Configuration 5, Thrust vs Time

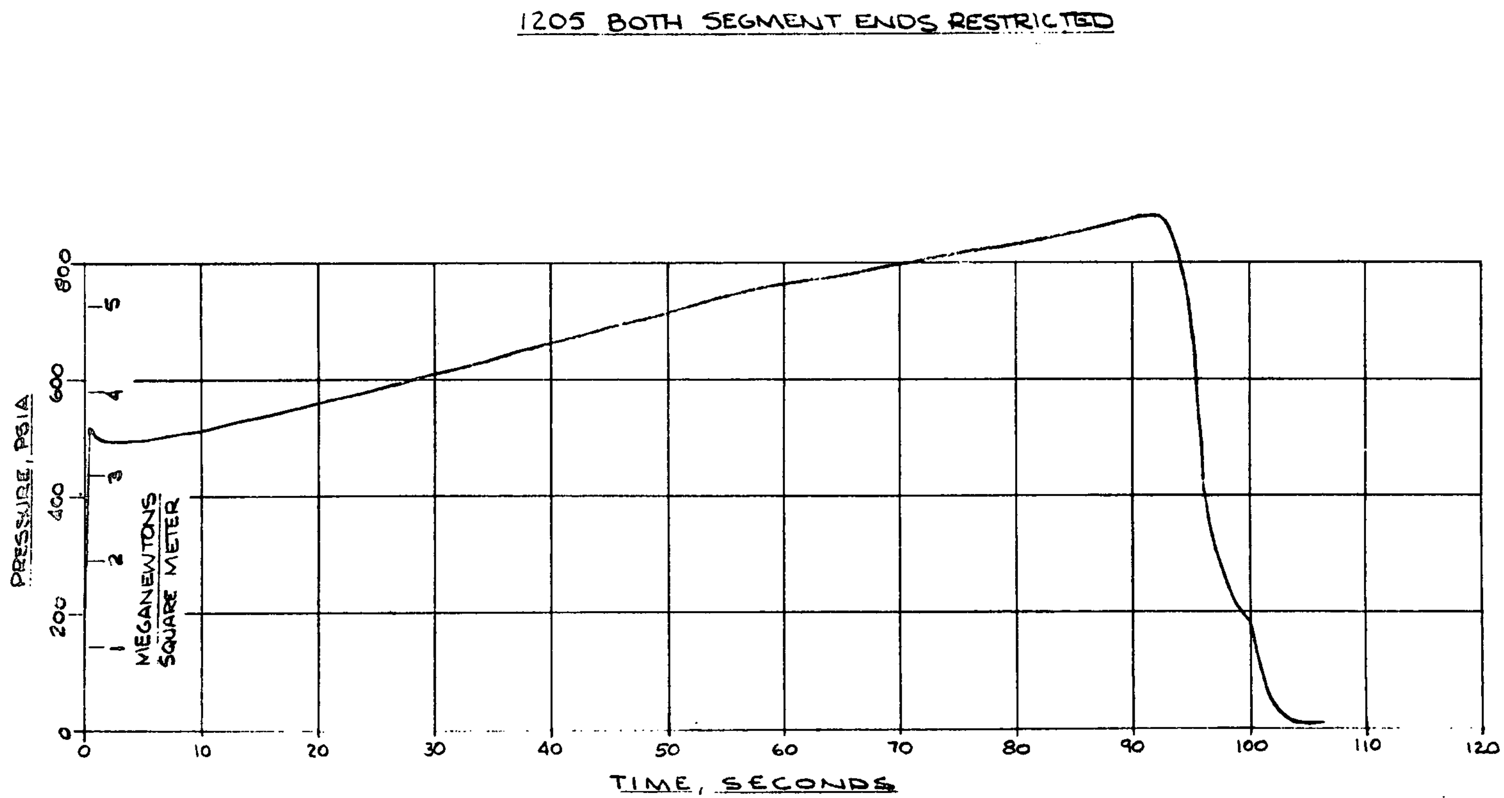


Figure 6A. Configuration 6, Pressure vs Time

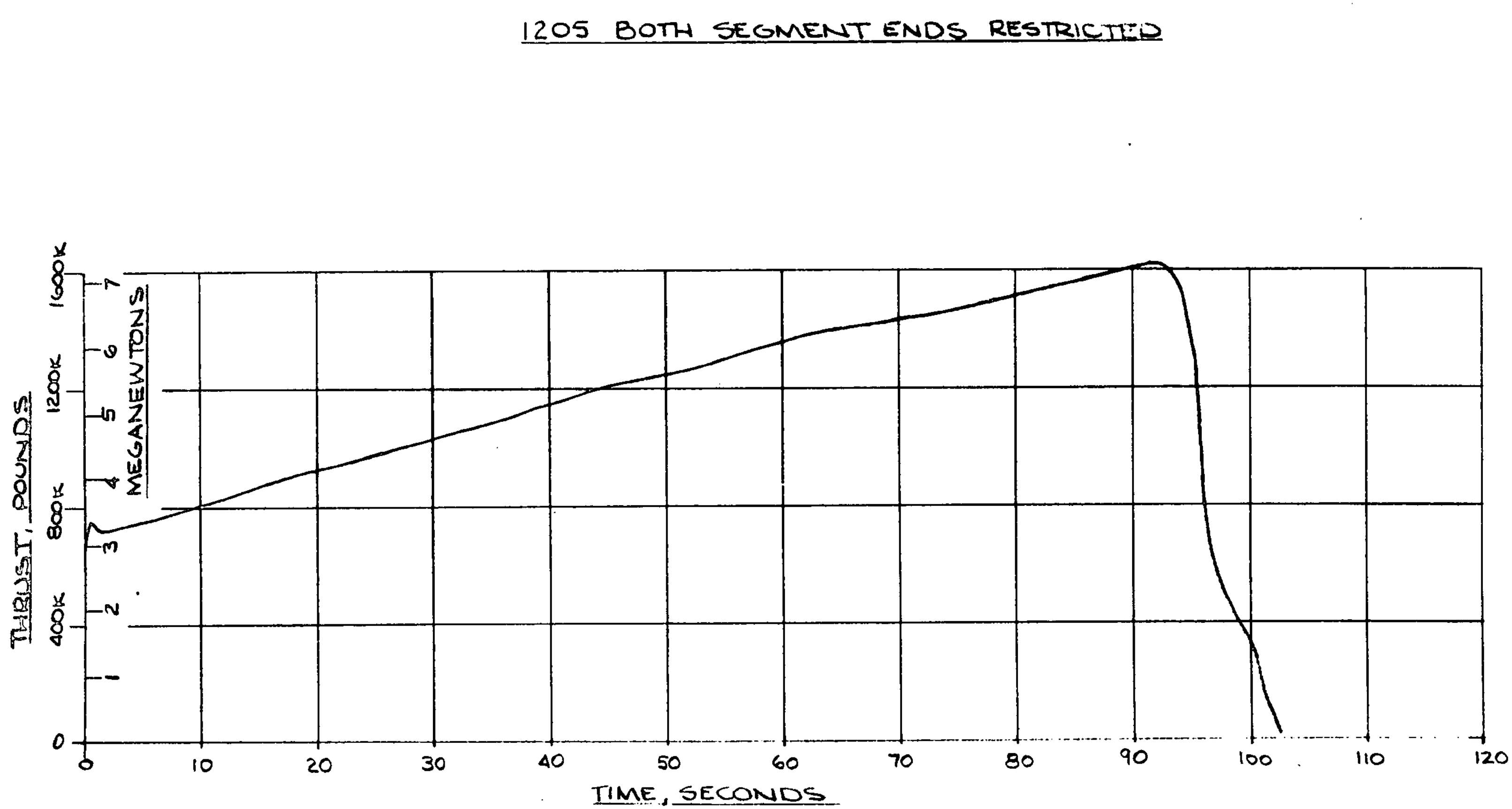


Figure 6B. Configuration 6, Thrust vs Time

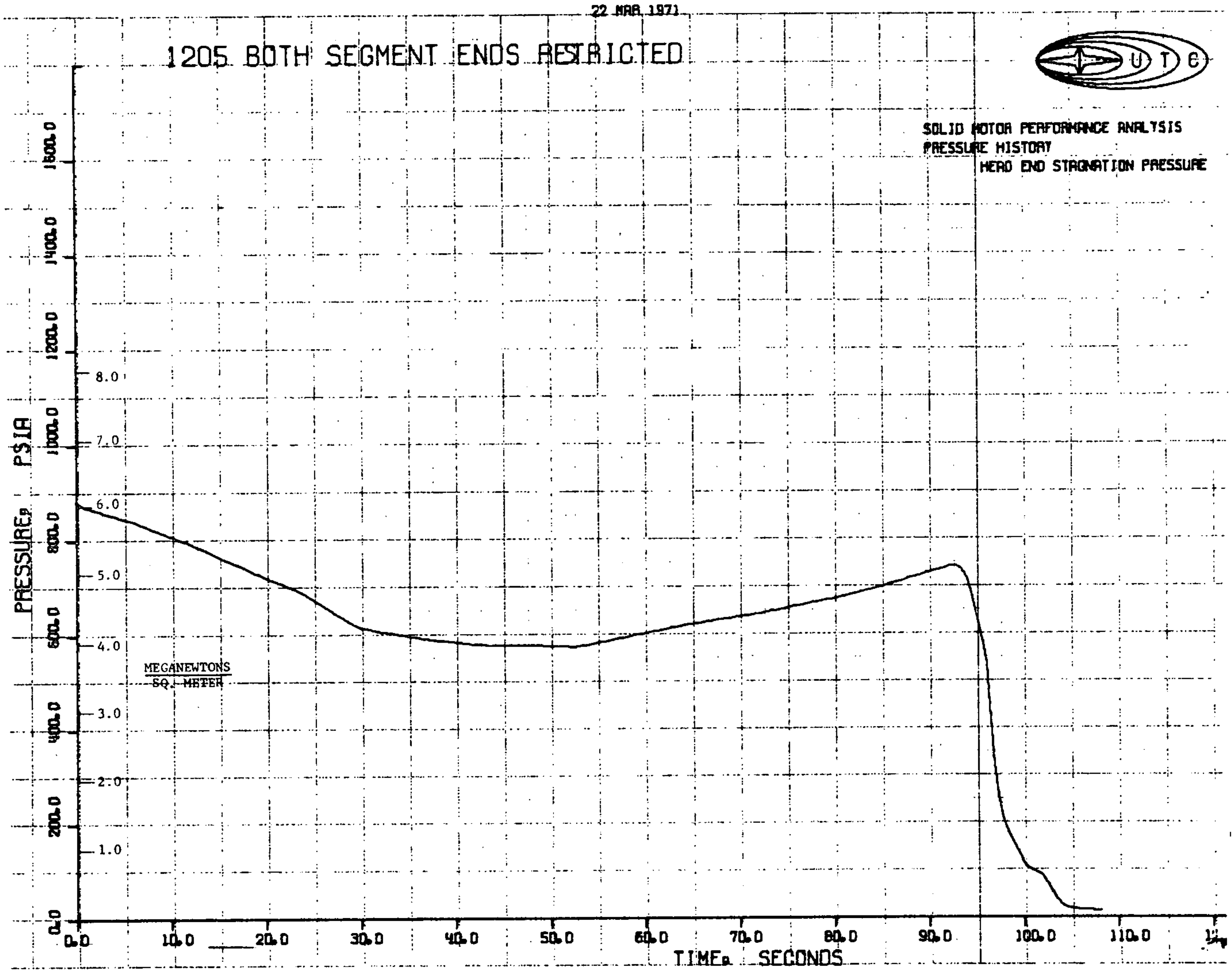


Figure 7A. Configuration 7, Pressure vs Time

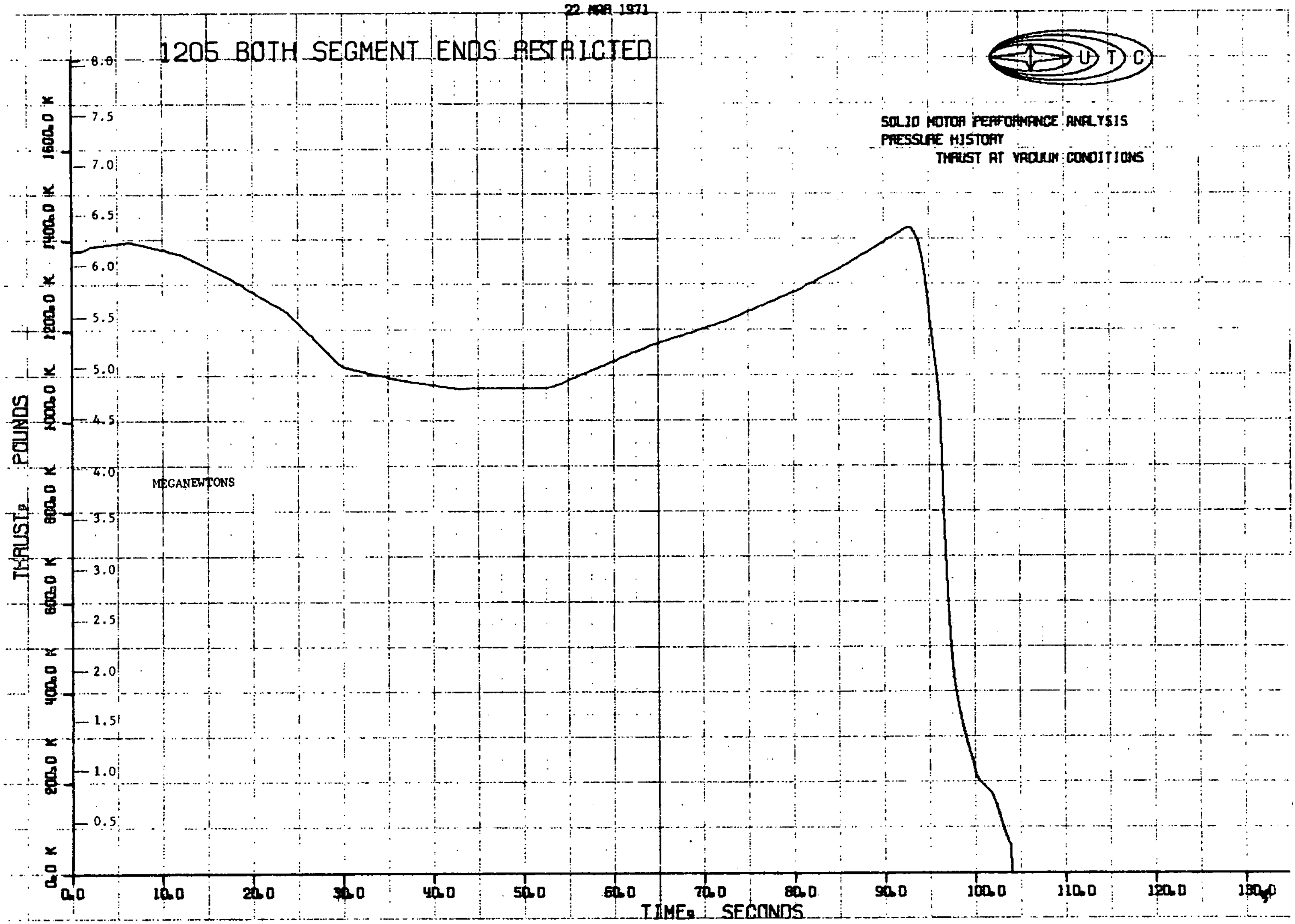


Figure 7B. Configuration 7, Thrust vs Time

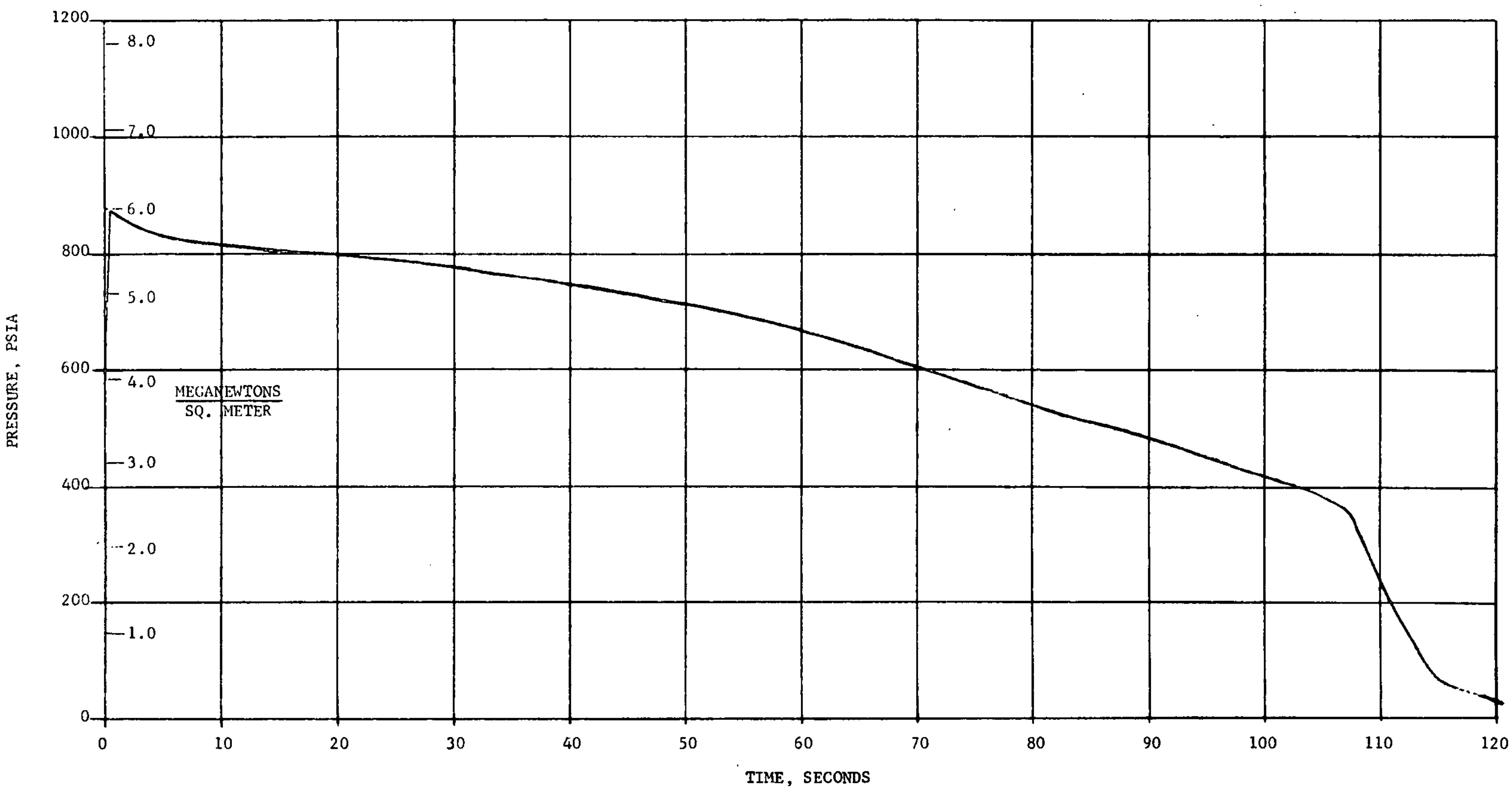


Figure 8A. Configuration 8, Pressure vs Time

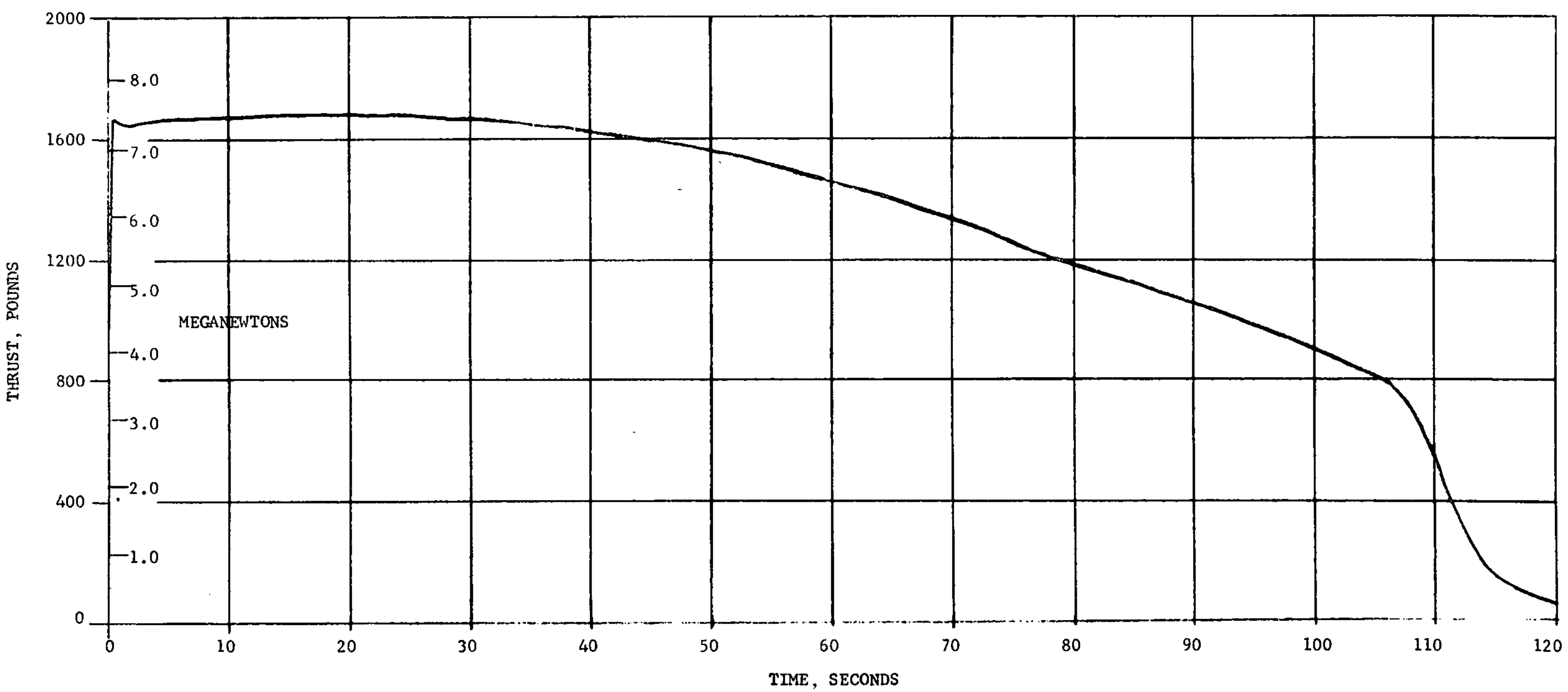


Figure 8B. Configuration 8, Thrust vs Time

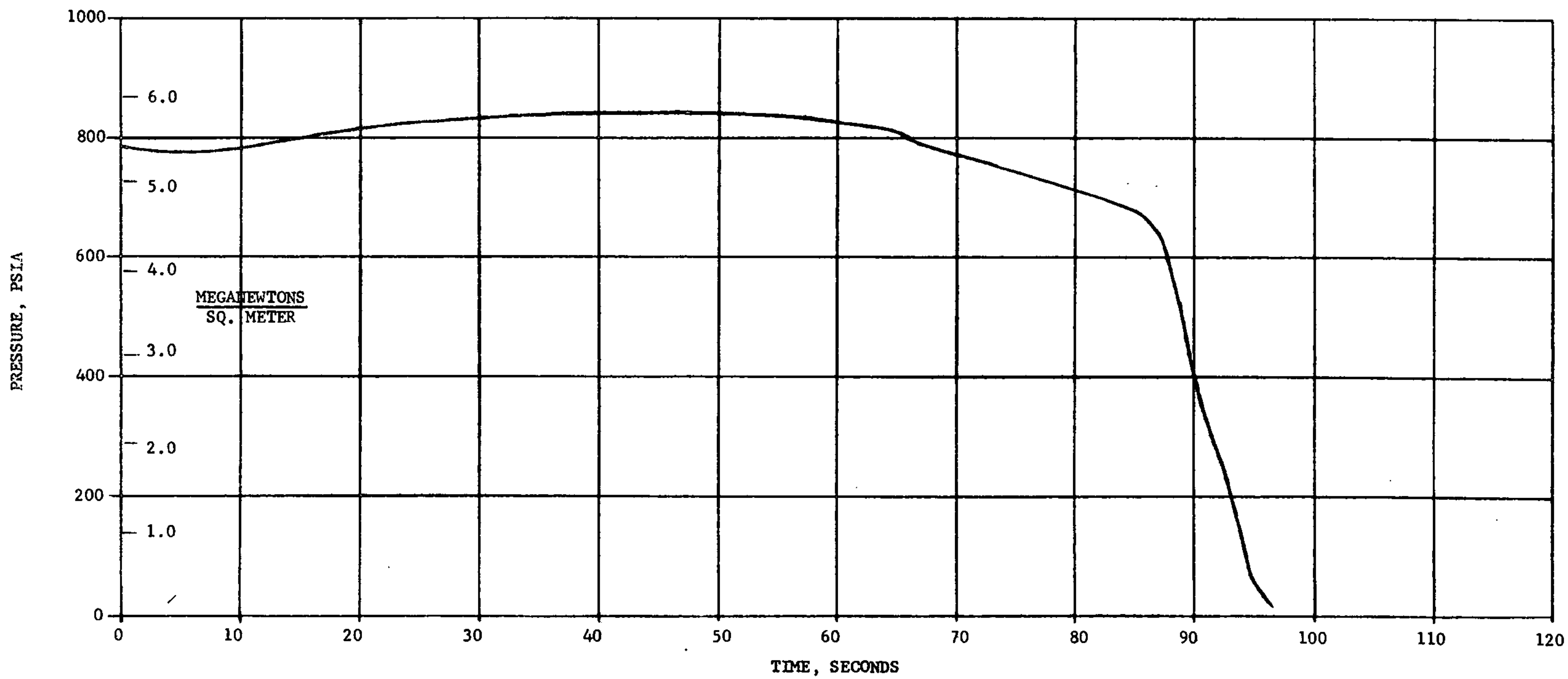


Figure 9A. Configuration 9, Pressure vs Time

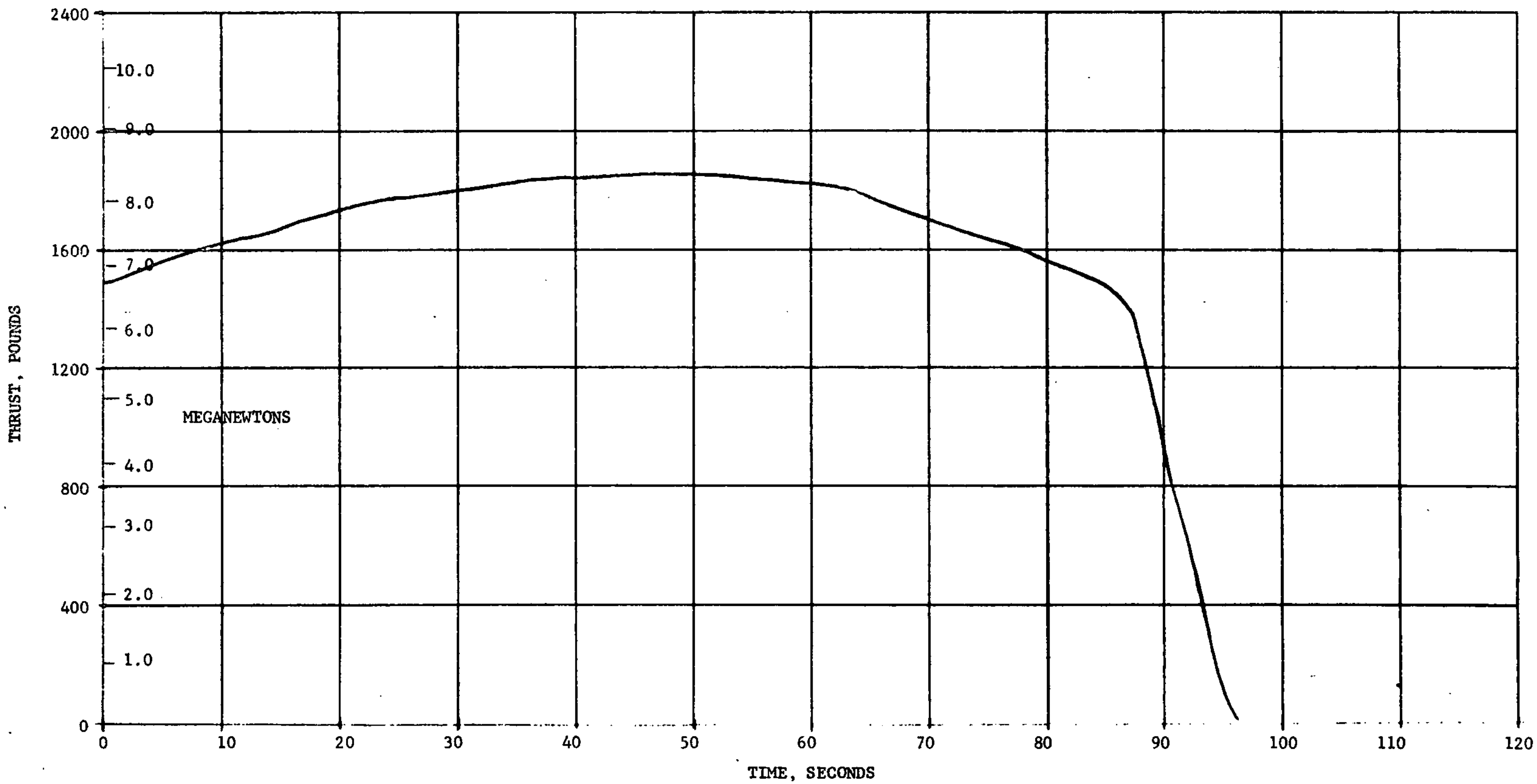


Figure 9B. Configuration 9, Thrust vs Time

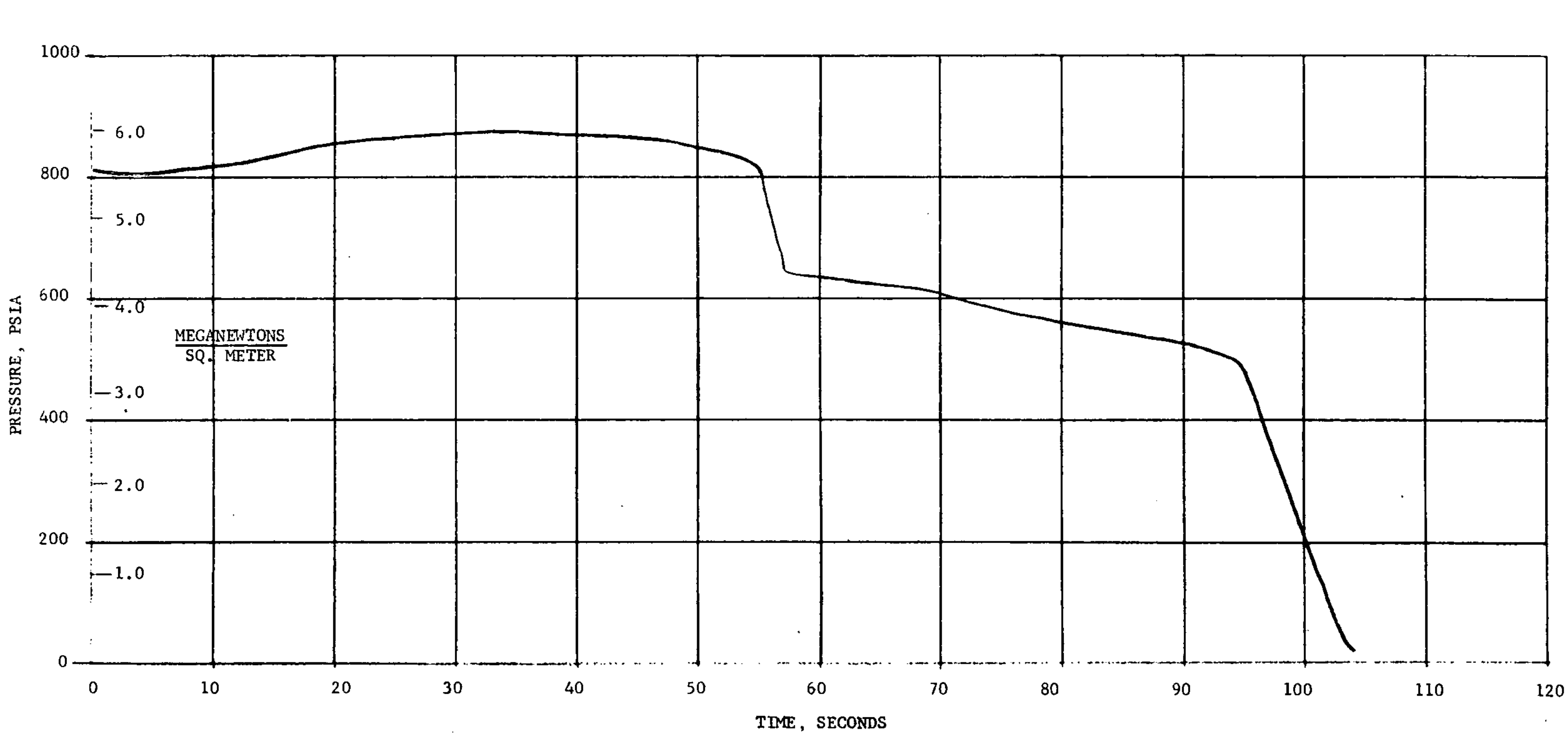


Figure 10A. Configuration 10, Pressure vs Time

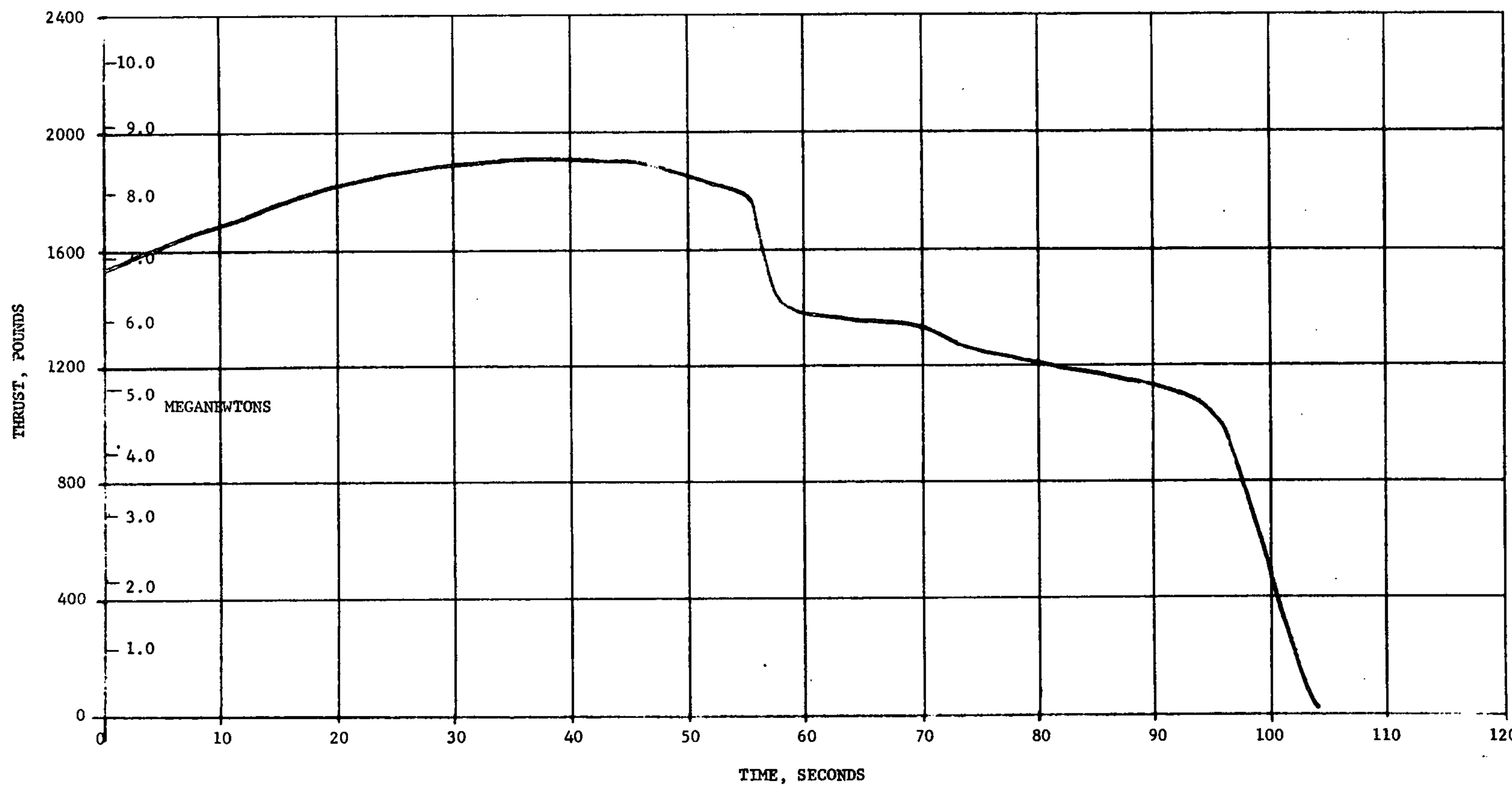


Figure 10B. Configuration 10, Thrust vs Time

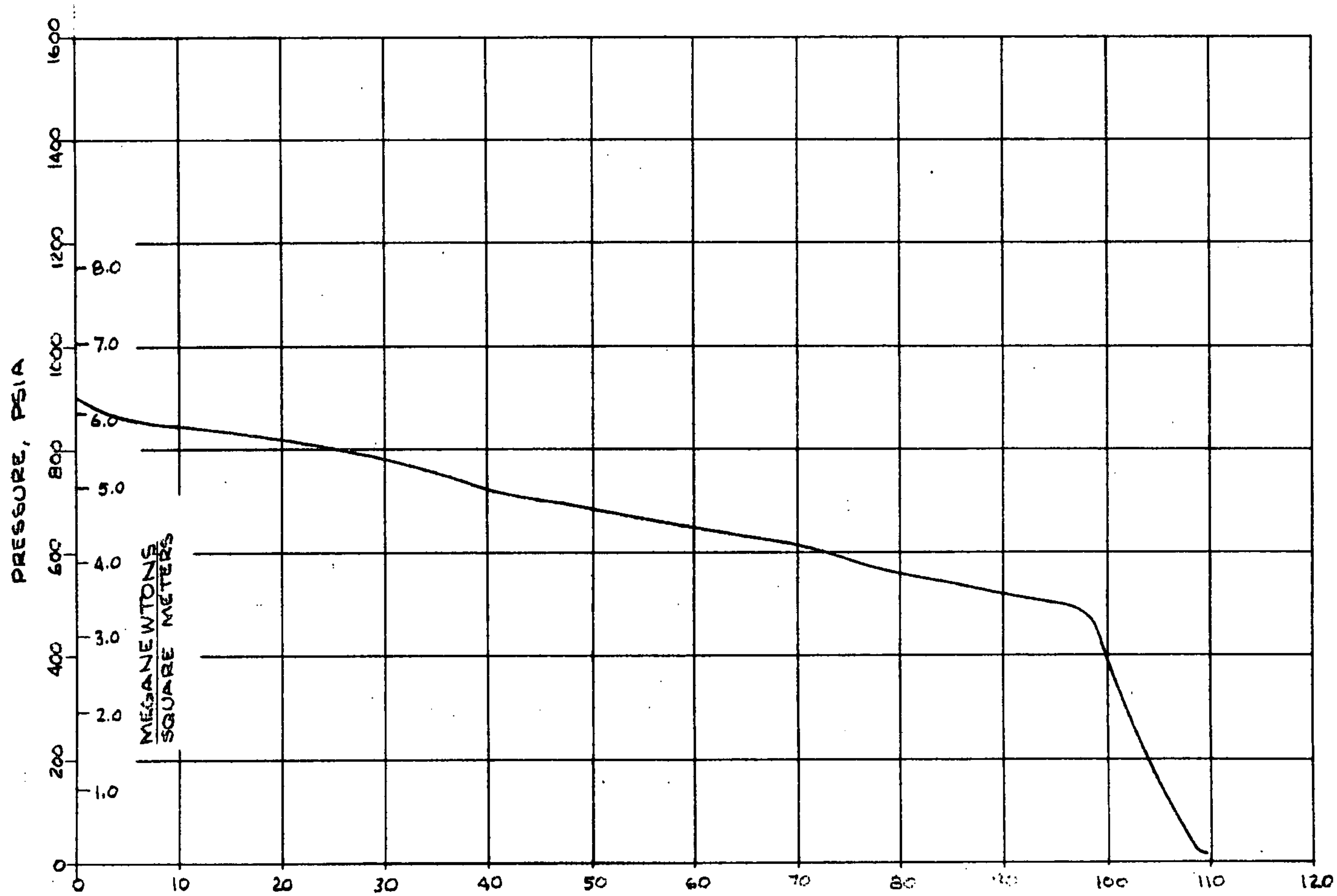


Figure 11A. Configuration 11, Pressure vs Time

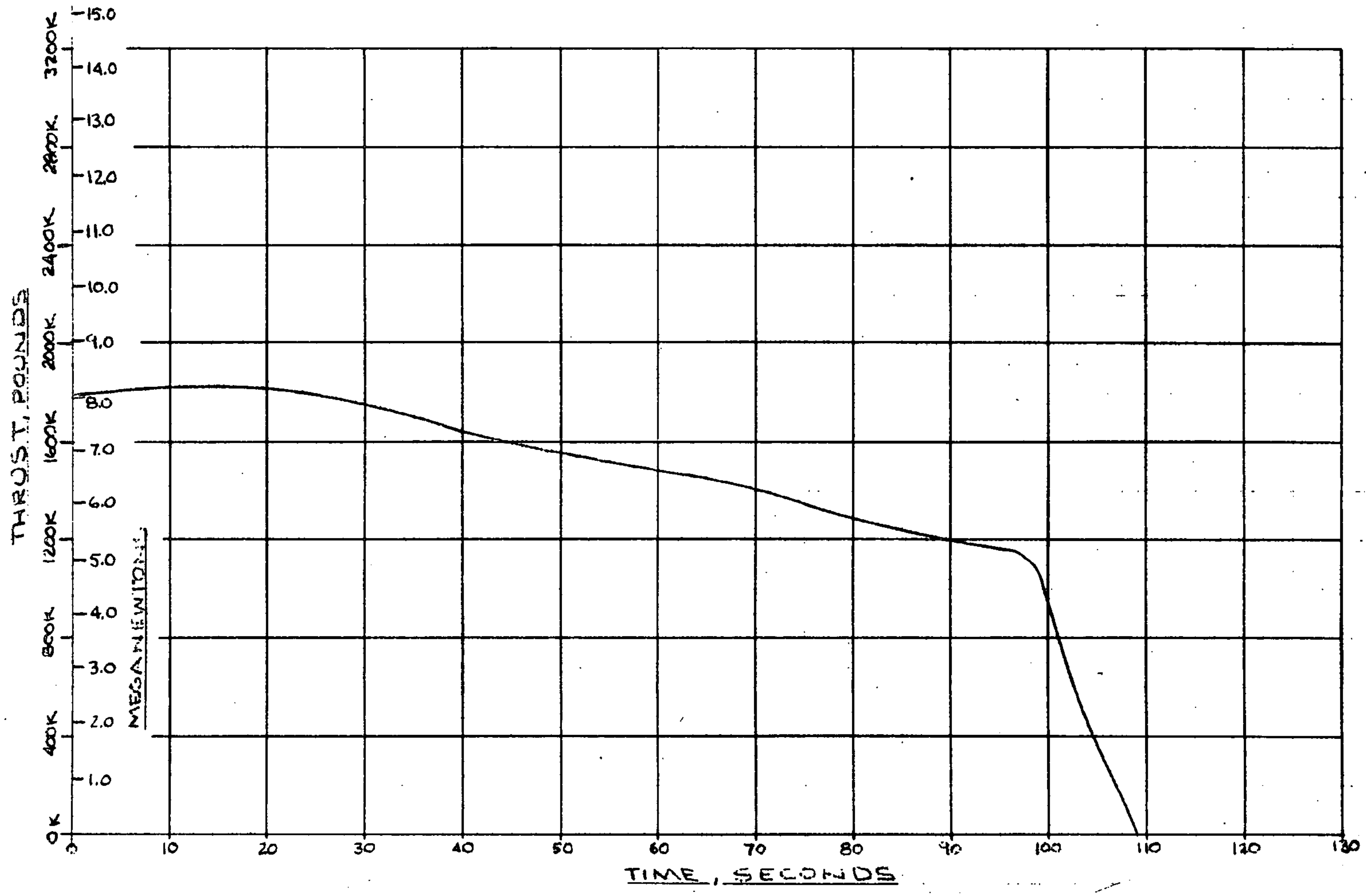


Figure 11B. Configuration 11, Thrust vs Time

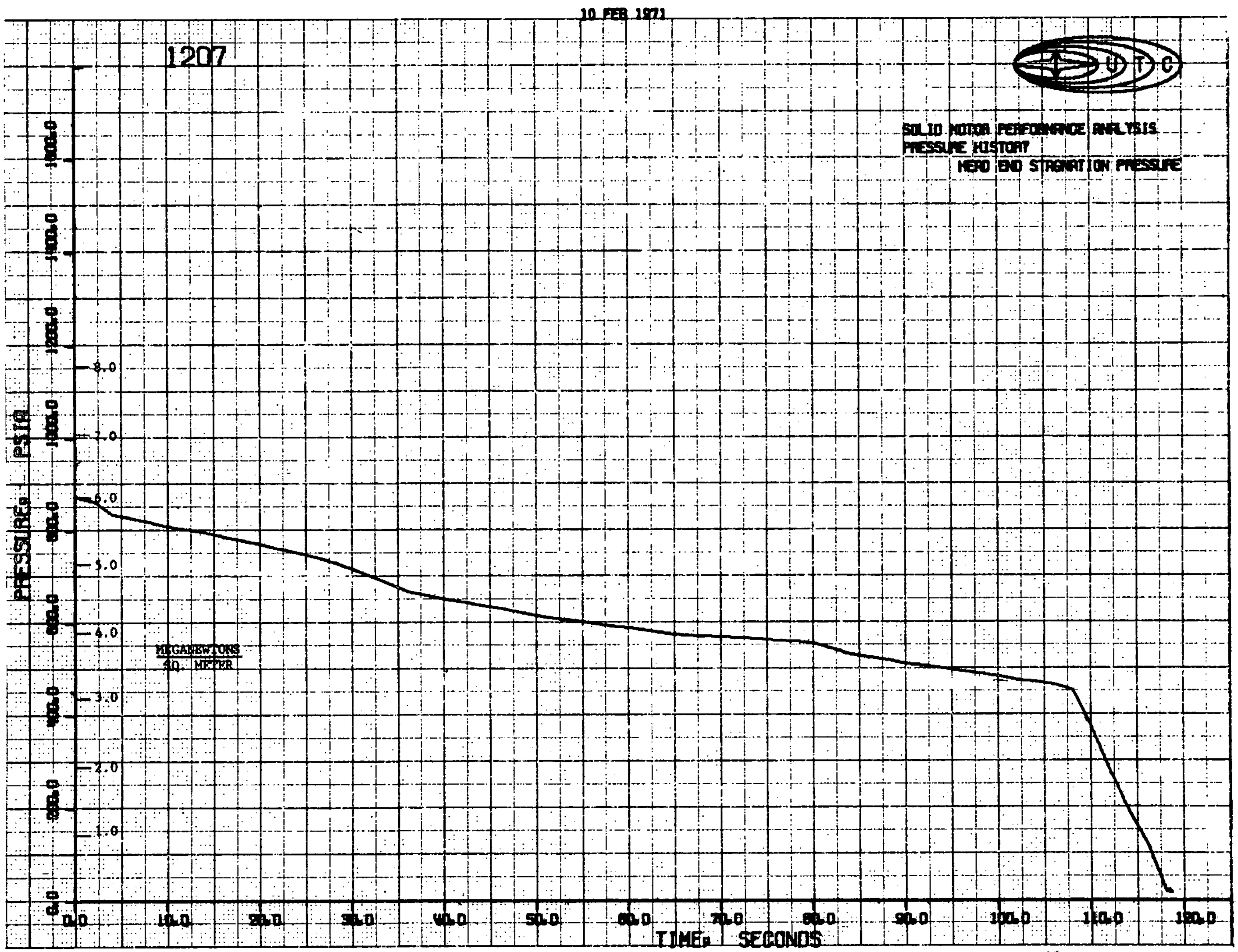


Figure 12A. Configuration 12, Pressure vs Time

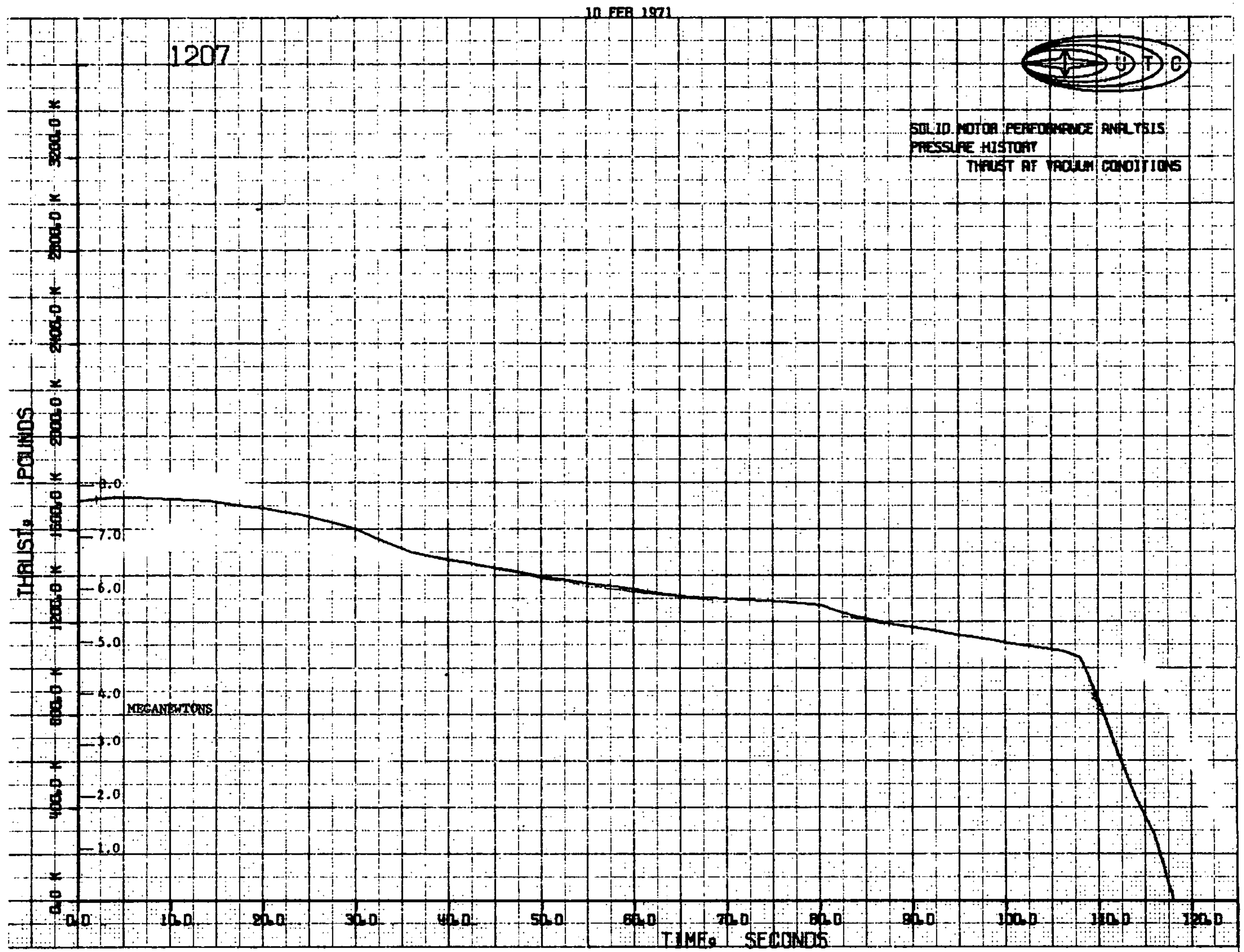


Figure 12B. Configuration 12, Thrust vs Time

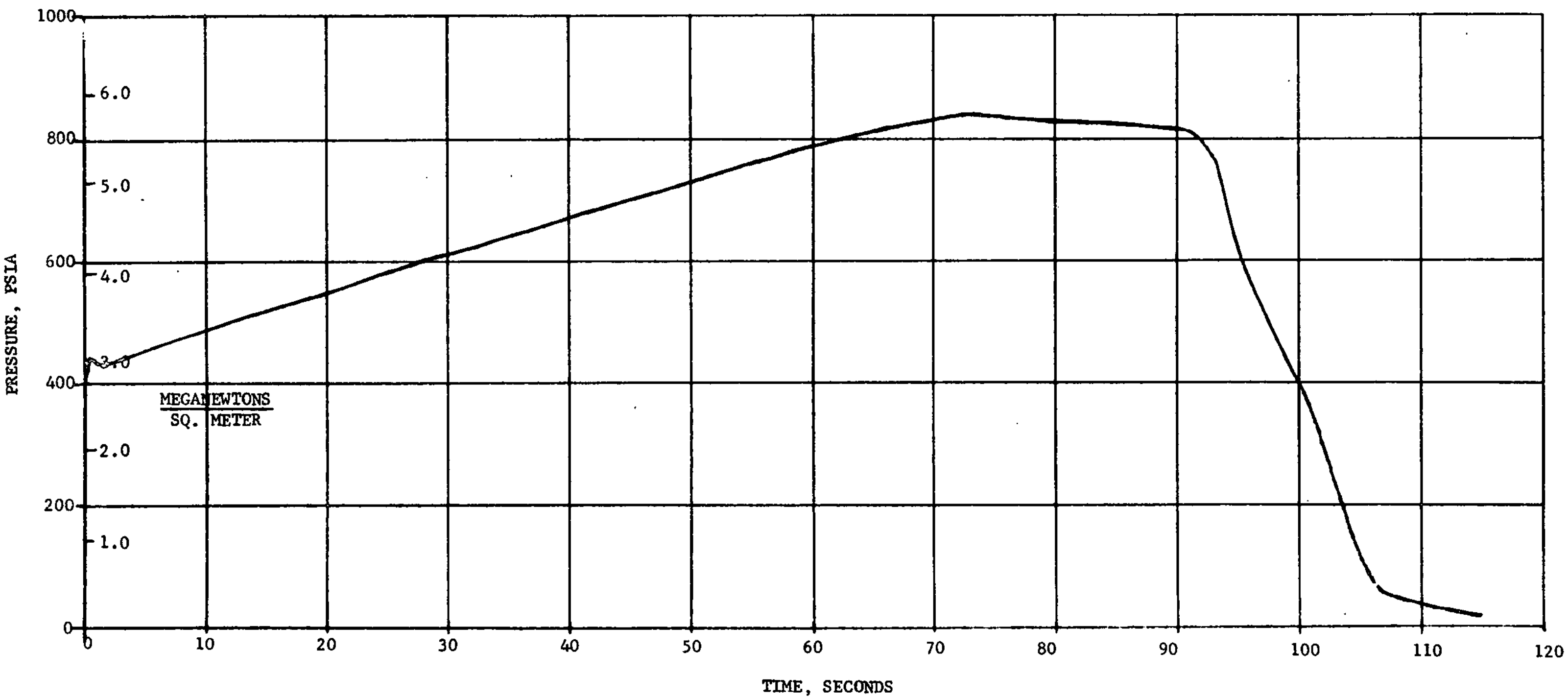


Figure 13A. Configuration 13, Pressure vs Time

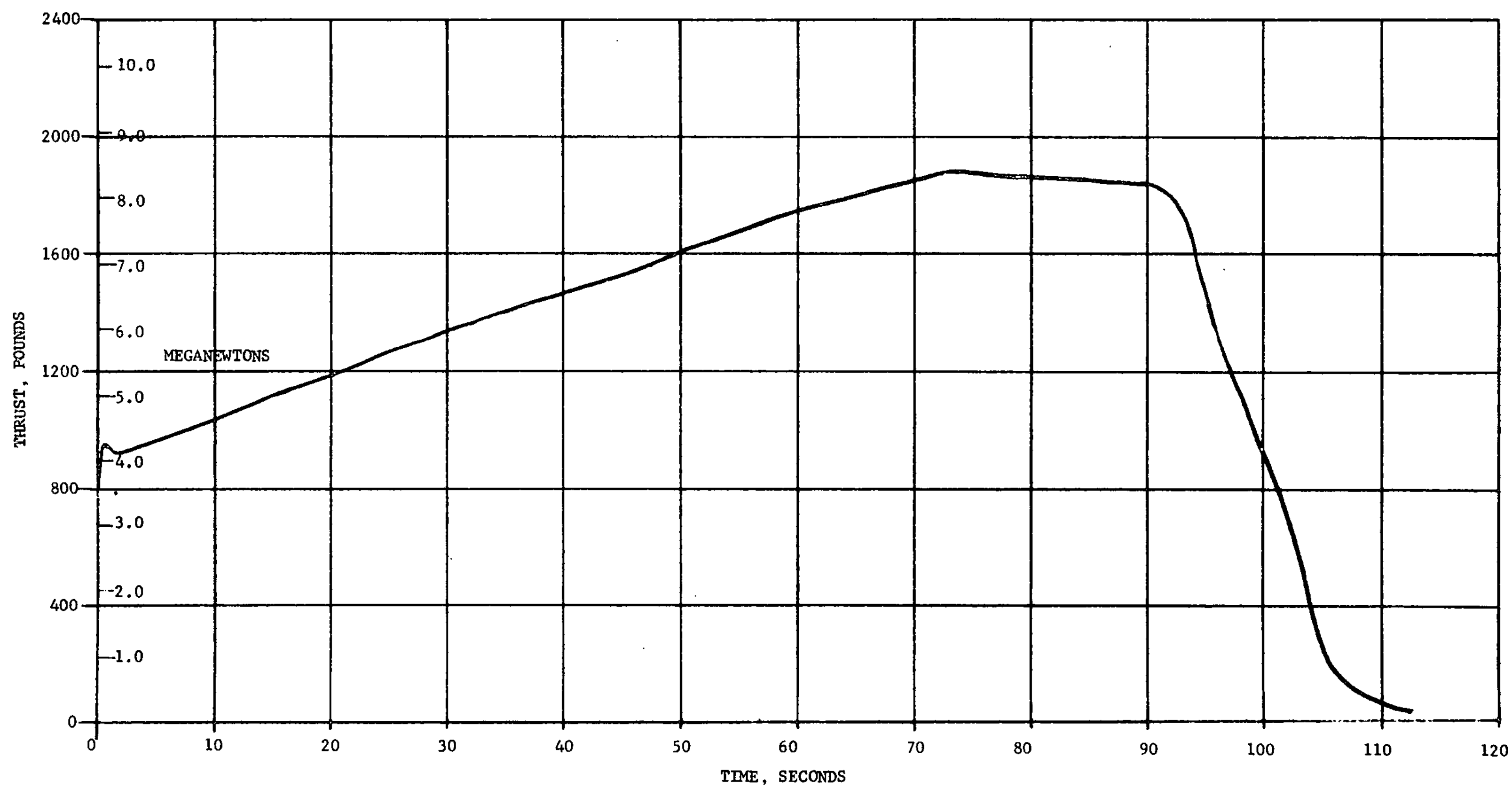


Figure 13B. Configuration 13, Thrust vs Time

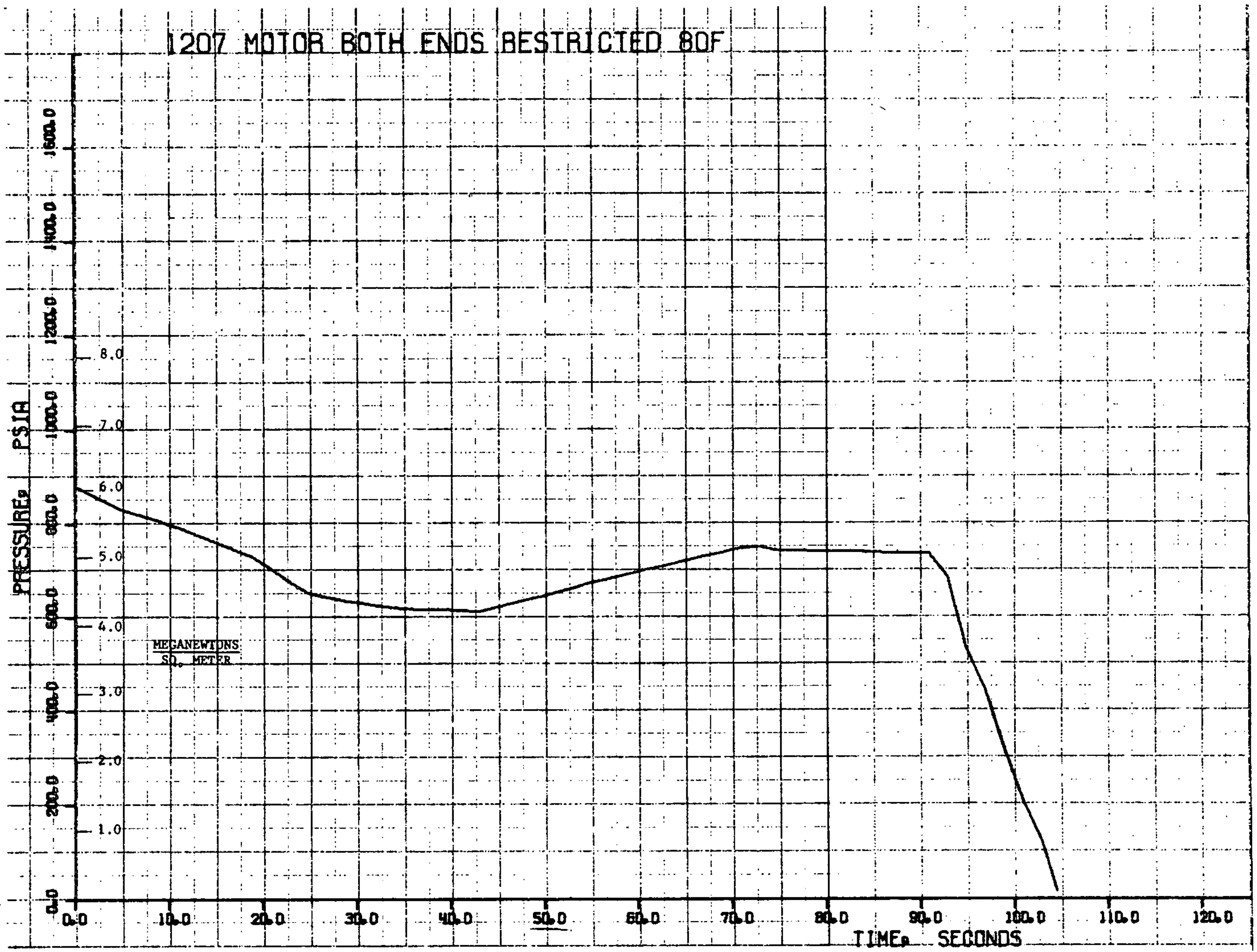


Figure 14A. Configuration 14, Pressure vs Time

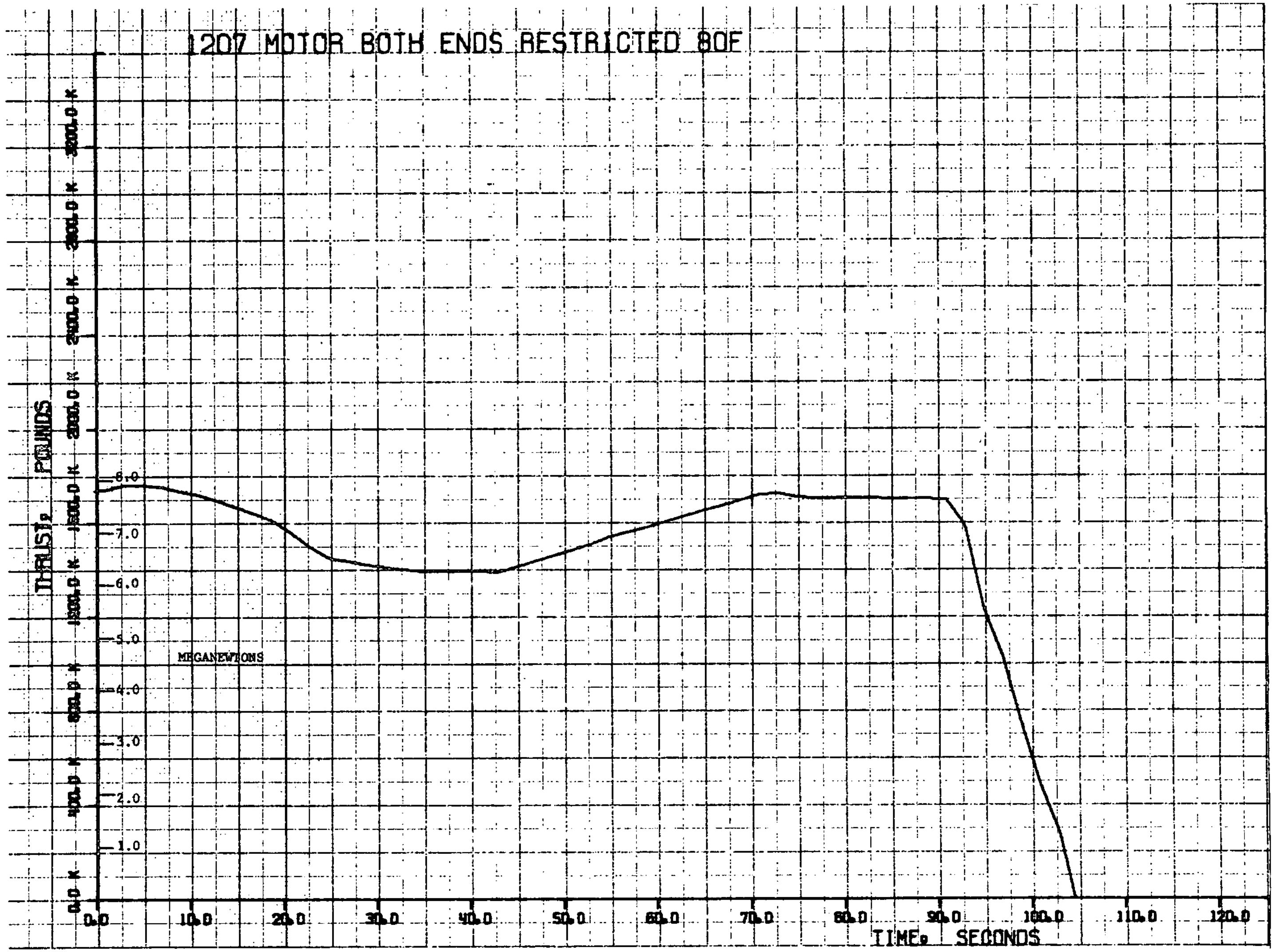


Figure 14B. Configuration 14, Thrust vs Time

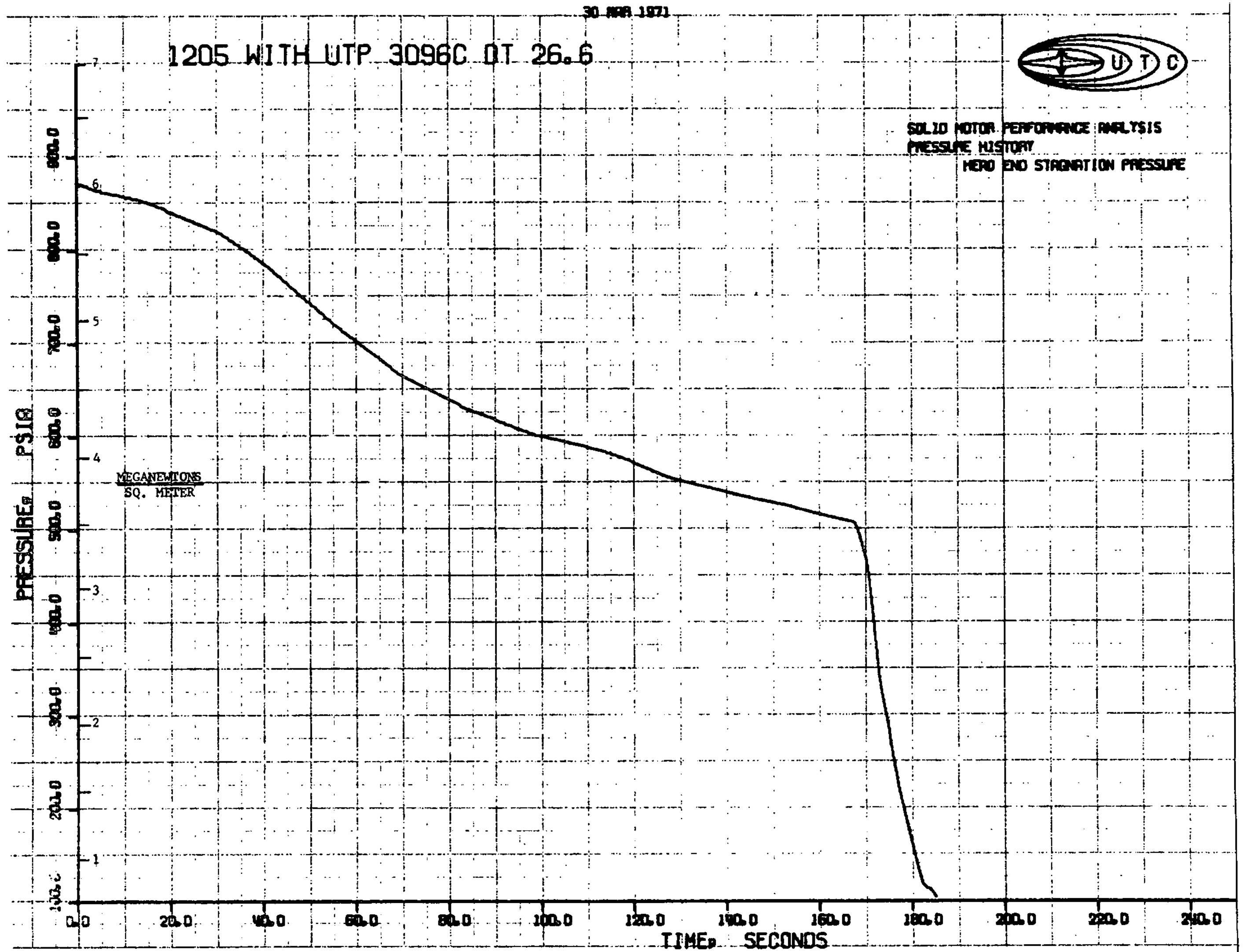


Figure 15A. Configuration 15, Pressure vs Time

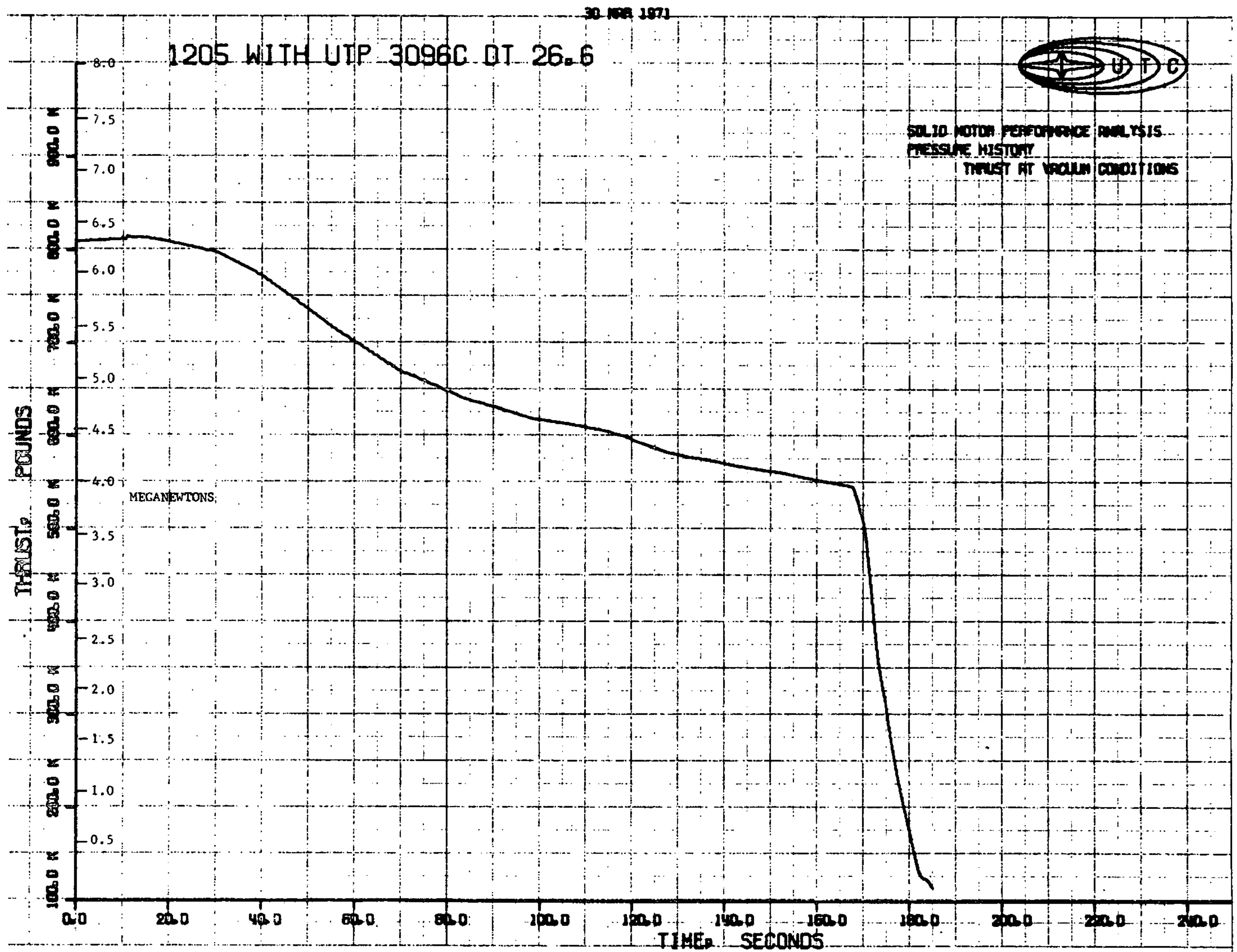


Figure 15B. Configuration 15, Thrust vs Time

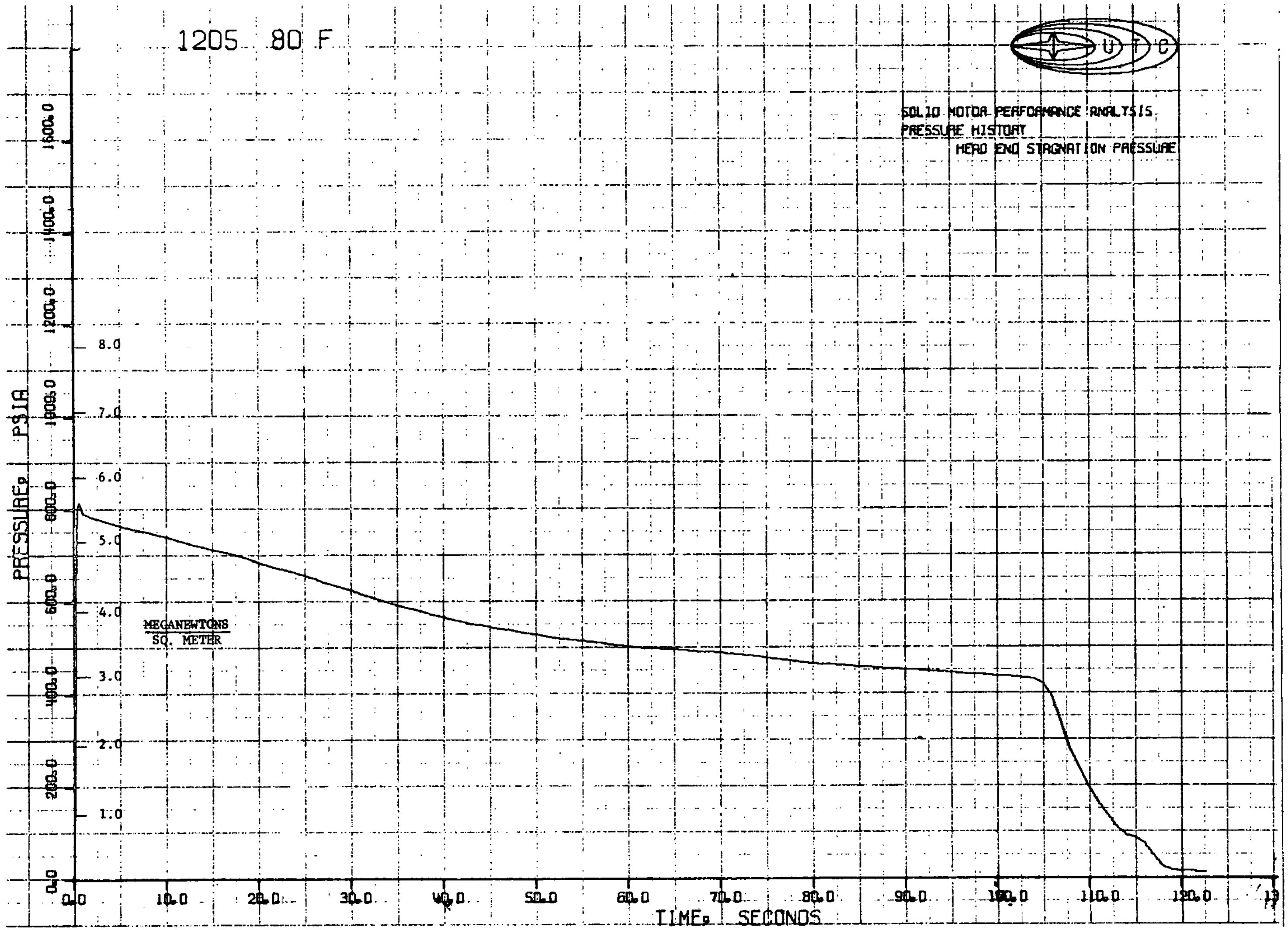


Figure 16A. Configuration 16, Pressure vs Time

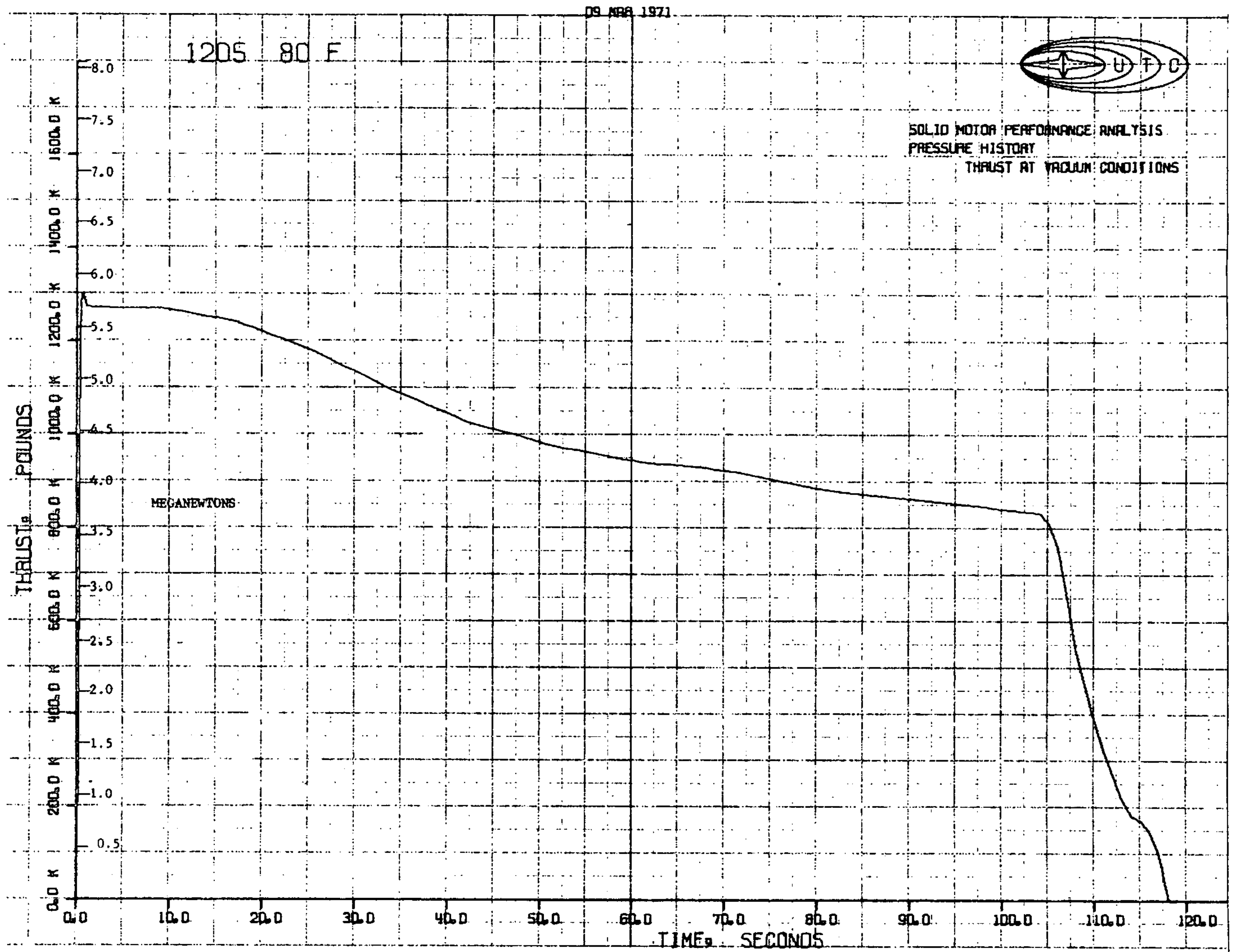


Figure 16B. Configuration 16, Thrust vs Time

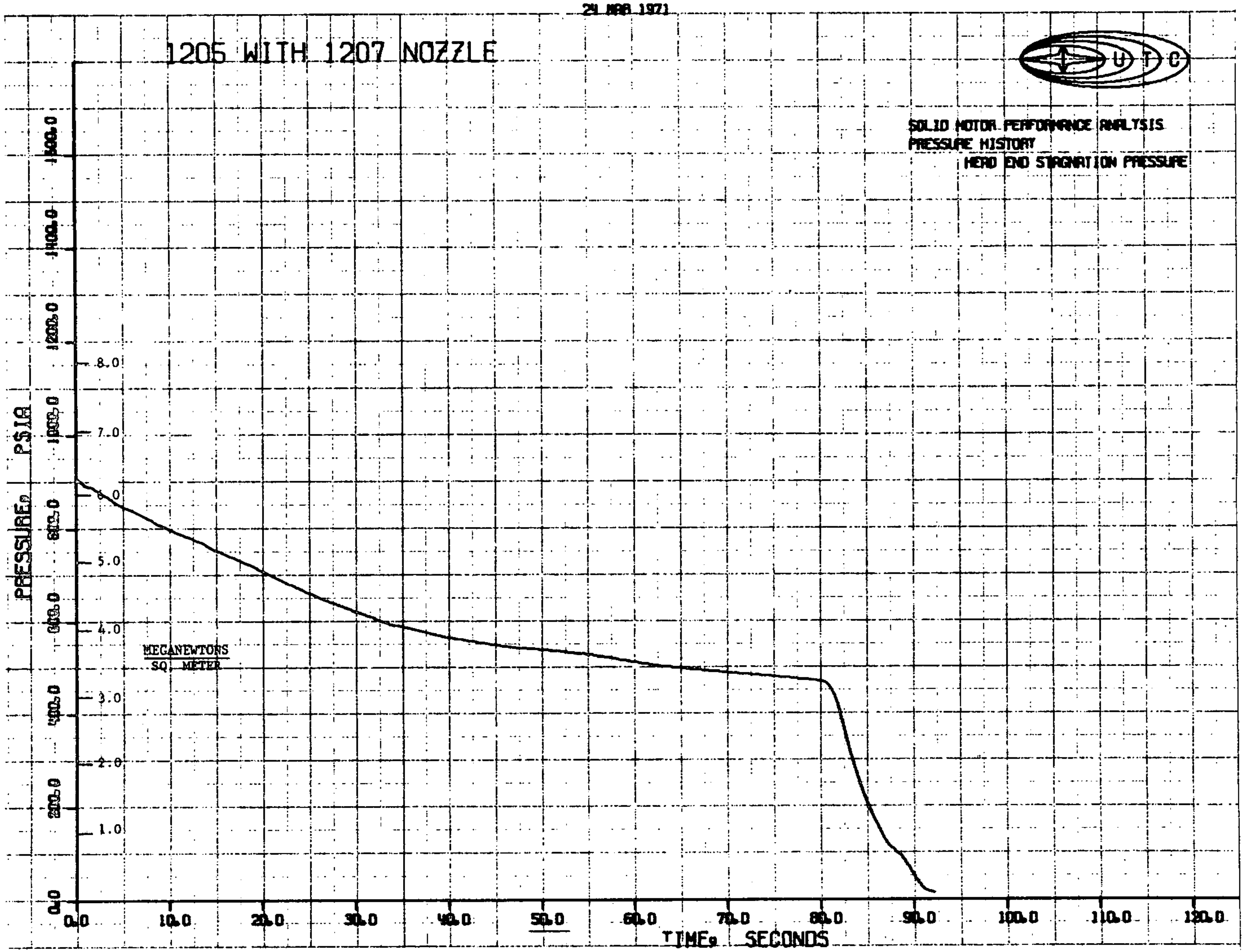


Figure 17A. Configuration 17, Pressure vs Time

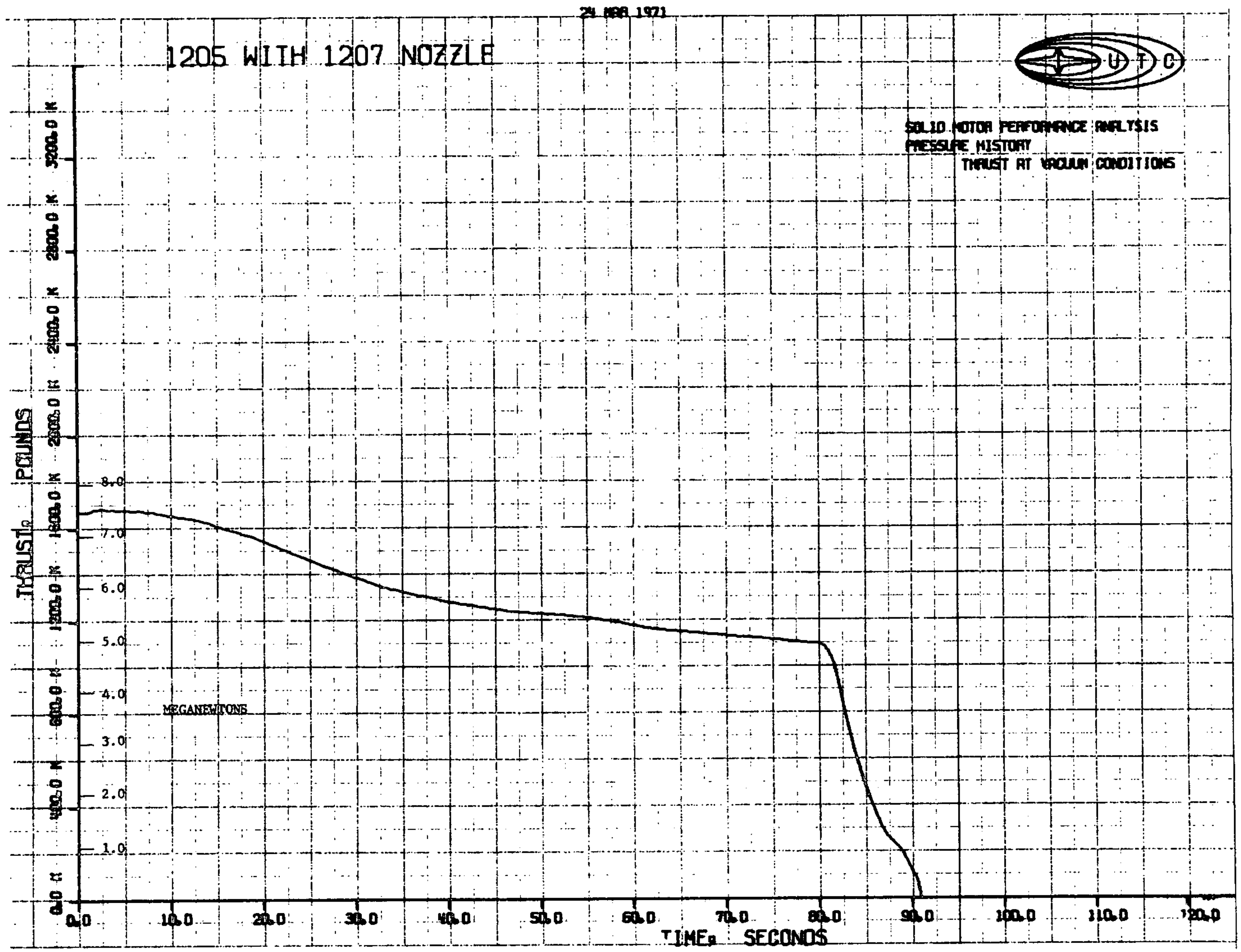


Figure 17B. Configuration 17, Thrust vs Time

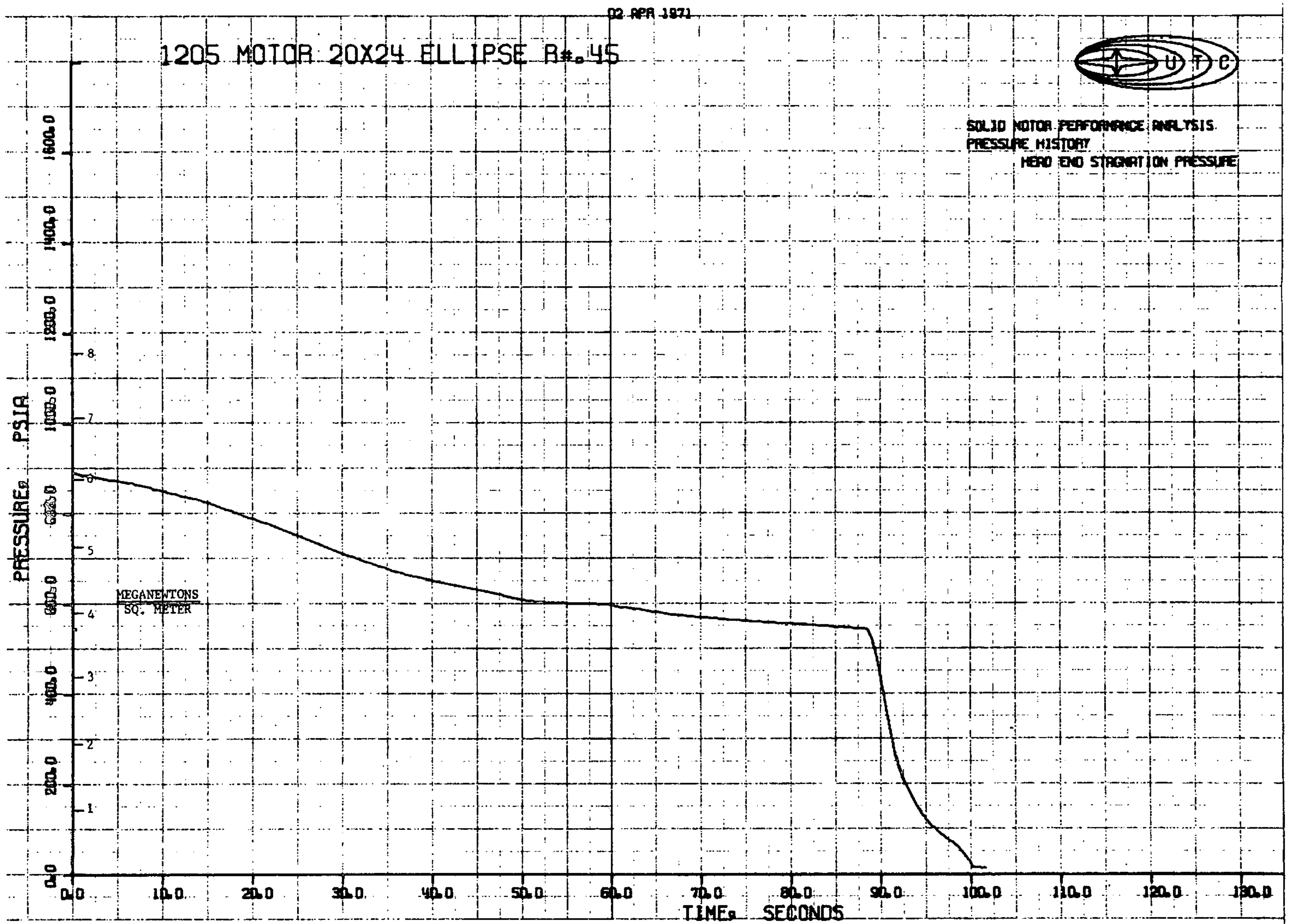


Figure 18A. Configuration 18, Pressure vs Time

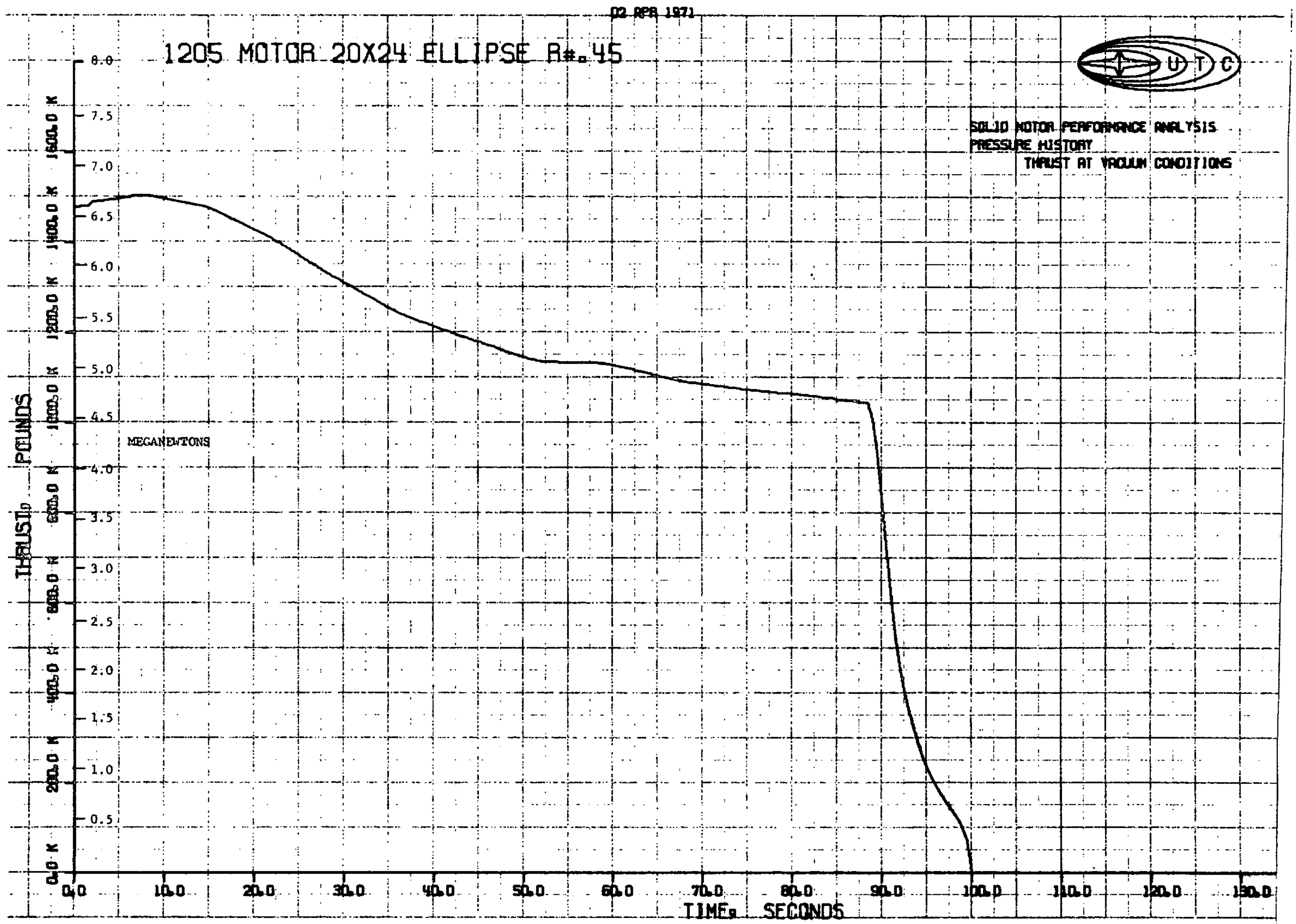


Figure 18B. Configuration 18, Thrust vs Time

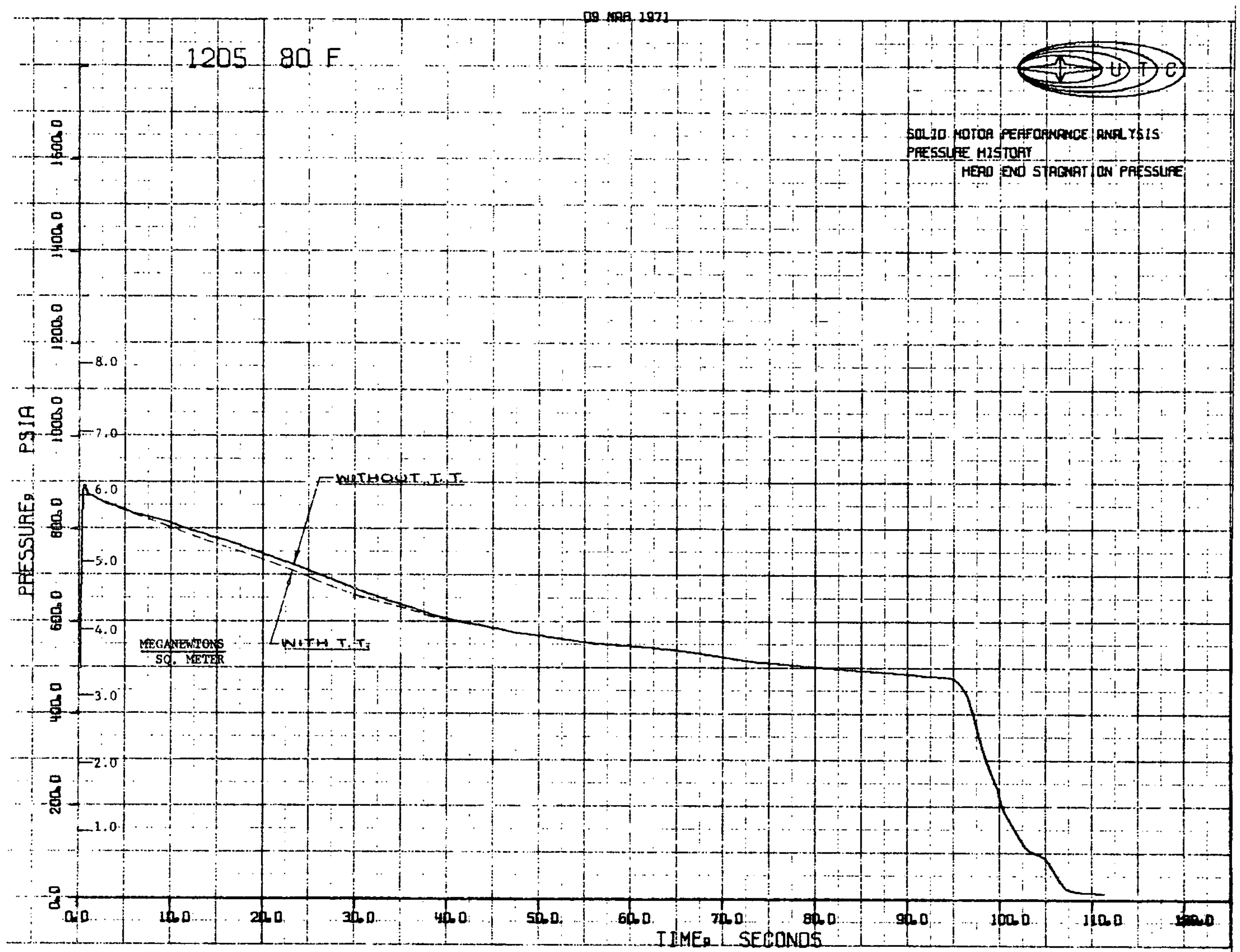


Figure 19A. Configuration 19, Pressure vs Time

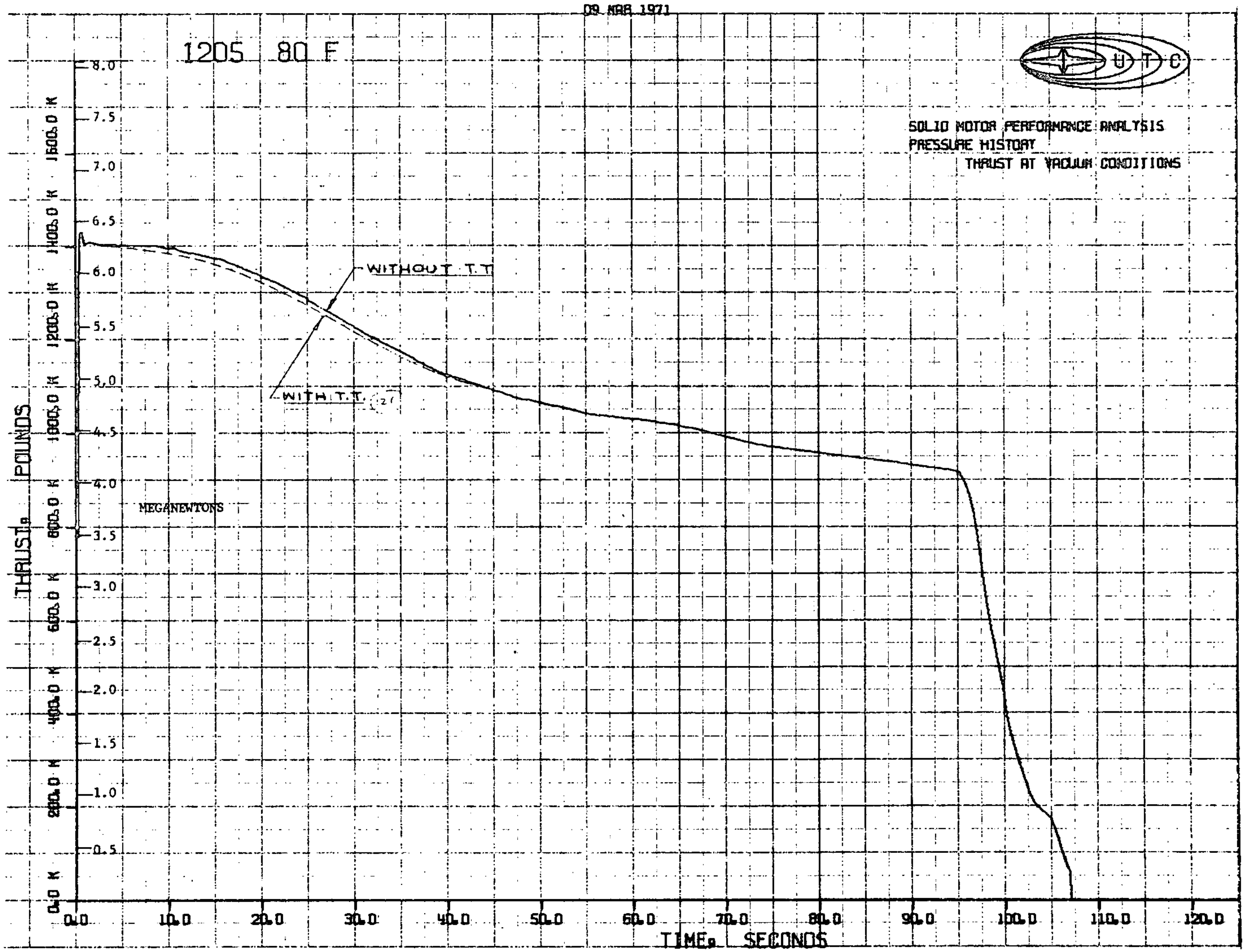


Figure 19B. Configuration 19, Thrust vs Time

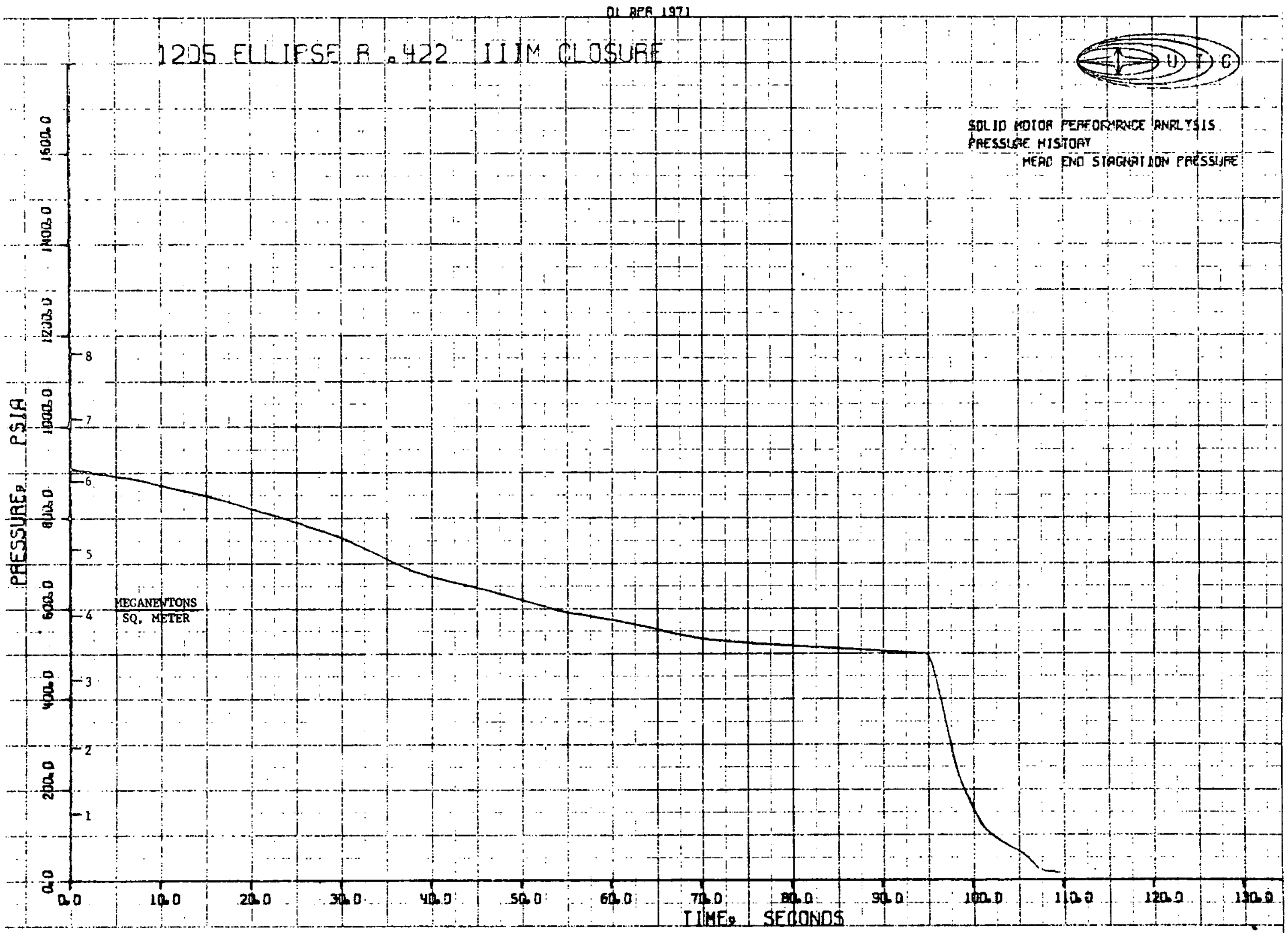


Figure 20A. Configuration 20, Pressure vs Time

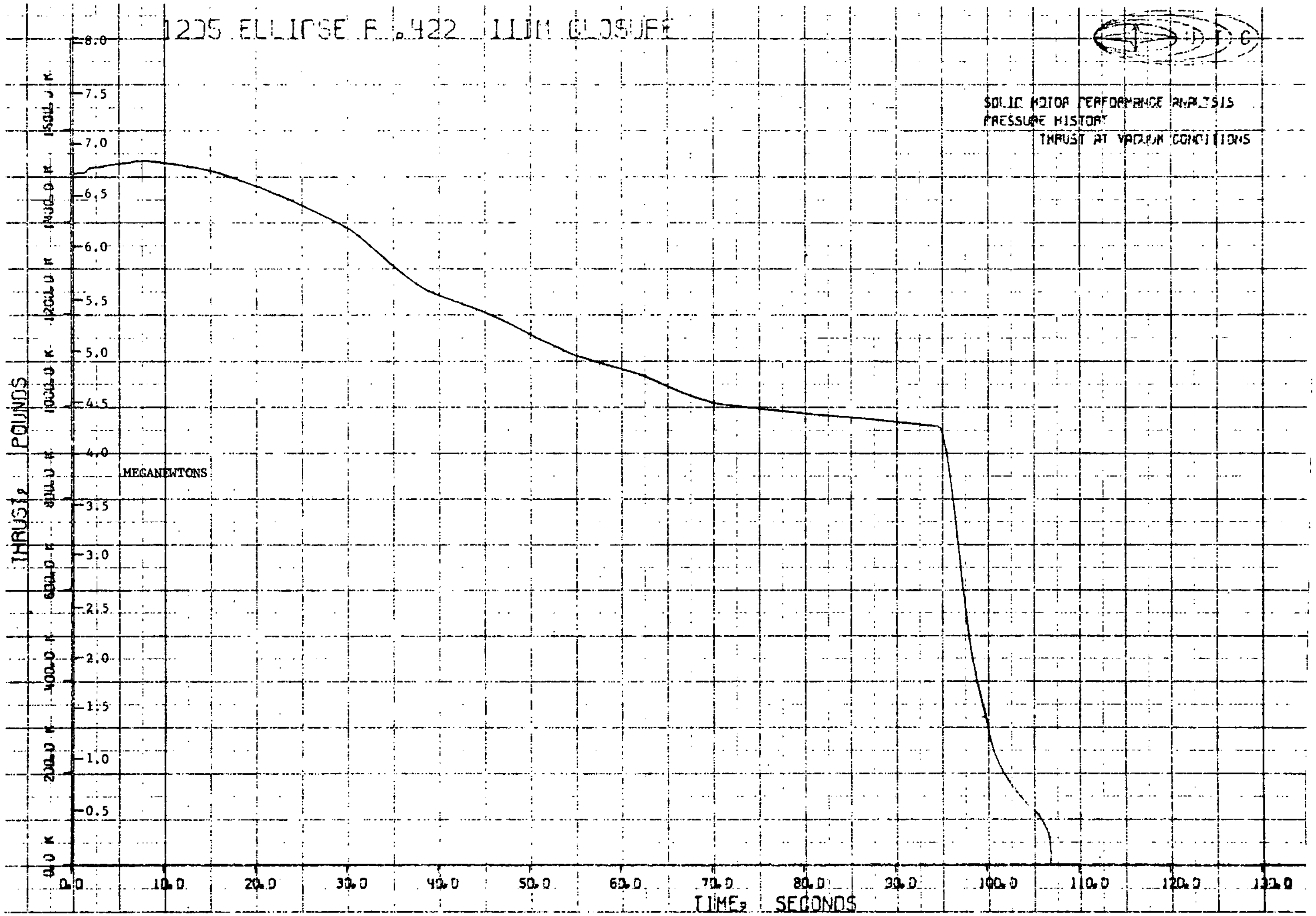


Figure 20B. Configuration 20, Thrust vs Time

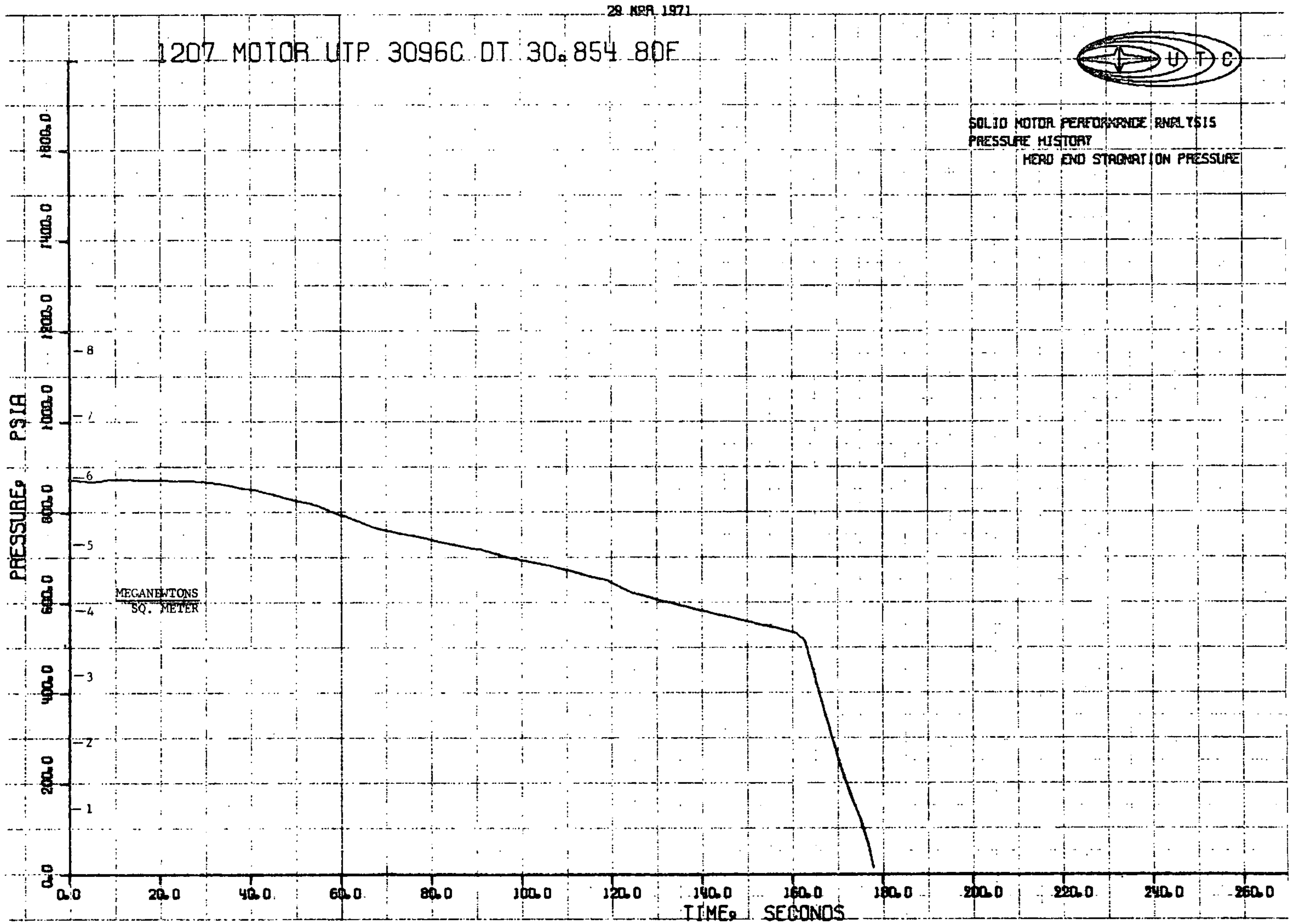


Figure 21A. Configuration 21, Pressure vs Time

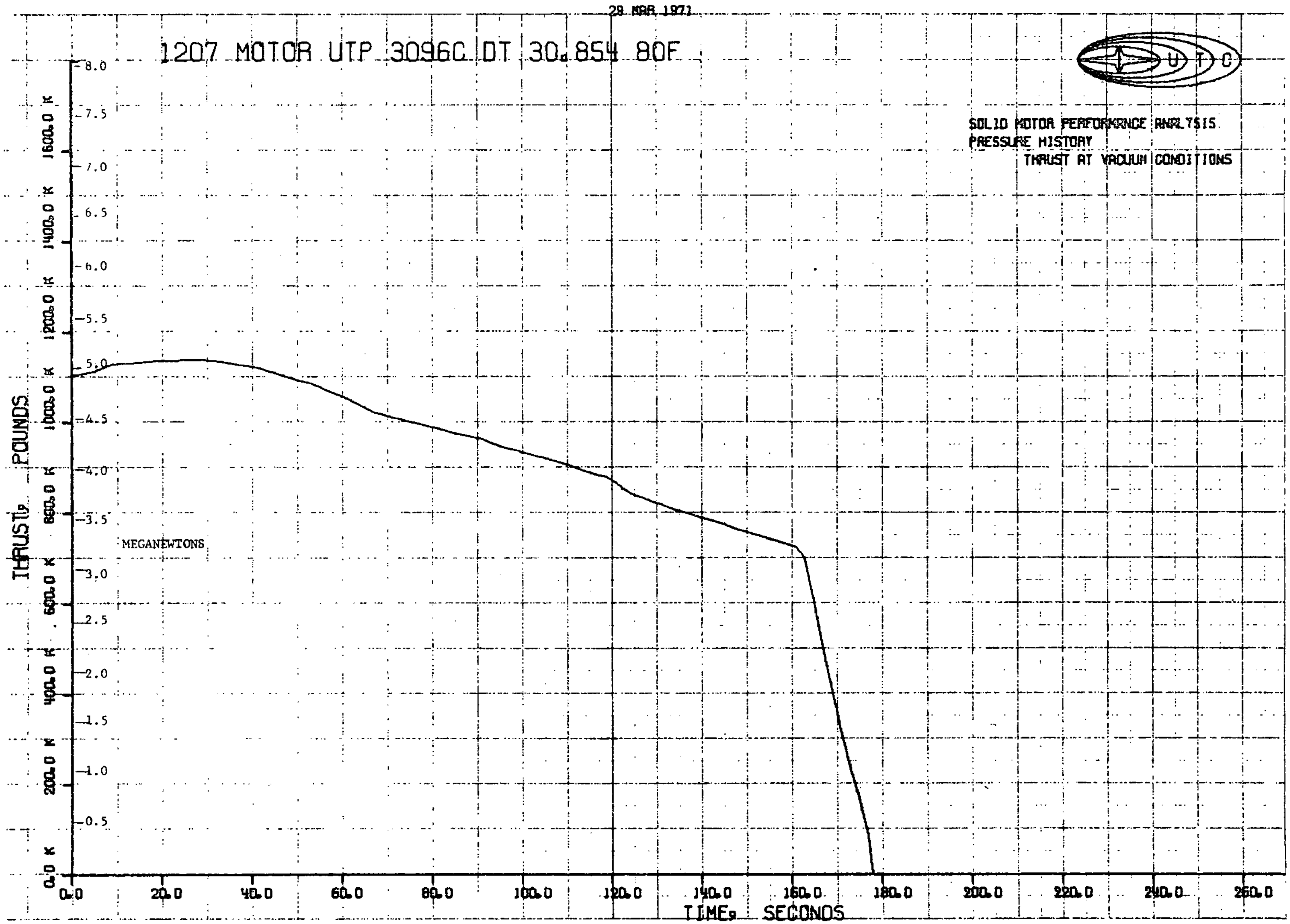


Figure 21B. Configuration 21, Thrust vs Time

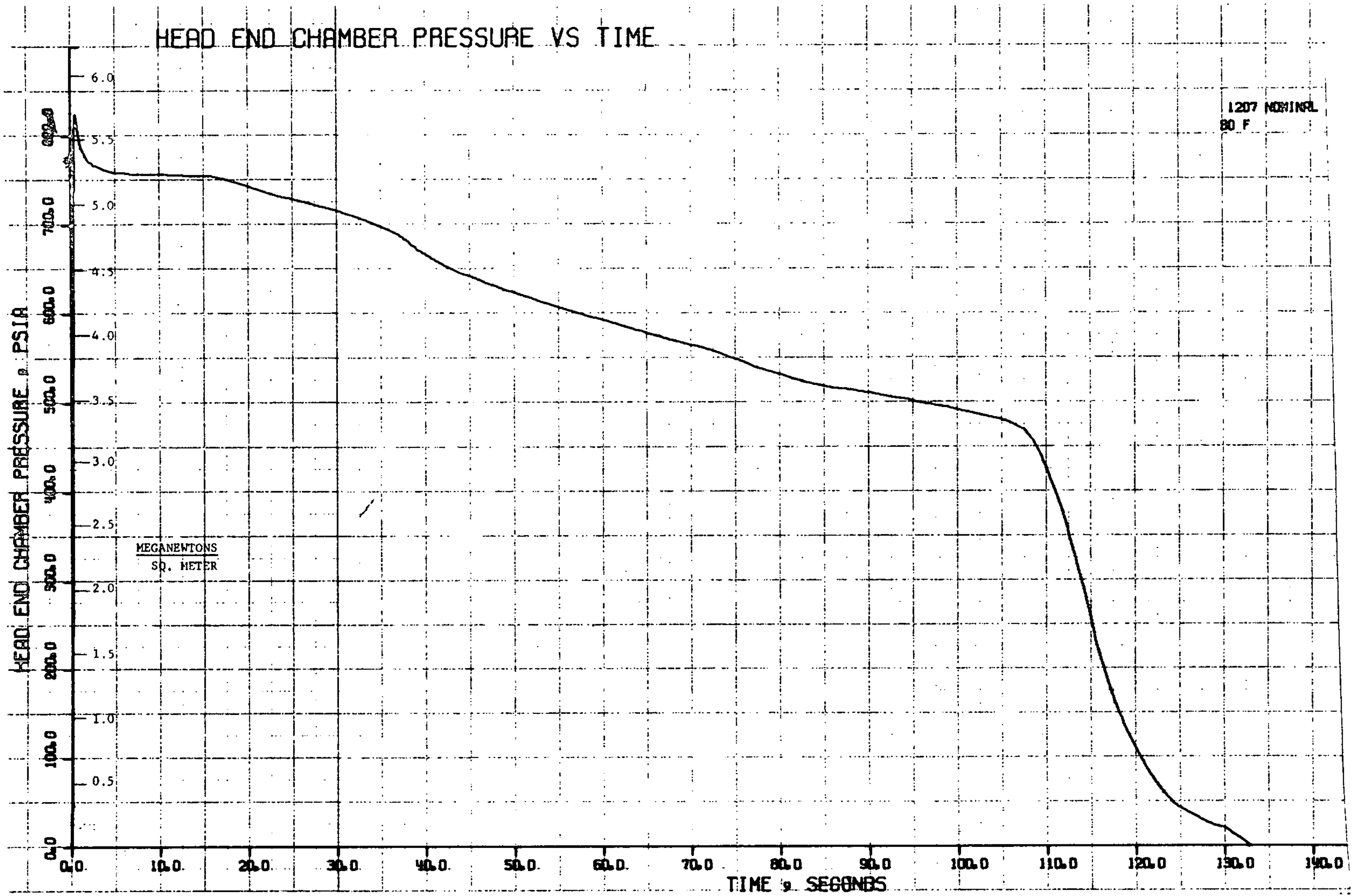


Figure 22A. Configuration 22, Pressure vs Time

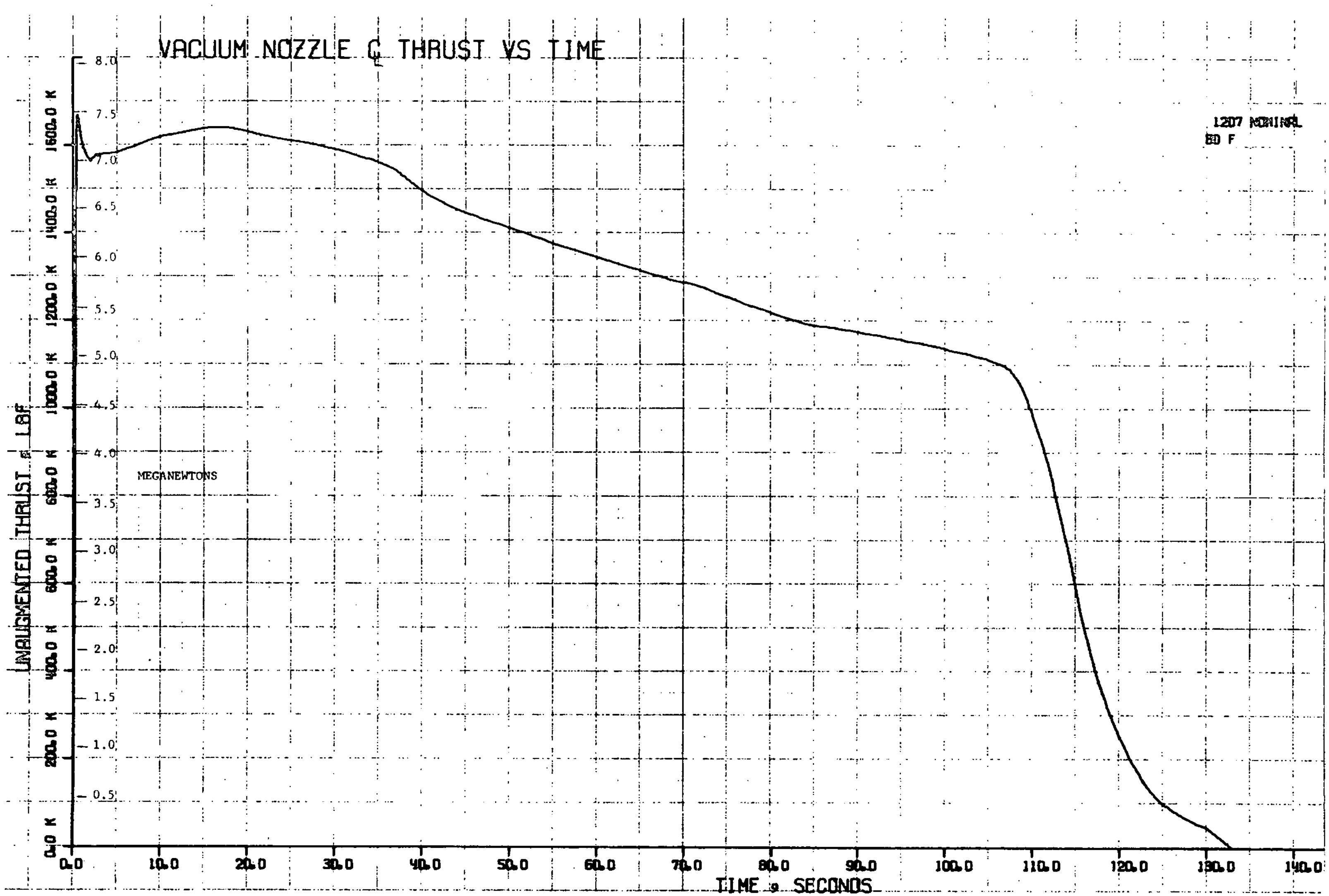


Figure 22B. Configuration 22, Thrust vs Time

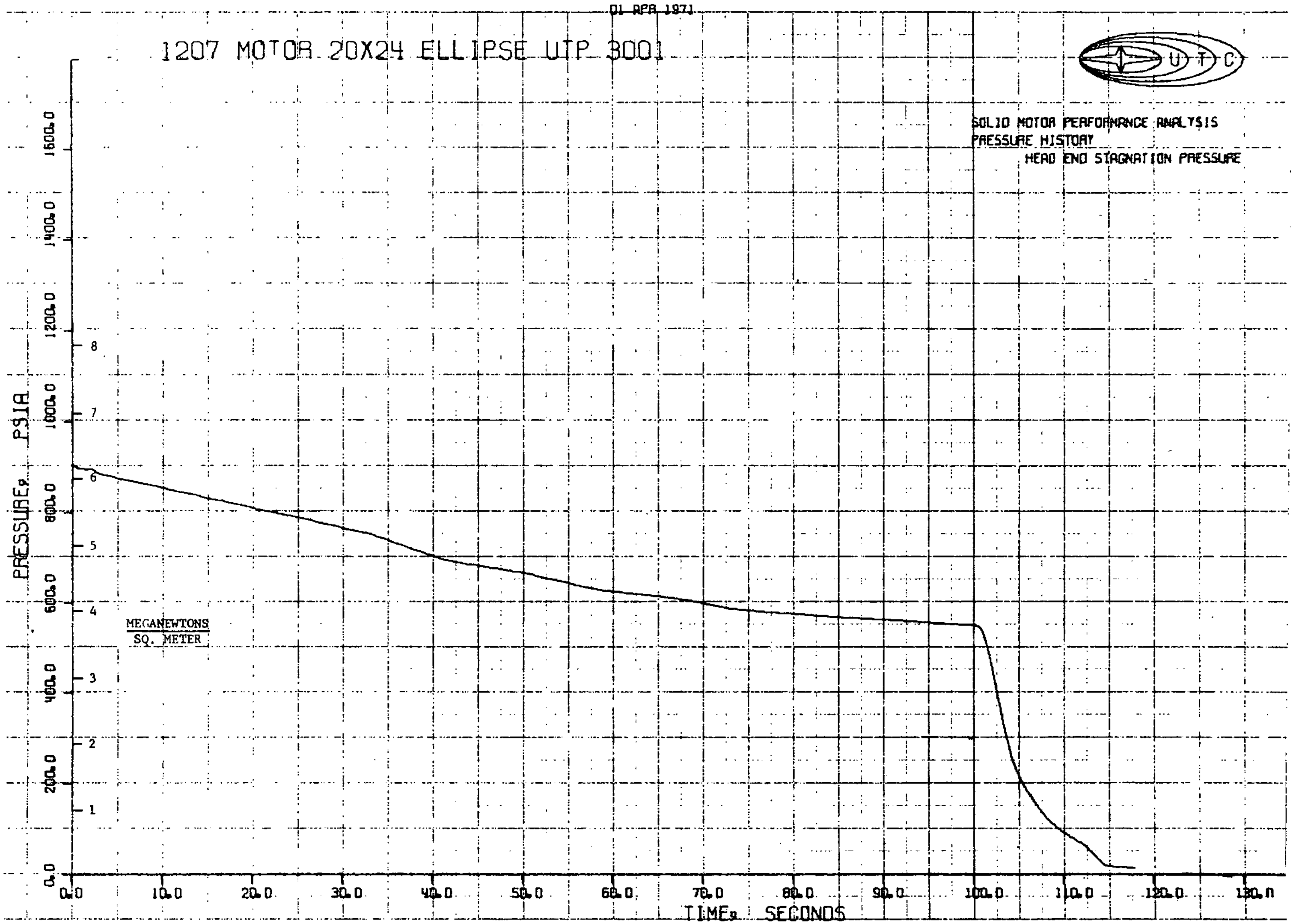


Figure 23A. Configuration 23, Pressure vs Time

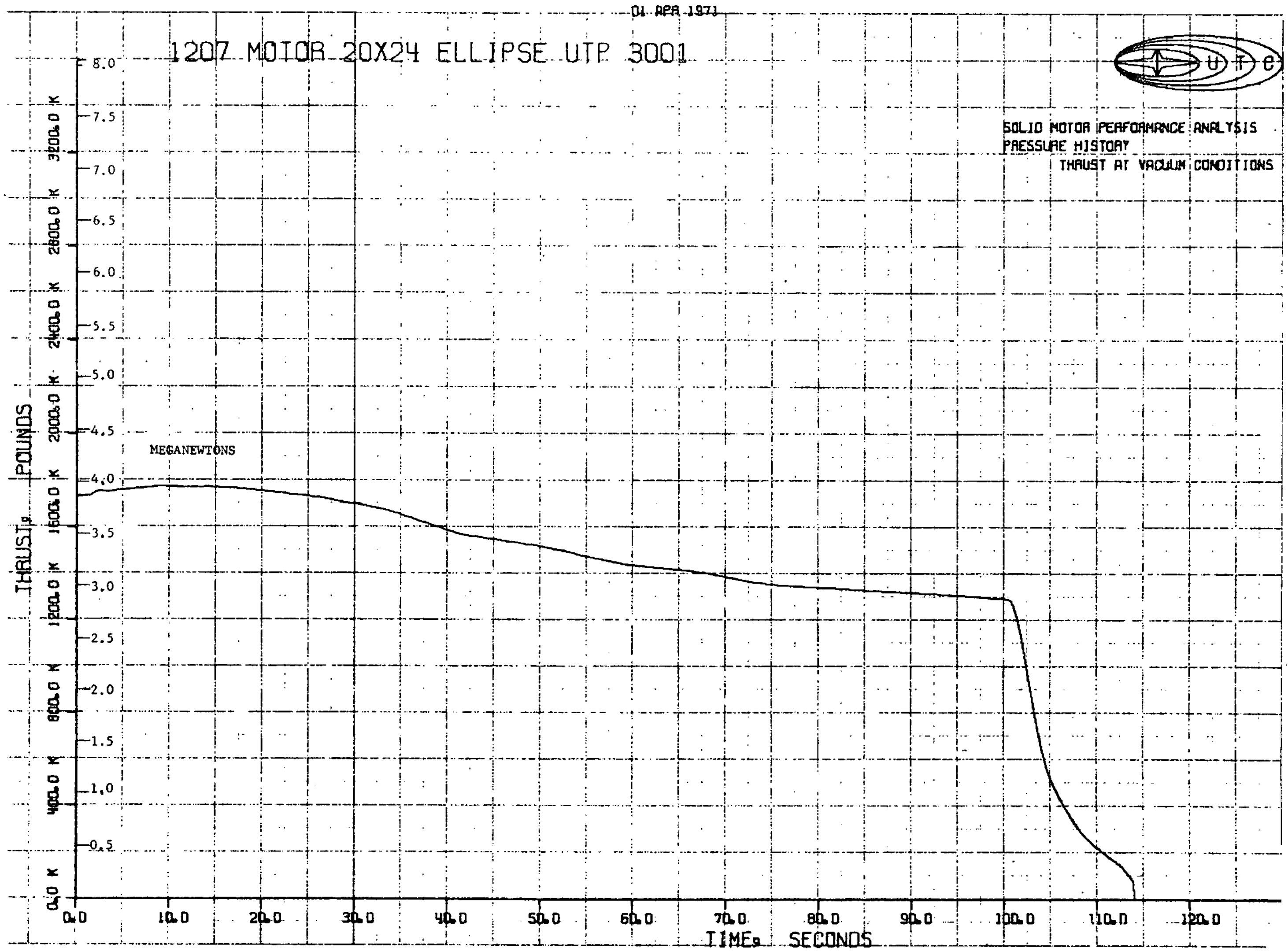


Figure 23B. Configuration 23, Thrust vs Time

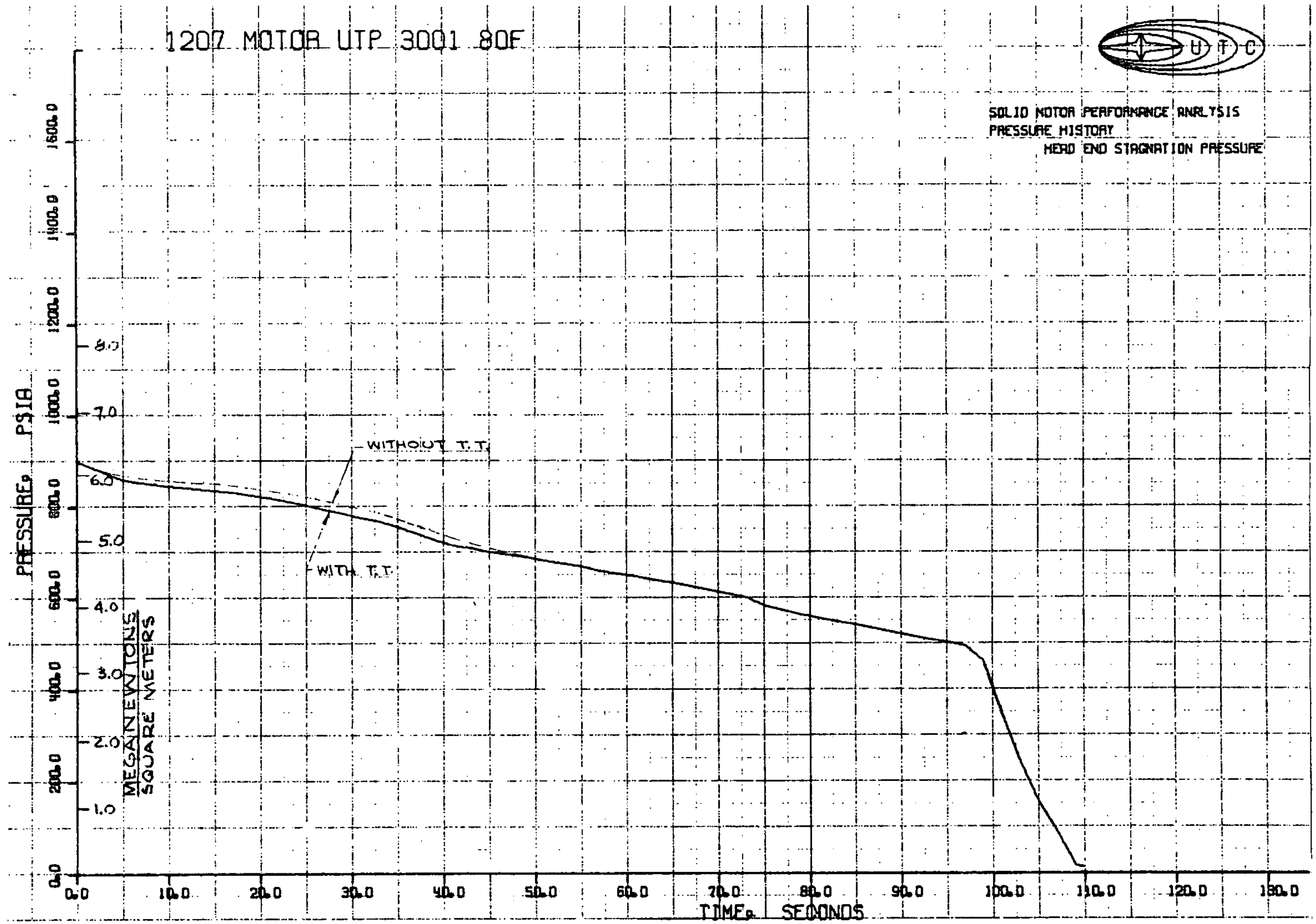


Figure 24A. Configuration 24, Pressure vs Time

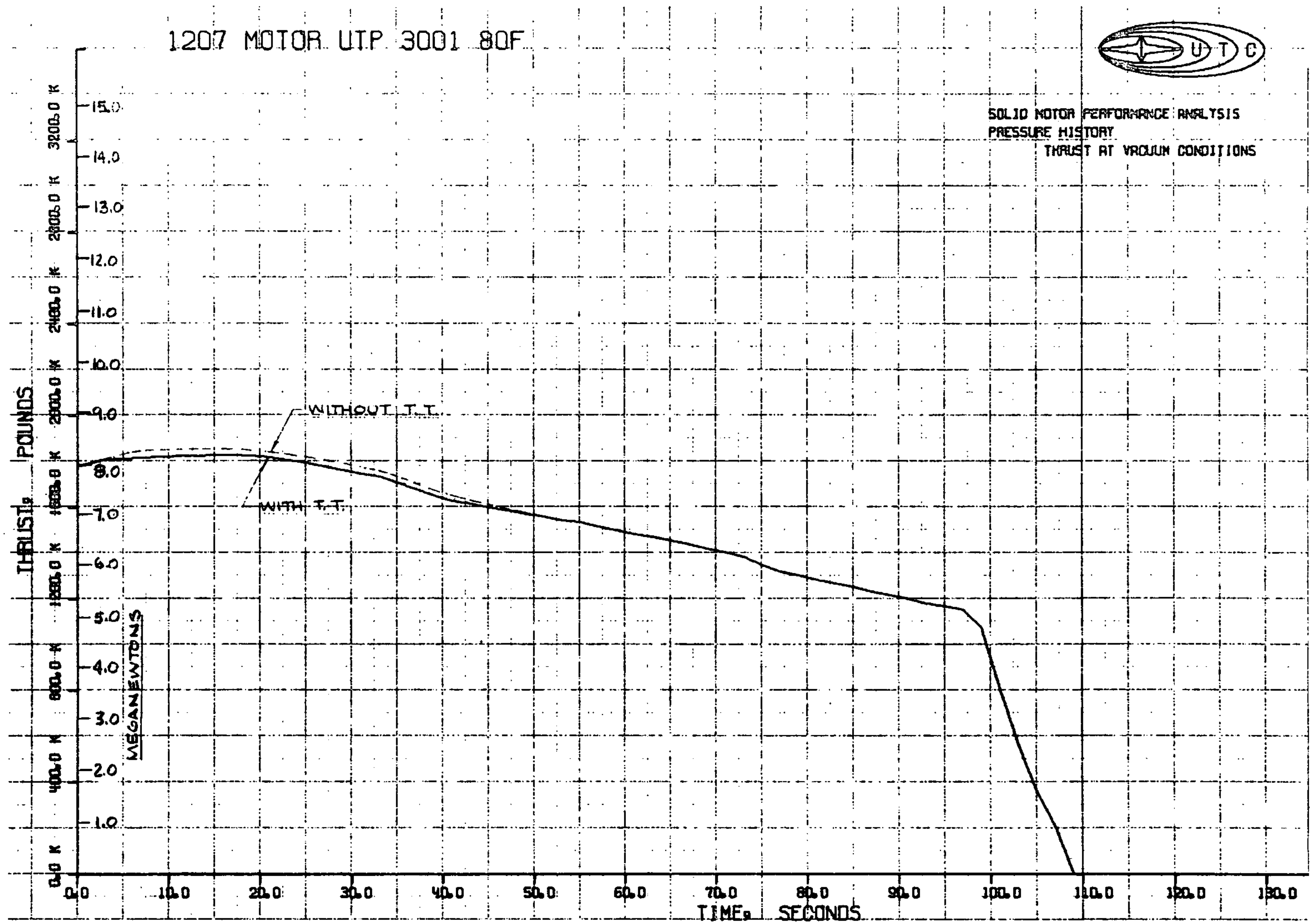


Figure 24B. Configuration 24, Thrust vs Time

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