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DEVELOPMENT OF COST-OPTIMIZED INSULATION SYSTEM FOR USE IN LARGE SOLID ROCKET MOTORS

Volume IV: Task IV - 260-In.-Dia Motor Insulation System Design and Process Plan

by:

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and

D. L. Nachbar, Project Manager, LMISD Program

AEROJET-GENERAL CORPORATION

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-11224
J. J. Pelouch, Jr., Project Manager

AEROJET GENERAL TIRE GENERAL

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FINAL REPORT

Development of Cost-Optimized Insulation System for Use in Large Solid Rocket Motors
Volume IV: Task IV - 260-In.-Dia Motor Insulation System Design and Process Plan

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NASA-Lewis Research Center
Cleveland, Ohio
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FOREWORD

The insulation development work described herein, which was conducted by the Solid Rocket Division of Aerojet-General Corporation, was performed under NASA Contract NAS3-11224. The work was accomplished under the management of the NASA Project Manager, Mr. J. J. Pelouch, Jr., Chemical Propulsion Division, NASA-Lewis Research Center.

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ABSTRACT

A program to develop a cost-optimized insulation system for large solid rocket motors was conducted by Aerojet-General Corporation under Contract NAS3-11224. Four tasks were derived to accomplish the program Task I, Survey and Screening; Task II, Process Demonstration; Task III, Material Performance Determination; and Task IV, Preparation of 260-in.-dia full-length motor insulation system Design and Process Plan. Task IV is the subject of this volume of the final report.

Preliminary designs based on observed material erosion rates were prepared for eight potential 260-in.-dia full-length motor insulation systems. Weight, production costs, and tooling concepts were derived from these preliminary designs for the various insulation systems. Trowelable IBT-100 insulated domes and nozzle and trowelable IBT-106 insulated sidewall and propellant boots were the selected insulation system. An alternative system, which incorporated USR-3800 in the aft dome and nozzle, was recommended. A requirement/capability analysis was conducted on the selected IBT-100/IBT-106 system. A material performance standard deviation of 15.1 percent and an allowable failure probability of 10^{-6} were the key parameters used for the R||C Analysis. Insulation material thicknesses required to protect against propellant defect diameters of 0-, 2-, 4-, 8-, and 12-in., and required insulation weight as a function of allowable propellant defect size were determined. The R||C Analysis results indicated that the most significant parameter controlling required insulation thickness, and subsequently total system weight, was the material performance standard deviation. The observed V-44 material performance standard deviation was used for this analysis, as there were insufficient performance data with the IBT materials upon which to base a standard deviation value.

The following are the final 260-FL motor IBT-100/IBT-106 insulation system design characteristics:

Total Weight, lb	44,645
Performance Standard Deviation, %	15.1
Allowable Probability of Failure	10^{-6}
Allowable Propellant Defect Size, in. dia	8
Estimated Production Cost per Motor	$141,684
Estimated Initial Tooling Cost	$75,900

A comparable V-44/V-45 insulation system would weigh 42,992 lb, and the estimated production cost would be $343,864, assuming a base-cost of $8.00 per lb installed. Suggested follow-on work includes verification of insulation-to-propellant bond strength without liner material; multiple small scale motor

ABSTRACT (cont)

tests with IBT-100 and IBT-106 to establish a material performance standard deviation; and to process and test the selected 260-FL motor insulation system in an intermediate size solid propellant motor.

NASA report numbers and corresponding volume numbers are as follows:

CR-72581	Volume I
CR-72582	Volume II
CR-72583	Volume III
CR-72584	Volume IV

I. SUMMARY

The objective of the Large Motor Insulation System Development (LMISD) Program is to evaluate low-cost insulation materials that are applicable to large solid-propellant rocket motors. Four tasks were derived to accomplish the planned objective. Task I, which is described in Volume I of this report, involved a survey of available materials applicable to large motors; selection of 20 candidate materials, including Gen-Gard V-44 and V-61 as controls; measurement of candidate material physical, chemical, mechanical, thermal, and adhesive properties; evaluation of material erosion resistance in three solid-propellant motor tests; evaluation of property measurement and motor test data; and selection of 12 materials, including V-44 control, for further evaluation in Tasks II and III. In Task II, which is the subject of this volume, candidate materials selected in Task I were installed into a 54-in.-dia motor chamber. Task III includes material performance determinations in five solid-propellant motor tests. Task IV is the preparation of a 260-in.-dia full length Motor cost-optimized insulation system design and process plan, using materials selected on the basis of data obtained from Tasks II and III.

The cost-optimized insulation system was designed for the 260-in.-dia full-length motor configuration related to the mission and performance of the 260/S-IVB vehicle defined by McDonnell-Douglas for the Saturn IB improvement study. Preliminary designs were prepared for the following potential insulation systems:

1. V-44 pressure-cured aft dome and nozzle
   V-45 pressure-cured fwd dome, sidewall, and propellant boots

2. IBT-100 troweled fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

3. IBT-100 troweled fwd and aft dome, and nozzle
   IBS-107 sprayed sidewall and propellant boots

4. IBT-106-1 troweled fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

5. IBC-111 cast fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

6. 40SD-80 cast fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

7. TI-H704B troweled (tamped) fwd and aft dome, and nozzle
   TI-H704B troweled (tamped) sidewall and propellant boots

8. IBT-100 troweled fwd dome
   USR-3800 pressure-cured aft dome and nozzle
   IBT-106-2 troweled sidewall and propellant boots

I. Summary (cont)

The preliminary insulation systems reflected only designs based on expected TLR-vs-Mach number performance, and did not include allowances for 3 sigma performance variations, propellant defects, material critical defect sizes, core misalignment, and premature exposure considerations. These preliminary designs were prepared only to show the relative cost and weight of each potential system.

Estimated recurring production costs for the various insulation systems were prepared, and included raw material, batch mixing, installation operations, NDT inspection, and labor and facility overhead costs.

The following table is an insulation system cost and weight summary:

Insulation System	Estimated Recurring** Production Cost Per Motor	Estimated** Non-Recurring Tooling Cost	Insulation Weight in Motor, lb
V-45/V-44 (control)	$ 173,680*	N/A	21,710
IBT-100/IBT-106	71,320	$ 75,900	22,545
IBT-100/IBS-107	72,913	178,800	20,920
IBT-106	77,219	75,900	24,485
IBC-111/IBT-106	89,078	124,900	25,275
40SD-80/IBT-106	146,513	124,900	35,790
IBT-100/USR-3800/IBT-106	79,938	68,900	19,789
TI-H704B	-	-	23,540

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* Estimated at $8.00/lb installed

** Excluded fixed-fee

The IBT-100/IBT-106 insulation system was recommended, with IBT-100/USR-3800/IBT-106 as an alternative.

The calculation of maximum allowable propellant defect size versus required insulation thickness was performed on the IBT-100/IBT-106 system by means of a requirements vs capability (R||C) analysis. In this type of analysis, statistical distributions are established for the requirement, expressed as the maximum exposure time that must be provided for, and the capability, expressed as the total time required to burn through propellant and insulation. In the usual R||C analysis, failure probability is calculated as the probability of the requirement exceeding the capability. In this analysis, however, the failure probability is known and the capability is reduced by the unknown term relating to minimum propellant defect size.

I. Summary (cont)

Several ground rules were specified by the NASA/LeRC Project Manager for the R||C Analysis. Primarily, the probability of burning through the insulation was assigned a limit criteria of 10^{-6}. Secondly, the variation in erosion rate for the IBT-100 and IBT-106 materials was assumed to be equivalent to that observed for V-44. The following summarizes the values used in the analysis:

Parameter	Av. Symbol	Value $\bar{X}$	Standard Deviation $s/\bar{X}\%$	Standard Deviation s, Units	Source
Propellant thickness consumed prior to web time, in.	t_w	Varies	0.22	Varies, in.	260-in. Reliability Study Final Report, plus maximum core shift of 0.25 in.
Propellant thickness consumed during tail-off, in.	t_{to}	2.5	0.22	0.005 in.	260-in. Reliability Study Final Report, plus maximum core shift of 0.25 in.
Propellant pouring rate prior to web time, in./sec	r_w	0.606	1.35	0.00818 in./sec	260-in. Reliability Study Final Report
Propellant burning rate during tail-off, in./sec	r_{to}	0.333	1.35	0.0045 in./sec	260-in. Reliability Study Final Report, plus maximum core shift of 0.25 in.
Insulation thickness, in.	t_i	Varies	Varies	0.0167 in.	Print tolerance of ± 0.050 assumed equal to ± 3 sigma.
Insulation erosion rate, in./sec	r_i	Varies	15.1	Varies, in./sec	$\frac{s}{\bar{X}}\%$ from V-44 insulation erosion data from Polaris A3 and Minuteman motor tests.

I. Summary (cont)

The R||C Analysis approach to insulation system design leads to a significant increase in inert stage weight. A comparison of calculated 260-FL motor insulation weights are presented as follows:

	Calculated Insulation System Weight, lb		
	1.5 Safety Factor	R/C Analysis No Allowable Propellant Voids	R/C Analysis 12-in.-dia Allowable Propellant Voids
Total Motor Insulation System Weight	22,545	40,495	46,005

Significant tradeoffs were conducted in conjunction with the R||C Analysis. The two parameters that most affect the required insulation thicknesses were the standard deviation of insulation erosion rate from the nominal, $(S)r_i$, and the probability of insulation burnthrough allowable limit, P(I). The following table shows the effect of reducing $(S)r_i$ from 15.1 to 7.5% and increasing P(I) from 10^{-6} to 10^{-3} on the required insulation thicknesses at two selected stations:

		Insulation Thickness, in.			
Station	1.5 Safety Factor	$(S)r_i = 0.151$ $P(I) = 10^{-6}$ No Allowable Propellant Voids	$(S)r_i = 0.075$ $P(I) = 10^{-6}$ No Allowable Propellant Voids	$(S)r_i = 0.151$ $P(I) = 10^{-3}$ No Allowable Propellant Voids	$(S)r_i = 0.075$ $P(I) = 10^{-3}$ No Allowable Propellant Voids
3*	0.70	1.09	0.50	0.58	0.42
13**	3.00	6.99	3.20	3.75	2.60

From the foregoing comparisons and tradeoffs, the most controlling parameter in relating the insulation system requirement to its capability is the standard deviation of material erosion rate from the nominal, $(S)r_i$, and the failure probability)(I),

The final 260-FL motor insulation system design characteristics are shown as follows:

Forward Dome:

Material	IBT-100
Weight, lb	7410
Installation process	Trowelable

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*Sta 3 - Equator, forward dome and sidewall
**Sta 13 - Nozzle step joint

I. Summary (cont)

Sidewall:	
Material	IBT-106
Weight, lb	16,630
Installation process	Trowelable
Aft Dome:	
Material	IBT-100
Weight, lb	11,005
Installation process	Trowelable
Nozzle:	
Material	IBT-100
Weight, lb	5,065
Installation process	Trowelable
Propellant boots:	
Material	IBT-106
Weight, lb	4,535
Installation process	Trowelable
Total insulation system weight, lb	44,645
Probability of insulation burnthrough, P(I)	10^{-6}
Material performance standard deviation, $S/\overline{X}$, %	15.1
Allowable propellant void dia, in.	8

The estimated 260-FL motor IBT-100/IBT-106 insulation system production cost is $141,684; the estimated initial tooling cost is $75,900. A comparable V-44/V-45 insulation system would weigh 42,993 lb, and the production cost per motor would be $343,864, assuming a base cost value of $8.00/lb installed.

Three areas of follow-on large motor insulation development work are recommended. First, propellant-to-insulation bondline tensile and shear strength tests should be repeated to verify deletion of liner material. Second, the IBT-100/IBT-106 performance values and selected processes used for the insulation system design should be verified in intermediate-size motor test firings. Third, small scale motor tests should be conducted to establish an IBT-100/IBT-106 material performance standard deviation value.

II. INTRODUCTION

A. PURPOSE OF REPORT

This document is the fourth volume in a series of final reports dealing with the major tasks of the Large Motor Insulation System Development (LMISD) Program, Contract NAS3-11224. This series of reports constitutes the LMISD Program final report. This report summarizes in detail the Task IV effort for the LMISD Program.

B. SCOPE OF EFFORT

This report volume summarizes in detail the Task IV effort for the LMISD Program. The following work was accomplished:

1. Eight preliminary 260-FL motor insulation system designs were prepared using various insulation materials either singly or in combination.
2. The weights of the various insulation systems were calculated.
3. Tooling concepts were derived for installation of the various materials.
4. Production and tooling costs were estimated for the eight preliminary insulation systems.
5. A tradeoff study was conducted based on cost and performance to select the most cost-optimized system.
6. The trowelable IBT-100/IBT-106 system was recommended for application to 260-FL motors, with IBT-100/USR-3800/IBT-106 as a desirable system.
7. A requirement/capability analysis was conducted on the selected system to establish a final design.
8. A design layout drawing was prepared showing the final 260-FL motor insulation system.
9. Final production and tooling cost estimates were prepared for the selected system.
10. An insulation system process plan was prepared.

III. PHASE I: 260-IN.-DIA MOTOR INSULATION SYSTEM DESIGN

A. 260-IN.-DIA MOTOR DEFINITION

The cost-optimized insulation system was designed for the 260-in.-dia full length motor configuration shown in Figure 1. A performance summary and predicted pressure-vs-time curve for this motor configuration are shown in Figures 2 and 3, respectively. In the tradeoff study prepared to select the cost-optimized system, stage weight, inert weight, burnout velocity, and stage cost per lb parameters were related to the mission and performance of the 260/SIVB vehicle defined by McDonnell-Douglas for their Saturn IB Improvement Study[1].

B. PRELIMINARY INSULATION SYSTEM DESIGN

Data obtained from Tasks I, II, and III were analyzed, and a tradeoff study emphasizing performance and processing was performed for the materials evaluated.

A preliminary design effort was performed to establish insulation thicknesses required at various sections of the motor. The preliminary design approach determined the required insulation thickness directly from expected material erosion (TLR) rates. Insulation design thicknesses were calculated as a product of thickness loss rate at full and reduced operating pressure, exposure time at full and reduced pressure, and a safety factor; the following equation was used:

$$t = (SF) \left[(P_c/600)^{0.3} (\theta_1) (TLR_1) + (\theta_2) (TLR_2) \right]$$

where: t is design thickness, in.

SF is the safety factor

$(P_c/600)^{0.3}$ is a correction factor for motor operating pressures other than 600 psi (for 260-in.-dia motor application, this term is unity)

θ_1 is exposure time to full motor operating pressure (web burning time), sec

TLR_1 is insulation material thickness loss rate at the Mach number of a local area ratio, in./sec

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1: Saturn IB Improvement Study (Solid First Stage) Phase II, Douglas Missile and Space Systems Division Report No. SM-51896, dated 30 March 1966.

θ_2 is exposure time to reduced operating pressure during tailoff, and afterburn, sec

TLR_2 is insulation material thickness loss rate at reduced pressure during tailoff and afterburn, in./sec

Exposure time is a function of web burning duration, propellant grain configuration, and propellant burning rate. Because the TLR is a function of operating pressure and gas velocity, each area of the motor was analyzed separately to determine the local conditions to which insulation is exposed.

A list of materials and installation processes which were applicable to various sections of a 260-in.-dia full length motor follows:

Material	Installation Process
Forward Dome	
V-45	precured components, secondarily bonded; V-61 joints
IBT-100	troweled
IBT-106-1	troweled
IBC-111	cast
40SD-80	cast
TI-H704B	special tamping process
Sidewall	
V-45	precured strips, secondarily bonded; lapped joints
IBT-106-2	troweled
IBS-107	sprayed
IBS-109	sprayed
TI-H704B	special tamping process
Aft Dome and Nozzle	
V-44	precured components, secondarily bonded; V-61 joints
USR-3800	precured components, secondarily bonded; V-61 joints
IBT-100	troweled
IBT-106-1	troweled
IBC-111	cast
40SD-80	cast
TI-H704B	special tamping process
Boots	
V-45	precured components, secondarily bonded; Germax V-45 seams
IBT-106-2	troweled
IBS-107	sprayed
TI-H704B	special tamping process

The first step in selecting the cost-optimized insulation system was to prepare preliminary insulation system designs using the materials in the foregoing table. Figure 4 is a summary of nominal material thickness loss rate-vs-initial Mach number performance data obtained from LMISD test motors in Tasks I and III. Included in Figure 4 are performance data for V-44 and IBT-100 obtained from actual large motor static test firings. In Figure 5, performance of IBT-106, 40SD-80, IBC-111, IBS-107, and TI-H704B were related to V-44 performance, using the LMISD Motor V-44 to 260-SL Motor V-44 performance ratio as a guideline. The expected large motor performance data (Figure 5) do not represent a final data summary. Actual performance data can be obtained only from insulation performance measured in actual large motor test firings. The data in Figure 5 were intended only to show material performance relative to V-44, and to provide a common performance basis for selecting a cost-optimized insulation system design.

Preliminary 260-FL insulation system designs using various combinations of candidate materials are shown in Figure 6 through 13; performance analysis summary sheets are shown in Figures 14 through 21. The following insulation systems were included:

1. V-44 pressure-cured aft dome, and nozzle
   V-45 pressure-cured fwd dome, sidewall, and propellant boots

2. IBT-100 troweled fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

3. IBT-100 troweled fwd and aft dome, and nozzle
   IBS-107 sprayed sidewall and propellant boots

4. IBT-106-1 troweled fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

5. IBC-111 cast fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

6. 40SD-80 cast fwd and aft dome, and nozzle
   IBT-106-2 troweled sidewall and propellant boots

7. TI-H704B troweled (tamped) fwd and aft dome, and nozzle
   TI-H704B troweled (tamped) sidewall and propellant boots

8. IBT-100 troweled fwd dome
   USR-3800 pressure-cured aft dome and nozzle
   IBT-106-2 troweled sidewall and propellant boots

III.B. Preliminary Insulation System Design (cont)

A weight summary of the foregoing insulation systems is shown in Figure 22.

Significantly, the preliminary insulation systems (Figures 6 through 13) show only designs based on expected TLR-vs-Mach number performance and did not include allowances for 3-sigma performance variations, propellant defects, material critical defect sizes, core misalignment, and premature exposure considerations. These preliminary designs were prepared to show the relative cost and weight of each potential system. When the final insulation system was recommended and approved by the NASA-LeRC Project Manager, a requirements/capability analysis was applied to the selected design. The application of R||C analyses to all potential insulation systems was beyond the program scope.

Estimated recurring production costs for the various insulation systems are shown in Figures 23 through 28. Raw material, batch mixing, installation operations, and NDT inspection costs were included. A summary of estimated tooling costs is shown in Figure 29.

The following table in an insulation system cost and weight summary:

	Estimated Recurring** Production Cost Per Motor	Estimated** Non-Recurring Tooling Cost	Insulation Weight in Motor, lb
V-45/V-44 (control)	$ 173,680*	N/A	21,710
IBT-100/IBT-106	71,320	$ 75,900	22,545
IBT-100/IBS-107	72,913	178,800***	20,920
IBT-106	77,219	75,900	24,485
IBC-111/IBT-106	89,078	124,900	25,275
40SD-80/IBT-106	146,513	124,900	35,790
IBT-100/USR-3800/IBT-106	79,938	68,900	19,789
TI-H704B			

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* Estimated at $8.00/lb installed

** Excluded fixed-fee

***Includes $125,000 estimated cost for automatic spray equipment

The cost and weight of the castable-trowelable systems, IBC-111/IBT-106 and 40SD-80/IBT-106, were prohibitive. The trowelable-sprayable system, IBT-100/IBS-107, was competitive on a weight basis. However, uncertainty of the installation process and the absence of large scale process demonstration removed this system from consideration. A more detailed analysis was required to compare the IBT-100/IBT-106 and IBT-100/USR-3800/IBT-106 systems. The latter system was more competitive on a weight (2755-lb differential) and non-recurring tooling cost basis ($7000 differential). However, the recurring production costs were higher ($14,217 differential). Performance tradeoffs[2] were applied as follows to determine overall net advantage or disadvantage of the lower weight, higher production cost system:

$$\partial V/\partial M_e = -0.01095 \text{ (ft/sec)/lbm}$$

$$\partial V/\partial M_s = 0.00118 \text{ (ft/sec)/lbm}$$

where V = velocity, ft/sec

M_e = inert wt, lbm

M_s = stage wt, lb

$$\partial V = \partial M_e \, (-0.01095)$$

$$\partial M_s = \frac{\partial M_e \, (-0.01095)}{0.00118}$$

The ∂M_e = -2755 lb, therefore, the reduction in stage weight, ∂M_s, is 25,055 lb. As reported also in Reference (a), the stage weight cost is $1.63/lb.

25,055 lb at $1.63/lb		$40,840	
Less differential production cost	=	-8,618	
		$32,222	recurring
		7,000	non-recurring
Total Advantage		$39,222	

The trowelable-pressure cured insulation system of IBT-100/USR-3800/IBT-106 presents a cost advantage over the IBT-100/IBT-106 trowelable system. Currently, the concern with full recommendation of the trowelable-pressure cured

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2: Aerojet-General Corporation Final Report, Study of Low-Cost Materials for 260-in.-Diameter Motors, Contract NAS7-513, 16 May 1969.

system was the processing characteristics of USR-3800 for large motor applications. USR-3800 contains a relatively high percentage of boric acid filler. Voids caused by boric acid expansion during the cooldown period of the cure cycle were encountered in the early experience with this material. Since then, fabrication problems apparently have been overcome; the material has been used successfully by Aerojet in the Polaris A3 motor and by Thiokol Chemical Corporation in the Poseidon motors.

It was recommended that IBT-100/IBT-106 be considered the primary insulation system, with IBT-100/USR-3800/IB T-106 as an alternative.

C. REQUIREMENTS/CAPABILITY ANALYSIS

The sequence of an insulation burnthrough failure originates with an advancement of the flame front at a rate faster than planned, resulting in the flame front traversing through the propellant or along the propellant-liner interface and eroding through the insulation prior to the end of action time. In terms of defects, any void, region of porosity, fissure, and crack in the grain or extending radially from either the inner or outer surface might be considered the initiator of the failure sequence. Included would be defects in the cylindrical part of the grain and at the base of the fin slots. Defects in the fins themselves would normally be excluded in this failure mode. Propellant-liner unbondedness can advance the flame front. Depending on motor geometry, any propellant-liner bond failure that results in a net increase in flame front advancement over that expected can be considered as an initiator of the failure sequence.

The calculation of maximum allowable undetected propellant defect size vs required insulation thickness was performed by means of a Requirements-vs-Capability (R||C) analysis[3]. In this type of analysis, statistical distributions are established for the requirement, expressed as the maximum exposure time that must be provided for, and the capability, expressed as the total time required to burnthrough propellant and insulation. In the usual R||C analysis, failure probability is calculated as the probability of the requirement exceeding the capability. In this analysis, however, the limit of failure probability is established and the capability is reduced by the unknown term relating to minimum propellant defect size. The basic R||C formulation[4], which assumes that the Requirement and Capability parameters are normally distributed, is as follows:

3: TEMPO Report 66TMP-90, The Analytical Approach and Physics-of-Failure Technique for Large Solid Rocket Reliability, Contract NAS7-383, General Electric Company, dated 1 March 1967.

4: TEMPO Report 68TMP-78, An Application of the Requirements-vs-Capability Analysis to Estimating Design Reliability of Solid Rocket Motors, Contract NAS7-556, General Electric Company, dated July 1968.

III.C. Requirements/Capability Analysis (cont)

$$\Phi = \frac{\bar{X}_c - \bar{X}_R}{\sqrt{(s)_c^2 + (s)_R^2}}$$

where X_c and $(s)_c$ are the average and standard deviation of the capability parameter, insulation erosion protection, seconds

$\bar{X}_R$ and $(s)_R$ are the average and standard deviation of the requirement parameter, required duration of erosion protection, seconds

Φ is the amount of pooled standard deviations between $\bar{X}_c$ and $\bar{X}_R$ that can be converted into the probability of R exceeding C.

To express the capability in terms of propellant thickness, and insulation thicknesses and erosion rates, and to take into account the reduction of the capability due to undetected voids, the basic formula was modified as follows:

$$\Phi = \frac{\frac{t_w}{r_w} + \frac{t_i}{r_i} - \frac{V}{r_w} - \bar{X}_R}{\sqrt{(s)_c^2 + (s)_R^2}}$$

where V = void diameter, in.

r_w = Propellant burning rate prior to web burn out, in./sec

t_w = Propellant thickness, in.

t_i = Insulation thickness, in.

r_i = Insulation erosion rate, in./sec

Solving for T_i, we obtain

$$t_i = r_i \left(\Phi \sqrt{(s)_c^2 + (s)_R^2} \right) + r_i \left(\frac{V}{r_w} \right) + r_i \left(\bar{X}_R - \frac{t_w}{r_w} \right)$$

III.C. Requirements/Capability Analysis (cont)

Presented in this method, the term $r_i \left(\overline{X}_R - \frac{t_w}{r_w} \right)$ is the insulation thickness required for the nominal duration for which the insulation is exposed to direct flame. The term $r_i \; \Phi \sqrt{(s)_c^2 + (s)_R^2}$ is the additional thickness required to provide protection for departures from nominal performance, while $r_i \left(\frac{V}{r_w} \right)$ is the additional thickness required to protect against undetected voids.

Several rules were specified by the NASA/LeRC Project Manager for the R||C Analysis. First, the probability of burning through the insulation was assigned a limit criteria of 10^{-6}. At this magnitude of failure mode probability, the amount of pooled standard deviations between $\overline{X}_c$ and $\overline{X}_R$ which can be converted into the probability of the Requirement exceeding the Capability, Φ , is 4.75. Second, the variation in erosion rate for the IBT-100 and IBT-106 materials was assumed to be equivalent to that observed for V-44. The following summarizes the parameter values used in the analysis:

Parameter	Symbol	Av. Value $\overline{X}$	Standard Deviation $s/\overline{X}$ %	Standard Deviation s, Units	Source
Propellant thickness consumed prior to web time, in.	t_w	Varies (Figure 29)	0.22	Varies, in.	Reference 5 Report, plus maximum core shift of 0.25 in.
Propellant thickness consumed during tail-off, in.	t_{to}	2.5	0.22	0.005, in.	Reference 5 Report, plus maximum core shift of 0.25 in.
Propellant burning rate prior to web time, in./sec	r_w	0.606	1.35	0.00818 in./sec	Reference 5 Report
Propellant burning rate during tail-off, in./sec	r_{to}	0.333	1.35	0.0045 in./sec	Reference 5 Report plus maximum core shift of 0.25 in.

5: Aerojet-General Corporation, Final Report, 260-Inch Motor Reliability Study, Contract NAS7-572, dated November 1968.

III.C. Requirements/Capability Analysis (cont)

Parameter	Symbol	Av. Value $\bar{X}$	Standard Deviation $s/\bar{X}$ %	Standard Deviation s, Units	Source
Insulation thickness, in.	t_i	Varies	Varies	0.0167 in.	Print tolerance of ±0.050 assumed equal to ± 3 sigma
Insulation erosion rate, in./sec	r_i	Varies (Figure 29)	15.1	Varies, in./sec	$\bar{X}$ from Figure 5 $\frac{s}{\bar{X}}$ % from V-44 insulation erosion data from Polaris A3 and Minuteman motor tests.

The following calculations were made:

1. $\bar{X}_R$ and (s_R)

The value for $\bar{X}_R$, the requirement, was evaluated as the time required for the propellant to burn through to the insulation at the point of maximum web thickness. The following formula was used:

$$\bar{X}_R = \frac{t_w}{r_w} + \frac{t_{to}}{r_{to}}$$

where t_w = maximum thickness of propellant consumed prior to web time, in.

r_w = propellant burning rate prior to web time, in./sec

t_{to} = maximum propellant thickness consumed during tailoff, in.

r_{to} = propellant burning rate during tailoff, in./sec

Using the value of 85.0 and 2.5 for t_w and t_o and the values of 0.606 and 0.333 in./sec for r_w and r_{to}, an $\bar{X}_R$ of 147.5 sec, equivalent to nominal action time, was obtained.

III.C. Requirements/Capability Analysis (cont)

The standard deviation of the requirement, $(s)_R$, was estimated from the propagation of variance formula:

$$(s)_R^2 = \left[\frac{1}{r_w} (s)_{t_w}\right]^2 + \left[\frac{t_w}{r_w^2} (s)_{r_w}\right]^2 + \left[\frac{1}{r_{to}} (s)_{t_{to}}\right]^2 + \left[\frac{t_{to}}{(r_{to})^2} (s)_{r_{to}}\right]^2$$

A value of 1.92 sec for $(s)_R$ was obtained, using the values shown in the foregoing parameter value table.

2. $(s)_c$

To simplify the calculation of the standard deviation of the capability $(s)_c$ it was assumed that:

$$X_c = \frac{t_w}{r_w} + \frac{t_i}{r_i}$$

and the effect of the undetected voids, $\frac{V}{r_w}$, was neglected in calculated $(s)_c$.

The formula for s_c then became:

$$(s)_c^2 = \left[\frac{1}{r_w} (s)_{t_w}\right]^2 + \left[\frac{t_w}{r_w^2} (s)_{r_w}\right]^2 + \left[\frac{1}{r_i} (s)_{t_i}\right]^2 + \left[\frac{t_i}{r_i^2} (s)_{r_i}\right]^2$$

Substituting the values from the foregoing parameter value table, the following expression was obtained:

$$s^2 = 0.00057\, t_w^2 + 0.000278 \frac{1}{r_i^2} + 0.0227 \frac{t_i^2}{r_i^2}$$

As this equation for s_c involved t_i, it was necessary to make an iterative solution for t_i in the equation derived earlier. The results for 18 locations in the 260-FL motor are shown in Figure 30. These data assume no propellant voids. Because of the simplifying assumption that the void effect term, $\frac{V}{r_w}$, did not affect s_c, the additional insulation required to protect for undetected voids was solved directly from the expression, $r_i \frac{V}{r_w}$, where r_i

is the erosion rate at the station being analyzed. A summary of total insulation thickness required for allowable propellant void diameters of 2-, 4-, and 8-, and 12-in. is presented in Figure 31. A plot of 260-FL insulation weight, excluding propellant boots, as a function of allowable propellant void diameter is shown in Figure 32.

The R||C Analysis approach to insulation system design led to a significant increase in inert stage weight. A comparison of calculated 260-FL motor insulation weights are presented in the following table:

	Calculated Insulation System Weight, lb		
Section of Motor	1.5 Safety Factor	R‖C Analysis No Allowable Propellant Voids	R‖C Analysis 12-in.-dia Allowable Propellant Voids
Forward dome	3,710	7,160	7,470
Sidewall	7,915	13,935	17,580
Aft dome	4,315	9,925	11,325
Nozzle	2,070	4,940	5,095
Propellant boots	4,535	4,535	4,535
Total	22,545	40,495	46,005

Applying the 260/S-IVB stage performance tradeoff previously described in Section III.B. of this report, the change in burnout velocity, stage weight, and stage cost were determined, and are summarized as follows:

	No Allowable Propellant Voids	12-in.-dia Allowable Propellant Voids
Burnout velocity, ∂V, ft/sec	-197	-257
Stage weight, ∂M_s, lb	+16,670	+21,770
Stage cost, at $1.63/lb	+$27,172	+$35,485

Other significant tradeoffs were conducted in conjunction with the R||C Analysis. The two parameters which most affect the required insulation thicknesses are the standard deviation of insulation erosion rate from the nominal, $(S)r_i$, and the probability of insulation burnthrough allowable limit, P(I). The following table shows the effect of reducing $(S)r_i$ from 15.1 to 7.5% and increasing P(I) from 10^{-6} to 10^{-3} on the required insulation thicknesses at two selected stations:

III.C. Requirements/Capability Analysis (cont)

Station*	1.5 Safety Factor	Insulation Thickness, in. $(S)r_i = 0.151$ $P(I) = 10^{-6}$ No Allowable Propellant Voids	$(S)r_i = 0.075$ $P(I) = 10^{-6}$ No Allowable Propellant Voids	$(S)r_i = 0.151$ $P(I) = 10^{-3}$ No Allowable Propellant Voids	$(S)r_i = 0.075$ $P(I) = 10^{-3}$ No Allowable Propellant Voids
3	0.70	1.09	0.50	0.58	0.42
13	3.00	6.99	3.20	3.75	2.60

*Station location identified in Figure 30.

From the foregoing comparisons and tradeoffs, the most controlling parameter in relating the insulation system requirement to its capability is the standard deviation of material erosion rate from the nominal, $(S)r_i$, and the failure probability, P(I). The allowable propellant void size parameter has a much smaller effect.

As shown in a previous table, the material erosion rate standard deviation, $S/\bar{X}$, was assumed to be 15.1%, which is the standard deviation value for V-44 rubber observed in numerous Polaris A3 and Minuteman motor tests. The newer IBX materials have not been tested in sufficient quantity to establish a realistic performance standard deviation value. Therefore, the R||C Analysis assumed that the standard deviation value for IBX materials would be equivalent to that of V-44. It is apparent that if the IBX material performance standard deviation value could be reduced to 0.075, which is in the range of that observed for V-45, the overall 260-FL motor insulation system weight could be significantly reduced, while still maintaining an allowable failure probability of 10^{-6}.

D. FINAL 260-IN.-DIA MOTOR INSULATION SYSTEM DESIGN

The final 260-FL motor insulation system design selected as a result of the LMISD Program effort is shown in Figure 33. The following table summarizes the insulation system weight characteristics:

Forward Dome:	
Material	IBT-100
Wt, lb	7410
Installation process	Trowelable
Sidewall:	
Material	IBT-106
Wt, lb	16,630
Installation process	Trowelable

III.D. Final 260-in.-dia Motor Insulation System Design (cont)

Aft Dome:	
Material	IBT-100
Wt, lb	11,005
Installation process	Trowelable
Nozzle:	
Material	IBT-100
Wt, lb	5,065
Installation process	Trowelable
Propellant boots:	
Material	IBT-106
Wt, lb	4,535
Installation process	Trowelable
Total Insulation System Wt, lb	44,645
Probability of Insulation Burnthrough, P(I)	10^{-6}
Material Performance Standard Deviation, $S/\overline{X}$, %	15.1
Allowable Propellant Void dia., in.	8

The estimated 260-FL motor IBT-100/IBT-106 insulation system production cost, detailed in Figure 34, is $141,684; the estimated initial tooling cost is $75,900. A comparable V-44/V-45 insulation system would weigh 42,993 lb, and the production cost per motor would be $343,864, assuming a base cost value of $8.00/lb installed.

IV. PHASE II: PROCESS PLAN

The general sequence of operations envisioned for installation of the IBT-100/IBT-106 insulation system into a 260-in.-dia full-length motor are as follows:

- Move 260-in.-dia motor case into insulation processing facility and mount on motor-driven turning rolls.
- Install lighting and equipment truss.
- Install environmental control equipment.
- Vacuum gritblast, clean, and prime case interior with Fuller 162-Y-22.
- Process and install forward and aft dome insulation.
- Cure dome insulation at ambient for 24 hr, then at 135°F for 48 hr.
- Install sidewall insulation.
- Cure sidewall insulation at ambient for 24 hr.
- During 24-hr ambient cure, install aft casting adapter.
- Cure dome insulation at 135°F for 48 hr.
- Apply DC-Q-92 release to forward and aft dome insulation surface.
- Install forward and aft propellant boots.
- Cure propellant boots at ambient for 24 hr, then at 135°F for 48 hr.
- Install precured aft boot extension.
- Complete NDT inspection.
- Complete all repairs if required.
- Remove environmental control equipment and lighting and equipment truss.
- Install mobile environmental control equipment.
- Move case to CCT facility for propellant loading.

The foregoing operations will require approximately 20 working days, assuming three-shift operation. The environmental control system must be capable of providing an interior temperature of 135 ± 5°F, and a relative humidity level of 30 percent, maximum. The motor-driven turning rolls must be capable of a minimum constant chamber speed of 2 revolutions per hour (rph).

For this process plan, processing of insulation materials is accomplished in G.H. Day Company 300-gal propellant mixers at the A-DD vertical batch mixing stations. However, for a 260-FL motor production program, in-line mixing equipment at the insulation processing facility may be desirable. After mixing a pressure diaphragm is installed in the mix bowl, and insulation materials is pressure-fed through the mix bowl bottom-draw off into 100-gal capacity mobile transport pots. The vertical batch mix bowl is shown in Figure 35. The mobile transport pot is similar to that shown in Figure 36. The transport pots then are moved to the insulation facility. The following table summarizes the insulation material batches required for insulating a 260-FL motor:

Section	Wt of Material Installed, lb	No. of Batches	Wt per Batch, lb	Total Wt of Material Mixed, lb
Forward Dome	7,410	6	4,500	27,000
Aft Dome	11,005			
Nozzle	5,060			
Sidewall	16,630	4-1/4	4,500	19,125
Propellant Boot	4,535	1-1/4	4,500	5,625
				51,750 lb

The following paragraphs describe the various operations required to insulate the 260-FL motor. A processing flow sheet showing the required processing operations is presented in Figure 37.

A. CHAMBER PREPARATION

The 260-FL chamber is mounted on turning rolls in the enclosed insulation facility. A truss beam, similar to that shown in Figure 38, will be installed. Lighting, hoisting and environmental control equipment will be attached to the truss. Vacuum blasting equipment will be moved into the chamber and the interior surface will be blasted with No. 80-grit sand. After removal of residual sand, the interior will be cleaned by multiple solvent washings, followed by application of Fuller 162-Y-22 primer.

IV. Phase II: Process Plan (cont)

B. FORWARD/AFT DOME INSULATION

A forward dome sweep template, similar to the concept shown in Figure 39, will be installed. IBT-100 will be dispensed through a 3-in.-dia flexible hose in front of the trowel, using overlapping passes, as demonstrated in Task II.

The aft dome sweep template will be installed as shown in Figure 40, and IBT-100 material will be dispensed and troweled in the same manner as that described for the forward dome. When aft dome material is installed, the aft sweep template tooling will be removed so that sidewall tooling can be installed following the dome insulation cure cycle.

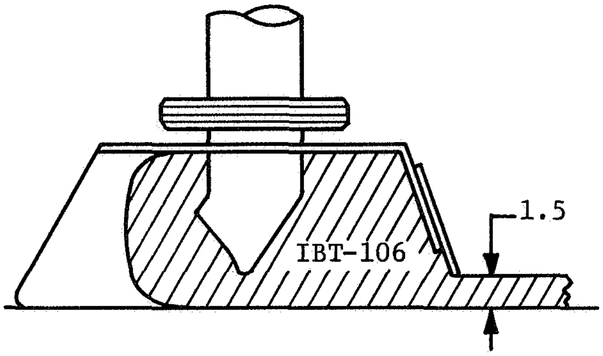
During the 24-hr ambient cure time, preliminary microwave and ultrasonic NDT inspection will be accomplished. If major repairs are required, they will be accomplished at this time. Following these operations, the 48 hr, 135°F cure cycle will be started.

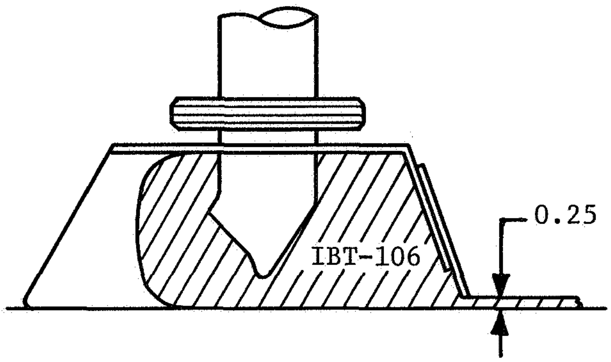
C. SIDEWALL INSULATION

After cooldown from the dome insulation cure cycle, sidewall insulation equipment will be moved into the chamber. This equipment will include a mobile trowel and a transport pot, as shown in Figure 41. During this time, the profiles of the forward and aft dome insulation will be recorded.

An IBT-106 loaded transport pot will be hoisted and installed on the mobile transfer pot base. A 3-in.-dia quick-opening valve will be installed on the bottom draw-off of the transfer pot. A 3-in.-dia by 8-ft-long flexible tube will be connected to the valve and to the mobile trowel. A compressed air hose will be connected and the transport pot will be pressurized to 60 psig. The valve will be opened, and, when the trowel annulus fills with material, the case turning rolls will be started. Material will be applied to the case sidewall in a continuous spiral pattern, as demonstrated previously in Task II of Contract NAS3-11224. The stepped portions of the sidewall, forward tangent to 150-in. aft and aft tangent to 274 in. forward, will be obtained by adjusting the width of the trowel material exit slot, as shown in the following sketch:

IV.C. Sidewall Insulation (cont)





When the first transport pot is empty, another full pot will be installed as previously described. This operation will be continued until sidewall insulation is applied in an area starting 12-in. aft of the forward tangent and continuing to a point 12-in. forward of the aft tangent. The 12-in. wide areas at each tangent will not be insulated at this time so that the caster on the dome and propellant sweep templates will be in contact with the case wall during propellant boot installation. All sidewall installation tooling will be removed from the chamber, and the 24 hr ambient cure cycle will begin, followed by 48 hr at 135°F.

D. PROPELLANT BOOT INSTALLATION

The forward and aft dome sweep templates will be adjusted to produce the required 0.65-in. boot thickness. DC-Q-92 silicone materials will be applied to the forward and aft dome insulation surfaces which require release. An IBT-106 forward propellant boot will be troweled over the released insulation surface using the method demonstrated in Task II of Contract NAS3-11224. The 12-in. wide area between the tangent and the cured sidewall will be filled after the dome portion of the propellant boot is installed. The same procedure will be followed to install the aft propellant boot. A wooden ramp will be placed over the uncured aft boot to provide egress of tooling and personnel. The boots will be cured for 24 hr at ambient, followed by 48 hr at 135°F.

E. FINAL OPERATIONS

The forward and aft sweep templates will be removed following dimensional inspection of the cured propellant boots. Final dimensional, microwave, and ultrasonic inspections will be completed. Any necessary repairs will be accomplished.

IV.E. Final Operations (cont)

During the previous three 24 hr ambient cure cycles following application of dome, sidewall, and boot material, the casting adapter and related components will be installed. After final inspection of the case insulation, the precured aft propellant boot extension will be bonded to the aft boot and then assembled to the casting adapter. The aft boot extension design or material selection has not been determined. However, the most cost-effective approach appears to be a heavy-gage polyethylene or fiberglass sheet, bonded to the aft boot and then attached to the casting adapter. The boot extension is intended to prevent propellant from flowing between the aft dome insulation and propellant boot during propellant over-casting operations. For this purpose, the bonded polyethylene sheet approach will be adequate and relatively easy to install.

A vacuum collar will be installed around the edge of the forward boot as a retainer during chamber movement. The forward boss and aft joint will be sealed, the interior of the case will be purged with an inert nitrogen gas environment, and the case will be moved to the casting facility.

V. RECOMMENDED FOLLOW-ON EFFORT

A. PROPELLANT-TO-INSULATION BONDLINE TENSILE/SHEAR TESTS

The bondline tensile and shear tests reported in Volume I of this final report indicated that a degradation occurred in the propellant-to-insulation bond after the insulation was aged at 180°F for several weeks. Evolution of volatile materials in the PBAN-epoxy insulation during high temperature exposure was the apparent cause of the bond degradation. Solvent wiping of the insulation surface or liner application restored the bond integrity. However, extended exposure of the motor insulation to temperatures higher than the 135 ± 5°F preheat and propellant cure temperature is not expected. Thus, the 180°F drying temperature environment used during the moisture absorption tests was not indicative of the expected environment. To allay any doubt as to the propellant-to-liner bond integrity, a series of double-plate, composite tensile/shear specimen tests are recommended. The composite specimens would consist of 4130 steel plate, Fuller 162-Y-22 primer, IBT-100 and IBT-106 insulation, and ANB-3350 propellant. The recommended test plan is as follows:

Amount of Specimens	Description
9	As-processed insulation (control)
9	1-month exposure to 80°F, 50% RH
9	1-month exposure to 135 ± 5°F
9	1-month exposure to 160 ± 5°F
9	2-month exposure to 80°F, 50% RH, followed by 1-month exposure to 135 ± 5°F

V.A. Propellant-to-Insulation Bondline Tensile/Shear Tests (cont)

The foregoing test series could be accomplished in conjunction with one or both of the other recommended follow-on efforts.

B. MATERIAL PERFORMANCE EVALUATION IN INTERMEDIATE SIZE MOTORS

Relative performance of the candidate insulation materials was measured in subscale solid-propellant motor tests. The most difficult part of the Tasks I and III motor tests was analysis of the insulation erosion data at the higher Mach number regions in a motor with a small nozzle size. Gas velocities from Mach 0.1 to 0.3 occurred in a relatively small region close to the motor throat. The concern was that the region between Mach 0.1 and sonic flow was so narrow that erosion at the higher Mach number regions would influence and distort erosion upstream at the lower Mach number regions. V-44 rubber specimens were included in each of the motor tests as a control to ensure that usable erosion data were obtained from the motor tests.

The erosion occurring in candidate insulation materials were compared with V-44 rubber performance, and comparative information was obtained. To design the 260-FL motor insulation system, the expected performance of IBT-100 and IBT-106 in large motor applications were estimated by applying the following relationship:

$$\begin{array}{l}\text{IBT-100/106 Performance}\\ \text{Expected in LSRM}\end{array} = \begin{array}{l}\text{IBT-100/106 Performance}\\ \text{in LMISD Motor}\end{array} \times \frac{\text{V-44 in LSRM}}{\text{V-44 in LMISD Motor}}$$

Although this method of determining expected material performance in large motors is empirical, it is not anticipated that a significant error is introduced. However, a logical follow-on effort to the current program is to demonstrate the installation process and performance of the selected insulation system in an intermediate-size motor, preferably in conjunction with an existing or planned program that includes one or more intermediate size motor test firings. The motor chambers would be insulated using the materials, processes, and tooling concepts planned for the 260-FL motor Material performance data up to approximately a gas flow Mach number region of 0.25 would be obtained.

C. DETERMINE MATERIAL PERFORMANCE STANDARD DEVIATION VALUE

Results of the Requirements/Capability Analysis approach to insulation system design led to a significant increase in the inert stage weight over the TLR, exposure time, safety factor product method of calculation. Insulation system weights were from 1.8 to 2.1 times greater. The two parameters which most affected the required insulation thicknesses were:

— $s/\bar{X}$, the material erosion rate standard deviation, and

— P(I), the allowable probability of insulation burnthrough.

V.C. Determine Material Performance Standard Deviation Value (cont)

Other parameters, such as allowable propellant defect size, propellant web thickness and burning rate variability, insulation thickness tolerance, and core misalignment, had a much lesser effect. The allowable failure probability, P(I), is a function of the mission reliability requirement, and is not related to any specific insulation system. The insulation performance deviation, $(s)r_i$, is related directly to material characteristics, and therefore can be measured and controlled. For the R||C Analysis, the material erosion rate standard deviation was assumed to be 15.1%, which is the standard deviation value for V-44 rubber observed in numerous Polaris A3 and Minuteman motor tests. The newer IBX materials have not been tested in sufficient quantity to establish a realistic performance standard deviation value. Therefore, the R||C Analysis assumed that the standard deviation value for IBX materials would be equivalent to that of V-44. It is apparent that if the actual IBX material performance standard deviation value were in the order of 0.075, which is in the range of that observed for V-45, the overall 260-FL motor insulation system weight could be significantly reduced, while still maintaining an allowable failure probability of 10^{-6}.

The recommended follow-on effort would be to establish an IBT-100 and IBT-106 material performance standard deviation. IBT-100 and IBT-106 would be tested in the existing LMISD motor.

The performance reproducibility of the LMISD motors was satisfactory, and accurate recordings of pre- and posttest insulation specimen profiles were possible. The program would be accomplished in two phases:

Phase I - Determine IBT-100/IBT-106/V-44 control motor-to-motor performance variability using material from one motor lot of PBAN and asbestos.

Phase II - Determine IBT-100/IBT-106/V-44 control performance variability using a second master PBAN and asbestos material lot.

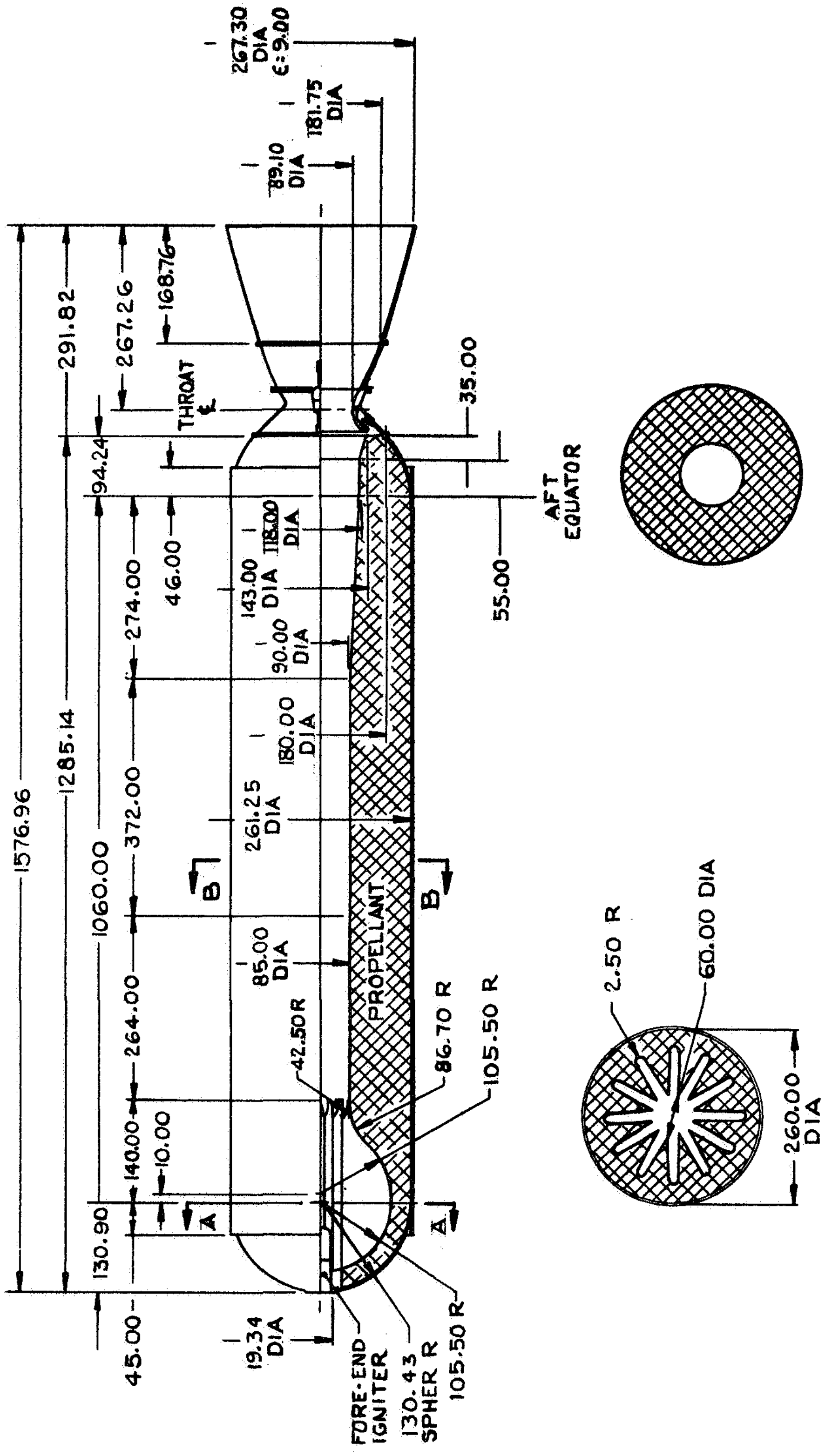
V.C. Determine Material Performance Standard Deviation Value (cont)

The test matrix for the Phase I performance variability determination would be as follows:

	High Moisture Content		Low Moisture Content	
	PBAN Content, low % Variability	PBAN Content, high % Variability	PBAN Content, low % Variability	PBAN Content, high % Variability
Asbestos Content, low % Variability	4 tests	4 tests	4 tests	4 tests
Asbestos Content, high % Variability	4 tests	4 tests	4 tests	4 tests

In Phase II, four tests would be conducted with a new lot of PBAN, and results would be compared with standard deviation for a single lot with content variability that produced the lowest deviation in previous tests. Four additional tests would be conducted with a new lot of PBAN and asbestos, and results would be compared with single lot deviation.

A total of 40 LMISD motor tests would be required to obtain a meaningful material performance standard deviation. IBT-100, IBT-106, and V-44 material would be processed into the test closure in the same way as that for the Tasks I and III LMISD motor tests. The results of this program would yield a $S/\overline{X}$ value for each material. In addition, the factors which produce the material performance variation would be isolated.



260-in.-dia Full Length Motor Configuration, Saturn IB Improvement Study

Figure 1

	12 Point Fin & Shell
Total impulse (vacuum), lbf-sec	908,140,000
Vacuum specific impulse, lbf-sec/lbm	267.0
Standard* specific impulse, lbf-sec/lbm	244.6
Propellant weight, lbm	3,400,000
Web action time, sec	139.3
Action time, sec	147.5
Maximum nominal pressure @ 80°F, psia	700
Average pressure (web action time), psia	594
MEOP, psia	764
Maximum nominal thrust @ 80°F, lbf	7,510,000
Average thrust (web action time), lbf	6,340,000
Web thickness, in	84.8
Propellant burning rate @ 600 psia, 80°F, in/sec	0.606
Burning rate pressure exponent	0.42
Nozzle throat area, initial/final, in^2	6235/6475
Nozzle throat diameter, initial/final, in^2	89.10/90.80
Nozzle half-angle, degrees	17.5
Expansion ratio, initial	11.0
Port/throat area ratio, average	1.3

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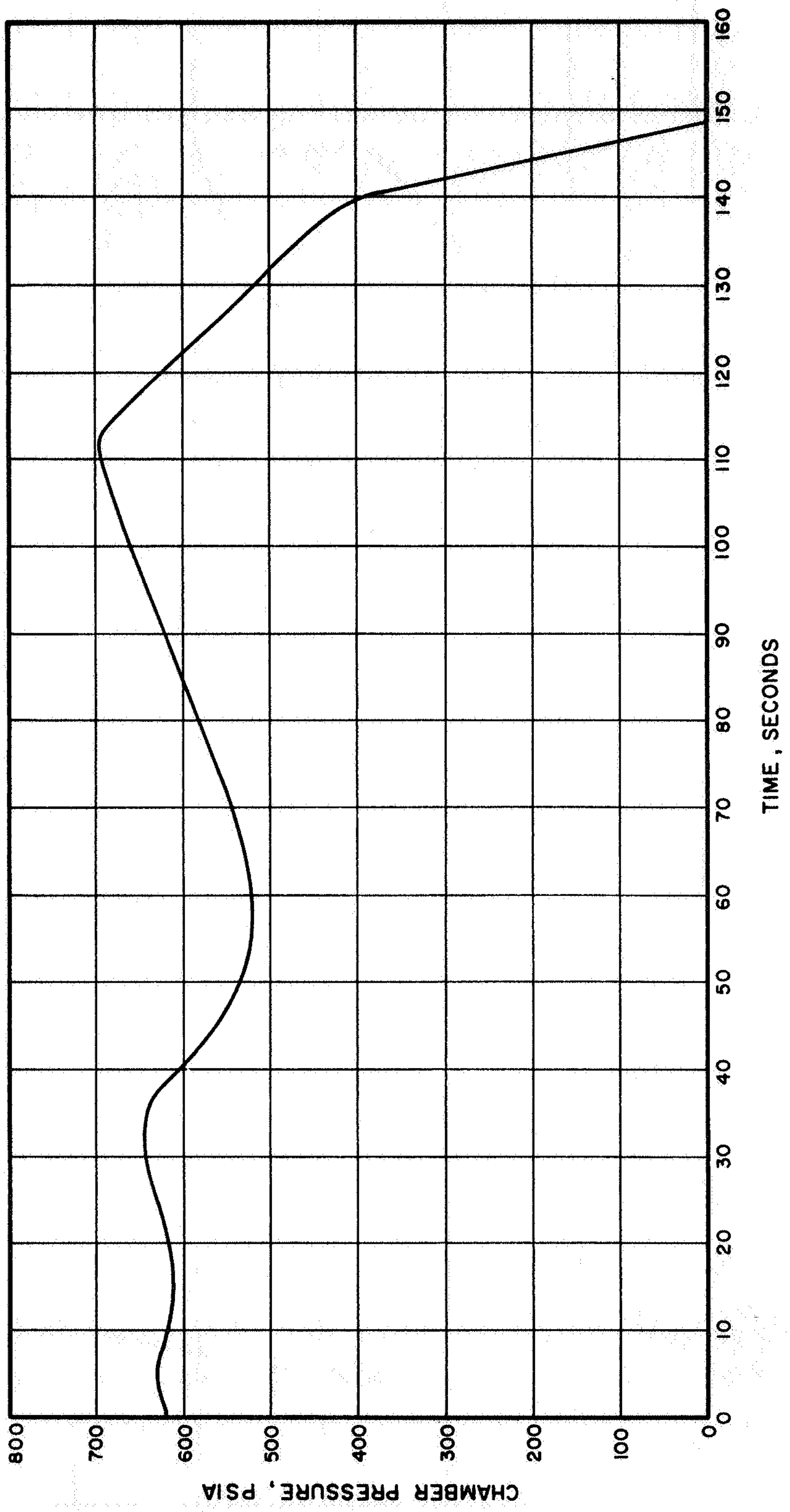
* 1000 psia chamber pressure, optimum expansion at sea level, 15° nozzle half-angle

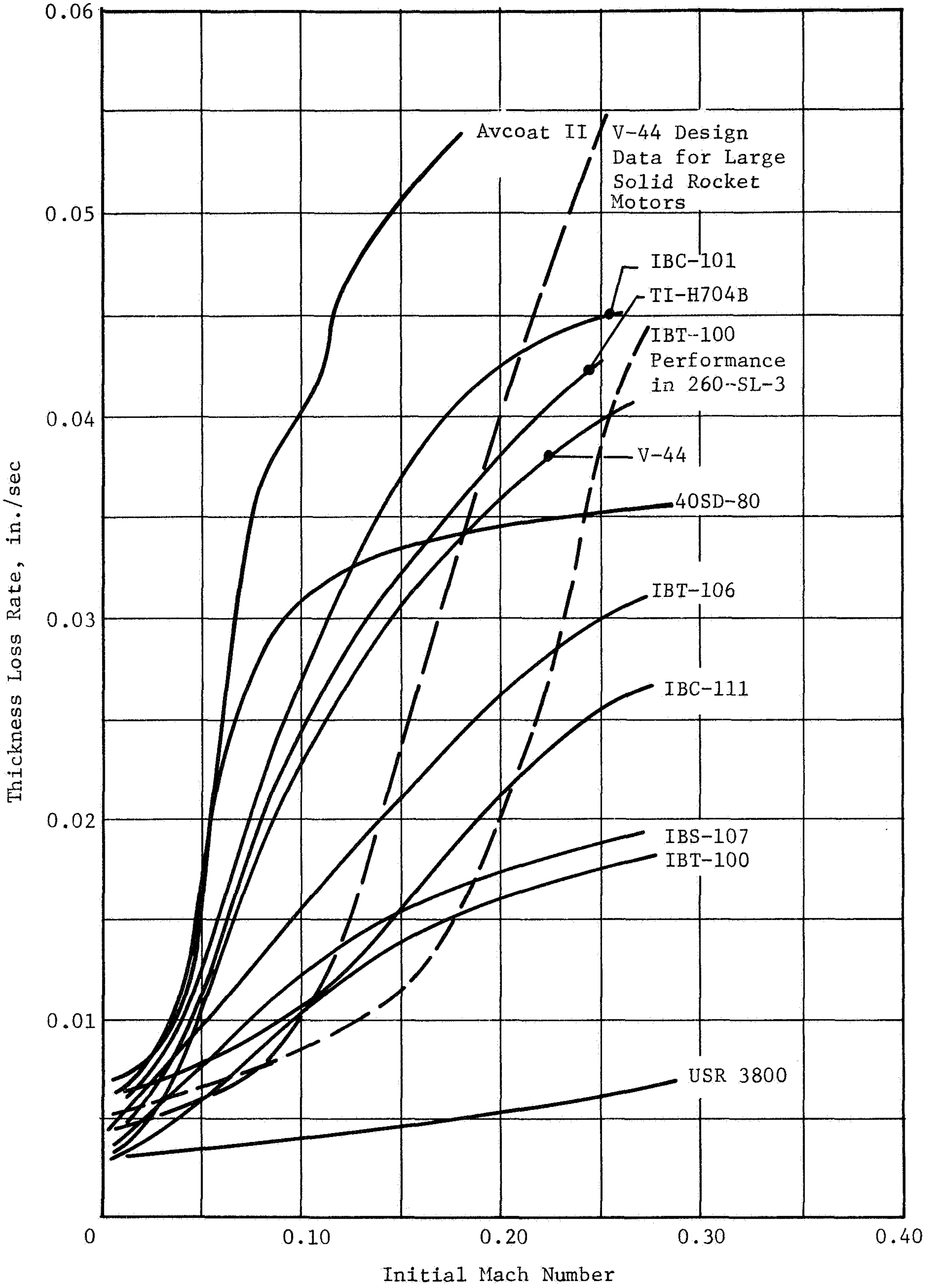
Performance Summary, 260-in.-dia Motor for Saturn IB Improvement Study

Figure 2



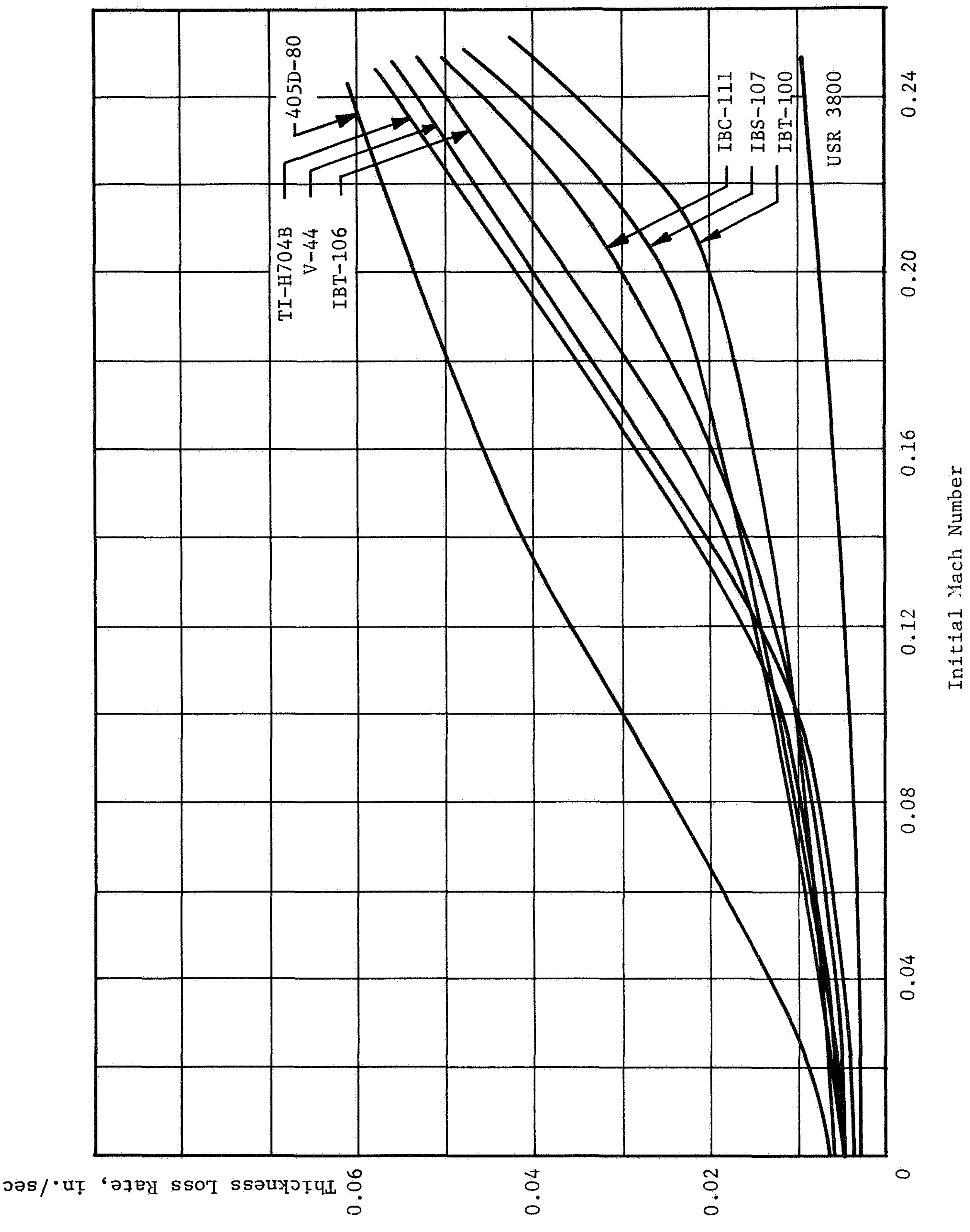
Predicted Performance Curve
260-In.-Dia Motor for Saturn IB Improvement Study

Figure 3



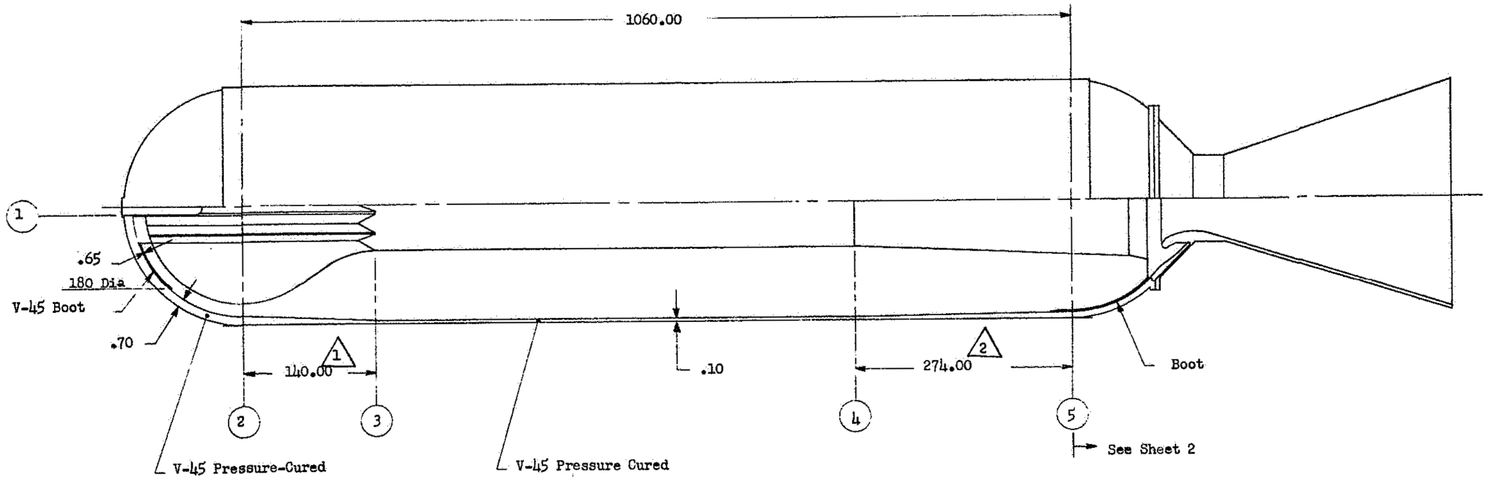
Summary of Nominal TLR-vs-Initial Mach Number Data
Obtained from LMISD Test Motors

Figure 4



Weight Loss if Virgin IBS-107 as a Function of Temperature

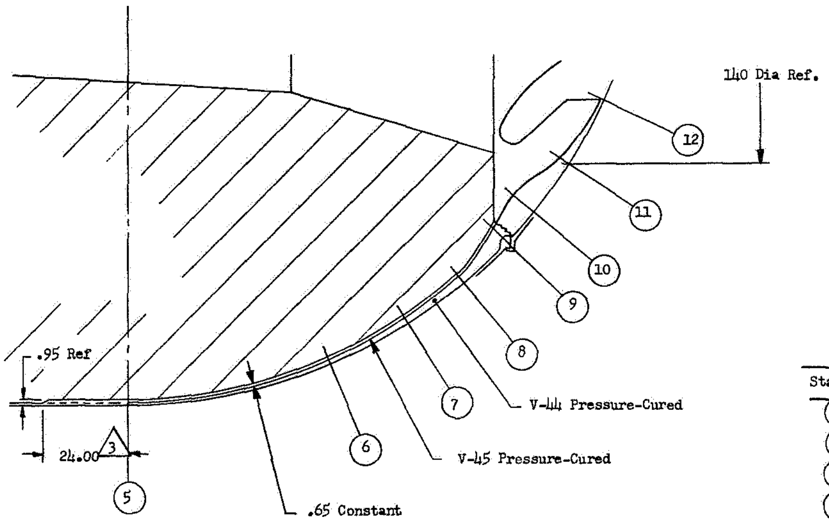
Figure 5



1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length
2 Insulation tapers from 0.10 to 0.40 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor
Chamber and Nozzle, V-44, V-45

Figure 6, Sheet 1 of 2

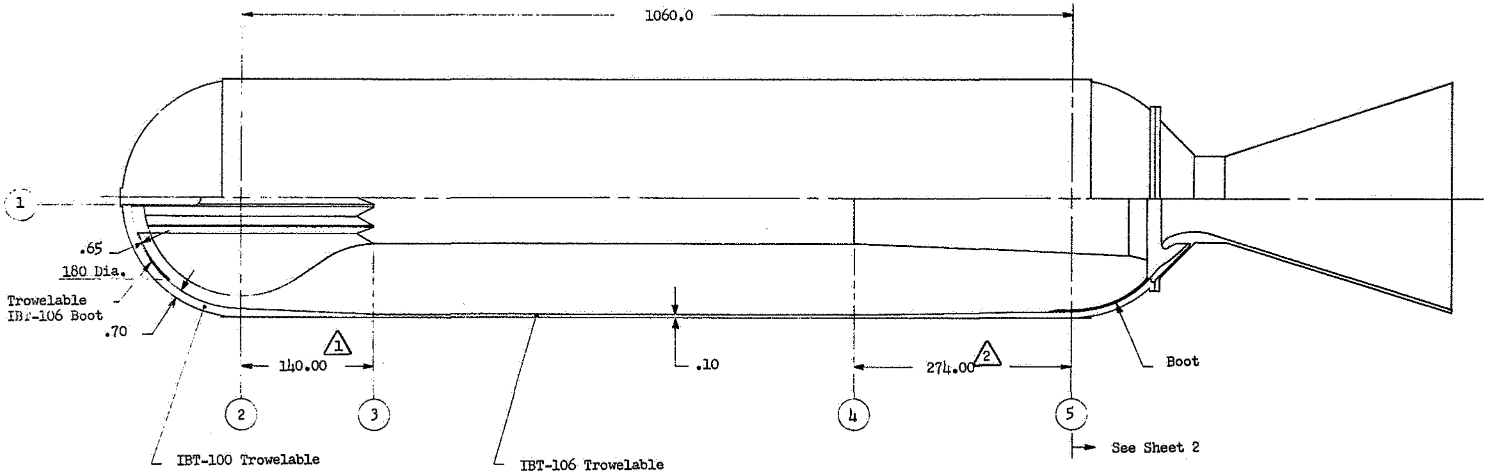


3 V-45 Boot bonded to V-45 Sidewall insulation. Boot is released aft of Station 5.

Station	Dia., Ref.	Thickness, in. ± .025
⑤	260.00	.40
⑥	240.00	.75
⑦	220.00	1.10
⑧	200.00	2.00
⑨	180.00	4.20
⑩	165.00	6.30
⑪	140.00	1.10
⑫	110.00	1.10

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, V-44, V-45

Figure 6, Sheet 2 of 2

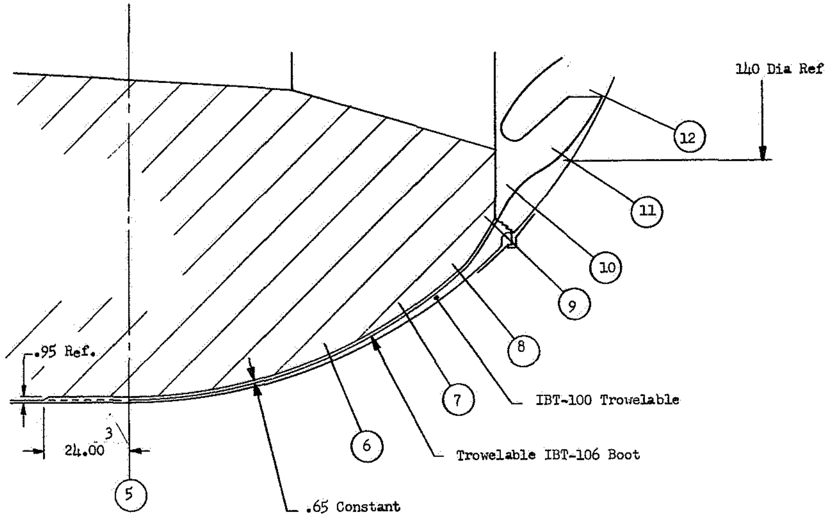


△1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length.

△2 Insulation tapers from 0.10 to 0.25 over the 274-in.-length.

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-100/IBT-106

Figure 7, Sheet 1 of 2

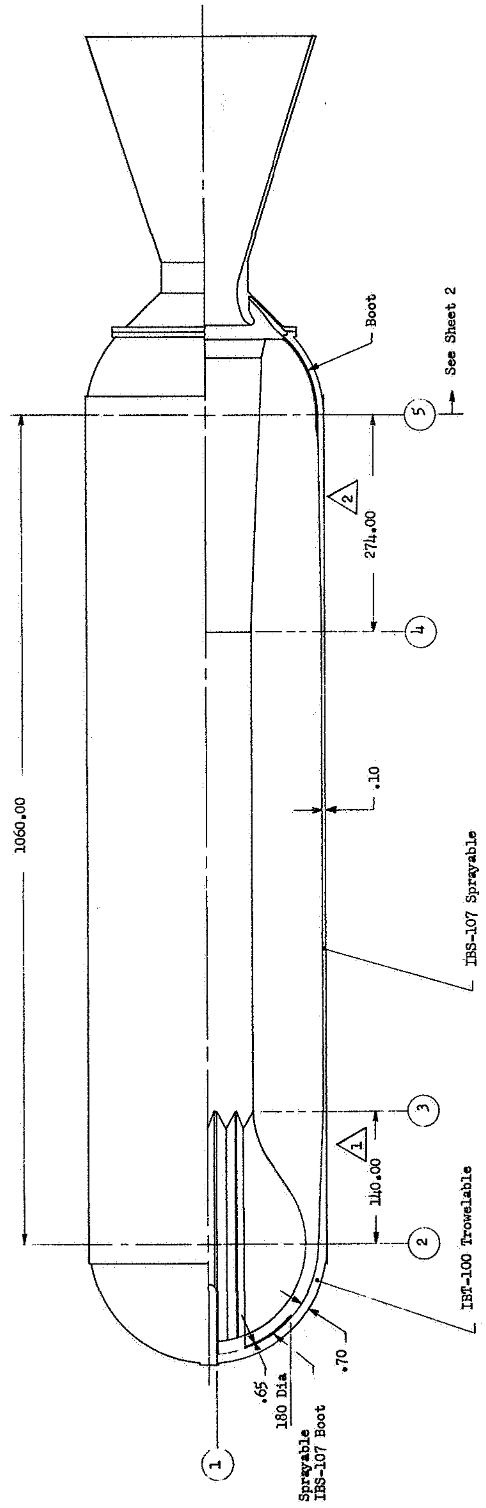


3 IBT-106 Troweled over IBT-106 Sidewall and IBT-100 Dome Insulation to form propellant boot. Nylon separator or DC-Q92 used to effect release aft of Station 5.

Station	Dia, Ref.	Thickness, in. ± .025
⑤	260.00	0.40
⑥	240.00	0.90
⑦	220.00	1.30
⑧	200.00	1.85
⑨	180.00	3.00
⑩	165.00	3.40
⑪	140.00	1.10
⑫	110.00	1.10

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-100/IBT-106

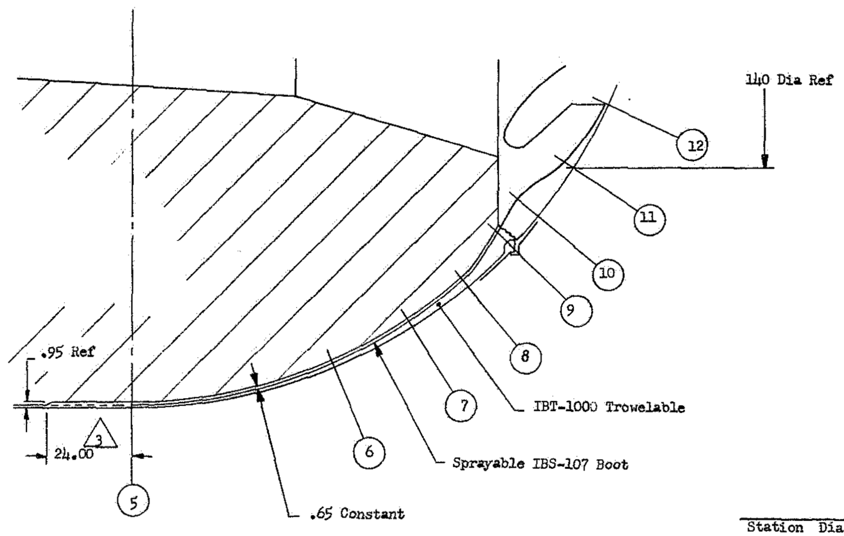
Figure 7, Sheet 2 of 2



1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length
2 Insulation tapers from 0.10 to 0.40 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor
Chamber and Nozzle, IBT-100/IBS-107

Figure 8, Sheet 1 of 2

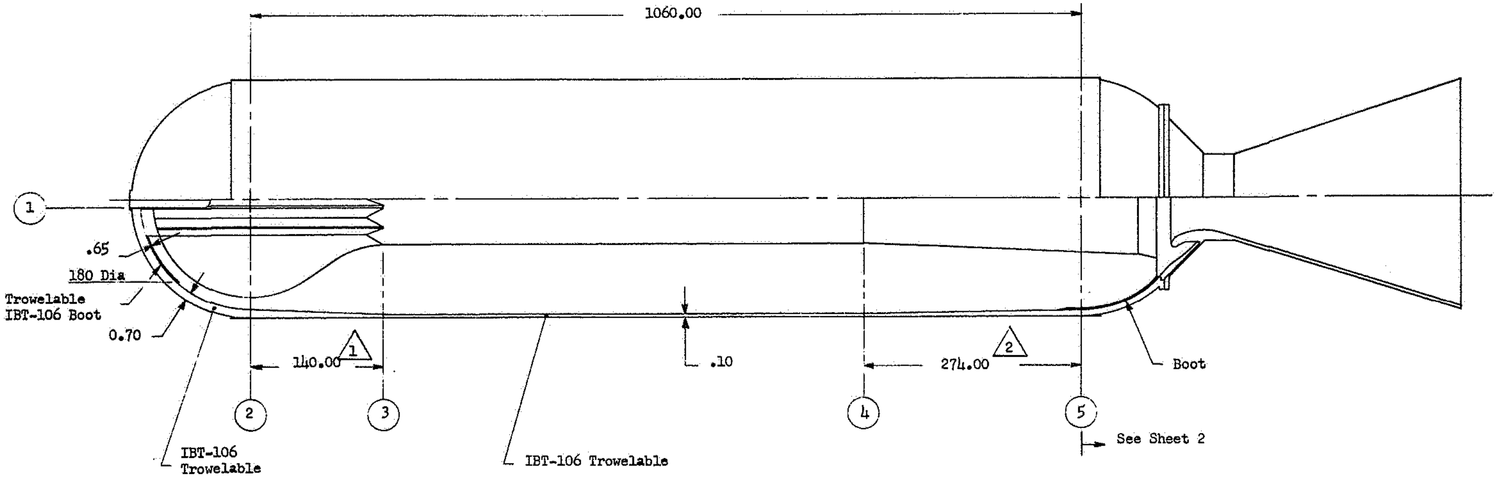


△3 IBS-107 sprayed over IBS-107 Sidewall and IBT-100 Dome Insulation to form propellant boot. Nylon separator or DC-Q92 used to effect release aft of station 5.

Station	Dia. Ref	Thickness, in ± .025
⑤	260.00	0.40
⑥	240.00	0.90
⑦	220.00	1.30
⑧	200.00	1.85
⑨	180.00	3.00
⑩	165.00	3.40
⑪	140.00	1.10
⑫	110.00	1.10

Figure 8, Sheet 2 of 2

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-100/IBS-107

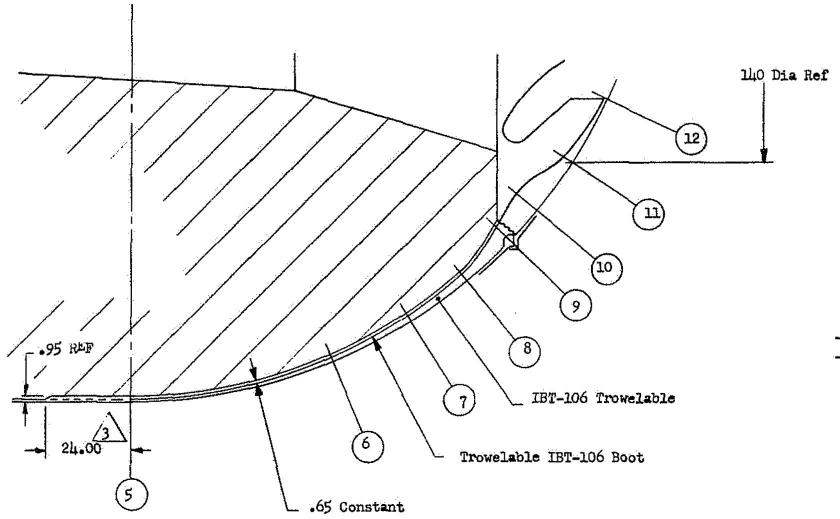


1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length

2 Insulation tapers from 0.10 to 0.40 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-106

Figure 9, Sheet 1 of 2

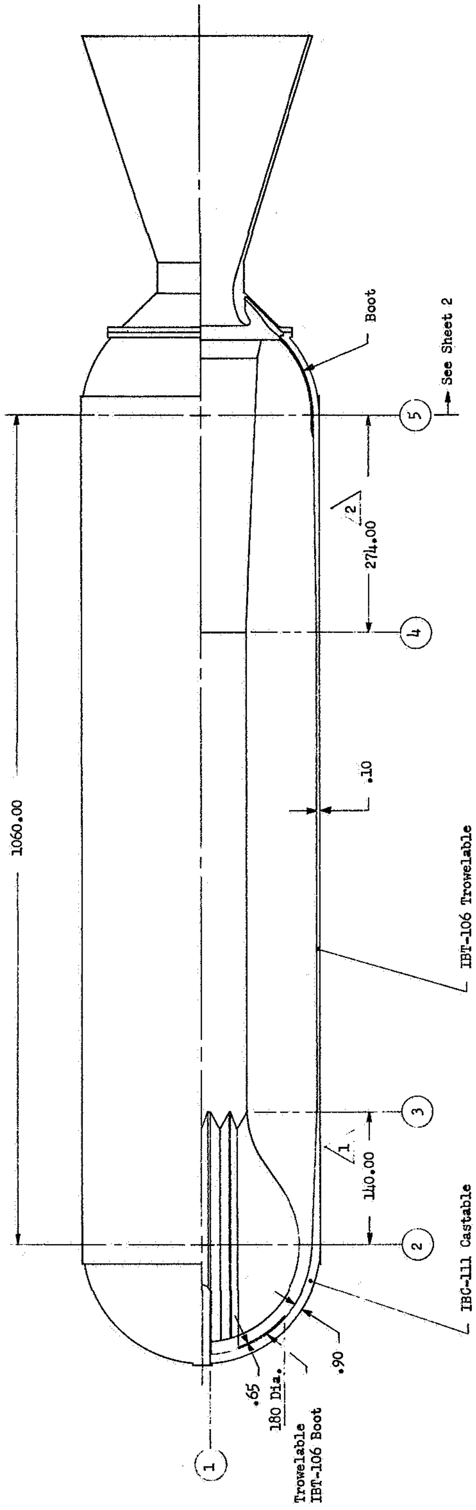


△3 IBT-106 troweled over IBT-106 sidewall and dome insulation to form propellant boot. Nylon separator or DC-492 used to effect release aft of Station 5

Station	Dia, Ref.	Thickness, in. ± .025
⑤	260.00	0.40
⑥	240.00	1.10
⑦	220.00	1.55
⑧	200.00	2.30
⑨	180.00	3.80
⑩	165.00	5.54
⑪	140.00	1.10
⑫	110.00	1.10

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-106

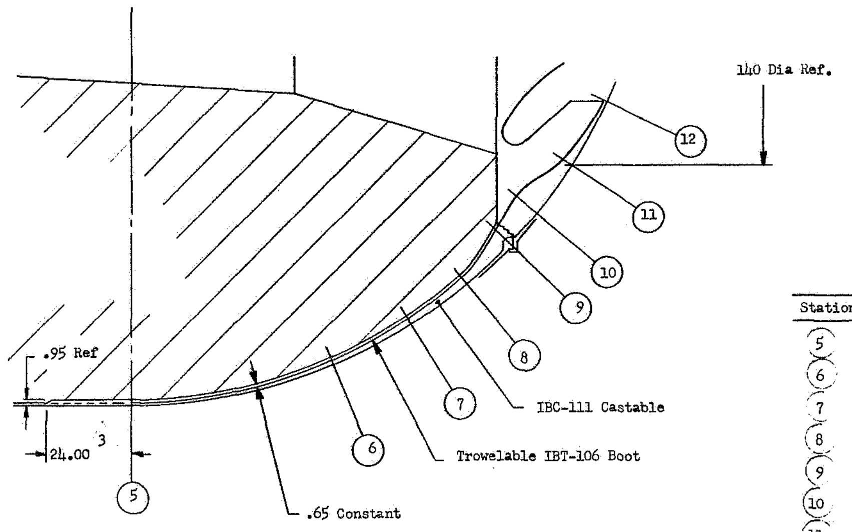
Figure 9, Sheet 2 of 2



1 Insulation tapers from 0.90 to 0.10 over the 140-in.-length
2 Insulation tapers from 0.10 to 0.45 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBC-111/IBT-106

Figure 10, Sheet 1 of 2

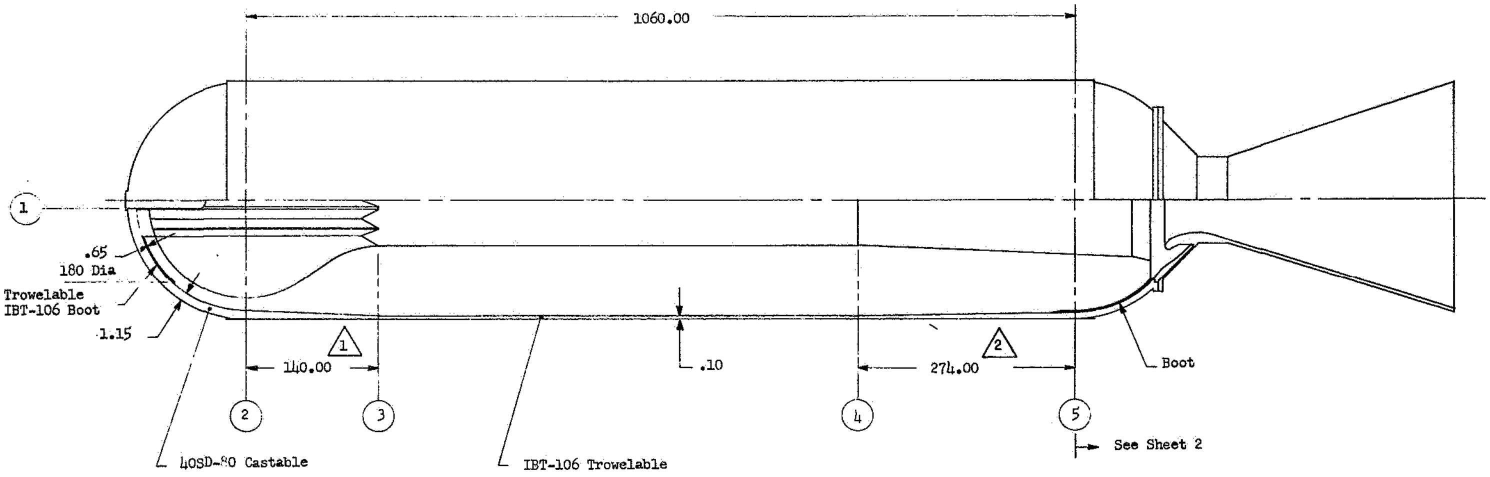


Station	Dia, Ref.	Thickness, in. ± .025
⑤	260.00	0.45
⑥	240.00	0.90
⑦	220.00	1.30
⑧	200.00	2.00
⑨	180.00	3.40
⑩	165.00	4.65
⑪	140.00	1.35
⑫	110.00	1.35

△3 IBT-106 troweled over IBT-106 sidewall and IBC-111 dome insulation to form propellant boot. Nylon separator or DC-Q92 used to effect release aft of Station 5

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBC-111/IBT-106

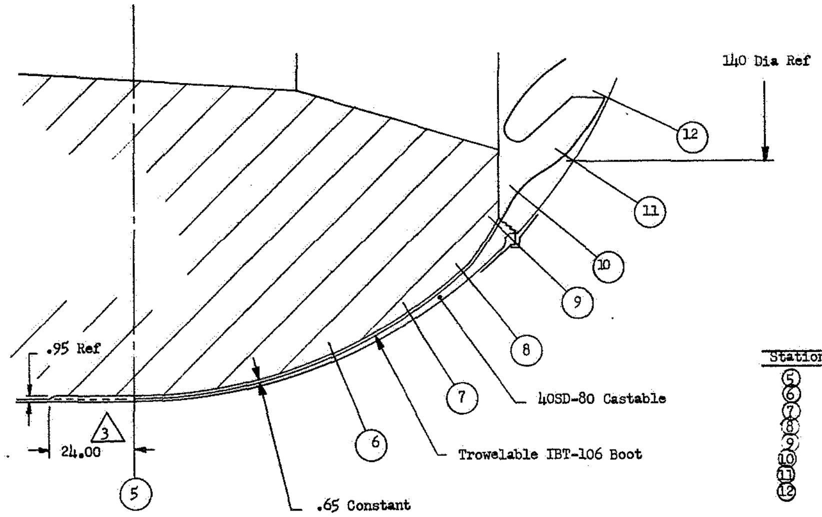
Figure 10, Sheet 2 of 2



△1 Insulation tapers from 1.15 to 0.10 over the 140-in.-length
△2 Insulation tapers from 0.10 to 0.55 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, 40SD-80/IBT-106

Figure 11, Sheet 1 of 2

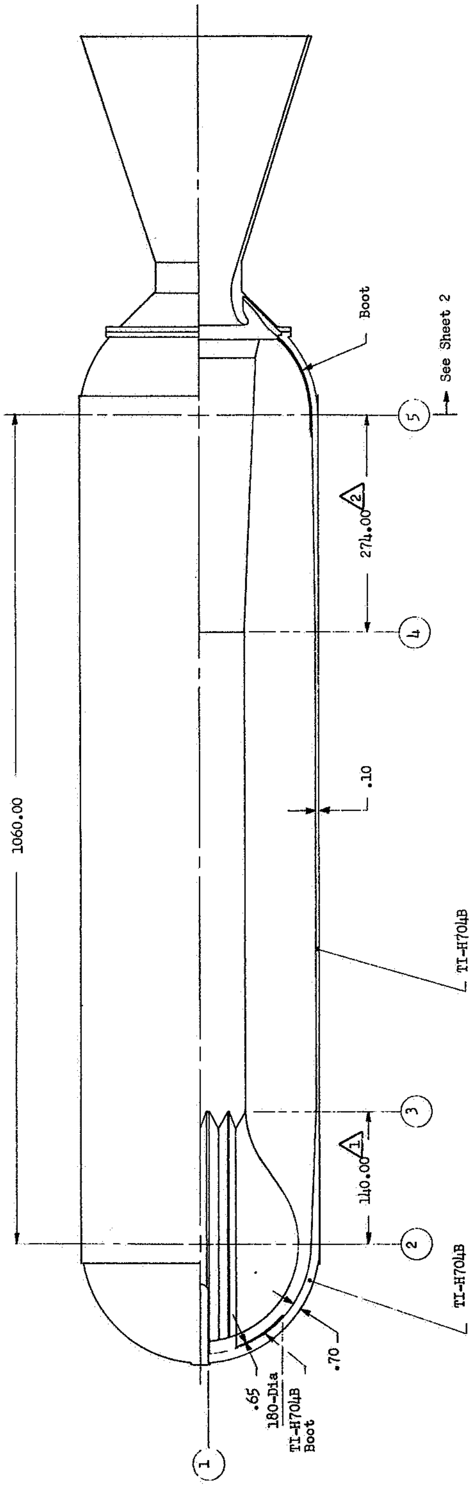


Station	Dia, Ref.	Thickness, in. + .025
⑤	260.00	0.55
⑥	240.00	2.30
⑦	220.00	3.35
⑧	200.00	5.35
⑨	180.00	8.60
⑩	165.00	10.05
⑪	140.00	1.55
⑫	110.00	1.55

△3 IBT-106 troweled over IBT-106 Sidewall and 40SD-80 dome insulation to form propellant boot. Nylon separator or DC-Q92 used to effect release aft of Station 5

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, 40SD-80/IBT-106

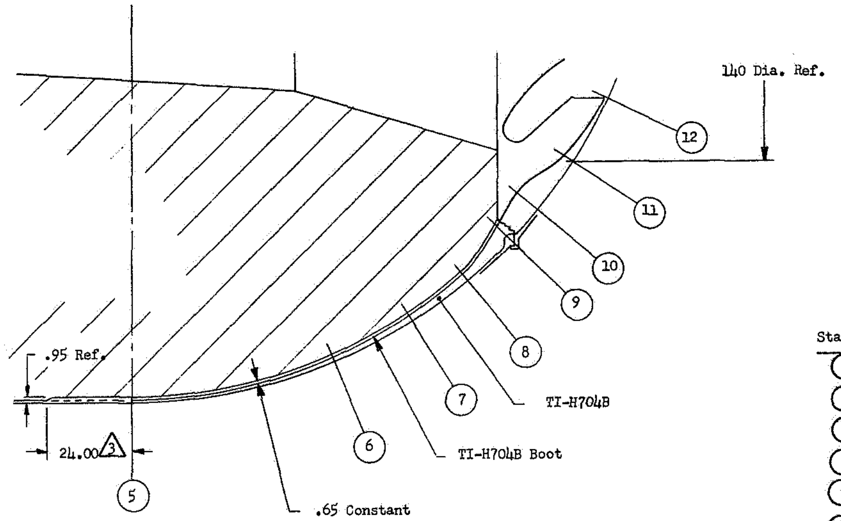
Figure 11, Sheet 2 of 2



△1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length
△2 Insulation tapers from 0.10 to 0.40 over the 274-in.-length

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, TI-H704B

Figure 12, Sheet 1 of 2

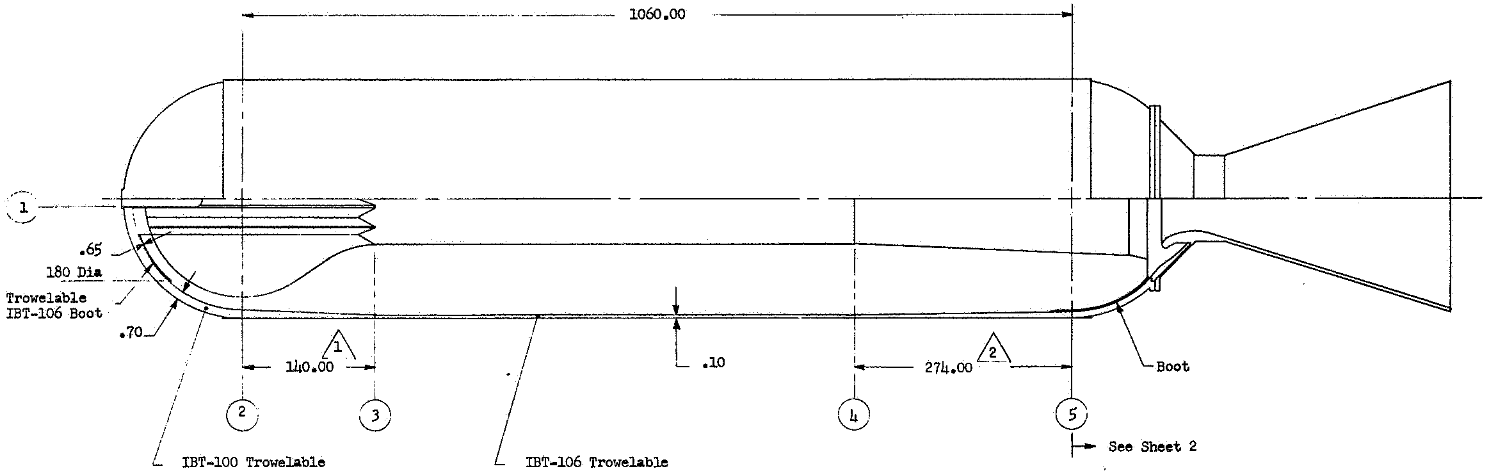


Station	Dia., Ref.	Thickness, in. ± .025
⑤	260.00	.40
⑥	240.00	1.00
⑦	220.00	1.40
⑧	200.00	2.30
⑨	180.00	4.65
⑩	165.00	6.70
⑪	140.00	1.10
⑫	110.00	1.10

△3 TI-H704B troweled over TI-H704B sidewall and dome insulation.
Boot is released aft of Station 5.

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, TI-H704B

Figure 12, Sheet 2 of 2

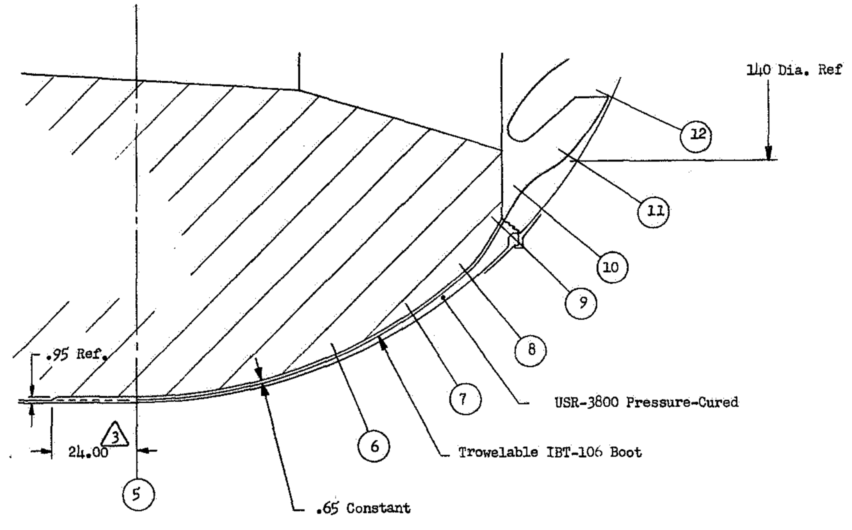


△1 Insulation tapers from 0.70 to 0.10 over the 140-in.-length

△2 Insulation tapers from 0.10 to 0.40 over the 274.00-in.-length.

Preliminary Insulation System Design for 260-FL Motor
Chamber and Nozzle, IBT-100/USR 3800/IBT-106

Figure 13, Sheet 1 of 2



Station	Dia. Ref.	Thickness, in ± .025
⑤	260.00	0.25
⑥	240.00	0.55
⑦	220.00	0.80
⑧	200.00	1.20
⑨	180.00	1.75
⑩	165.00	2.15
⑪	140.00	0.70
⑫	110.00	0.70

△3 IBT-106 troweled over IBT-106 sidewall and USR-3800 dome insulation to form propellant boot. Nylon or DC-Q92 used to effect release aft of Station 5.

Preliminary Insulation System Design for 260-FL Motor Chamber and Nozzle, IBT-100/USR 3800/IBT-106

Figure 13, Sheet 2 of 2

Station [1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure, sec [2]	Design TLR, in/sec [3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	V-45	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
③	140-in. aft of forward tangent	V-45	-	-	0/12	-/.003	.036	.054	.10
③ thru ④	Sidewall	V-45	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	V-45	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	V-44	-	-	40/12	.005/.003	.200 + .036 = .236	.354	.40
⑥	Aft dome 240-in.-dia	V-44	7.52	0.08	60/12	.0075/.003	.450 + .036 = .486	.729	.75
⑦	Aft dome 220-in.dia	V-44	6.34	0.09	80/12	.0085/.003	.680 + .036 = .716	1.074	1.10
⑧	Aft dome 200-in.-dia	V-44	5.23	0.11	106/12	.012/.003	1.272 + .036 = 1.308	1.962	2.00
⑨	Step joint 180-in.-dia	V-44	4.23	0.14	138/12	.020/.003	2.760 + .036 = 2.796	4.194	4.20
⑩	Nozzle 165-in.-dia	V-44	3.55	0.17	138/12	.030/.003	4.140 + .036 = 4.176	6.264	6.30
⑪	Nozzle 140-in.-dia	V-44		-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
⑫	Nozzle 110-in.-dia	V-44		-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
Propellant	Fwd & Aft	V-45	-	-	138	.003	.414	.62	.65

Insulation System: V-44 Pressure-cured aft dome, nozzle; V-45 Fwd Dome, sidewall, boots

---

[1] See Figure 6

[2] Exposure at full pressure/exponent during tail-off and after burn

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn.

V-44/V-45 Performance Analysis Summary

Figure 14

Station [1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure sec [2]	Design TLR, in/sec [3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward Dome	IBT-100	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
③	140-in.-aft of forward tangent	IBT-106	-	-	0/12	-/.003	.036	.054	-
③ thru ④	Sidewall	IBT-106	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	IBT-106	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	IBT-100	-	-	40/12	.005/.003	.200 + .036 = .236	.354	.40
⑥	Aft dome 240-in.-dia	IBT-100	7.52	0.08	60/12	.009/.003	.540 + .036 = .576	.864	.09
⑦	Aft dome 220-in.-dia	IBT-100	6.34	0.09	80/12	.010/.003	.800 + .036 = .836	1.254	1.30
⑧	Aft dome 200-in.-dia	IBT-100	5.23	0.11	106/12	.011/.003	1.166 + .036 = 1.202	1.803	1.85
⑨	Step joint 180-in.-dia	IBT-100	4.23	0.14	138/12	.014/.003	1.932 + .036 = 1.968	2.952	3.00
⑩	Nozzle 165-in.-dia	IBT-100	3.55	0.17	138/12	.016/.003	2.208 + .036 = 2.244	3.366	3.40
⑪	Nozzle 140-in.-dia	IBT-100	-	-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
⑫	Nozzle 110-in.-dia	IBT-100		-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
Propellant Boots	Fwd & Aft	IBT-106	-	-	138	.003	.414	.62	.65

Insulation System: IBT-100 Trowelable Dome and Nozzle; IBT-106 Trowelable Sidewall and Propellant Boots.

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[1] See Figure 7

[2] Exposure at full pressure/exposure during tail-off and after burn.

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn.

IBT-100/IBT-106 Performance Analysis Summary

Figure 15

Station[1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure sec[2]	Design TLR, in/sec[3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness + .025
① thru ②	Forward dome	IBT-100	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
③	140-in.-aft of fwd tangent	IBT-100	-	-	0/12	-/.003	.036	.054	-
③ thru ④	Sidewall	IBS-107	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	IBT-107	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	IBT-107	-	-	40/12	.005/.003	.200 + .036 = .236	.354	.40
⑥	Aft dome 240-in.-dia	IBT-100	7.52	0.08	60/12	.009/.003	.540 + .036 = .576	.864	.90
⑦	Aft dome 220-in.-dia	IBT-100	6.34	0.09	80/12	.010/.003	.800 + .036 = .836	1.254	1.30
⑧	Aft dome 220-in.-dia	IBT-100	5.23	0.11	106/12	.011/.003	1.166 + .036 = 1.202	1.803	1.85
⑨	Step joint 180-in.-dia	IBT-100	4.23	0.14	138/12	.014/.003	1.932 + .036 = 1.968	2.952	3.00
⑩	Nozzle 165-in.-dia	IBT-100	3.55	0.17	138/12	.016/.003	2.208 + .036 = 2.244	3.366	3.40
⑪	Nozzle 140-in.-dia	IBT-100	-	-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
⑫	Nozzle 110-in.-dia	IBT-100		-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
Propellant Boots	Fwd & Aft	IBS-107	-	-	138	.003	.414	.62	.65

Insulation System: IBT-100 Trowelable Dome and Nozzle
IBS-107 Sprayable Sidewall and Propellant Boots.

---

[1] See Figure 8

[2] Exposure at full pressure/exposure during tail-off and afterburn.

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn.

IBT-100/IBS-107 Performance Analysis Summary

Figure 16

Station[1]	Location/dia	Material	Area Ratio A/A*	Mach No.	Exposure sec[2]	Design TLR, in/sec[3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	IBT-106	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
③	140-in.-aft of forward tangent	IBT-106	-	-	0/12	-/.003	.036	.054	-
③ thru ④	Sidewall	IBT-106	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	IBT-106	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	IBT-106	-	-	40/12	.005/.003	.200 + .036 = .236	.354	.40
⑥	Aft dome 240-in.-dia	IBT-106	7.52	0.08	60/12	.011/.003	.660 + .036 = .696	1.044	1.10
⑦	Aft dome 220-in.-dia	IBT-106	6.34	0.09	80/12	.012/.003	.960 + .036 = .996	1.494	1.55
⑧	Aft dome 200-in.-dia	IBT-106	5.23	0.11	106/12	.014/.003	1.484 + .036 = 1.520	2.280	2.30
⑨	Step joint 180-in.-dia	IBT-106	4.23	0.14	138/12	.018/.003	2.484 + .036 = 2.520	3.780	3.80
⑩	Nozzle 165-in.-dia	IBT-106	3.55	0.17	138/12	.026/.003	3.588 + .036 = 3.624	5.436	5.50
⑪	Nozzle 140-in.-dia	IBT-106	-	-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
⑫	Nozzle 110-in.-dia	IBT-106		-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
Propellant Boots	Fwd & Aft	IBT-106	-	-	138	.003	.414	.62	.65

Insulation System: IBT-106 Trowelable Dome, Nozzle, Sidewall, and Propellant Boots

---

[1] See Figure 9

[2] Exposure at full pressure/exposure during tail-off after afterburn

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn

IBT-106 Performance Analysis Summary

Figure 17

Station [1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure sec [2]	Design TLR, in/sec [3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	IBC-111	-	-	138/12	.004/.004	.552 + .048 = .600	.90	.95
③	140-in.-aft of forward tangent	IBC-111	-	-	0/12	-/.004	.048	.072	-
③ thru ④	Sidewall	IBT-106	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	IBC-106	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	IBC-111	-	-	40/12	.006/.004	.240 + .048 = .288	.432	.45
⑥	Aft dome 240-in.-dia	IBC-111	7.52	0.08	60/12	.009/.004	.540 + .048 = .588	.882	.90
⑦	Aft dome 220-in.-dia	IBC-111	6.34	0.09	80/12	.010/.004	.800 + .048 = .848	1.272	1.30
⑧	Aft dome 200-in.-dia	IBC-111	5.23	0.11	106/12	.012/.004	1.272 + .048 = 1.320	1.980	2.00
⑨	Step joint 180-in.-dia	IBC-111	4.23	0.14	138/12	.016/.004	2.208 + .048 = 2.256	3.384	3.40
⑩	Nozzle 165-in.-dia	IBC-111	3.55	0.17	138.12	.022/.004	3.036 + .048 = 3.084	4.626	4.65
⑪	Nozzle 140-in.-dia	IBC-111		-	138/12	.006/.004	.828 + .048 = .876	1.314	1.35
⑫	Nozzle 110-in.-dia	IBC-111		-	138/12	.006/.004	.828 + .048 = .876	1.314	1.35
Propellant Boots	Fwd & Aft	IBT-106	-	-	138	.003	.404	.62	.65

Insulation System: IBC-111 Castable Dome and Nozzle; IBT-106 Trowelable Sidewall and Propellant Boot.

---

[1] See Figure 10

[2] Exposure at full pressure/exposure during tail-off and after burn.

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn.

IBC-111/IBT-106 Performance Analysis Summary

Figure 18

Station [1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure sec [2]	Design TLR, in/sec [3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	40SD-80	-	-	138/12	.005/.005	.690 + .060 = .750	1.125	1.15
③	140-in.-aft of forward tangent	40SD-80	-	-	0/12	-/.005	.060	.090	-
③ thru ④	Sidewall	IBT-106	-	-	0/12	-/.003	.036	.054	.10
④	274-in.-fwd of aft tangent	IBT-106	-	-	20/12	.005/.003	.100 + .036 = 1.36	.204	.25
⑤	Aft tangent	40SD-80	-	-	40/12	.007/.005	.280 + .060 = .340	.510	.55
⑥	Aft dome 240-in.-dia	40SD-80	7.52	0.08	60/12	.024/.005	1.440 + .060 = 1.50	2.250	2.30
⑦	Aft dome 220-in.-dia	40SD-80	6.34	0.09	80/12	.027/.005	2.160 + .060 = 2.220	3.330	3.35
⑧	Aft dome 200-in.-dia	40SD-80	5.23	0.11	106/12	.033/.005	3.498 + .060 = 3.558	5.337	5.35
⑨	Step joint 180-in.-dia	40SD-80	4.23	0.14	138/12	.041/.005	5.658 + .060 = 5.728	8.592	8.60
⑩	Nozzle 165-in.-dia	40SD-80	3.55	0.17	138/12	.048/.005	6.624 + .060 = 6.684	10.026	10.05
⑪	Nozzle 140-in.-dia	40SD-80	-	-	138/12	.007/.005	.966 + .060 = 1.026	1.539	1.55
⑫	Nozzle 110-in.-dia	40SD-80		-	138/12	.007.005	.966 + .060 = 1.026	1.539	1.55
Propellant Boot	Fwd & Aft	IBT-106	-	-	138	.003	.414	.62	.65

Insulation System: 40SD-80 Castable Dome and Nozzle; IBT-106 Trowelable Sidewall and Propellant Boot.

---

[1] See Figure 11

[2] Exposure at full pressure/exposure during tail-off and after burn.

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and after burn.

40SD-80/IBT-106 Performance Analysis Summary

Figure 19

Station [1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure, sec [2]	Design TLR in/sec [3]	Thickness, in.	Thickness X 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	TI-H704B	-	-	138/2	.003/.003	.414 + .036 = .45	.675	.70
③	140-in. aft of forward tangent	TI-H704B	-	-	0/12	-/.003	.036	.054	.10
③ thru ④	Sidewall	TI-H704B	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	TI-H704B	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft Tangent	TI-H704B	-	-	40/12	.005/.003	.200 + .036 = .236	.354	.40
⑥	Aft dome 240-in.-dia	TI-H704B	7.52	0.08	60/12	.010/.003	.600 + .036 = .636	.954	1.00
⑦	Aft dome 220-in.-dia	TI-H704B	6.34	0.09	80/12	.011/.003	.880 + .036 = .916	1.374	1.40
⑧	Aft dome 200-in.-dia	TI-H704B	5.23	0.11	106/12	.014/.003	1.484 + .036 = 1.520	2.280	2.30
⑨	Step joint 180-in.-dia	TI-H704B	4.23	0.14	138/12	.022/.003	3.036 + .036 = 3.072	4.608	4.65
⑩	Nozzle 165-in.-dia	TI-H704B	3.55	0.17	138/12	.032/.003	4.416 + .036 = 4.452	6.678	6.70
⑪	Nozzle 140-in.-dia	TI-H704B	-	-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
⑫	Nozzle 110-in.-dia	TI-H704B	-	-	138/12	.005/.003	.690 + .036 = .726	1.089	1.10
Propellant Boots	Fwd & Aft	TI-H704B	-	-	138	.003	.414	.62	.65

Insulation: TI-H704B domes, nozzle, sidewall, and propellant boots.

[1] See Figure 12

[2] Exposure at full pressure/exposure during tail-off and afterburn.

[3] Thickness loss rate at full pressure/thickness loss rate rate during tail-off and afterburn.

TI-H704B Performance Analysis Summary

Figure 20

Station[1]	Location/Dia	Material	Area Ratio A/A*	Mach No.	Exposure sec[2]	Design TLR in/sec[3]	Thickness, in.	Thickness x 1.5	Nominal Design Thickness ± .025
① thru ②	Forward dome	IBT-100	-	-	138/2	.003/.003	.414 + .036 = .450	.675	.70
③	140-in.-aft of forward tangent	IBT-106	-	-	0/12	-/.003	.036	.054	-
③ thru ④	Sidewall	IBT-106	-	-	0/12	-/.003	.036	.054	.10
④	274-in. fwd of aft tangent	IBT-106	-	-	20/12	.005/.003	.100 + .036 = .136	.204	.25
⑤	Aft tangent	USR-3800	-	-	40/12	.003/.003	.120 + .036 = .156	.234	.25
⑥	Aft dome 240-in.-dia	USR-3800	7.52	0.08	60/12	.005/.003	.300 + .036 = .336	.504	.55
⑦	Aft dome 220-in.-dia	USR-3800	6.34	0.09	80/12	.006/.003	.480 + .036 = .516	.774	.80
⑧	Aft dome 200-in.-dia	USR-3800	5.23	0.11	106/12	.007/.003	.742 + .036 = .778	1.167	1.20
⑨	Step joint 180-in.-dia	USR-3800	4.23	0.14	138/12	.008/.003	1.104 + .036 = 1.140	1.710	1.75
⑩	Nozzle 165-in.-dia	USR-3800	3.55	0.17	138/12	.010/.003	1.380 + .036 = 1.416	2.124	2.15
⑪	Nozzle 140-in.-dia	USR-3800	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
⑫	Nozzle 110-in.-dia	USR-3800	-	-	138/12	.003/.003	.414 + .036 = .450	.675	.70
Propellant Boots	Fwd & Aft	IBT-106	-	-	138	.003	.414	.62	.65

Insulation System: IBT-100 Trowelable Fwd Dome; IBT-106 Trowelable Sidewall and Propellant Boots; USR-3800 Pressure-Cured Aft Dome and Nozzle

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[1] See Figure 13

[2] Exposure at full pressure/exposure during tail-off and afterburn.

[3] Thickness loss rate at full pressure/thickness loss rate during tail-off and afterburn.

IBT-100/USR 3800/IBT-106 Performance Analysis Summary

Figure 21

	IBT-100 Domes/Nozzle IBT-106 Sidewall/Boots	IBT-100 Domes/Nozzle IBS-107 Sidewall/Boots	IBT-106 Domes/Nozzle IBT-106 Sidewall/Boots	IBC-111 Domes/Nozzle IBT-106 Sidewall/Boots	40SD-80 Domes/Nozzle IBT-106 Sidewall/Boots
Forward Dome	3710 lb	3710 lb	3780 lb	4735 lb	5705 lb
Sidewall	7915	6835	7915	8785	10,090
Aft Dome	4315	4315	5340	4575	10,595
Nozzle	2070	2070	2915	2645	4865
Forward Boot	1970	1735	1970	1970	1970
Aft Boot	2565	2255	2565	2565	2565
Total Weight	22,545 lb	20,920 lb	24,485 lb	25,275 lb	35,790 lb

	V-44 Aft Dome/Nozzle V-45 Fwd Dome/Sidewall/Boots	TI-H704B Domes/Nozzle TI-H704B Sidewall/Boots	IBT-100 Fwd Dome; USR-3800 Aft Dome/Nozzle IBT-106 Sidewall/Boots
Forward Dome	3395 lb	3545 lb	3710 lb
Sidewall	7115	7425	7915
Aft Dome	4100	5025	2550
Nozzle	2940	3200	1070
Forward Boot	1810	1890	1970
Aft Boot	2350	2455	2565
Total Weight	21,710 lb	23,540 lb	19,780 lb

Insulation System Weight Summaries

Figure 22

RAW MATERIAL			
Weight in motor, IBT-100	10,095 lb		
10% loss factor	1,010		
	11,105 lb @ $1.00/lb	$11,105	
Weight in motor, IBT-106	12,450 lb		
10% loss factor	1,245		
	13,695 lb @ $1.00/lb	13,695	
Total Raw Material Cost			$24,800
PROCESSING/INSTALLATION:			
IBT-100/IBT-106 batch mixing:			
24,800 lb mixed @ $0.60/lb		14,880	
IBT-100 installation in domes and nozzle:			
10,095 lb installed @ $0.80/lb		8,076	
IBT-106 installation in sidewall:			
7,915 lb installed @ $0.72/lb		5,700	
IBT-106 installation of propellant boots:			
4,535 lb installed @ $1.32/lb		5,986	
NDT Inspection:			
10,095 lb domes/nozzle @ $0.48/lb		4,846	
7,915 lb sidewall lb @ $0.43/lb		3,404	
4,535 lb boots @ $0.80/lb		3,628	
Total Processing/Installation Cost			46,520
Estimated Insulation System Production Cost/Motor (Excluding Fixed Fee and Tooling)			$71,320

Estimated IBT-100/IBT-106 Insulation System
Production Cost

Figure 23

Raw Material

Weight in motor, IBT-100, lb	$10,095	
10% loss factor	1,010	
	11,105 lb at $1.00/lb	11,105
Weight in motor, IBS-107, lb	10,825	
10% loss factor	1,085	
	$11,910 lb at $1.75/lb	20,843
Total raw material cost		$31,948

Processing/Installation

IBT-100/IBS-107 batch mixing:	
23,015 lb mixed at $0.60/lb	$13,809
IBT-100 installation in domes and nozzle:	
10,095 lb installed at $0.80/lb	8,076
IBS-107 installation in sidewall:	
6,835 lb installed at $0.75/lb	5,127
IBS-107 installation of propellant boot:	
3,990 lb installed at $0.75/lb	2,993
NDT Inspection:	
10,095 lb domes/nozzle at $0.48/lb	4,846
6,835 lb sidewall at $0.43/lb	2,940
3,990 lb boots at $0.80/lb	3,192
Total Processing/Installation Cost	$40,983

Estimated Installation System Production Cost/Motor (Excluding Fixed Fee and Tooling)	$72,931

---

*Estimated

Estimated IBT-100/IBS-107 Insulation System Production Cost

Figure 24

RAW MATERIAL			
Weight in motor, IBT-106	24,485 lb		
10% loss factor	2,450		
	26,935 lb @ $1.00	$26,935	
Total Raw Material Cost			$26,935
PROCESSING/INSTALLATION			
IBT-106 batch mixing:			
26,935 lb mixed @ $0.60/lb		$16,161	
IBT-106 installation in domes and nozzle:			
12,035 lb installed @ $0.80/lb		9,628	
IBT-106 installation in sidewall:			
7,915 lb installed @ $0.72/lb		5,700	
IBT-106 installation for propellant boots:			
4,535 lb installed @ $1.32/lb		5,986	
NDT Inspection:			
12,035 lb domes/nozzle @ $0.48/lb		5,777	
7,915 sidewall @ $0.43/lb		3,404	
4,535 lb boots @ $0.80/lb		3,628	
Total Processing/Installation Cost			50,284
Estimated Insulation System Production Cost Motor (Excluding fixed fee and tooling)			$77,219

Estimated IBT-106 Insulation
System Production Cost

Figure 25

RAW MATERIAL			
Weight in motor, IBC-111	11,995 lb		
10% loss factor	1,200		
	13,155 lb @ $2.00/lb	$26,310	
Weight in motor, IBT-106	13,320 lb		
10% loss factor	1,335		
	14,655 lb @ $1.00/lb	14,655	
Total Raw Material Cost			$40,965
PROCESSING/INSTALLATION			
IBC-111/IBT-106 batch mixing:			
27,810 lb mixed @ $0.60/lb		16,686	
IBC-111 installation in dome and nozzles:			
11,955 lb installed @ $0.50/lb		5,978	
IBT-106 installation in sidewall:			
8,785 lb installed @ $0.72/lb		6,326	
IBT-106 installation of propellant boots:			
4,535 lb installed @ $1.32/lb		5,986	
NDT inspection:			
11,955 lb domes/nozzle @ $0.48/lb		5,739	
8,785 lb sidewall @ $0.43/lb		3,778	
4,535 lb boots @ $0.80/lb		3,628	
Total Processing/Installation Cost			48,113
Estimated Insulation System Production Cost/Motor (Excluding Fixed Fee and Tooling)			$89,078

Estimated IBC-111/IBT-106 Insulation
System Production Cost

Figure 26

RAW MATERIAL

Weight in motor, 40SD-80	21,165 lb		
10% loss factor	2,120		
	23,285 lb @ $2.80/lb	$65,198	
Weight in motor, IBT-106	14,625 lb		
10% loss factor	1,465		
	16,090 lb @ $1.00 lb	16,090	
Total Raw Material Cost			$81,288

PROCESSING/INSTALLATION

40SD-80/IBT-106 batch mixing:		
39,375 lb mixed @ $0.60/lb	23,625	
40SD-80 installation in domes and nozzle:		
21,165 lb installed @ $0.50/lb	10,583	
IBT-106 installation in sidewall:		
10,090 lb installed @ $0.72/lb	7,265	
IBT-106 installation of propellant boots:		
4,535 lb installed @ $1.32/lb	5,986	
NDT inspection:		
21,165 lb domes/nozzle @ $0.48/lb	10,159	
10,090 lb sidewall @ $0.43/lb	4,339	
4,535 lb boots @ $0.80/lb	3,628	
Total Processing/Installation Cost		65,225
Estimated Insulation System Production Cost/Motor (Excl. Fixed Fee and Tooling)		$146,513

Estimated 40SD-80/IBT-106 Insulation
System Production Cost

Figure 27

RAW MATERIAL

Weight in motor, IBC-100	3,710 lb		
10% loss factor	375		
	4,085 lb @ $1.00/lb	$ 4,085	
Weight in motor, USR-3800	3,620 lb		
10% loss factor	365		
	3,985 lb @ $1.40/lb	$ 5,579	
Weight in motor, IBT-100	12,450 lb		
10% loss factor	1,245		
	13,695 lb @ $1.00/lb	$13,695	
			$23,359

PROCESSING/INSTALLATION

IBT-100/IBT-106 batch mixing:	
17,789 lb mixed @ $0.60/lb	10,668
IBT-100 installation in fwd dome:	
3,710 lb installed @ $0.80/lb	2,968
USR-3800 installation in aft dome and nozzle:	
3,620 lb installed @ $6.20/lb*	22,444

---

*$8.00/lb V-44 installed (V-44 raw material cost, $3.20 - USR-3800 raw material cost, $1.80).

Estimated IBT-100/USR-3800/IBT-106
Insulation System Production Cost

Figure 28, Sheet 1 of 2

Processing/Installation (cont.)

IBT-106 installation in sidewall		
7,915 lb installed @ $0.72/lb	$5,700	
IBT-106 installation of propellant boots:		
4,535 lb installed @ $1.32 lb	5,986	
NDT Inspection:		
3,710 lb dome @ $0.48/lb	1,781	
7,915 lb sidewall @ $.43/lb	3,404	
4,535 lb boot @ $0.80/lb	3,628	
Total Processing/Installation Cost		$56,579
Estimated Insulation System Production Cost/Motor (Excluding Fixed Fee and Tooling)		$79,938

Estimated IBT-100/USR-3800/IBT-106 Insulation System Production Cost

Figure 28, Sheet 2 of 2

1. Tooling common to all candidate insulation systems:

Truss beam (1)	$18,000
Truss beam support (1)	4,000
Insulation pot stand (1)	6,000
	$28,000

2. Forward dome - troweled:

Sweep template (1)	$10,000

3. Forward dome - case:

Forward dome mold, female (1)	$ 2,500
Forward dome mold, male (6)	36,000
	$38,500

4. Sidewall - troweled:

Movable trowel, weighted (1)	$ 3,500
Ramp (1)	800
Lightweight insulation pot (2)	10,000
	$14,300

5. Aft dome and nozzle - troweled:

Sweep template, dome (1)	$ 8,000
Spider support (1)	6,000
Sweep template, nozzle (1)	800
Nozzle cure shroud (1)	1,000
	$15,800

6. Aft dome and nozzle - cast:

Aft dome mold, female (1)	$ 1,500
Aft dome mold, male (6)	24,000
Nozzle mold, female (1)	800
Nozzle mold, male (4)	10,000
	$36,300

Tooling Estimate for Various Insulation
System Installation Methods

Figure 29, Sheet 1 of 2

7. Propellant boots - troweled:

Sweep template, fwd boot (1)	$ 2,000
Sweep template, aft boot (1)	3,000
Vacuum bag, fwd (1)	800
Vacuum bag, aft (1)	2,000
	$ 7,800

8. Nozzle - pressure cured:

Mandrel	$ 8,000
Vacuum bag	800
	$ 8,800

Tooling Estimate for Various Insulation
System Installation Methods

Figure 29, Sheet 2 of 2

Station	Location	Propel. Thickness Inches	Time to Burn through Propellant seconds	Insul. Exposure Time Seconds	Mach No.	Insulation Eros. Rate, in./sec	Req. Insul. Thickness for Nominal Exposure Time, Inch.	Req. Insul. Thickness for Depature from Nominal, in.	Total Insulation Required (Assuming No Voids) In.
1.	Ign. Boss	0	0	147.5	-	.003	.44	1.13	1.57
2.	Fwd Equator	24.5	40.4	107.1	-	.003	.32	.84	1.16
3.	Sta. 2 plus 35-in.	28.0	46.2	101.3	-	.003	.30	.79	1.09
4.	Sta. 2 plus 80-in.	52.0	85.9	61.6	-	.003	.19	.49	.68
5.	Sta. 2 plus 150-in.	87.5	147.5	0	-	.003	0	.13	.13
5a.	Sta. 8 minus 300-in.	87.5	147.5	0	-	.003	0	.13	.18
6.	Sta. 8 minus 274-in.	85.0	140.0	7.5	-	.003	.02	.16	.38
7.	Sta. 8 minus 47-in.	73.0	120.0	27.5	.07	.0035	.10	.28	.92
8.	Aft Equator	70.6	116.4	31.1	.07	.008	.25	.67	.94
9.	Sta. 8 plus 12.5 in.	70.0	115.5	32.0	.08	.008	.26	.68	1.84
10.	At 240-in.-dia	52.4	86.7	60.8	.09	.0085	.52	1.32	3.26
11.	At 220-in.-dia	31.3	51.7	95.8	.11	.0095	.91	2.35	4.70
12.	At 200-in.-dia	15.0	25.6	121.9	.14	.0110	1.34	3.36	6.99
13.	Nozzle Joint (180-in.-dia)	0	0	147.5	.17	.0135	1.99	5.00	7.95
14.	At 165-in.-dia	0	0	147.5	-	.0160	2.36	5.59	2.60
15.	At 140-in.-dia	0	0	147.5	-	.005	.74	1.96	2.60
16.	At 110-in.-dia	0	0	147.5	-	.005	.74	1.96	1.5
N/A	Propellant Boots	0	0	138.0	-	.003	.42	1.08	.13

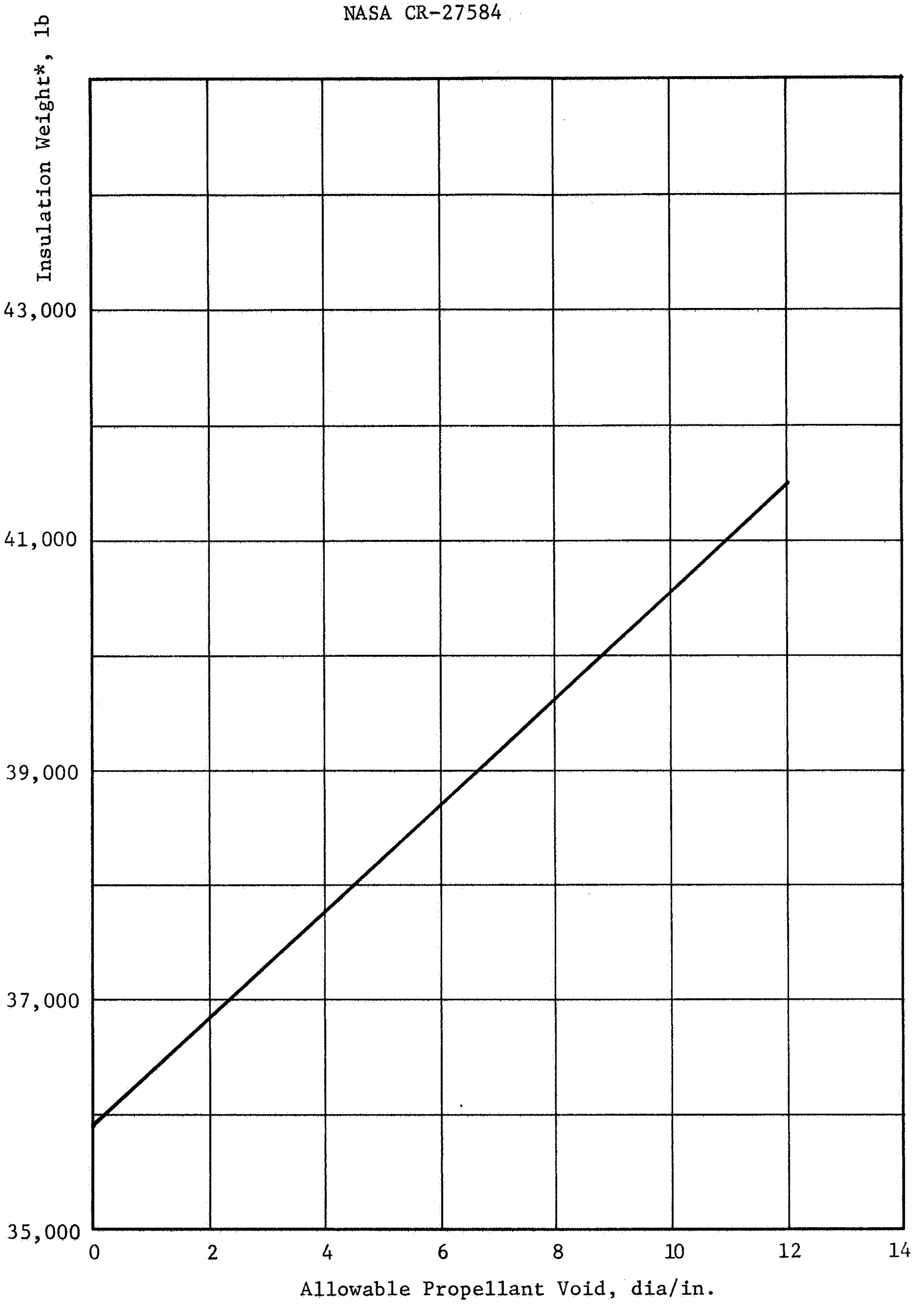
Summary of Insulation Burnthrough Calculations

Figure 30

Station	Location	No Voids	2" Dia Void	4" Dia Void	8" Dia Void	12" Dia Void
1.	Ign. Boss	1.57	1.58	1.59	1.61	1.63
2.	Fwd. Equator	1.16	1.17	1.18	1.20	1.22
3.	Sta. 2 plus 35-in.	1.09	1.10	1.11	1.13	1.15
4.	Sta. 2 plus 80-in.	.68	.69	.70	.72	.74
5.	Sta. 2 plus 150-in.	.13	.14	.15	.17	.19
5a.	Sta. 8 minus 300-in.	.13	.14	.15	.17	.19
6.	Sta. 8mminus 274-in.	.18	.19	.20	.22	.24
7.	Sta. 8 minus 47-in.	.38	.39	.40	.42	.45
8.	Aft Equator	.92	.95	.97	1.03	1.08
9.	Sta. 8 plus 12.5-in.	.94	.97	.99	1.05	1.10
10.	At 240-in.-dia	1.84	1.87	1.90	1.95	2.02
11.	At 220-in.-dia	3.26	3.29	3.32	3.39	3.45
12.	At 200-in.-dia	4.70	4.74	4.77	4.85	4.92
13.	Nozzle Joint (180-in.-dia)	6.99	7.03	7.08	7.17	7.26
14.	At 165-in.-dia	7.95	N/A	N/A	N/A	N/A
15.	140-in.-dia	2.60	N/A	N/A	N/A	N/A
16.	At 110-in.-dia	2.60	N/A	N/A	N/A	N/A

Calculated Insulation Thicknesses Required to Protect
Against Propellant Void Diameters of 0-, 2-, 4-, 8-, and 12-in.

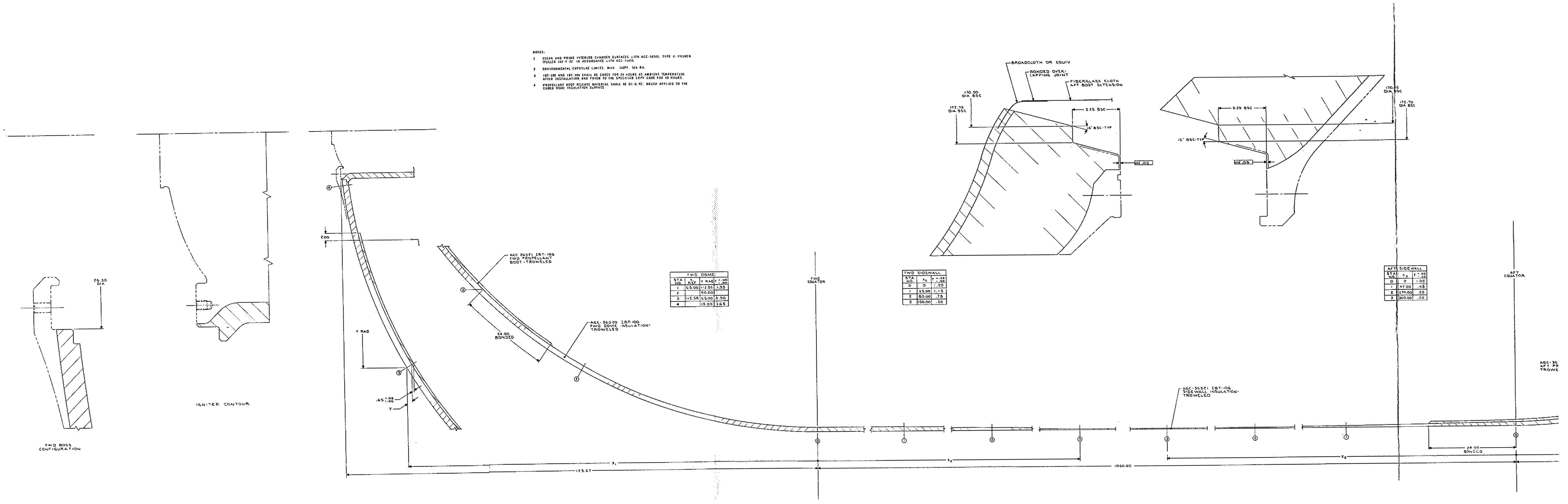
Figure 31



*Excluding Propellant Boots

Insulation Weight-vs-Allowable Propellant Void Diameter

Figure 32



NOTES:

1 CLEAN AND PRIME INTERIOR CHAMBER SURFACES WITH AGC-34345, TYPE II PRIMER (FULLER 162-Y-22) IN ACCORDANCE WITH AGC-35434.

2 ENVIRONMENTAL EXPOSURE LIMITS, MAX: 140°F, 50% RH.

3 IBT-100 AND IBT-106 SHALL BE CURED FOR 24 HOURS AT AMBIENT TEMPERATURE AFTER INSTALLATION AND PRIOR TO THE SPECIFIED 135°F CURE FOR 48 HOURS.

4 PROPELLANT BOOT RELEASE MATERIAL SHALL BE DC-Q-92, BRUSH APPLIED TO THE CURED DOME INSULATION SURFACE

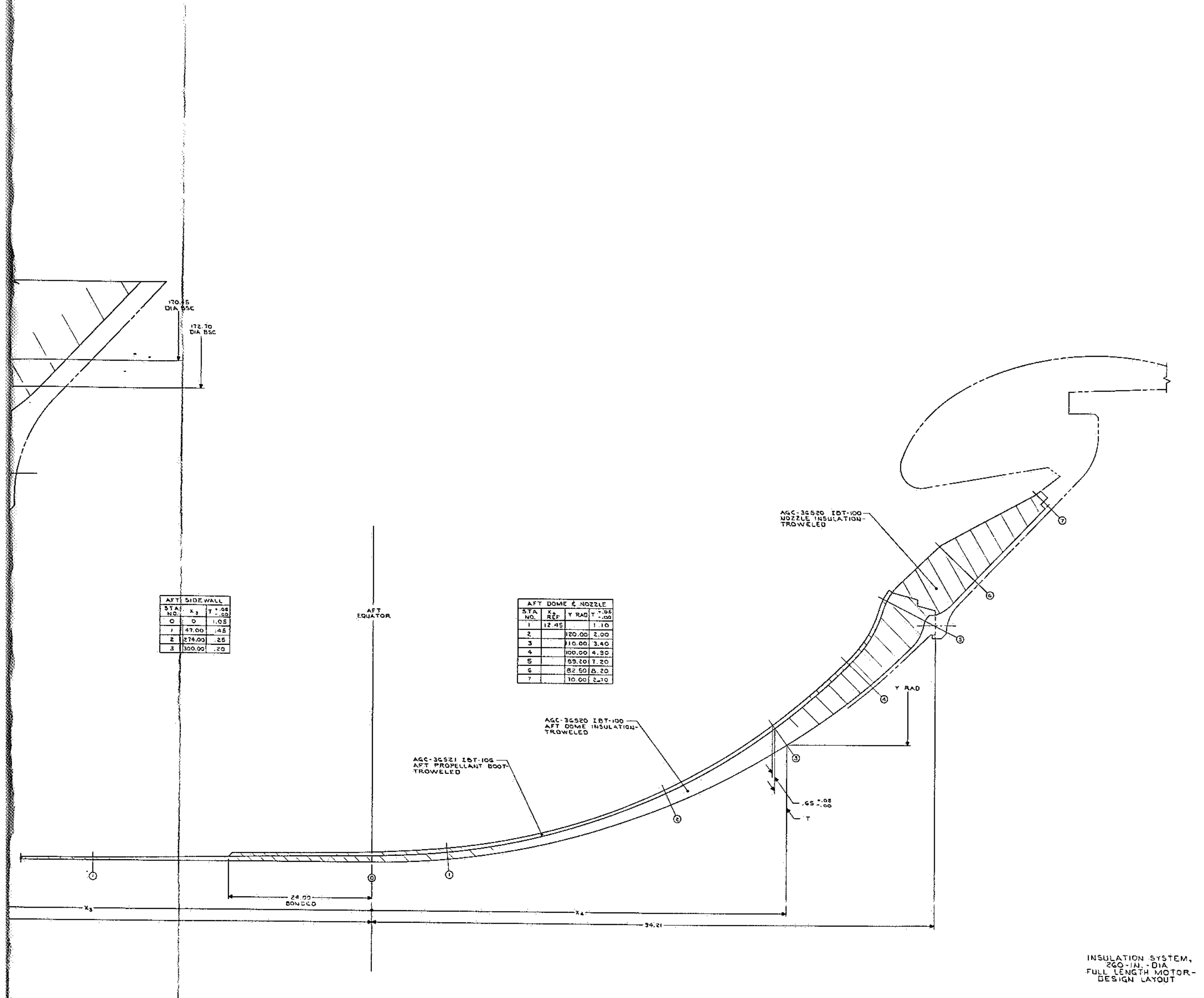
FWD DOME			
STA NO.	X_1 REF	Y RAD	T $^{+.05}_{-.00}$
1	65.00	112.58	1.35
2		90.00	
3	112.58	65.00	1.50
4		15.00	1.65

FWD SIDEWALL		
STA NO.	X_2	T $^{+.05}_{-.00}$
0	0	1.20
1	35.00	1.15
2	80.00	.75
3	150.00	.20

AFT SIDEWALL		
STA NO.	X_3	T $^{+.05}_{-.00}$
0	0	1.05
1	47.00	.45
2	274.00	.25
3	300.00	.20

FOLD-OUT #1

FOLD-OU



AFT SIDEWALL		
STA NO.	X_3	$T^{+.05}_{-.00}$
0	0	1.05
1	47.00	.45
2	274.00	.25
3	300.00	.20

AFT DOME & NOZZLE			
STA NO.	X_4 REF	Y RAD	$T^{+.05}_{-.00}$
1	12.45		1.10
2		120.00	2.00
3		110.00	3.40
4		100.00	4.90
5		89.20	7.20
6		82.50	8.20
7		70.00	2.70

FOLD-OUT #2

260-In.-Dia Full-Length Motor Insulation System Design Layout

Figure 33

Raw Material:

6 Batches of IBT-100 @ 4500 lb/batch	= 27,000 lb @ $1.00/lb	$27,000	
5.5 Batches of IBT-106 @ 4500 lb/batch	= 24,750 lb @ $1.00/lb	24,750	
Total Raw Material Cost			$ 51,750

Processing/Insulation:

IBT-100/IBT-106 batch mixing: 51,750 lb mixed @ $0.60/lb	$31,050	
IBT-100 installation in domes and nozzle: 23,480 lb installed @ $0.80/lb	18,874	
IBT-106 installation in sidewall: 16,630 lb installed @ $0.72/lb	11,974	
IBT-106 installation of propellant boots: 4,535 lb installed @ $1.32/lb	5,986	
NDT Inspection:		
23,480 lb domes/nozzle @ $0.48/lb	11,271	
16,630 lb sidewall @ $0.43/lb	7,151	
4,535 lb propellant boots @ $0.80/lb	3,628	
Total Processing/Installation Cost		89,934
Estimated Insulation System Production Cost per Motor (Excluding Fixed Fee)		$141,684
Estimated Initial Tooling Cost		$ 75,900

Estimated IBT-100/IBT-106 Insulation System Production Cost

Figure 34

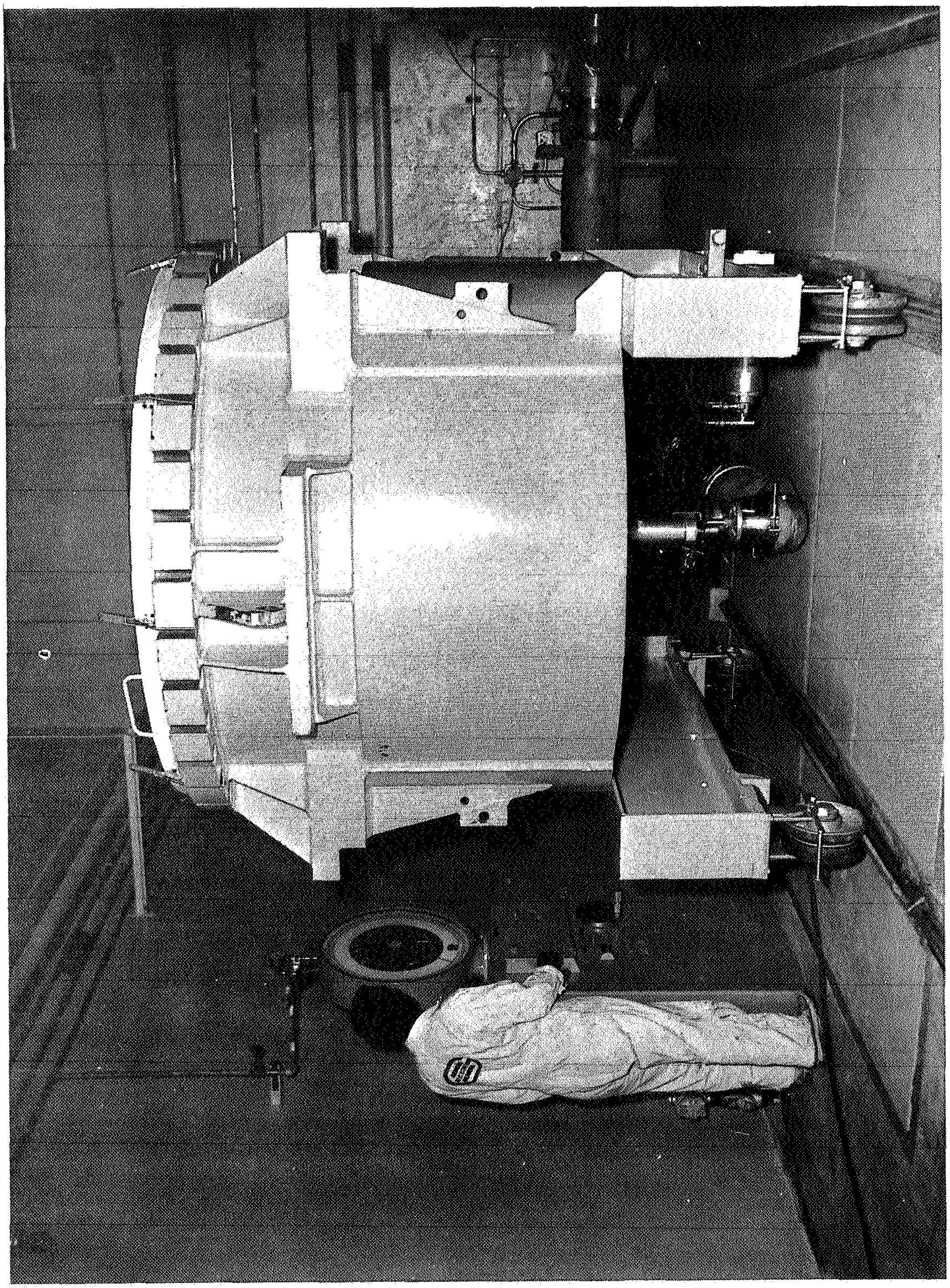
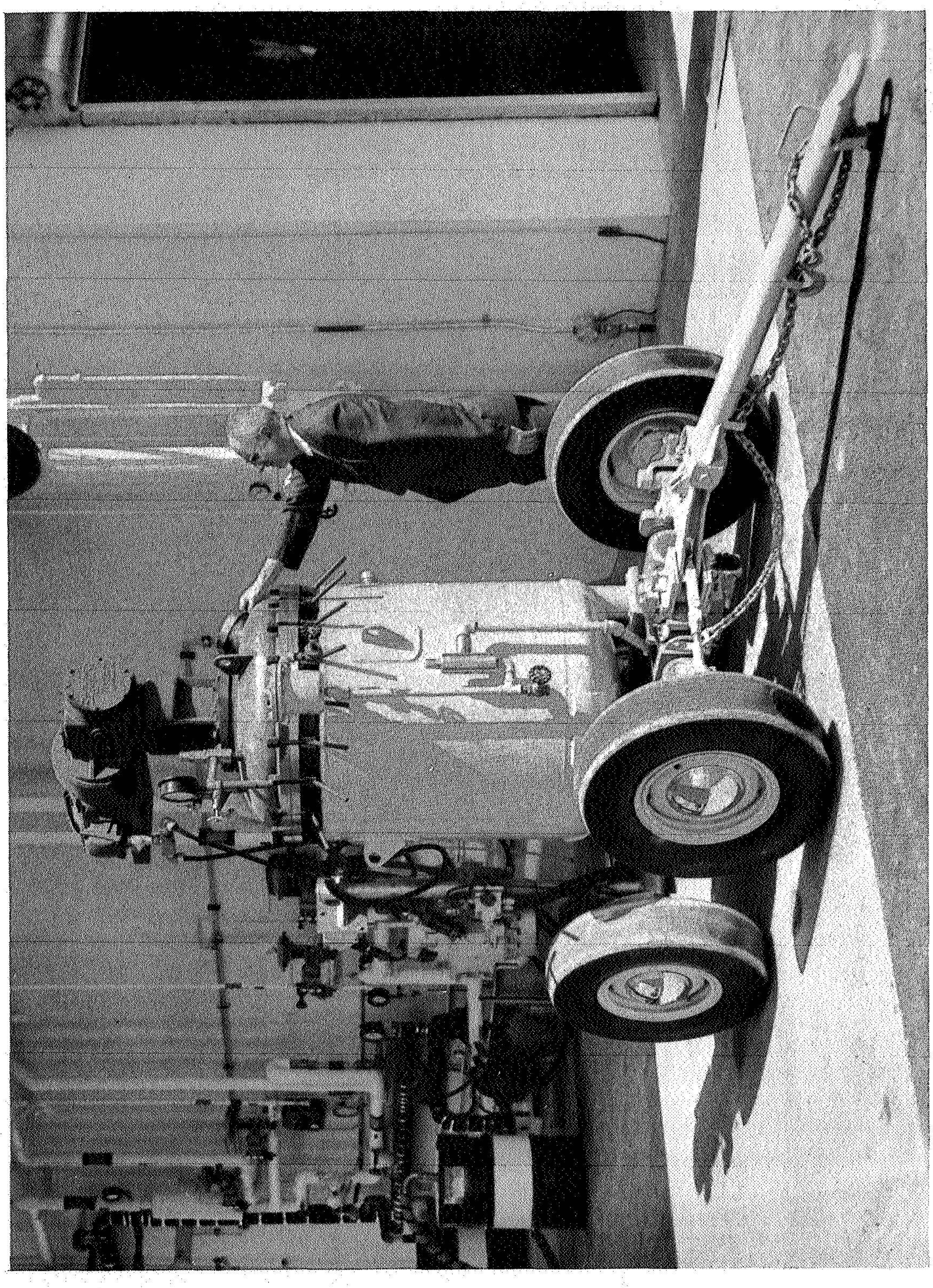


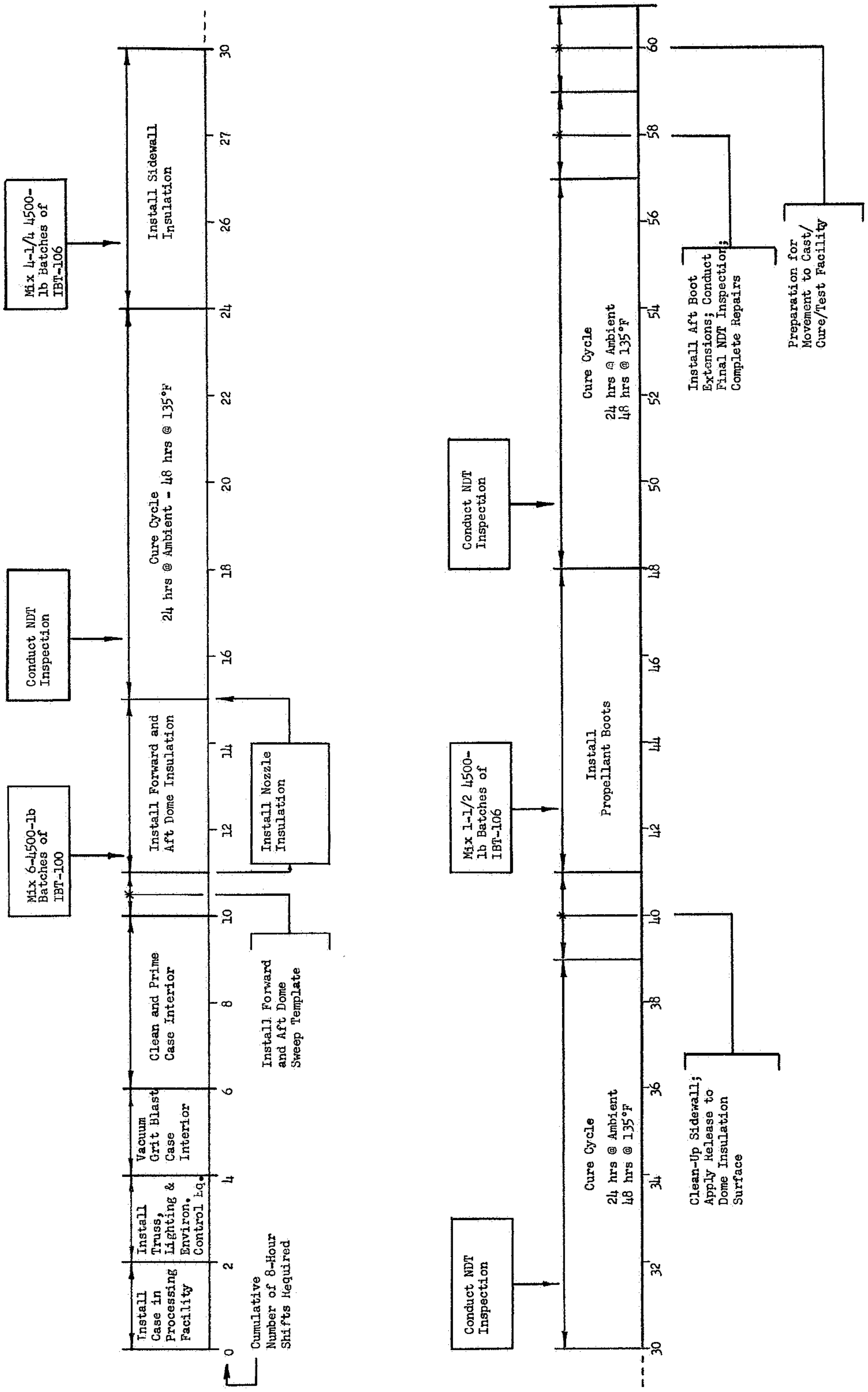
Figure 35

Bowl for Vertical Batch Mix Stations



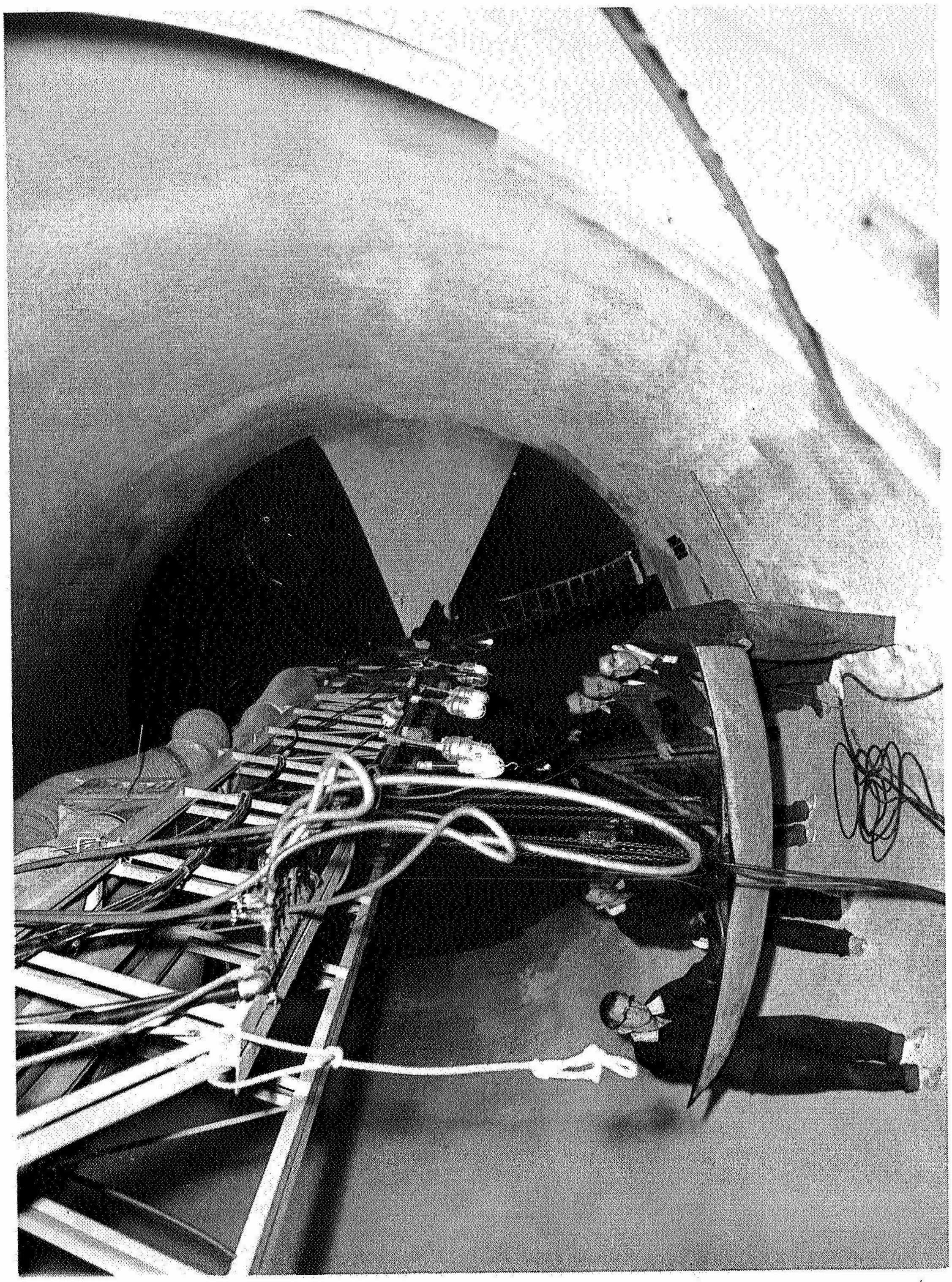
Propellant Liner Transfer Pot

Figure 36



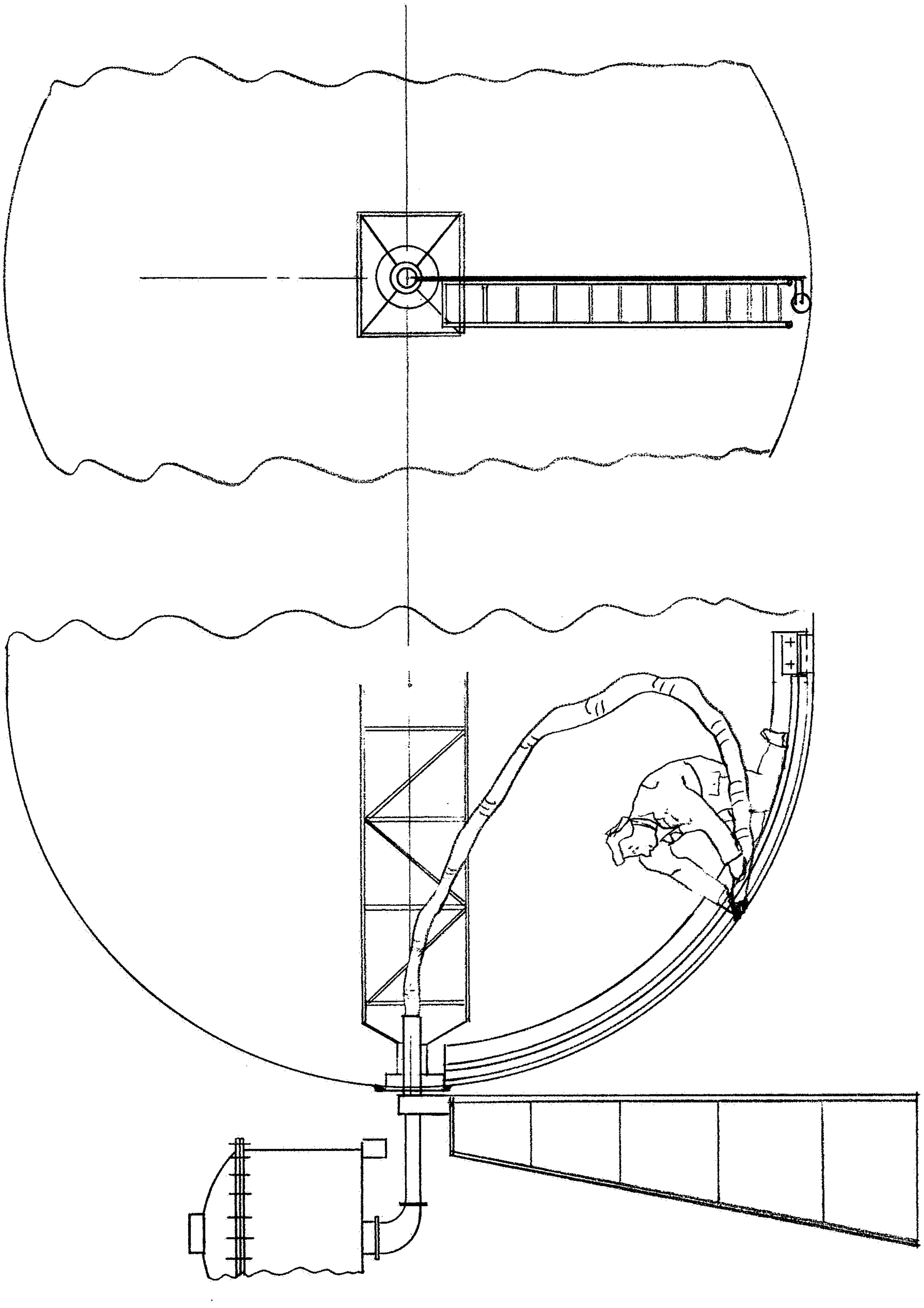
260-FL Motor Insulation System Process Flow Sheet

Figure 37



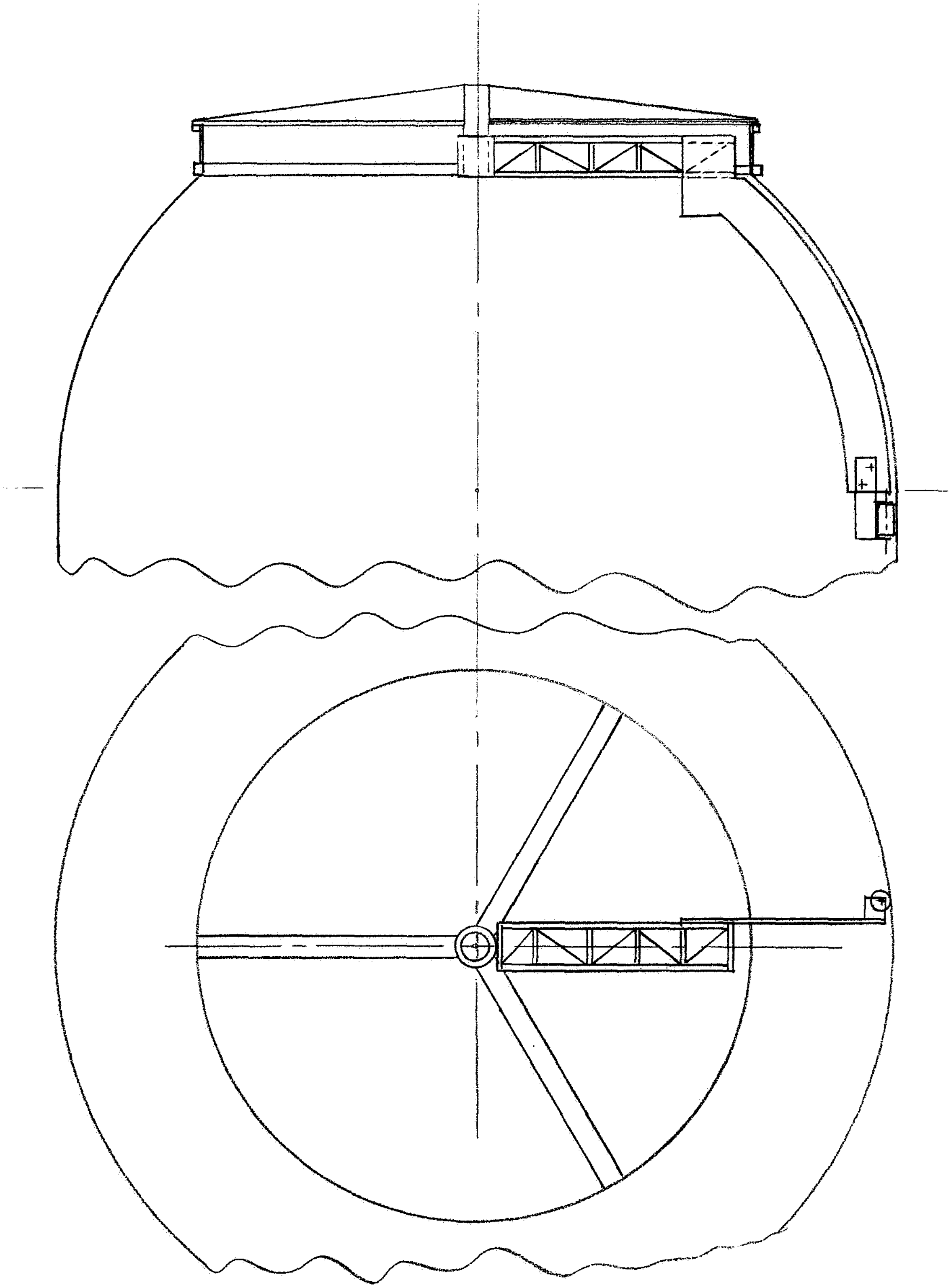
Heavy-Duty Equipment Truss for 260-SL Motor Insulation Processing

Figure 38



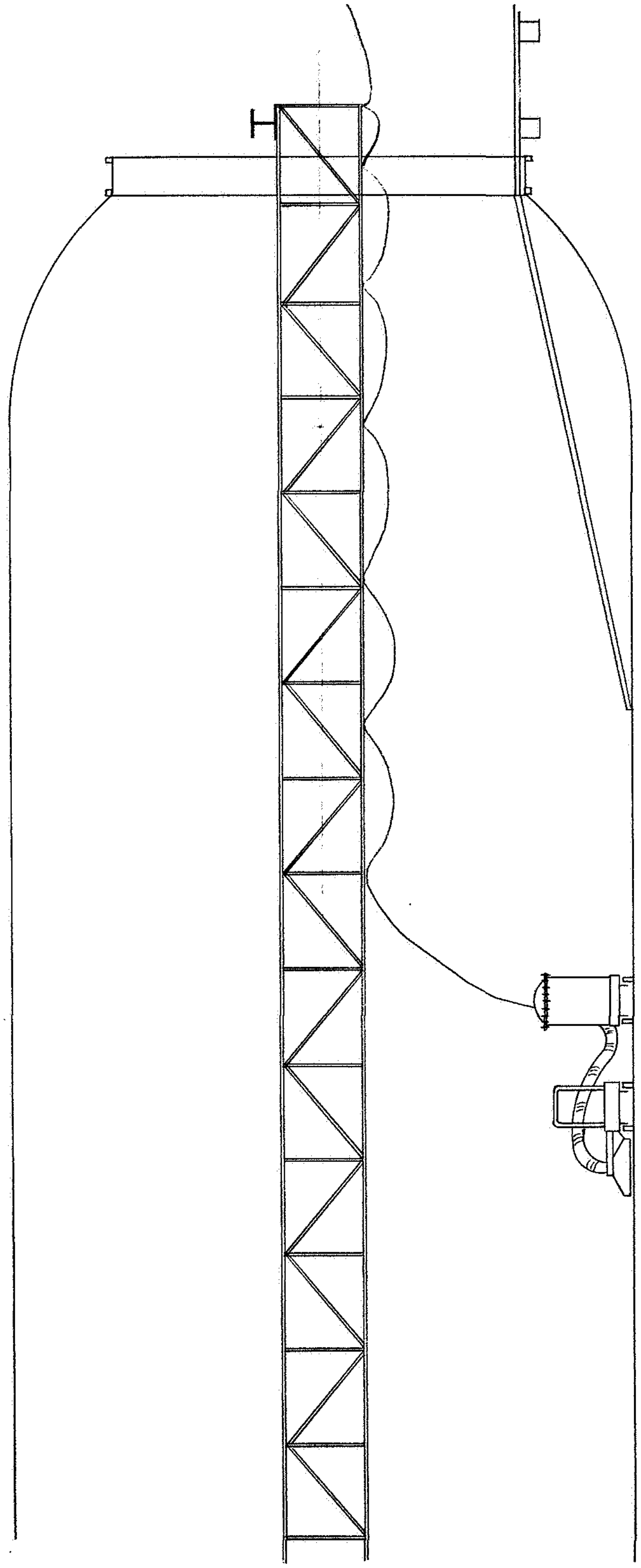
Forward Dome Sweep Template Concept

Figure 39



Aft Dome Sweep Template Concept

Figure 40



Sidewall Insulation Process Tooling Concept

Figure 41

APPENDIX

COST BASIS FOR INSULATION PROCESSING OPERATIONS

Material Cost

IBT-100	$1.00/lb
IBT-106	1.00/lb
IBT-107	1.75/lb
IBC-111	2.00/lb
40SD-80	2.80/lb

Assumed 10% Material Loss Factor

Batch Mixing at A-DD: $600/1000lb

Estimated Installation Span Times (See Volume II)

IBT-106 Sidewall - Troweled	Hr	Shifts
Setup time	8	(1)
Installation	36	(4.5)
Cure, ambient	24	(3)
135°F	48	(6)
Clean-up	8	(1)
TOTAL	124 hr	(15.5 shifts)

IBT-100 Domes - Troweled	Hr	Shifts
Setup time	8	(1)
Installation	32	(4)
Cure, ambient	24	(3)
135°F	48	(6)
Clean-up	8	(1)
TOTAL	116 hr	(15 shifts)

IBT-106 Propellant Boots (Troweled)	Hr	Shifts
Setup time	8	(1)
Fwd boot installation	24	(3)
Aft boot installation	32	(4)
Cure, ambient	24	(3)
135°F	48	(6)
Clean-up	16	(2)
TOTAL	152 hr	(19 shifts)

Estimated Installation Span Times (see Volume II) (cont)

IBC-111 Domes (cast)	Hr	Shifts
Setup time	24	(3)
Cast time, fwd	12	(1.5)
Cast time, aft	12	(1.5)
Cure, ambient	24	(3)
135°F	48	(6)
Mold removal	8	(1)
Fill joints	8	(1)
Clean-up	16	(2)
TOTAL	152 hr	(19 shifts)

Estimated Labor Hours and Cost

1. Domes/Nozzle (basis, 10,000 lb Installed)

	S/H	H/H
Setup		
6 operators - 1 shift	8	48
Forward Dome - Troweled		
6 operators - 4 shifts		192
1 foreman - 4 shifts	32	
1 engineer - 4 shifts	32	
Aft Dome - Troweled		
6 operators - 4 shifts		192
1 foreman - 4 shifts	32	
1 engineer - 4 shifts	32	
Nozzle - Troweled		
6 operators - 3 shifts		144
1 foreman - 3 shifts	24	
1 engineer - 3 shifts	24	

Estimated Labor Hours and Cost (cont)

1. Domes/Nozzle (basis, 10,000 lb Installed) (cont)

	S/H	H/H
<u>Cure Time</u>		
2 hr/shift of cure	-	20
<u>Clean-Up</u>		
6 operators - 1 shift	8	48
TOTAL TIME	192	644
COST	$7,924	

$$\frac{\$7{,}924}{10{,}000\ \text{lb}} = \$0.80/\text{lb installed}$$

2. <u>Sidewall (basis 8,000 lb Installed)</u>

<u>Setup</u>		
6 operators - 1 shift	8	48
<u>Sidewall - Troweled</u>		
8 operators - 4.5 shifts		288
2 foremen - 4.5 shifts	72	
2 engineers - 4.5 shifts	72	
<u>Cure Time</u>		
2 hr/shift of cure	-	20
<u>Clean-Up</u>		
6 operators - 1 shift	8	48
TOTAL TIME	160	404
COST	$5,668	

$$\frac{\$5{,}668}{8000\ \text{lb}} = \$0.72/\text{lb installed}$$

3. <u>Propellant Boots (basis, 4,500 lb Installed)</u>

<u>Setup</u>		
6 operators - 1 shift	8	48

Estimated Labor Hours and Cost (cont)

3. Propellant Boots (basis, 4,500 lb Installed) (cont)

Forward Boot - Troweled	S/H	H/H
6 operators - 3 shifts		144
1 foreman - 3 shifts	24	
1 engineer - 3 shifts	24	
Aft Boot - Troweled		
6 operators - 4 shifts		192
1 foreman - 4 shifts	32	
1 engineer - 4 shifts	32	
Cure Time		
2 hr/shift of cure	-	20
Clean-Up/Inspection Assistance		
6 operators - 2 shifts		96
1 foreman - 2 shifts	16	
TOTAL TIME	136	500
COST	$5,922	

$\frac{\$5,922}{4,500\ \text{lb}}$ = \$1.32/lb installed

4. *Cast Domes/Nozzle (basis, 12,000 lb Installed)*

Setup	S/H	H/H
6 operators - 3 shifts		144
1 foreman - 3 shifts	24	
1 engineer - 3 shifts	24	
Forward Dome - Cast		
6 operators - 1.5 shifts		72
1 foreman - 1.5 shifts	12	
1 engineer - 1.5 shifts	12	

Estimated Labor Hours and Cost (cont)

4. Cast Domes/Nozzle (basis, 12,000 lb Installed) (cont)

	S/H	H/H
Nozzle - Cast		
6 operators - 1.5 shifs		72
1 foreman - 1.5 shifts	12	
1 engineer - 1.5 shifts	12	
Cure Time		
2 hr/shift of cure	-	20
Mold Removal		
4 operators - 1 shift	8	32
Fill Joints		
2 operators - 1 shift	8	16
Clean-Up		
2 operators - 2 shifts	16	32
TOTAL TIME	152	460
COST	$5,922	

$\frac{\$5,922}{12,000 \text{ lb}}$ = $0.50/lb installed

NDT Inspection: 60% of installation cost

Domes/Nozzle: $0.80.1b x 60% = $0.48/lb

Sidewall: $0.72/lb x 60% = $0.43/lb

Propellant Boots: $1.32/lb x 60% = $0.80/lb

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