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

by

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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 vehicles based on the 120-in.- (3.05 m) diameter SRM. Those results were subsequently confirmed in additional OART studies which were supported by work at McDonnell Douglas Astronautics Co. and at UTC during the first half of 1970.

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 and results obtained from this study are summarized in the following six sections of this volume. A detailed account of the analytical techniques and results are presented in volume II of this final report.

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.

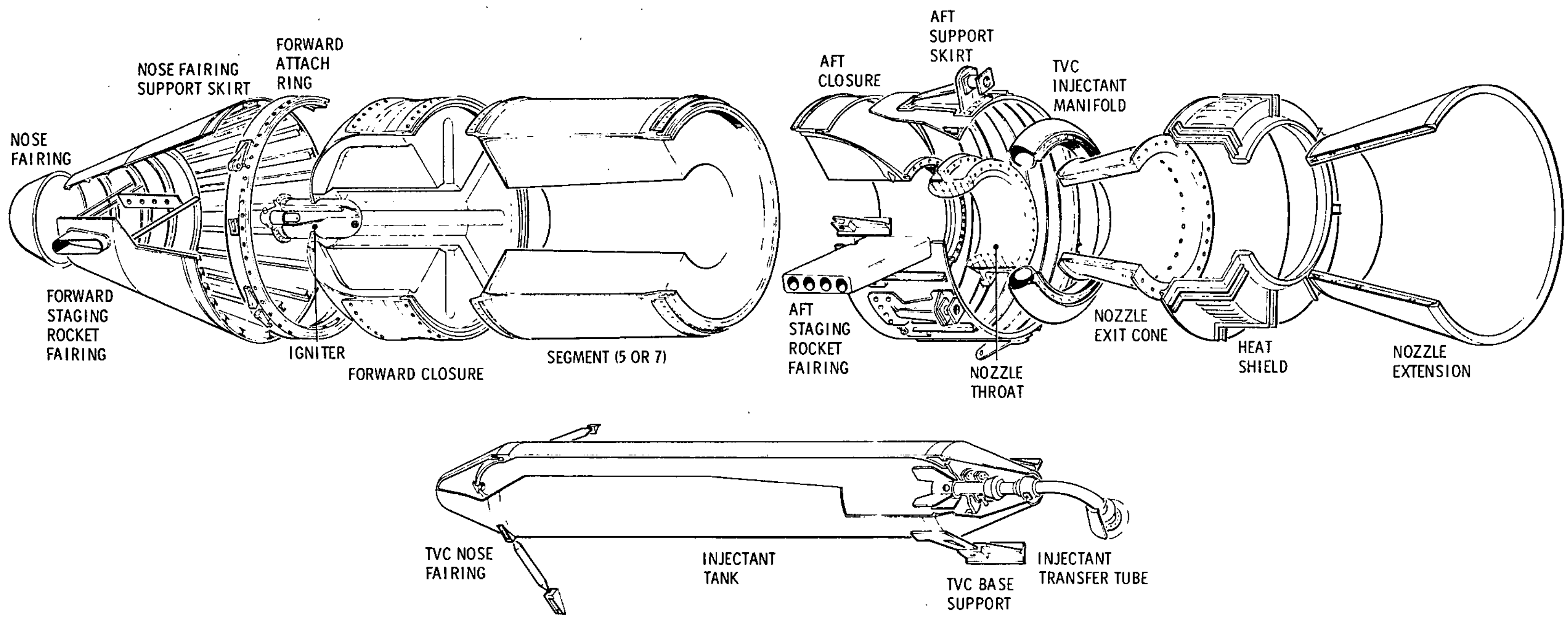

Figure 1. Components of UA 1205 and UA 1207 SRMs

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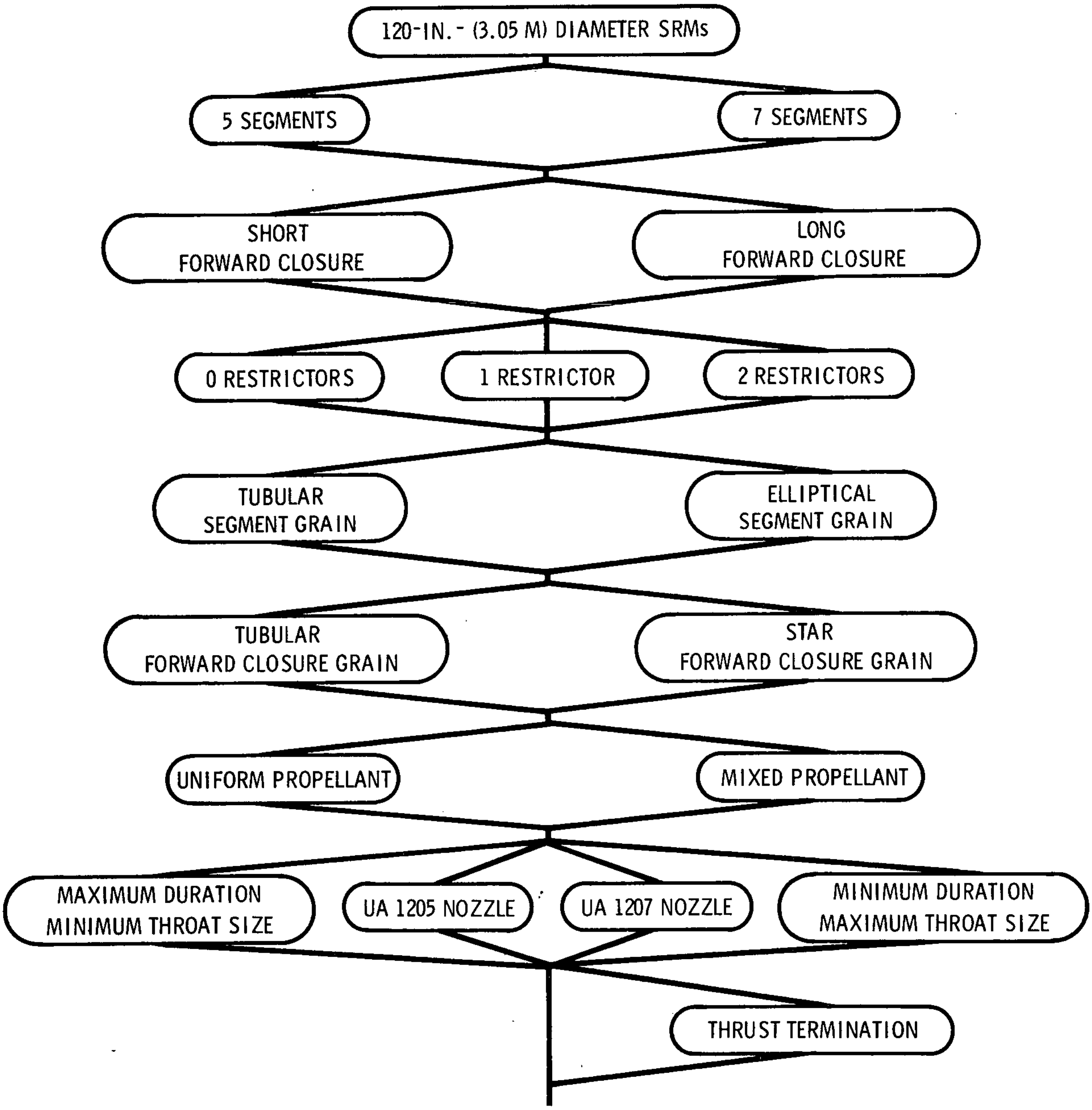

Figure 2. Design Parameters for 120-in.- (3.05 m) Diameter SRMs

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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.

Figure 3 illustrates typical effects of varying the number of restrictors on the segment end faces. A standard UA 1207 motor, configuration 11, (forward segment end faces restricted) is shown together with configuration 8 (no end retrictors) and configuration 13 (both ends restricted). The regressive thrust profile of configuration 8 and the progressive thrust profile of configuration 13 result from the variation in burning surface achieved by selective inhibitor application.

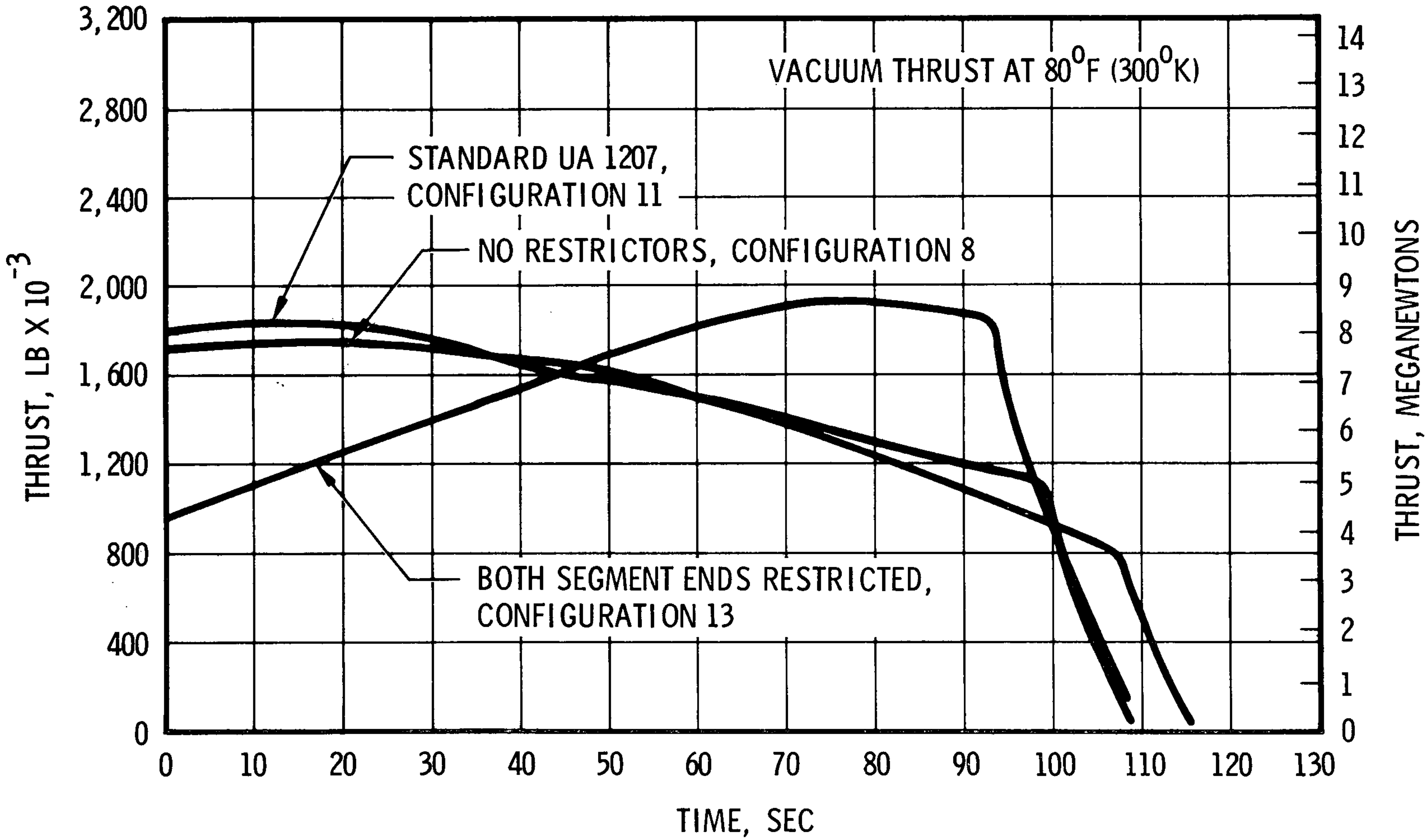

Figure 3. Effect of Segment Restrictors on UA 1207 Ballistic Characteristics

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Figure 4 illustrates the strong influence which the design of the forward closure grain can have on SRM characteristics. Configurations 13 and 14 are UA 1207 SRMs in which both ends of all segments are restricted. Configuration 13 has a tubular forward closure loaded with the same propellant as in the segments. This forward closure design does not greatly alter the basic progressive tendency of the doubly restricted segments. However, the forward closure of configuration 14 uses a star grain and a propellant with a higher burning rate. The larger burning surface of the star geometry and the higher burning rate increase gas generation, significantly raising the initial thrust level. Because the star grain burns out first, the characteristics of the remaining segments predominate. The overall result is a saddle-shaped curve which is useful in minimizing aerodynamic heating and loads problems in some launch vehicles.

Discussion of the other design parameters and their individual or collective effects of performance are discussed in volume II. An envelope of the total thrust-time range demonstrated for the 24 selected designs is shown in figure 5. Desired performance (within reason) for a particular vehicle application can be obtained by selective parameter changes. The results of this study indicate that these performance variations can be easily obtained once the desired characteristics and requirements are specified.

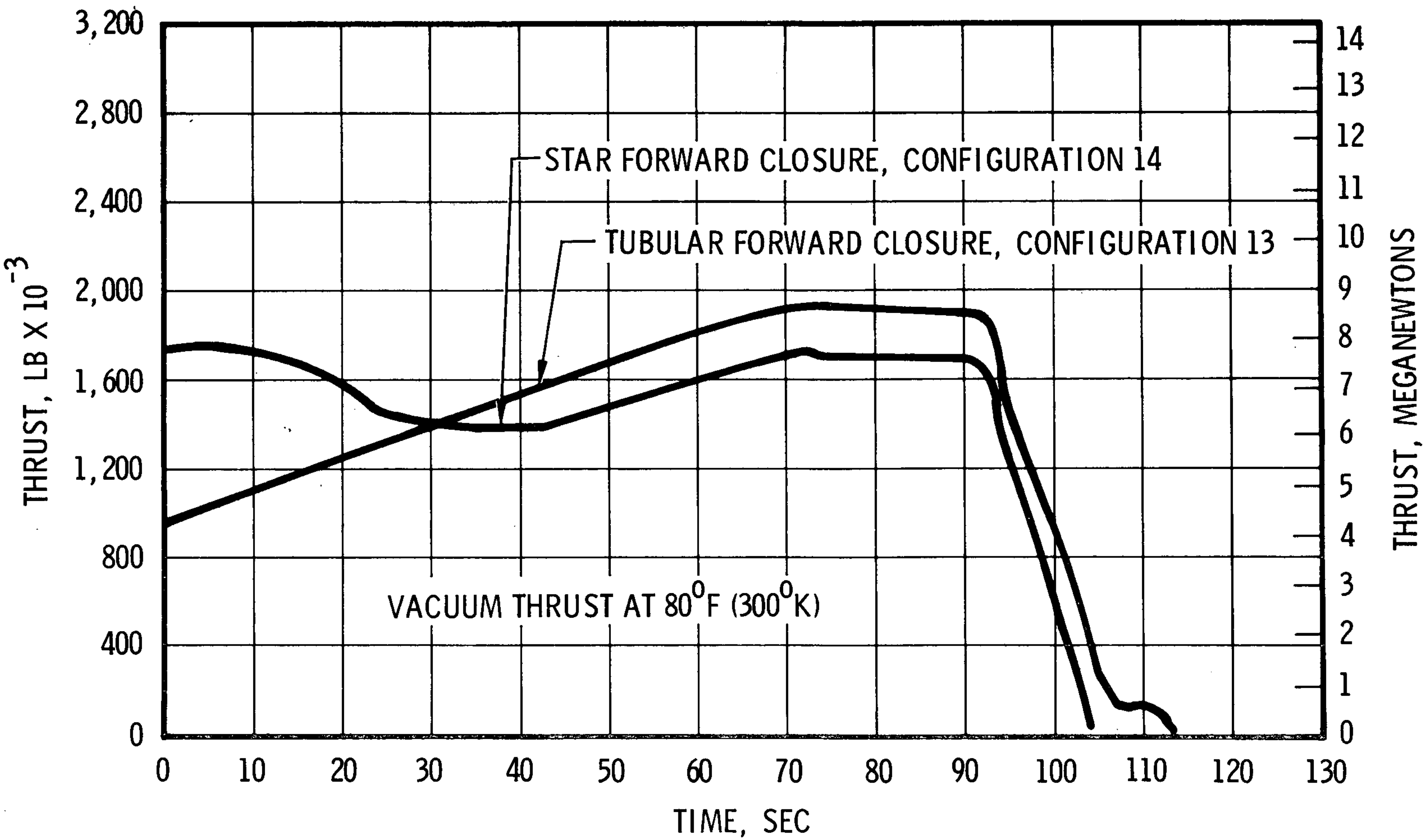

Figure 4. Effect of Forward Closure Grain on Ballistic Performance of Doubly Restricted UA 1207

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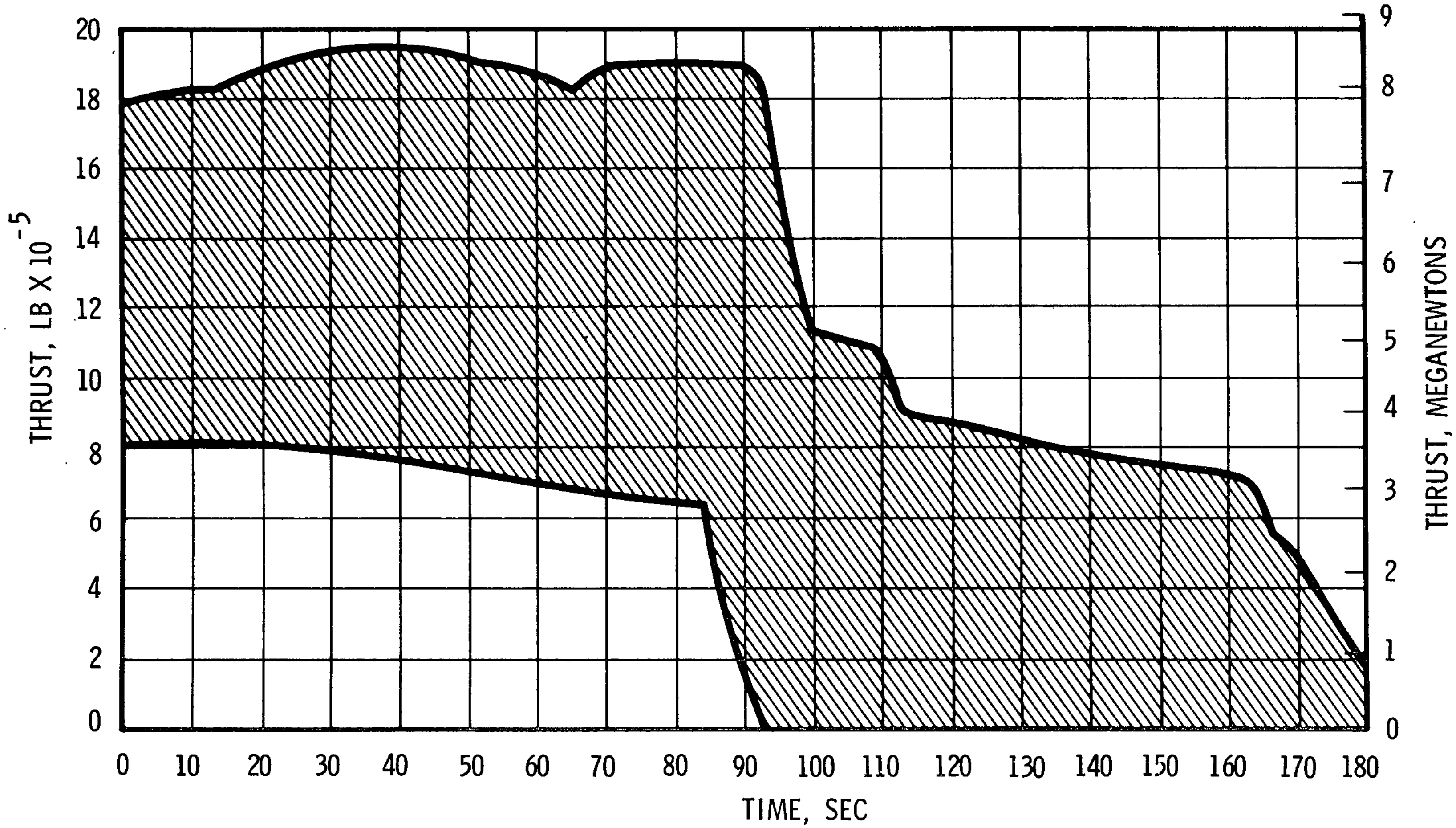

Figure 5. Envelope of Thrust-Time Capability

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3.0 IMPLEMENTATION OF TECHROLL MOVABLE NOZZLE SEAL

The TECHROLL movable nozzle seal is an invention developed at UTC to provide an omniaxis SRM nozzle gimbal bearing with low internal deflection torque. The seal (see figure 6) is a constant-volume, fluid-filled bearing. The two rolling convolutes allow nozzle movement while containing the motor chamber pressure. The nozzle is deflected by moving the internal fluid from one side of the seal to the other. Nozzle blowout loads are reacted by the seal internal pressure, which is retained by the shell structure and the rolling convolutes.

Use of the TECHROLL seal movable nozzle as a replacement for the current LITVC system on the UA 1207 120-in.- (3.05 m) diameter SRM was first discussed in a UTC technical memorandum, TM-15-70-U4, dated December 1970. That document concentrated upon the technical design aspects of the TECHROLL seal mechanism and its actuation requirements. For this study, an analysis was made of installation of the TECHROLL seal into a UA 1207 SRM with specific emphasis on defining the changes required to the aft closure installation and propellant grain. The design of the nozzle was altered to accept mechanical actuator loads and to reduce the exit cone liner thickness consistent with elimination of injectant fluid erosion. The TECHROLL seal system was then compared with the baseline UA 1207 LITVC system, and the merits of each system were identified and evaluated.

In comparing the TVC systems on the basis of a single SRM, three principal advantages are offered by the TECHROLL seal nozzle (1) a reduction of approximately 9% in total hardware costs per SRM, (2) a 10,000-lb (4,536 kg) decrease in inert weight per SRM, and (3) a capability for steering control far in

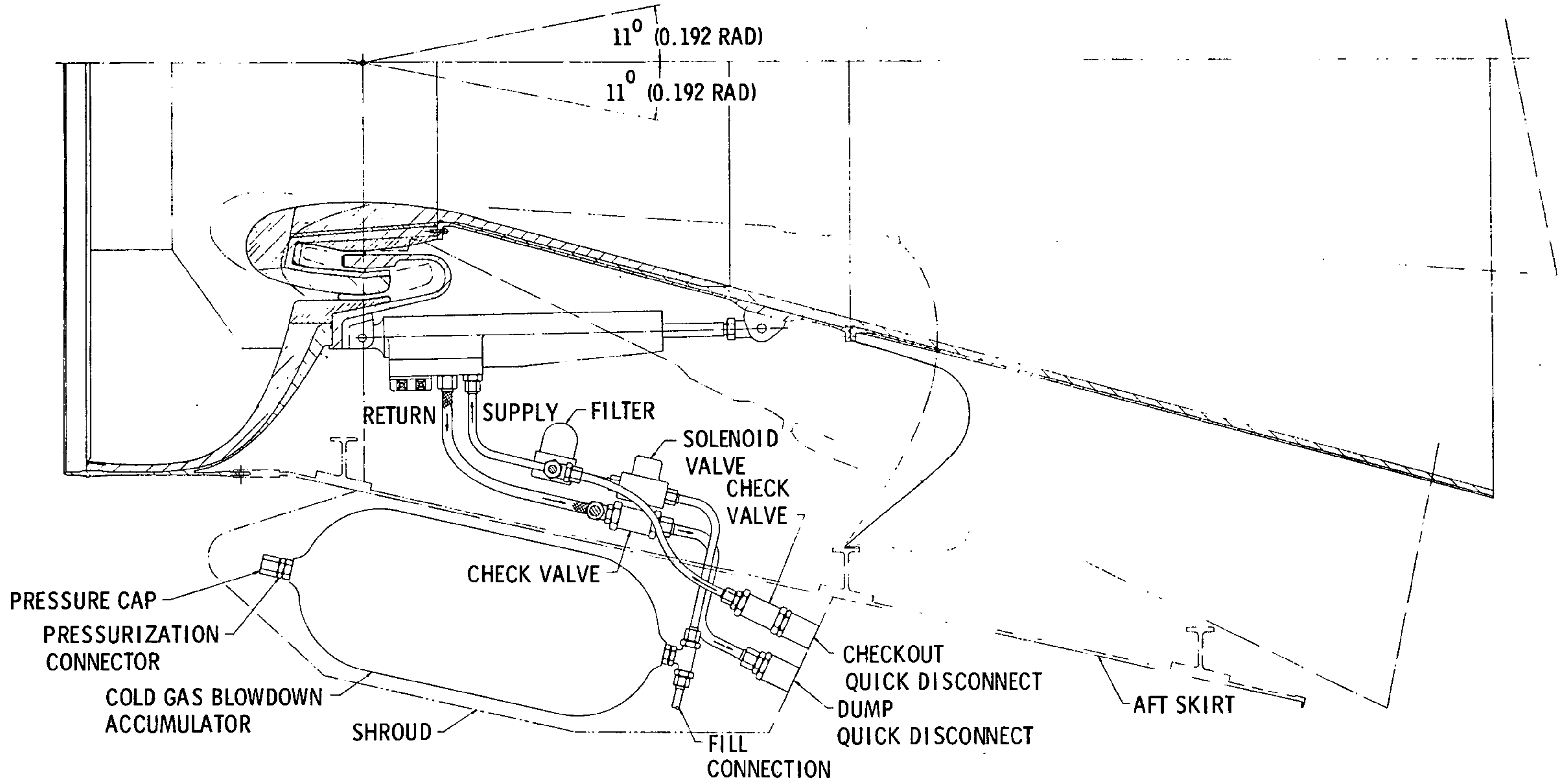

Figure 6. TECHROLL Seal/Aft Closure Installation

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excess of LITVC system capabilities. Any one of these three advantages is significant; combined, they should not be ignored in future modifications to the 120-in.- (3.05 m) diameter SRM.

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° (0.052 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 probably can be reduced if the UA 1207 SRMs are utilized on larger vehicles with an increased number of SRMs per stage. However, use of the SRMs on a vehicle with a winged payload or upper stage can cause the deflection requirements to increase. For example, deflection requirements of 10° (0.174 rad) to 15° (0.262 rad) have been indicated in recent booster studies for winged payloads. Therefore, a third TECHROLL seal design modification (see figure 6) was made to provide a deflection angle of 11° (0.192 rad) and satisfy some of these possible future requirements.

4.0 TRADE STUDIES FOR TECHROLL SEAL/LITVC

The preparation of TECHROLL seal movable nozzle TVC system designs for the 120-in.- (3.05 m) diameter SRMs, as discussed in section 3.0, permitted a realistic comparison with the current operational LITVC system. Trade studies conducted in this program made these comparisons not only on the basis of individual SRM characteristics, but also for typical clustered configurations of interest for future launch vehicles.

Comparison and selection of a steering system for the clustered 120-in.- (3.05 m) diameter SRMs should be based on factors such as performance, weight, complexity, service requirements, adaptability to the application, and cost. Tradeoffs between the LITVC and TECHROLL seal system were made based on the above quantitative and qualitative parameters. Table I shows the major items compared and summary comments based on the detailed discussion in volume II.

Comparison of the TECHROLL movable nozzle seal and LITVC systems leads to a preference for the TECHROLL seal design based on its advantages of an estimated 5% vehicle payload increase through a reduction in inert weight, a 9% savings in recurring costs, reduced system and operating complexity, and greater steering deflection capability. Further detailed design studies are required to define the actuation and power system and its reliability. Final economic justification for the TECHROLL seal requires a knowledge of the mission model to determine the total savings in recurring costs compared to investment required for nonrecurring costs.

TABLE I

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 should be developed prior to serious reliability evaluation
Cost		+	9% reduction in recurring cost as reported in section 7.0

5.0 CLUSTERED STAGE STUDIES

The 120-in.- (3.05 m) diameter SRM has been developed and qualified for use on the Titan III launch vehicles. The UA 1205 SRM is operational and is used in pairs as stage 0 of the Titan III-C and Titan IIID vehicles. Both the UA 1205 and UA 1207 SRMs could also be used as clustered lower stages which, along with a liquid high-energy upper stage such as the S-IVB, could form the basis for a versatile launch vehicle system with payloads ranging from a nominal 50,000 lb (22,680 kg) to 100,000 lb (45,360 kg) or more by merely changing the number of SRMs in the cluster. The six clusters listed below were selected by NASA as the basis for this part of the study to determine the clustering requirements, structural weights, and optimum clustering arrangements. Maximum advantage was taken of the exiting Titan III attachment structure design and SRM motor case strength.

Cluster Designation	Number of SRMs in First Stage	Number of SRMs in Second Stage
2 + 1	2	1
3 + 1	3	1
4 + 1	4	1
5 + 1	5	1
4 + 2	4	2
5 + 2	5	2

Initial investigations indicated that attachment structures similar to those of the current Titan III could be used to assemble the SRMs into clusters of first and second stages for the launch vehicle. Modifications will be required to withstand the higher loadings of the new vehicle. New thrust collection and forward attach linkages must also be designed. Weights of these new structures will vary with the cluster configuration and result in average stage structural weight fractions of about 2%. The clustering arrangement for a typical case is illustrated in figure 7 for the 4 + 1 design concept. Detailed technical discussions and thrust and weight data for all other designs are shown in volume II. The 5 + 2 cluster configuration should be noted for its unique solution to a problem in vehicle balance and compactness.

An analysis of the cluster arrangement with the most severe base heating environment indicates that the use of approximately 0.6 in. (1.5 cm) of Dow Corning silicone insulation should provide adequate thermal protection. This additional insulation represents an increase in inert weight of about 300 lb (136 kg) per SRM.

Evaluation of nozzle size and cant angle relationships for the clustered stages suggests the use of current nozzle expansion ratios of 8.0 or 9.2 on the first-stage SRMs and an expansion ratio of 15.0 on the second-stage SRMs. These values are near optimum for physical arrangement constraint, 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 6° (0.104 rad) required with the current Titan vehicle. Center- or second-stage nozzles should be uncanted.

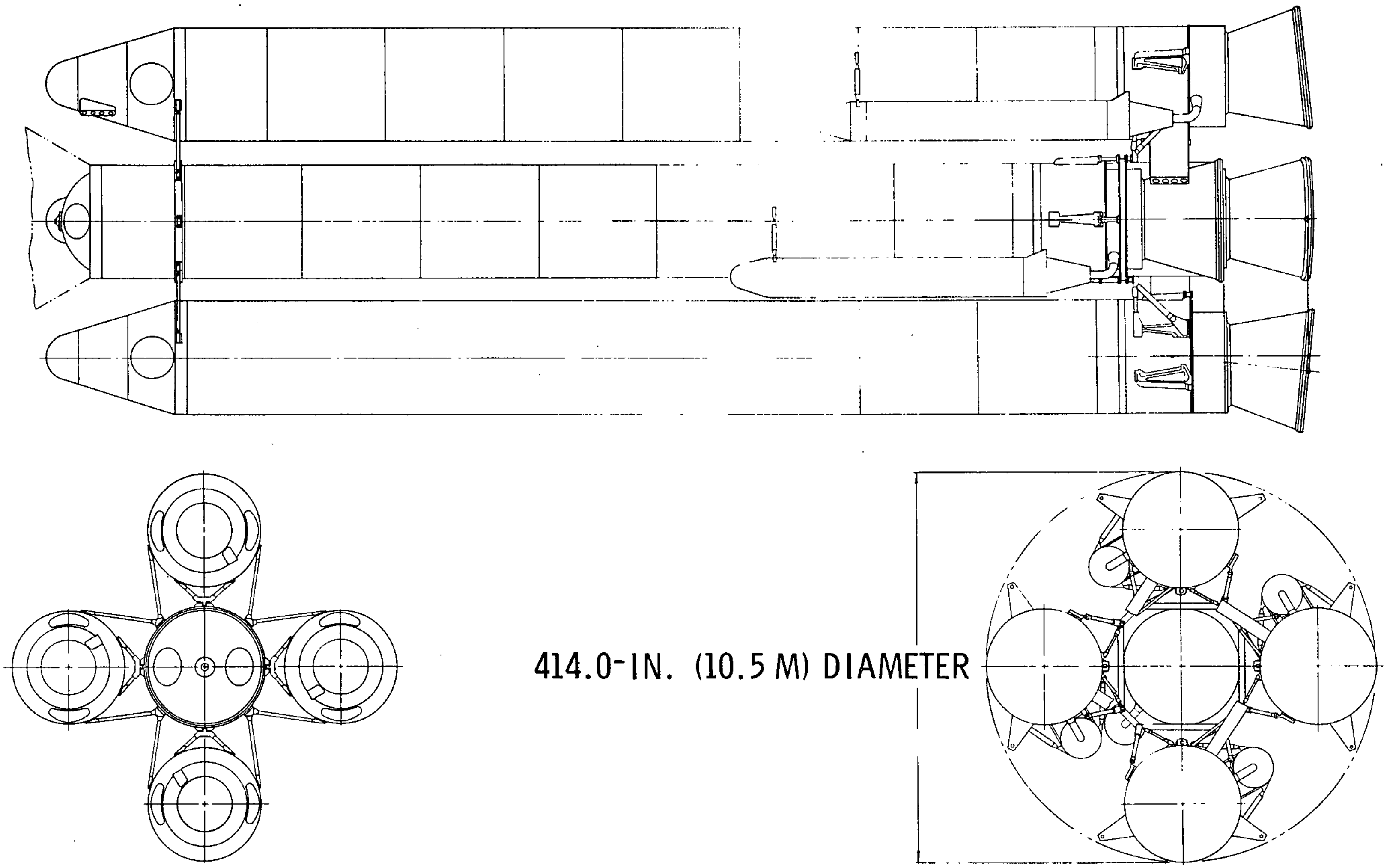

Figure 7. Configuration of Four-Plus-One Cluster

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6.0 PROGRAM DEFINITION

Sections 2.0 through 5.0 of this report have presented technical data for design modifications which offer a potential performance or cost improvement for the 120-in.- (3.05 m) diameter SRMs and the launch vehicle system of which they are a part. A full evaluation of the modifications must include a thorough analysis of the development and production programs which must be carried out before the concepts are used for operational hardware. Development programs include development testing to acquire data for confirming or completing design features and qualification testing to demonstrate the adequacy of the designs to meet the operational requirements. Production programs involve evaluation of available manufacturing processes, tools, and facilities and determining how to produce the modified design and the desired quantity. The launch operations require a thorough review to adequately define requirements for any new equipment, facility, or techniques that are required to support the new designs at planned launch rates.

The three areas - development, manufacturing and launch operations - for the SRM modifications and stage configurations described in sections 2.0 through 5.0 were examined. Development programs have been defined for each of the design modifications; the tooling and facilities requirements for producing the new designs at the required rates have been estimated. New requirements for launch operations, AGE, and procedures and support have also been designated. However, launch facilities requirements for the new cluster configurations already have been partially studied* and were not part of this study.

* "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 NAS10-6776.

Examination of the development schedules (figures 8 and 9) indicates that for the UA 1205 SRM, a period of 42 months is required for incorporation of ballistic modifications and completion of stage structural testing and other activities prior to launch of the first flight vehicle. For the UA 1207 SRM, this time period increases to about 52 months because of the added static testing required to complete PFRT. If the TECHROLL seal movable nozzle is incorporated into either the UA 1205 or UA 1207, the additional development and full-scale static test requirements result in a development program duration of about 57 months to first test flight. Analysis of the program schedules indicates that the development schedule can be shortened by 4 to 12 months if the need for a shortened schedule is critical. Acceleration in the development schedule should result in only nominal cost increases.

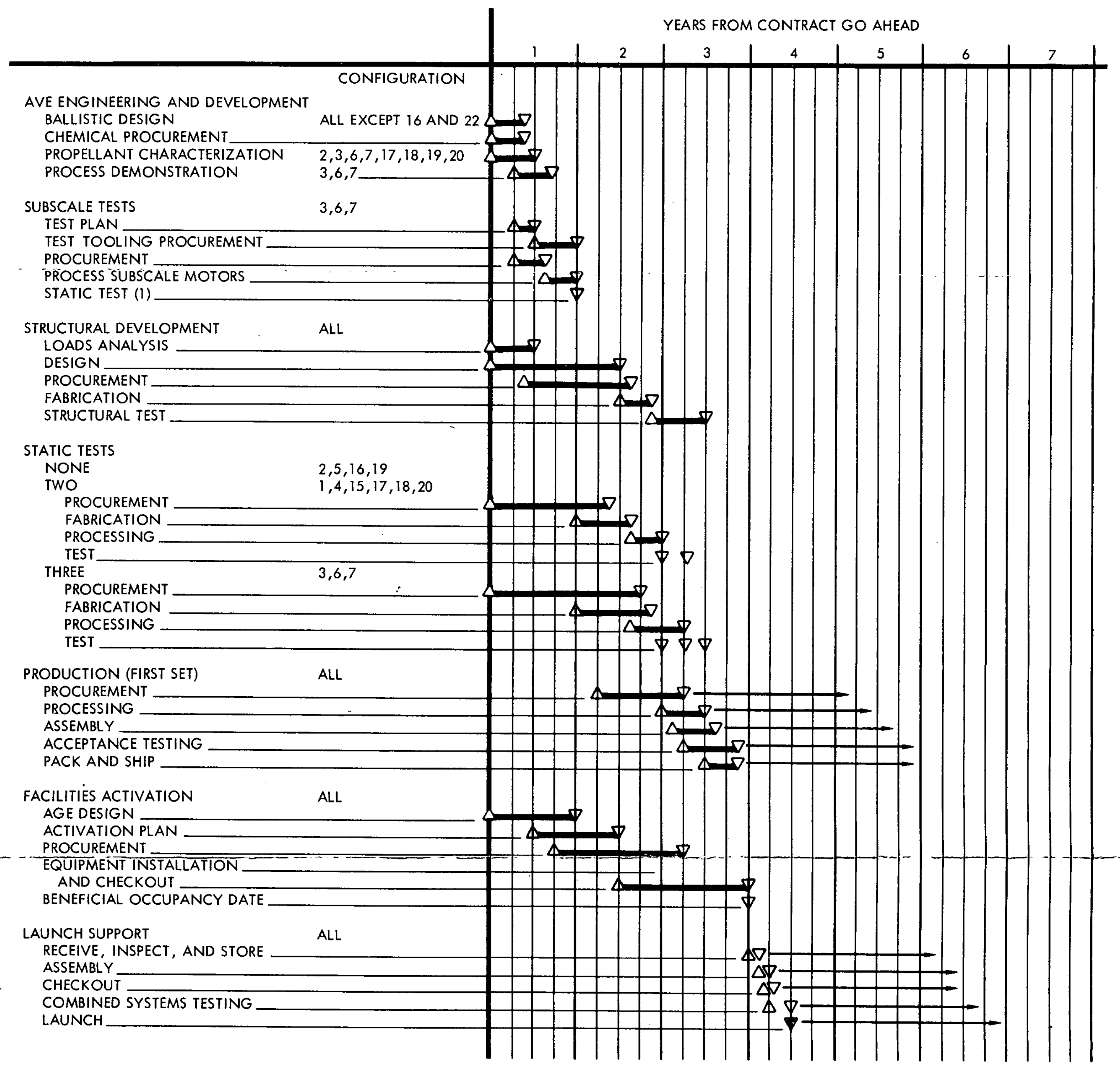

Figure 8. UA 1205 SRM Ballistic Modification and Structural Design Milestone Schedule

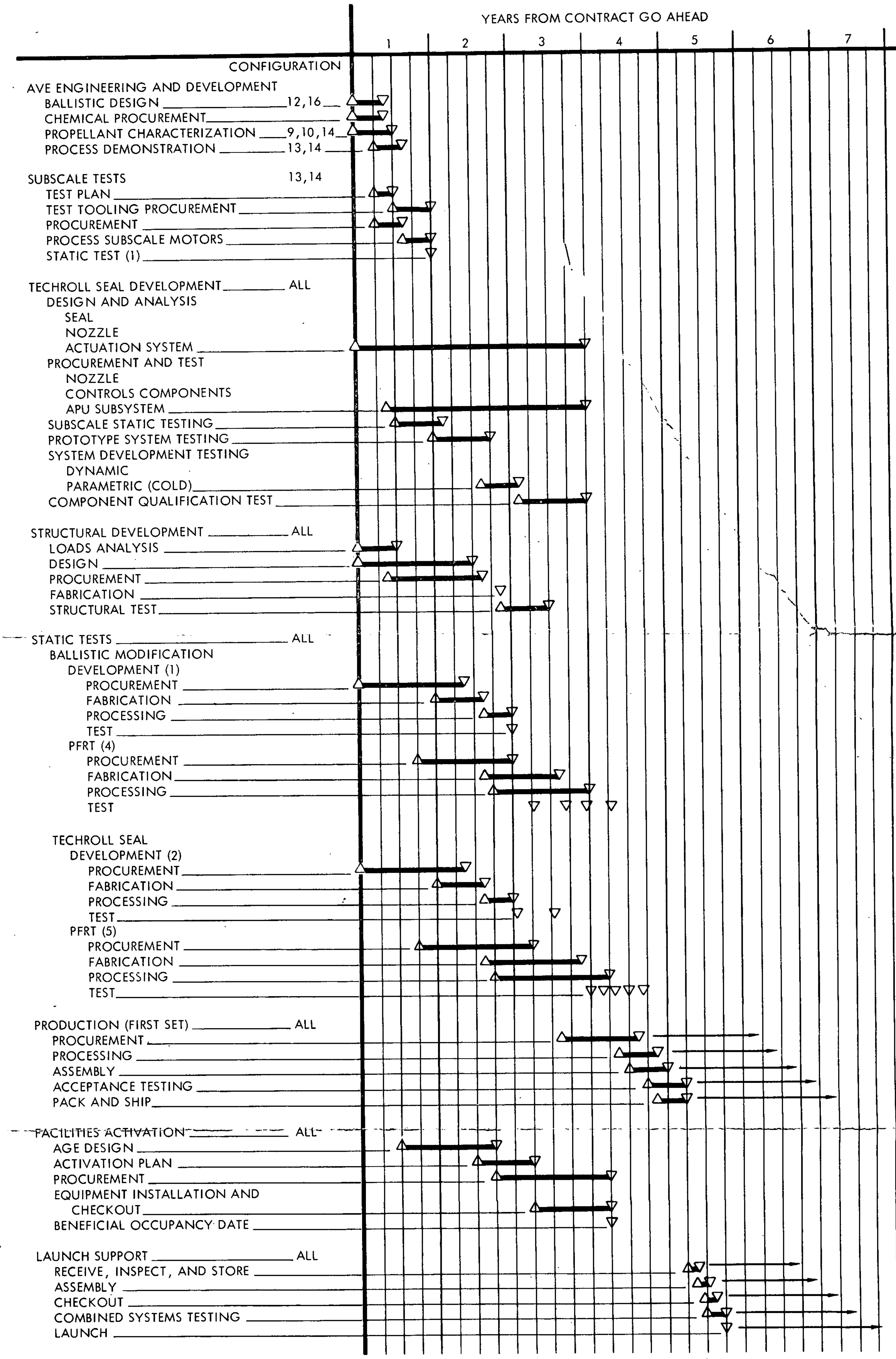

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Figure 9. UA 1207 SRM Ballistic Modification or TECHROLL Seal Milestone Schedule

7.0 PROGRAM COSTS

The cost of those modifications which would improve the performance or cost effectiveness of the 120-in.- (3.05 m) diameter SRMs as launch vehicle stages have been estimated as part of this study. These costs are categorized as nonrecurring or recurring costs and are summarized in tables II and III. Thus, preliminary planning and budgeting may be performed for programs using a 120-in.- (3.05 m) diameter SRM design and a cluster configuration from section 5.0. Combining these data with estimates of costs for the upper stages, payloads, and other program elements would yield the total costs required for program evaluation.

The cost data 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 dollar values, and no provisions are included for price escalation due to inflation.

Estimates of nonrecurring and recurring costs have been made for the development and production of clustered two-stage SRM boosters incorporating any of the modifications which have been defined. The modifications are defined briefly in figure 2, and the six configurations for clustered boosters are discussed in section 5.0. The data and procedures presented will allow the program planner to determine budgetary costs for launch vehicle programs utilizing the 120-in.- (3.05 m) diameter SRM. Data for various vehicle launch rates corresponding to annual SRM production rates (as high as 35 per year) for clustered stages are presented.

The configurations studied involve nonrecurring stage costs ranging from a low of $12 million to a high of $44.6 million, depending on the design modifications incorporated into the selected SRM and the cluster size. The significant nonrecurring cost difference between the UA 1205 and UA 1207 SRM is created by the four static tests required to complete the UA 1207 PFRT. Table II presents a summary of the range which may be expected in the costs of the various nonrecurring program elements. Costs for design, testing, static testing, tooling, test hardware, and AGE are included in the nonrecurring costs. Further discussion of the cost items may be found in volume II.

The recurring cost for each configuration varies with the launch rate and the number of SRMs per vehicle. The design options do not represent a significant cost variation within the precision of this report. Table III provides further detail of the recurring costs of the various ballistic designs as clustered into the six vehicle concepts.

TABLE II

ESTIMATED SRM STAGE SUMMARY COSTS

(1971 Dollars x 10^6)

	UA 1205	UA 1207
NONRECURRING COSTS		
Ballistic modifications	$ 0* to 8.9	$ 11.4* to 15.0
TECHROLL seal nozzle	14.1 to 21.0	10.4 to 13.2
Straight nozzle development	0.3	0.3
Attach structure design and test	2.0* to 4.2	2.6* to 4.2
Tooling for 15 SRMs/year	4.6*	4.6*
AGE for 15 SRMs/year	3.8* to 5.2	4.3* to 5.7
Program costs	1.6*	1.6*
	$12.0* to 45.8	$24.5 to 44.6

* Minimum program cost items

TABLE III

ESTIMATED SRM CLUSTER COSTS AS LAUNCHED

(1971 Dollars x 10^6)

Vehicle Configuration		15 SRMs/year		35 SRMs/year	
		LITVC	TECHROLL Seal	LITVC	TECHROLL Seal
2 + 1	UA 1205	7.2	6.5	6.6	6.0
	UA 1207	8.4	7.6	7.6	6.9
3 + 1	UA 1205	9.6	8.7	8.7	7.9
	UA 1207	11.1	10.1	10.1	9.2
4 + 1	UA 1205	12.1	11.0	10.9	9.9
	UA 1207	14.0	12.7	12.7	11.6
5 + 1	UA 1205	14.5	13.2	13.2	12.0
	UA 1207	16.7	15.2	15.3	13.8
4 + 2	UA 1205	14.4	13.1	13.0	11.7
	UA 1207	16.6	15.0	15.2	13.8
5 + 2	UA 1205	16.9	15.4	15.3	13.8
	UA 1207	19.4	17.7	17.8	16.1