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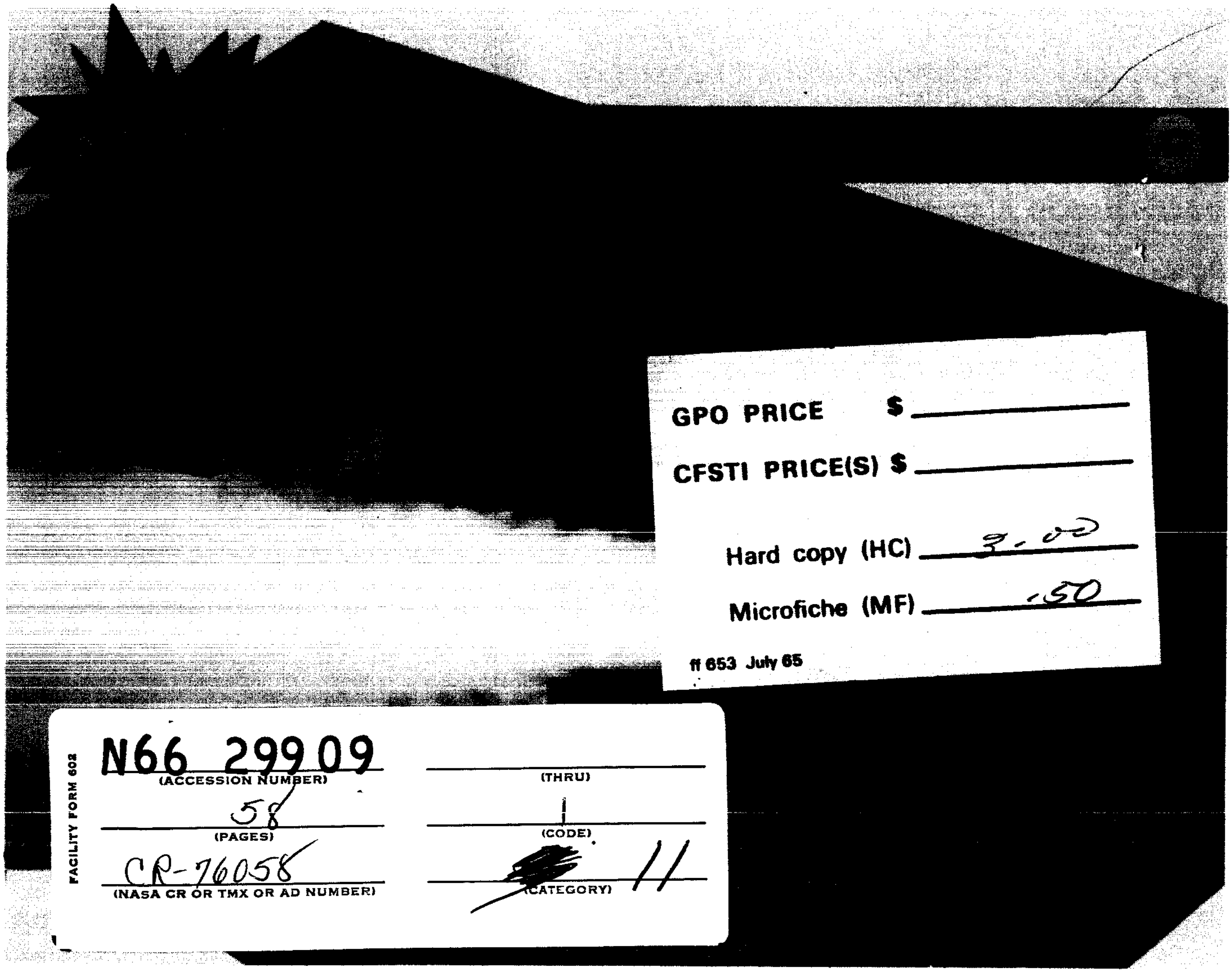
DESIGN HANDBOOK FOR PROTECTION OF LAUNCH COMPLEXES FROM SOLID PROPELLANT EXHAUST

MARCH 1966



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Contract NAS10-2300

DESIGN HANDBOOK FOR PROTECTION OF LAUNCH COMPLEXES FROM SOLID PROPELLANT EXHAUST

March 1966

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Approved

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Martin-Marietta Corporation
Martin Company
Denver Division
Denver, Colorado

FOREWORD

This document is submitted under Exhibit II, Paragraph I.E of Contract NAS10-2300 to summarize, in handbook form, the results of work performed under Contracts NAS10-389, NAS10-1107, and NAS10-2300. These investigations were prompted by a need to develop supporting technology for launch facilities applicable to potential improvements of the Saturn IB and Saturn V space vehicle systems. The handbook has been prepared under the direction of NASA at the John F. Kennedy Space Center, Kennedy Space Center, Florida.

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1.0 INTRODUCTION

Large solid rocket motors (SRMs) are being considered for a variety of applications involving augmented and improved Saturn launch vehicles, and it is desired to use existing launch facilities, where possible, for these vehicles. In the process of evaluating existing facilities for applicability and the modifications needed to accommodate the many proposed configurations, it became apparent that little was known about the effects of solid propellant rocket exhaust on flame deflectors, launch duct walls, launchers, umbilical masts, umbilical towers, etc. Liquid rocket motor technology was not applicable because of the absence of aluminum particles commonly used in the SRM grains. This handbook was prepared to satisfy the need for solid propellant rocket exhaust effects data.

1.1 Scope of Applicability

The data shown in this handbook have been obtained from from model tests and full-scale launches and are based on the effects of specific SRMs on specific launch facility configurations. Certain SRM parametric variations were made during the model tests that broaden the applicability of the data, and several candidate deflector and GSE coatings were evaluated. In general, however, the information is applicable to a narrow spectrum of design problems and further expansion and refinement are needed to enhance its usefulness. The specific applicability and limitations of the erosion data shown are as follows:

Flame Deflector Erosion Data

- Applicable Deflector Configurations

  J deflector

  30-deg impingement angle (with and without a 6-deg lateral nozzle cant)

  Initial nozzle-to-deflector standoff distance - 3 nozzle exit diameters

  Impingement point - approximately at point of tangency of curved and flat surfaces

Radius of curved section - 1.7 nozzle exit diameters (data are conservative for larger radii)

- Deflector Coatings - Fondu Fyre WA-1, Fondu Fyre XB-1, Portland Cement, Harbison-Walker Fused Silica Castable
- Rocket Motors - PBAA propellants with varying percents of aluminum, chamber pressures from 400 to 1200 psia and nozzle exit diameters of 20 to 220 in.
- Liftoff Thrust-to-Weight Ratios - 1.0 to 3.0.

<u>Vertical Surface Erosion Data</u> (umbilical mast, tower, etc)

- Coated Vertical Surface Location - 1.5 nozzle exit diameters from exhaust plume centerline
- Thermal Protective Coatings - silicones and epoxies
- SRM and Liftoff Characteristics - same as for deflectors.

1.2 Method for Use

Every effort has been made to make each curve and nomograph in this handbook self-explanatory. Care should be exercised to assure the applicability of the data shown to the specific design problem being worked.

2.0 ENVIRONMENTS CREATED BY EXHAUST

This chapter discusses and presents data relative to the thermal, pressure, and acoustic environment created by solid rocket motors; the effect of liftoff acceleration on erosion; and key parameters to be considered in the design of a launch facility.

2.1 Motor Characteristic Effects

Motor characteristics data most often used in launch facility design include plume pressures, temperatures, total heating rates, radiation emissions, and sound pressure levels. Data of this type were obtained during the SPREE program (Ref 1) and during full-scale firings of United Technology Corporation (UTC) 120-in. solid rocket motors (SRMs).

Plume Pressures and Temperatures

SPREE plume data (Fig. 1 thru 4) were obtained using SRMs having PBAA-based propellants containing 7% aluminum by weight. The low percentage of aluminum was used in an effort to obtain good temperature and pressure measurements. Measurement problems have been encountered when grains with higher aluminum percentages were used. Because of the limited quantity of aluminum in the SPREE formulation, the severity of the exhaust environment was somewhat less than contemporary solids and allowances are required when using the data. Figures 1 and 2 show the results of a single plume traversing probe. Dual plume probe data are shown in Fig. 3 and 4. Surface pressures on an umbilical mast situated a constant 1.5 nozzle exit diameters laterally from a plume centerline are shown in Fig. 5 as a function of liftoff distance.

Total Heating Rate

The rate at which heat was delivered to an asymptotic calorimeter situated on a vertical surface 1.5 nozzle exit diameters from an SRM exhaust plume centerline during a simulated liftoff is shown in Fig. 6. Umbilical mast heating rate data similarly obtained during a full-scale Titan IIIC launch is also shown in Fig. 6. The heating rates shown would, of course, be higher if the missile were to drift toward the surfaces during launch.

Radiation

Thermal radiation data were obtained during two static firings of UTC 120-in. SRMs exhausting vertically upward. One firing was made with TVC injection and the other without it. Calorimeters were located and oriented as shown in Fig. 7. Average radiation flux values obtained are listed in Table 1. The maximum measured radiation fluxes for the firing without TVC injection are also listed. Note that the N_2O_4 TVC injectant reduces the radiation levels. Apparent plume emissive power data derived from information in Table 1, in NACA TN 2836 and in UTC Report No. ER-UTC-63-174 are shown in Fig. 8.

Sound Pressure Levels

Near field acoustic spectra obtained at four discrete times during a Titan IIIC launch are shown in Fig. 9. The data were obtained via a microphone located at the top of the umbilical tower some 31 ft (3.5 nozzle exit diameters) from each UTC 120-in. SRM.

2.2 Liftoff Acceleration Effects

Liftoff acceleration has a pronounced effect on the erosion of deflectors and umbilical mast thermal protective coatings. During SPREE testing it was found that deflector erosion correlates closely with the total heat to which a deflector is exposed. At low acceleration rates the high temperature environment is prolonged and the total heat is much greater than at the higher accelerations. It was determined that erosion varied inversely as the square root of liftoff acceleration when acceleration was expressed in terms of nozzle diameters (D) separation per unit time (Fig. 10).

The numbers preceding the square root sign in Fig. 10 represent the maximum erosion depth (0.63 in.) and the pounds of material eroded (5.75) from a small-scale Fondu Fyre WA-1 J deflector for a liftoff acceleration resulting in a 50D nozzle-to-deflector separation at the end of 10 sec (initial nozzle-to-deflector separation was 3D and hold down was 200 msec, hence the 47 and 9.8 sec). There is excellent agreement between the analytically derived curves and the experimental data.

2.3 Key Design Parameter Identification

Deflector Design Considerations

The purpose of a flame deflector is to redirect the flow of exhaust gases from a rocket motor in an expedient manner. The deflector designer must consider many factors in arriving at the configuration best suited for the application he has in mind. Paramount among these factors is the protection of the launch vehicle during liftoff since some vehicles would destroy themselves if launched from an improperly designed facility. The designer must also consider deflector degradation in the light of the number of launches anticipated from the pad he is designing.

A vehicle such as Minuteman can be launched in a very severe environment without damaging itself, and the ground base design problem is minimized. Vehicles like Titan IIIC and certain improved Saturn configurations using a combination of liquid and solid stages are quite vulnerable to the launch environment, however, and must be protected through proper design. The flame deflector, for instance, must not allow flashback or backflow of hot exhaust gases since these will most certainly damage components in the base region of the liquid stage and possibly even the solid stage. The overpressure resulting from booster ignition must be minimized or protected against through baffling because the pressures may be high enough to rupture a tank bottom or damage important accessories.

A facility could be designed to circumvent flashback and ignition overpressure problems through minimizing exhaust impingement angles and maximizing deflector turn radius, vehicle-to-deflector standoff distance, and exhaust duct size. However, this practice would result in an extremely large and costly launch facility. The deflector would be large and, at least at ETR, extend well above ground level necessitating higher service structures. The designer, therefore, must consider facility size and height minimization if economy is to be practiced. He must, however, be on guard against the false economies inherent in the compact-facility approach through lack of providing for vehicle growth. This lack is evident in several existing facilities.

Deflector Design Parameters

Current compact-facility flame deflector design practice for vehicles having a liquid core and SRM strap-ons calls for a deflector configured as follows:

Flame centerline-to-deflector impingement angle - 30 deg

Deflector radius of curvature - 1.7 nozzle exit diameters

Nozzle exit-to-deflector standoff distance - 3 nozzle exit diameters

Centerline of impingement - on or slightly upstream of point of tangency of curved and flat surfaces.

If these rules of thumb are followed, the airborne vehicle will be protected adequately from the launch environment and deflector degradation will be minimal if vehicle liftoff thrust-to-weight ratio is 1.3 or greater.

Exhaust Duct Design

Exhaust duct geometry has a considerable effect on the acoustic and ignition overpressure environment. Open ducts reduce the strength of the overpressure pulse but add to the severity of the acoustic environment, whereas closed ducts allow acoustic directivity but aggrevate the ignition overpressure pulse (especially when the cross sectional area is small). Figure 11 shows a relationship between exhaust flow rate and the cross sectional area of a closed exhaust duct that was determined to be satisfactory on the basis of Titan IIIC experience. The ignition overpressure pulse occurring as a result of this duct geometry relationship was approximately 6 psig and some baffling was required to protect the core of the airborne vehicle. A lower ignition overpressure pulse would be expected with an open duct.

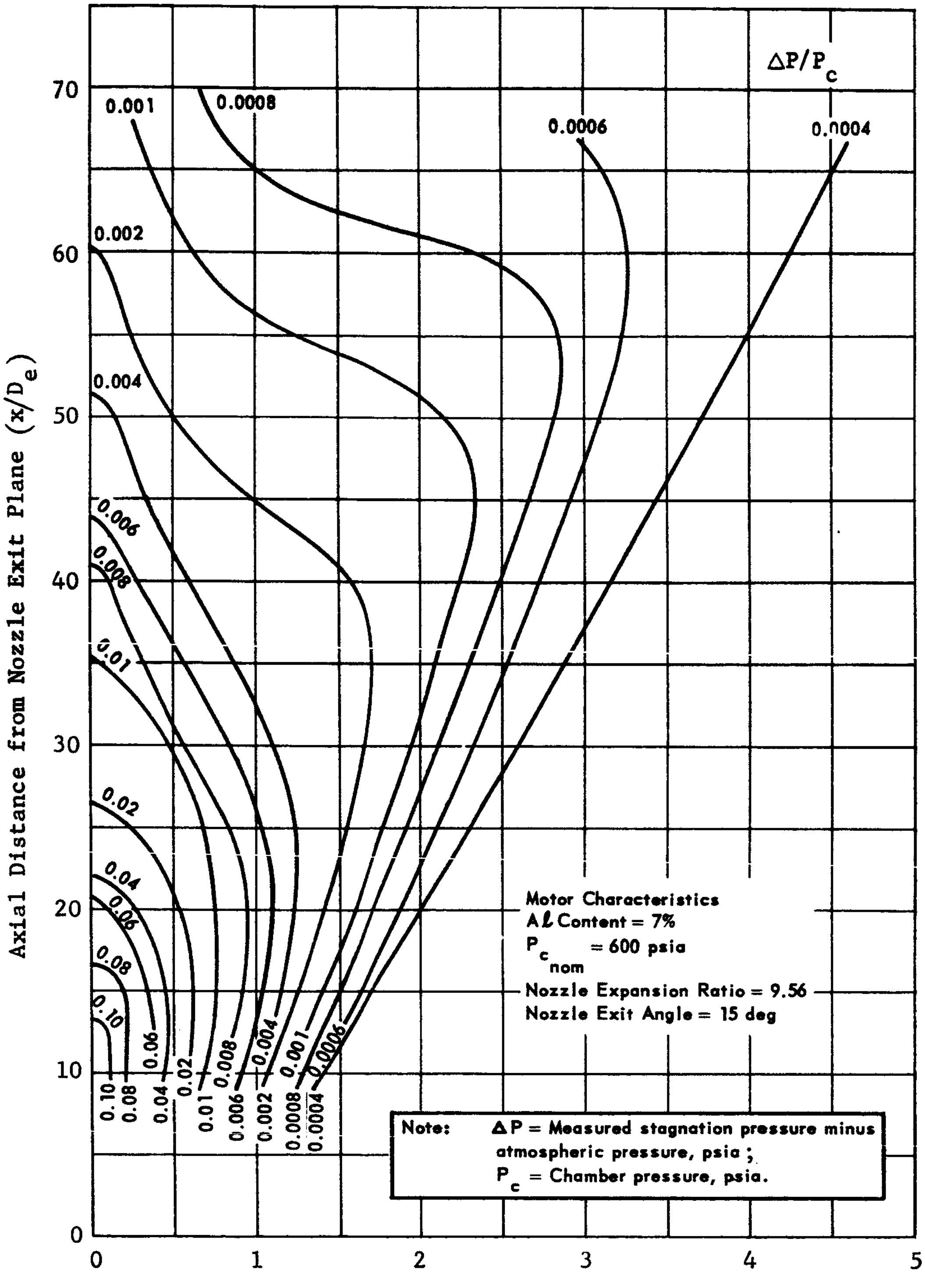


Fig. 1 Exhaust Plume Pressure Profile

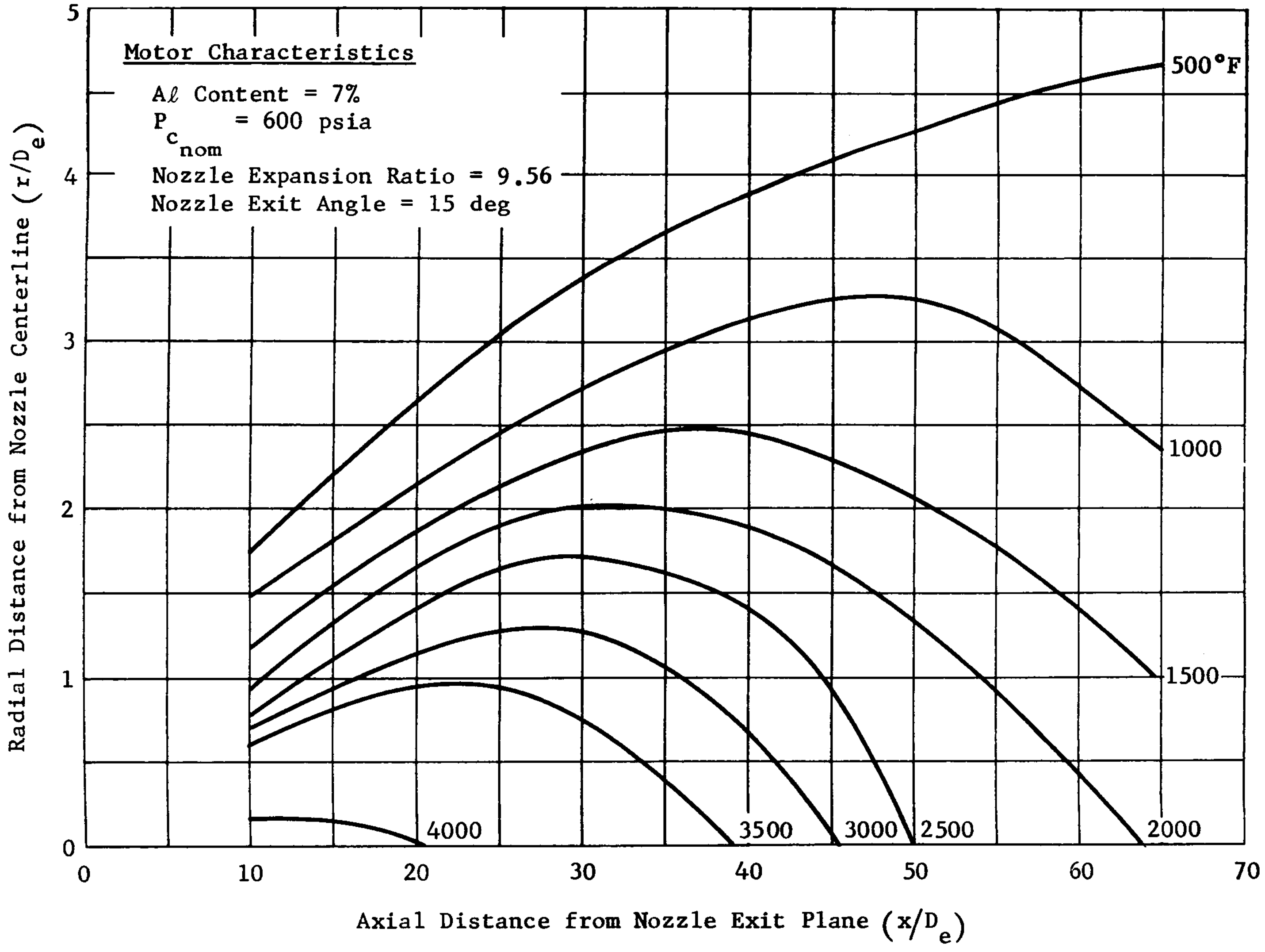


Fig. 2 Exhaust Plume Stagnation Temperature Profile

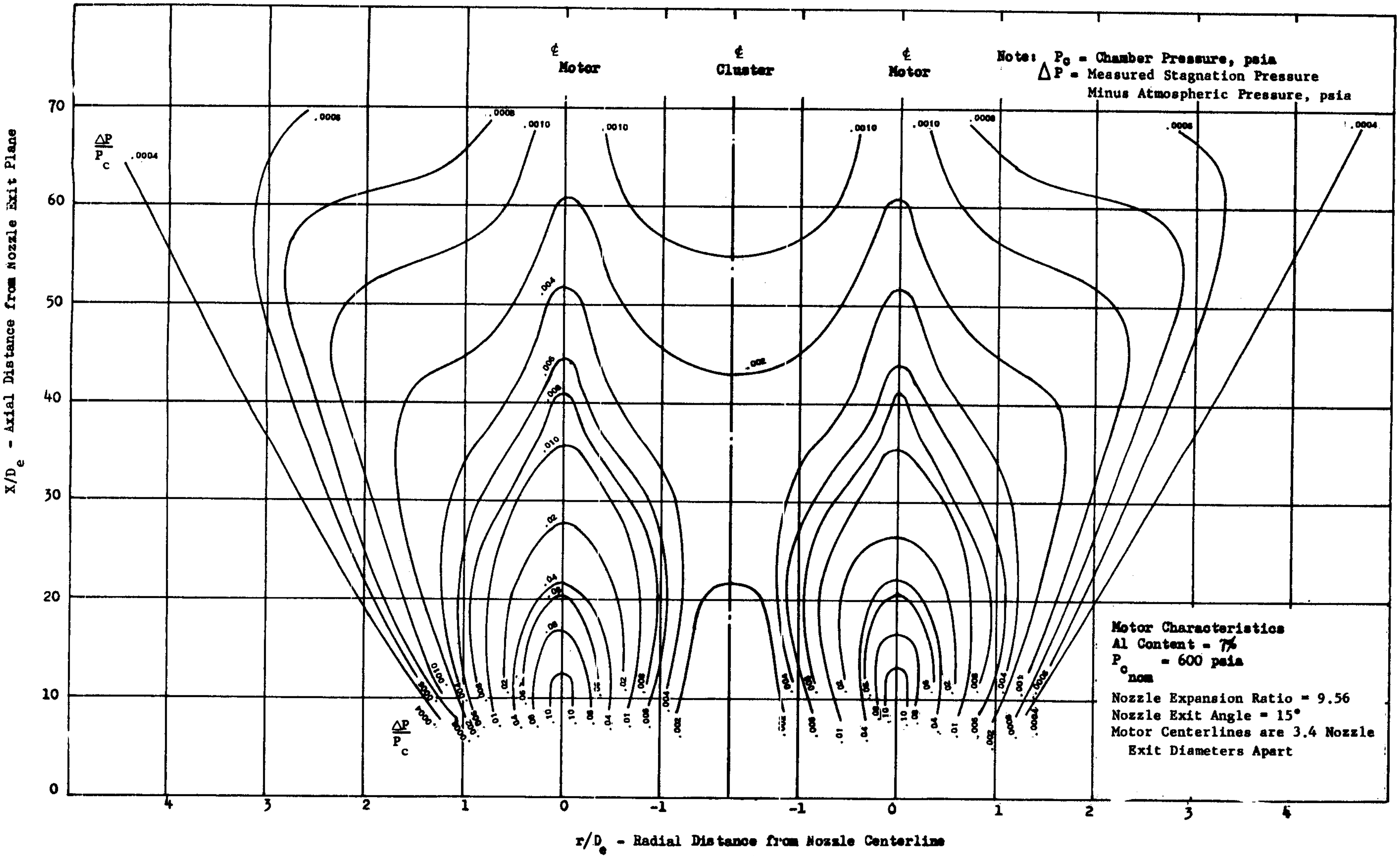
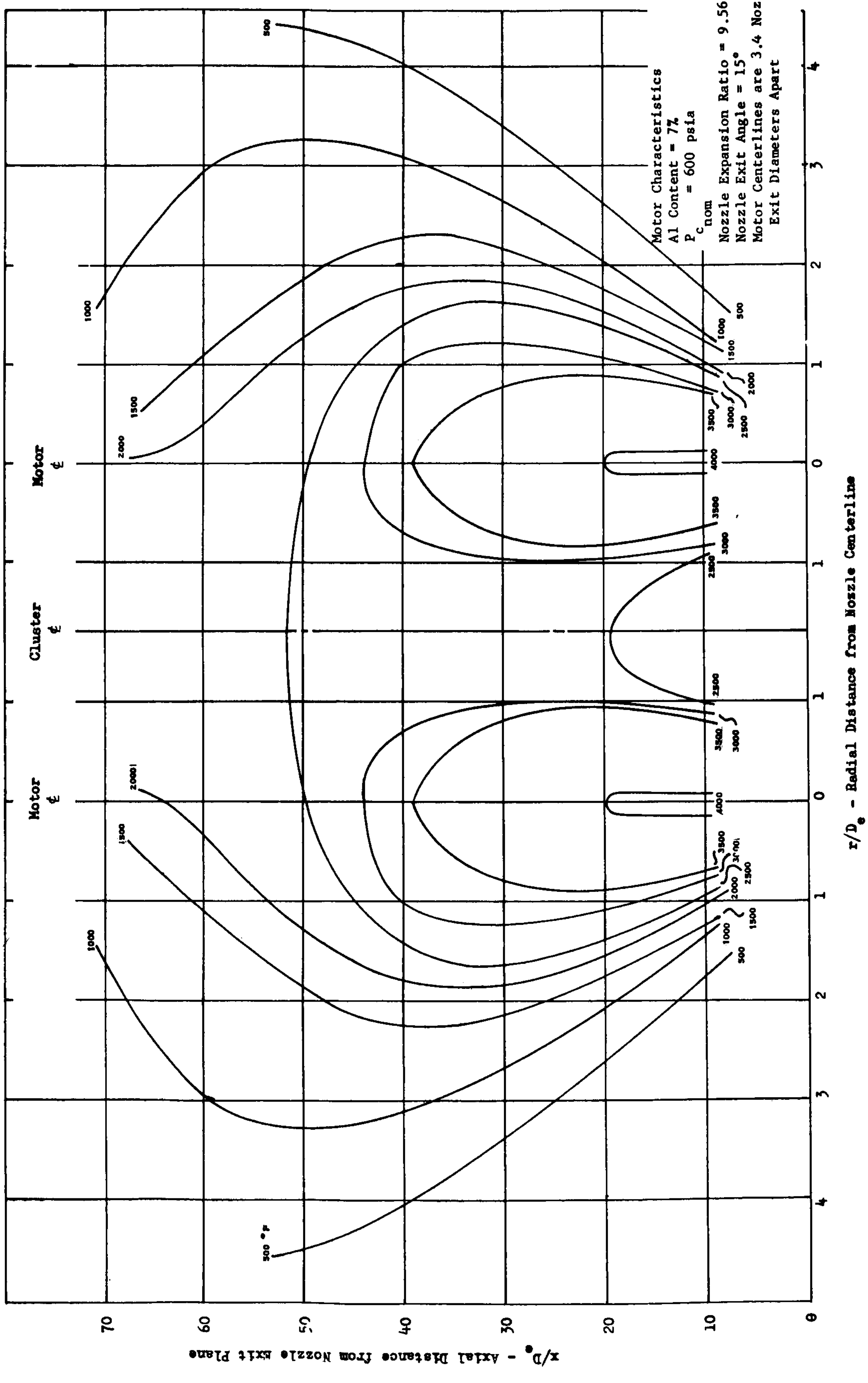


Fig. [illegible] Dual Motor Exhaust Plume Pressure Profile



Motor Characteristics
Al Content = 7%
$P_{c_{nom}}$ = 600 psia
Nozzle Expansion Ratio = 9.56
Nozzle Exit Angle = 15°
Motor Centerlines are 3.4 Nozzle
Exit Diameters Apart

Fig. 4 Dual Motor Exhaust Plume Stagnation Temperature Profile

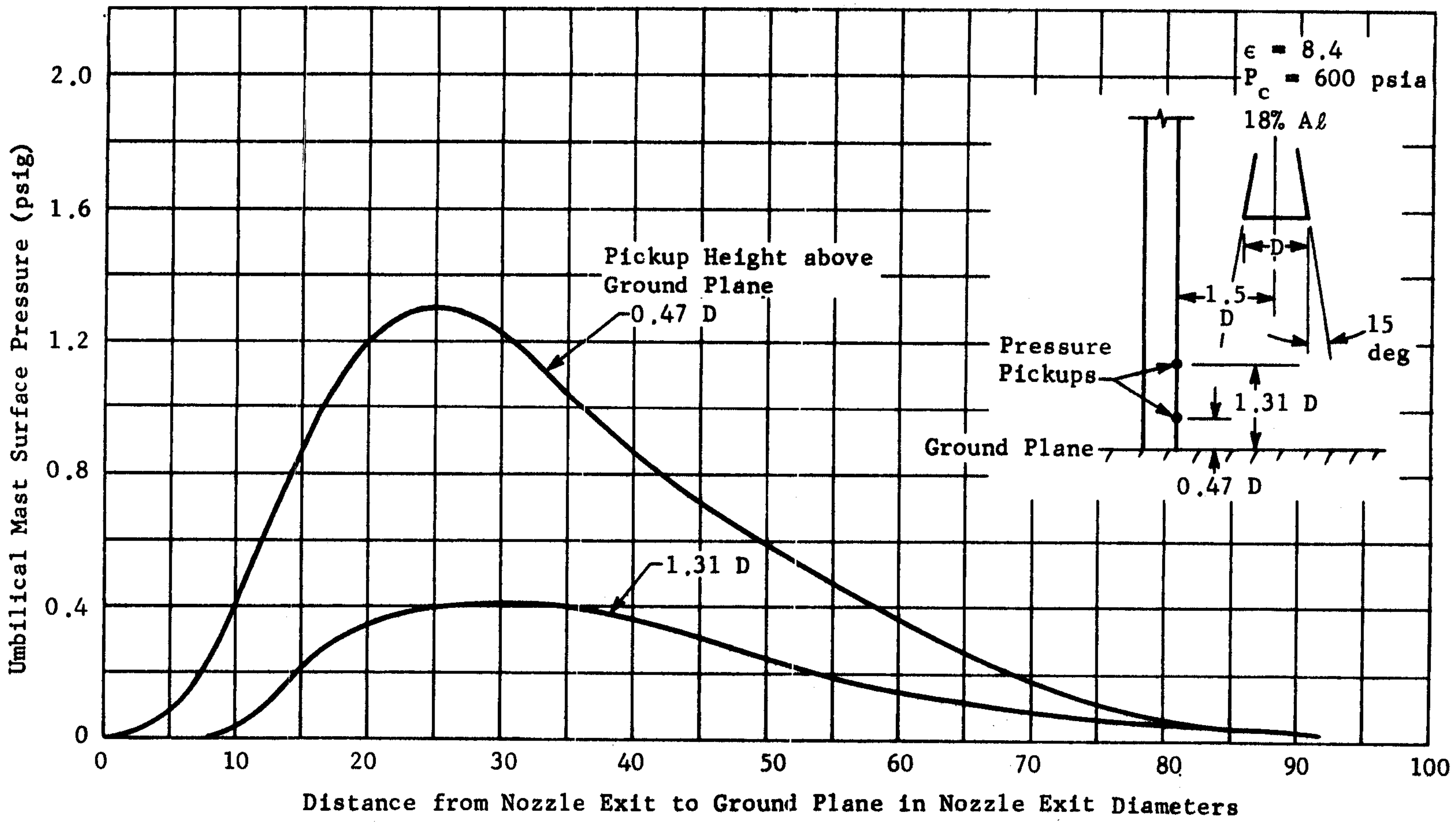


Fig. 5 Variation of Umbilical Mast Surface Pressure during Liftoff

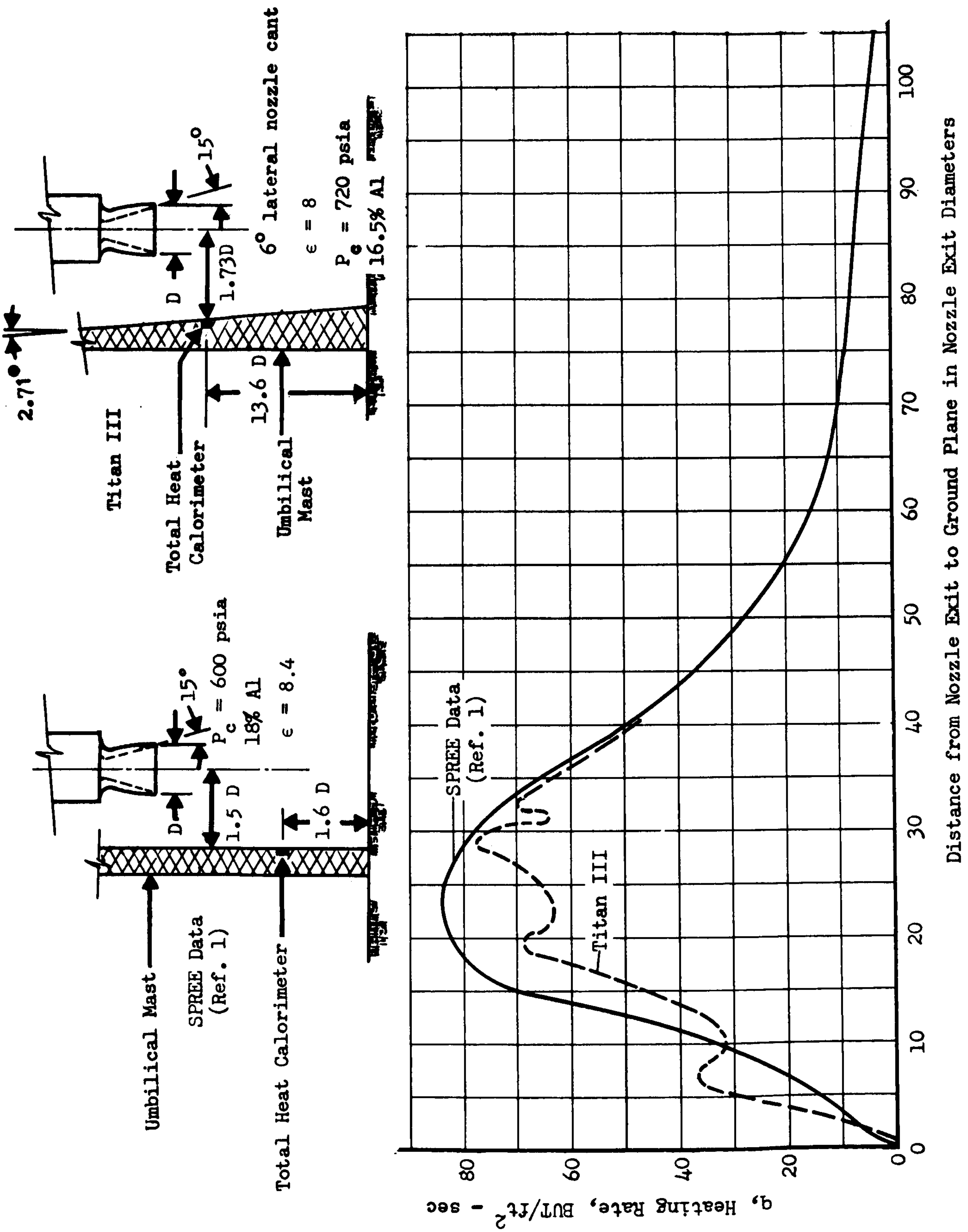


Fig. 6 Umbilical Mast Heating Environment during Liftoff

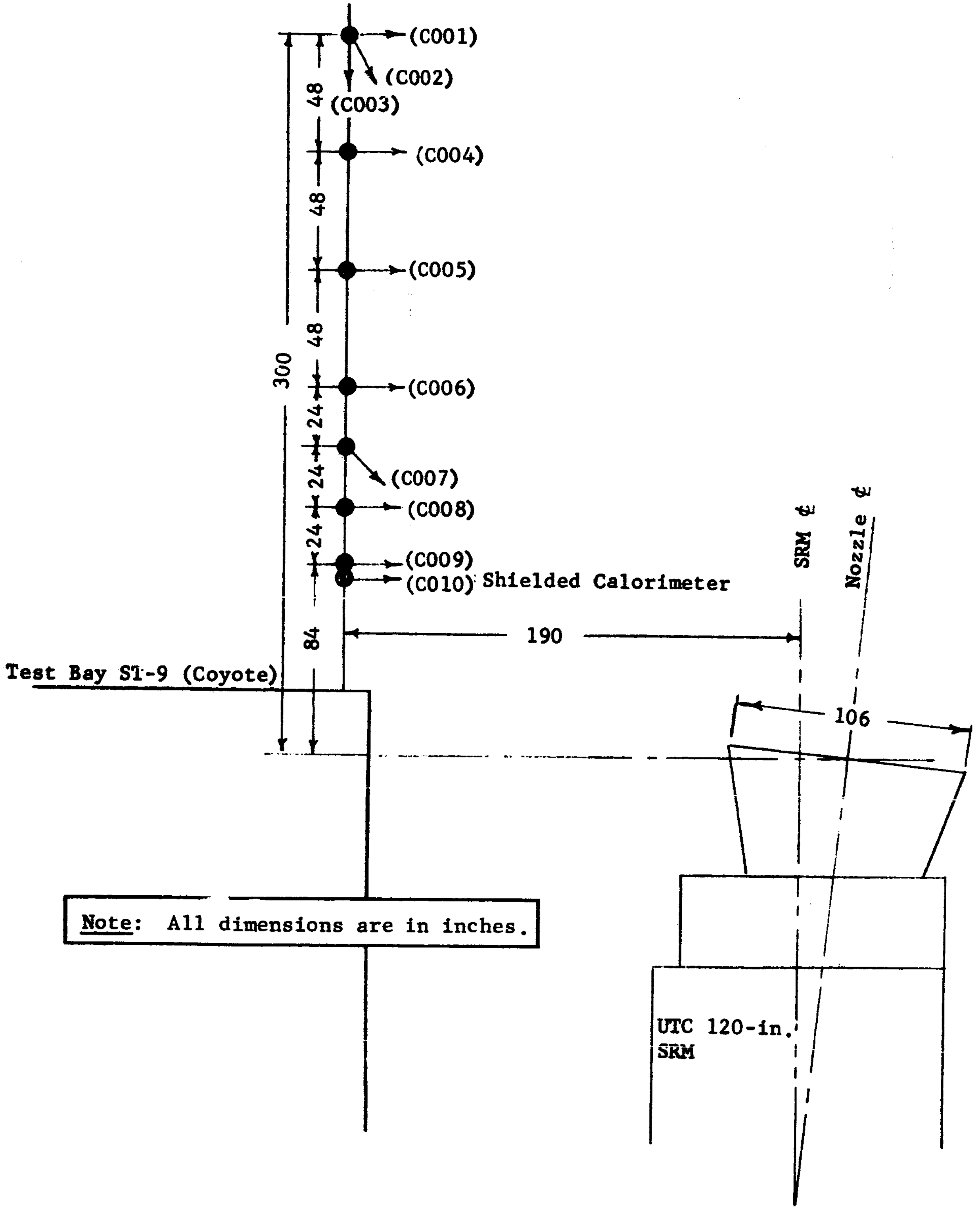


Fig. 7 Radiation Calorimeter Locations UTC 120-in. SRM

Table 1 UTC 120 in. SRM Radiation Data

Sensor	Without TVC Injection $q_{max.}$ (Btu/ft^2-sec)	Without TVC Injection q_{avg} (Btu/ft^2-sec)	With TVC Injection q_{avg} (Btu/ft^2-sec)
C001	11.09	10.68	9.25
C002	10.36	9.88	7.00
C003	4.82	4.66	3.10
C004	10.78	10.43	8.75
C005	11.29	10.82	8.55
C006	10.06	9.59	8.40
C007	5.36	4.65	3.70
C008	9.23	8.05	7.50
C009	8.49	8.09	7.30
C010	1.66	1.04	0.55

Note: $q_e = \frac{q_{inc}}{F_{Ae}} = \frac{q_{abs}}{\alpha F_{Ae}}$.

q_e Apparent plume emissive power.

q_{inc} Radiation incident on calorimeter.

q_{abs} Radiation absorbed by calorimeter.

α Absorbtivity ≈ 0.89.

F_{Ae} Radiation source shape factor (actual shape factor is unknown, but it is known that the factor is somewhere between values for a 15-deg cone and a cylinder.

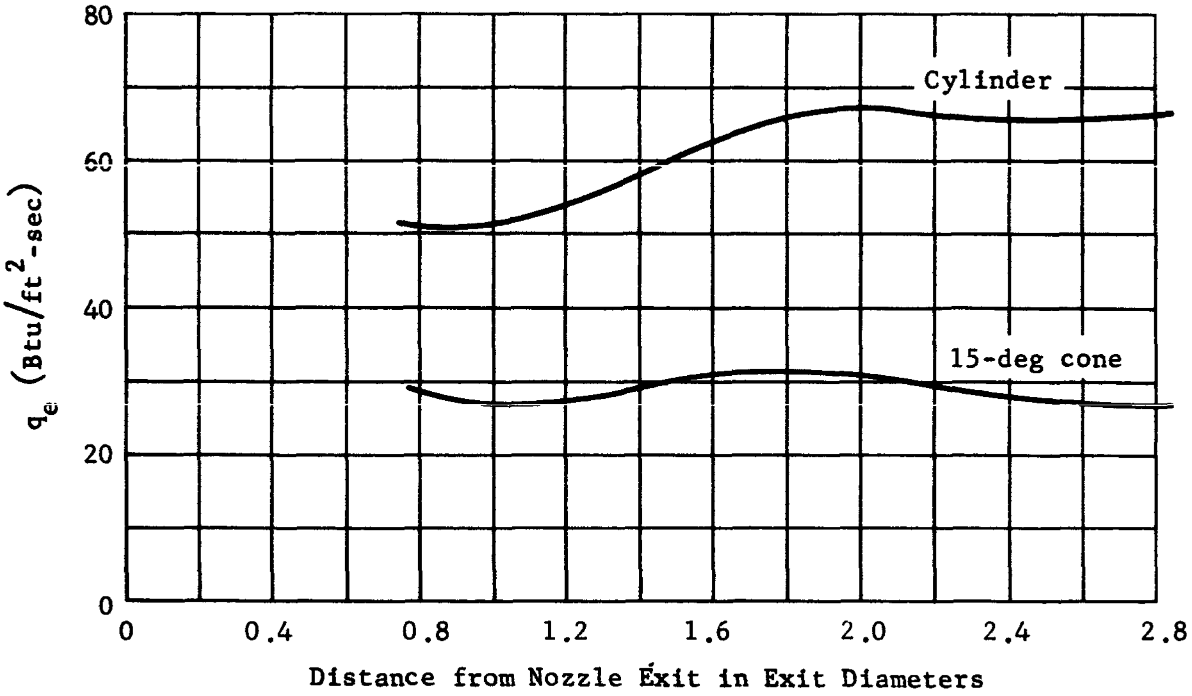


Fig. 8 UTC 120-in. SRM Apparent Plume Emissive Power

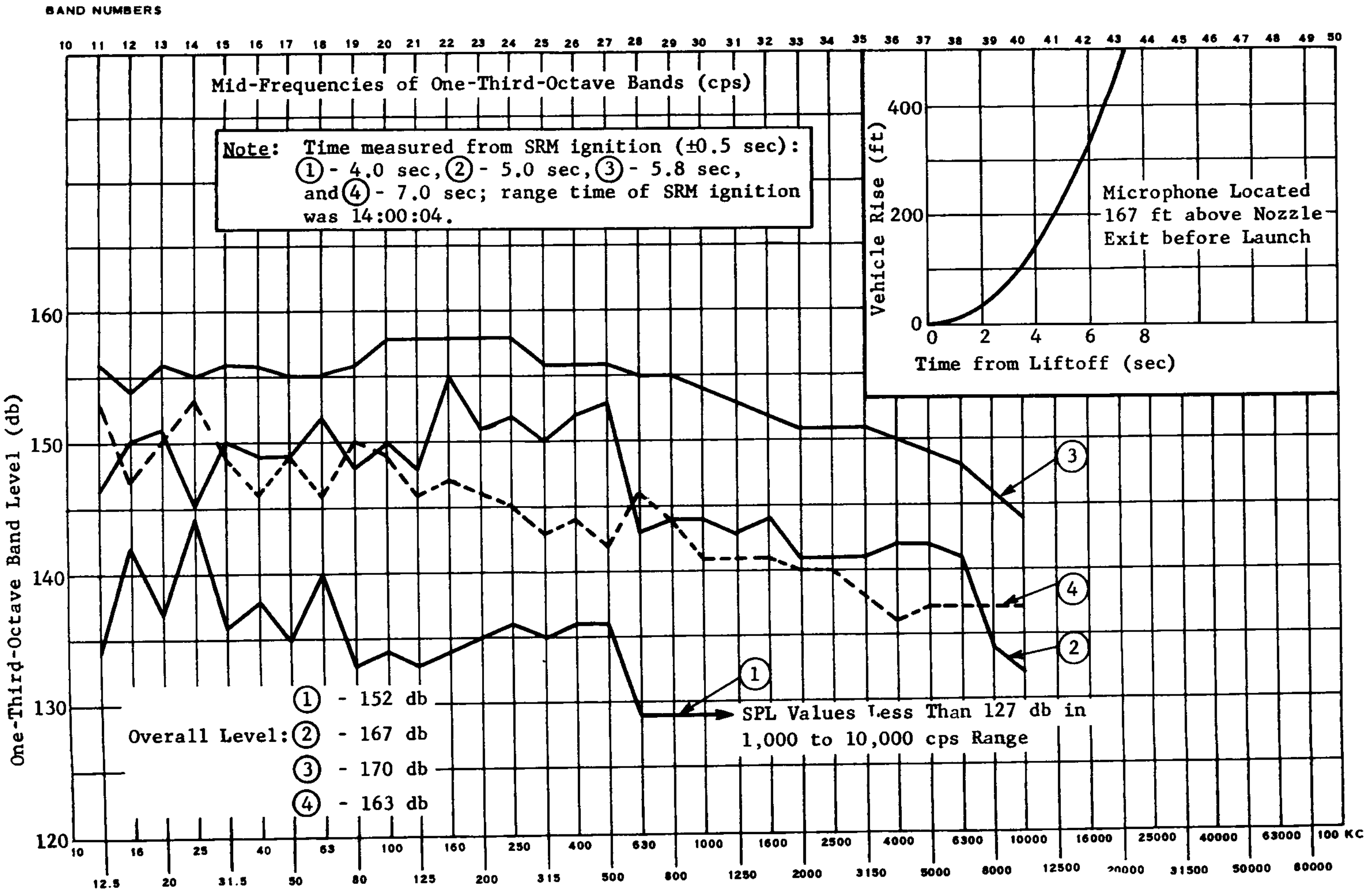


Fig. 9 Correlation of Acoustic Spectra vs Time - Measurement No. 8020 on Umbilical Tower

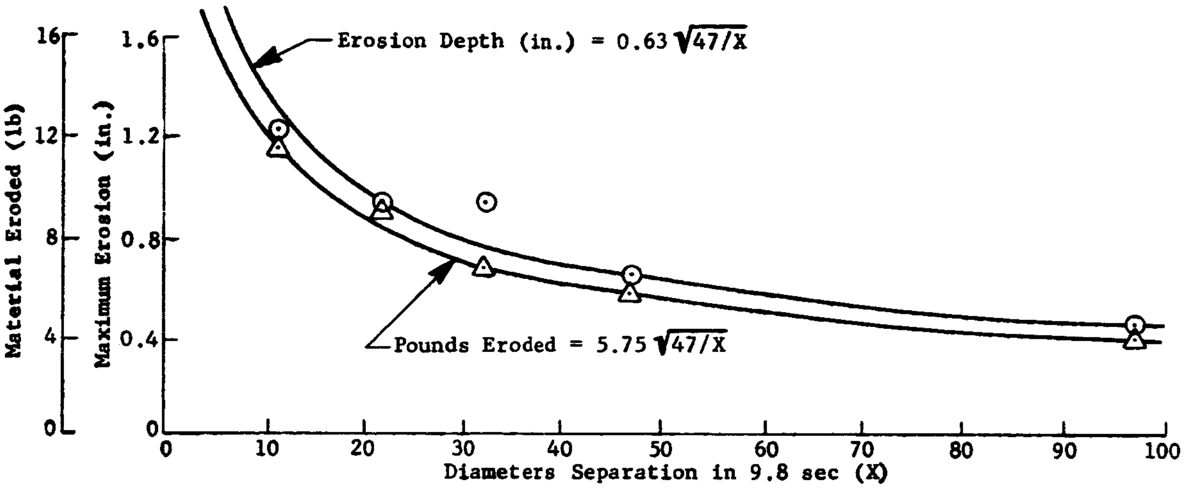


Fig. 10 Effect of Liftoff Acceleration on Erosion

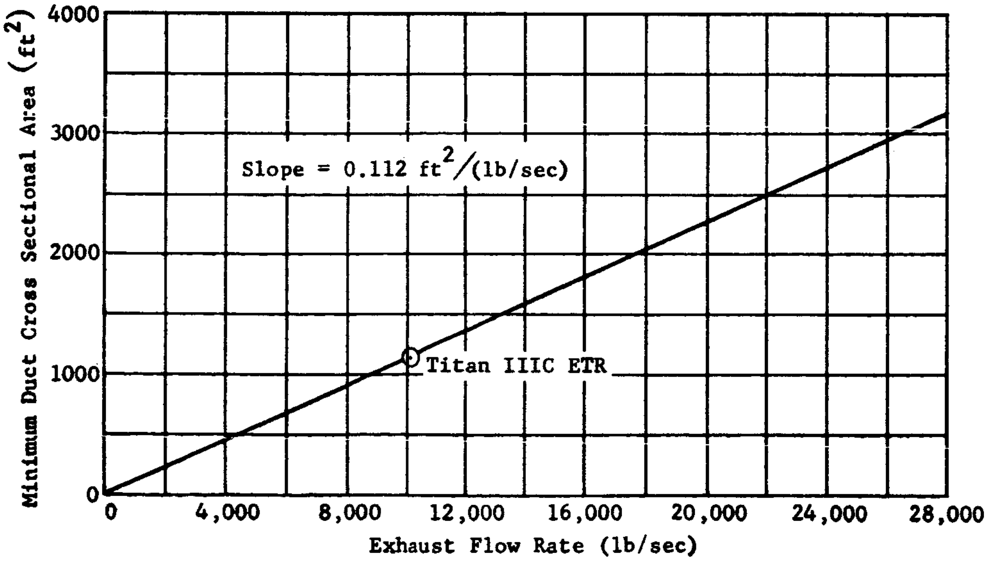


Fig. 11 Exhaust Duct Sizing Nomograph

3.0 DEFLECTOR COATINGS

3.1 Selection of Coating

There are several factors that enter into the choice of material to be used as a coating in jet impingement areas. Probably the most significant factor is the surface temperature expected to result from the jet impingement. When surface temperatures remain below 1000°F, an ordinary Portland cement concrete can be used. For surface temperatures ranging between 1000 and 1500°F Portland cement mixes may be used but aggregates in which quartz is the primary phase should be avoided and basic igneous rock, nonglassy blast furnace slag, or clay-based manufactured aggregate should be substituted. At temperatures above 1500°F the Portland cement-aggregate bond deteriorates seriously weakening the concrete. Flame deflector surfaces are generally heated to temperatures well above 1500°F and need the protection afforded by a refractory concrete. A refractory concrete deflector coating should have the following characteristics:

1) High resistance to thermal shock;

2) High strength at high temperature;

3) Negligible change in length at very high temperature;

4) Spall resistance;

5) Resistance to crack propagation;

6) Resistance to acoustic shock;

7) Good insulation properties to prevent the conduct of heat to the steel reinforcement (the steel, when heated, will expand and crack the concrete);

8) Ability to be applied by the Gunite process;

9) Ability to be cured by normal procedures without cracking.

3.2 Characteristics of Materials and Installation Methods

The characteristics of four candidate Harbison-Walker deflector coating materials and Fondu Fyre WA-1 and XB-1 are shown on the data sheets on the following pages. Note the high strength of these materials at high temperatures and the small percentage linear change. The approximate chemical analysis of Fondu Fyre WA-1 and XB-1 is also given together with methodology for mixing, placement, bonding, finishing and curing, and a guide specification for pneumatic placement.

DATA SHEET 1

Brand Name: HARBISON-WALKER HARCAST ES

Description: A refractory castable consisting of calcined grog blended with a high purity calcium aluminate binder.

Uses: Developed to be used in extreme abrasion applications such as petroleum refinery equipment cyclones and piping.

Features: Adaptable for gunning, casting, or trowelling. Highly abrasion resistant. Excellent strength throughout its temperature range. Must be predampened before gunning.

Technical Data: Physical Properties (Typical)

Maximum service temperature	2800°F
Weight required per cu ft	131
Approximate water required per 100 lb	1¼ gal.
Bulk density after drying at 230°F	140
Modulus of rupture (lb/sq in.)	
After drying at 230°F	1100 to 1350
After heating at 1000°F	1000 to 1300
After heating at 1500°F	1000 to 1300
After heating at 2700°F	3000 to 3700
Cold crushing strength (lb/sq in.)	
After drying at 230°F	6500 to 9500
After heating at 1000°F	6000 to 9300
After heating at 1500°F	6000 to 9500
After heating at 2700°F	14,000 +
Linear change (%)	
After drying at 230°F	Negligible
After heating at 1000°F	Negligible
After heating at 1500°F	Negligible
After heating at 2700°F	-0.5 to -1.2

Note: All data based on cast samples. Above data obtained after heating for 5 hr at the indicated temperatures. For data if vibration cast or gunned, consult our Pittsburgh office. All data subject to reasonable deviations and, therefore, should not be used for specification purposes.

Shipping Data: Shipped in 100-lb multi-wall moisture-proof sacks.

Location	Railroad
Fulton, Mo.	GM&O

DATA SHEET 2

Brand Name: HARBISON-WALKER EXTRA STRENGTH CASTABLE

Description: Blended mixture of carefully sized hard-fired refractory aggregate and hydraulic binder.

Uses: Ash pits, hoppers and ducts, annealing furnace car tops, tunnel kiln car bottoms, oil refining vessel linings, cyclones, iron blast furnace mains, rotary kiln coolers and chain sections, hoods and dust chambers, rocket launching pads, and warm-up aprons.

Features: Strongest refractory castable in its temperature range. High density and low permeability. Resistant to mechanical impact and abrasion. Satisfactory for pneumatic gun emplacement. Conforms to ASTM Classification C401-60, Class A and B.

Technical Data: Physical Properties (Typical)

Maximum service temperature	2400°F
Pounds of dry castable required per cu ft	121
Approximate amount of water required for pouring	1-3/4 to 2 US gal./100 lb
Bulk density after drying at 230°F (lb/cu ft)	130
Modulus of rupture (lb/sq in.)	
After drying at 230°F	900 to 1150
After heating at 1000°F	400 to 600
After heating at 1500°F	400 to 600
After heating at 2300°F	450 to 750
Cold crushing strength (lb/sq in.)	
After drying at 230°F	4100 to 6500
After heating at 1000°F	3100 to 4500
After heating at 1500°F	3100 to 4500
After heating at 2300°F	2700 to 3100
Linear change (%)	
After drying at 230°F	Negligible
After heating at 1000°F	0.0 to -0.2
After heating at 1500°F	0.0 to -0.3
After heating at 2300°F	-0.1 to -1.0

Note: All data obtained on cast samples. If vibration cast or gunned, consult our Pittsburgh office. All data subject to reasonable deviations and, therefore, should not be used for specification purposes.

Shipping Data: Shipped in 100-lb multi-wall moisture-proof sacks.

DATA SHEET 3

Brand Name: HARBISON-WALKER EXTRA STRENGTH CASTABLE LI

Description: Prepared from high-fired calcined clays and low-iron calcium aluminate binder with plasticizers.

Uses: Tunnel kiln car bottoms, oil refining vessel linings, cyclones, iron blast furnace mains, iron blast furnace upper in wall and top.

Features: This castable has excellent strength throughout its entire range and combined iron content of less than 2%. May be gunned, cast, trowelled, or rammed.

Technical Data: Physical Properties (Typical)

Maximum service temperature	2600°F
Weight required per cu ft	122 lb
Approximate water required per 100 lb	1-3/4 to 2 US gal.
Bulk Density after Drying at 230°F	129
Modulus of rupture (lb/sq in.)	
After drying at 230°F	850 to 1050
After heating at 1000°F	370 to 560
After heating at 1500°F	350 to 550
After heating at 2500°F	1000 to 1800
Cold crushing strength (lb/sq in.)	
After drying at 230°F	4000 to 5500
After heating at 1000°F	3300 to 4400
After heating at 1500°F	2500 to 4000
After heating at 2500°F	4300 to 5400
Linear change (%)	
After drying at 230°F	Negligible
After heating at 1000°F	-0.2
After heating at 1500°F	0.0
After heating at 2500°F	+0.5

Note: All data based on cast samples. Above data obtained after heating for 5 hr at the indicated temperatures. For data if vibration cast or gunned, consult our Pittsburgh office. All data subject to reasonable deviations and, therefore, should not be used for specification purposes.

Shipping Data: Shipped in 100-lb multi-wall moisture-proof sacks.

Location	Railroad
Clearfield, Pa.	PRR - NYC - B&O
Fulton, Mo.	GM&O

DATA SHEET 4

Brand Name: HARBISON-WALKER SPECIAL MIX 13-65 FUSED SILICA CASTABLE

Description: Blended mixture of carefully sized aggregate of fused silica bound by calcium-aluminate hydraulic setting cement.

Uses: Rocket launch pad facilities.

Features: Adaptable for vibration casting and pneumatic gunning. High resistance to thermal shock.

Technical Data:

Bulk density (lb/cu ft)	115
Approximate water required when cast (%)	13.5
Cold crushing strength (lb/sq in.)	
After drying at 230°F	4500 to 5500
After heating at 2000°F	2100 to 2500
Linear change (%)	
After heating to 1500°F	0.1

Note: Test samples were soaked at 2000°F until uniformly heated and then quenched immediately into room temperature water. After five cycles of such treatment, no loss in cold crushing strength was noted as compared to strength of samples merely submitted to a soaking heat of 2000°F, cooled and then tested.

DATA SHEET 5

Brand Name: FONDU FYRE WA-1 AND XB-1

Technical Data:

	WA-1	XB-1
Density (lb/ft^3)	115	180
Compressive strength (psi @ 7 days)	5000	3000
Transverse bending	916	430
Modulus of elasticity (10^6 psi @ 7 days)	4.3	4.3
Porosity (%)	16	25
Coefficient of thermal expansion (in. x 10^{-6}/°F)	5.6	5.6
Coefficient of thermal conductivity (Btu/hr/ft^2/°F/in.)	3.5 to 4.5	11 to 13
Specific Heat (Btu/lb°F) estimated at 0°C	0.185	0.145

DATA SHEET 6

APPROXIMATE CHEMICAL ANALYSIS OF FONDU FYRE (%)

WA-1		XB-1	
SiO_2	34.0	ZrO_2	53.0
Fe_2O_3	11.5	SiO_2	27.0
$A\ell_2O_3$	26.5	$A\ell_2O_3$	16.0
FeO	1.2	CaO	3.6
CaO	20.1	Fe_2O_3, MgO, Na_2O	0.4
TiO_2	0.5		100.0
Na_2O	4.2		
MgO, K_2O, and Ignition Loss	2.0		
	100.0		

DATA SHEET 7

FONDU FYRE REFRACTORY CONCRETE

Recommended Construction Practices

Description - Fondu Fyre is a carefully premixed combination of selected refractory aggregates and a hydraulic setting binder. Two types are available: WA-1 and XB-1. Both are delivered in 100-lb bags and require only the addition of clean water before placement.

WA-1 is designed for use as shielding from radiant heat and short-duration flame impingement in all areas of launch buckets and flame deflectors. It is used also as a refractory concrete base for XB-1.

XB-1 is designed for use as a highly resistant topping for WA-1 in flame impingement areas. It is especially resistant to thermal shock, high temperatures, and severe erosion.

Mixing - Contamination, mixing time and water content are critical to the mixing of Fondu Fyre. To avoid flash set, all mixing and handling equipment for Fondu Fyre must be free of lime from Portland Cement or plaster. Conventional concrete mixing equipment is satisfactory.

Mixing time should be kept to a minimum and the batch discharged as soon as it is homogeneous and plastic. This time is usually no more than 5 minutes and should not exceed 12 minutes to avoid premature setting and strength loss.

Only enough water to obtain a stiff but freely plastic mix should be added. The maximum water for pour batches should be about 2.0 gal. per 100-lb bag of WA-1 and 1.6 gal. per 100-lb bag of XB-1. These water contents will produce a 1- to 2-in. slump, good workability, and nominal strength. Harshness and strength increase with less water. Minimum water contents for pouring are 1.5 and 1.2 gal. per 100 lb of WA-1 and XB-1, respectively. Average weights of the bags should be determined before adding water.

For gunite placement, best results are obtained when using gunite equipment that allows mixing and partial wetting of the material ahead of the hydrating nozzle. This wetting compensates for the absence of the usual aggregate moisture. The final amount of water should be controlled by the nozzleman to obtain the best placement of material.

DATA SHEET 7 (cont)

Placement - Fondu Fyre is usually deposited in uniform layers on concrete or steel surfaces that have been prepared as described below under bonding. Horizontal surfaces can be covered by either pouring or Guniting. Sloping surfaces too steep to pour can be covered by either Guniting or by the use of a large nozzle plaster gun. Fondu Fyre also can be formed and poured for special reinforced walls or other castable shapes. Nominal coverages for Fondu Fyre are:

WA-1 Poured		WA-1 Gunite Placement	
Thickness (in.)	Sq Ft/100-lb Bag	Thickness (in.)	Sq Ft/100-lb Bag
2½	4.1	2½	3.5
3	3.4	3	2.9
3½*	2.9	3½*	2.5
4	2.6	4	2.2

XB-1 Poured or Plastered	XB-1 Gunite Placement
1½-in. thick - 4.5 sq ft/100 lb	1½-in. thick - 3.5 sq ft/100 lb

---

*Recommended thickness.

Bonding - Standard methods can be used to bond Fondu Fyre to Portland cement surfaces. Old concrete surfaces should be cleaned and roughened by sandblasting. Application to new concrete should be made while the surface is still green. Metal anchorage for reinforcement can be flush shells, explosive studs, or drilled and grouted bar placed at 18 in. on centers. Poured-in-place reinforcing bar should be used for anchorage to new concrete. Reinforcement consisting of Bufnel Gripsteel surface armor (or equal) can then be welded to the anchors, keeping the armor at least ¼-in. above the concrete. The steel and concrete surface should then be moistened and cooled before Fondu Fyre placement. The minimum Fondu Fyre cover over the armor should be 1½ in.

All XB-1 topping should be bonded directly to WA-1 base as soon as the base will support it and before the initial set of the base occurs. This set will normally occur one hour after placing by Guniting and one and one-half hours when poured. Weather conditions can increase or decrease these times. The WA-1 base surface should not be trowelled smooth before applying the XB-1.

DATA SHEET 7 (concl)

Fondu Fyre can be applied to steel surfaces by welding Bufnel Gripsteel (or equal) to the steel surface and then completing the placement the same way as for Portland concrete surfaces.

Joints - Joints and surface irregularities in line with direct flame impingement cause accelerated turbulent erosion and should be avoided. When construction joints are required, they should be placed at the geometrical breaks in the finished surface. Expansion and contraction joints are not required where adequate reinforcement and base support are provided.

Finishing - A relatively smooth and uniform surface is required. This can be obtained usually with one or two passes of a wood or steel float. Trowelling of poured surfaces should be minimized to prevent pumping of fines. Irregular Gunite surfaces should be trowelled smooth. Water should not be added to aid finishing operations.

Curing - The surface is usually ready for curing about 4 to 5 hr after placement. When a wetted finger will not disturb the surface fines, the area is ready for curing. Curing should be accomplished by a very light water spray. This spray should not be applied until the Fondu Fyre has hardened sufficiently so that the water does not disturb the surface fines. Curing should be continued for 24 hr. Fondu Fyre can be fired on 24 hr after installation; however, performance is improved if the material can cure for 3 to 7 days.

DATA SHEET 8

FONDU FYRE REFRACTORY CONCRETE

Guide Specification for Pneumatically-Placed Concrete

Scope of Work - The builder will provide all labor, materials, tools, and equipment and will perform all operations to complete the placement of Fondu Fyre pneumatically-placed refractory concrete as shown on the drawings and described in these specifications.

Codes and Specifications - The following codes and specifications, together with current revisions, will form a part of this section of the specifications.

American Concrete Institute 805 Recommended Practice for the Application of Mortar by Pneumatic Pressure.

Gunite Contractors Association General Specifications G-55-61.

American Society for Testing Materials A185 Specifications for Welded Steel Wire fabrics for Concrete.

Materials - Materials furnished by the builder will be new stock conforming to their respective designated specifications.

Fondu Fyre dry ingredients will be as manufactured by Designed Concretes Company, Santa Fe Springs, California, in preportioned quantities.

Mixing water will be potable.

Wire fabric will conform to ASTM A185, or where surface armor is used, will be at least 3/4 in. x 14 gage Bufnel Gripsteel or equal.

Special Inspection - The builder will obtain the services of the manufacturer's technical representative to inspect and advise on the mixing, placement, and curing operations of Fondu Fyre.

Reinforcement - Before Fondu Fyre placement, all metal anchorage and reinforcement will be free from rust, scale, grease, or other coatings that may reduce the bond.

Reinforcement will not be placed, or allowed to remain within the top 1½ in. of the finished Fondu Fyre surface.

DATA SHEET 8 (cont)

Placing - Fondu Fyre will be placed by experienced nozzlemen in accordance with best practices of the trade. When enclosing reinforcing, care will be taken to remove loose sand or rebound from the surfaces before Guniting the Fondu Fyre.

Fondu Fyre will be premixed with clean water, approximately ½ to 1 gal. of water to 100 lb of dry material, before being admitted to the hose. Final hydration will take place in the Gunite nozzle.

The proportion of water to cement contained in Fondu Fyre will be the minimum required to produce a Gunite mixture which, when shot, will form a homogeneous mass containing neither sags or dry sand formation.

Surfaces to receive Fondu Fyre will be thoroughly cleaned of all debris, loose particles and dust. Just before receiving Fondu Fyre the surfaces will be wetted as approved by the owner's representative.

Compression test samples will be shot as required by the owner's representative and in accordance with ACI 805.

Finishing - Fondu Fyre surfaces will be finished with a steel trowel to provide a smooth, sandy textured surface.

Curing - Curing will be accomplished using a very light water spray or mist. Curing compounds will not be permitted.

Curing will commence not sooner than the formation of a fines-retaining surface crust or glaze (usually 4 to 5 hr) and proceed continuously for a period of not less than 24 hr.

Bonding - Bonding of Fondu Fyre topping mixtures to fresh Fondu Fyre base mixtures will be accomplished by applying the topping as soon as the base will support the mixture and before initial set of the base has occurred.

Bonding of Fondu Fyre to concrete bases will be accomplished by using a system of shear resistant metal anchor rods in combination with wire mesh or not less than 3/4 in. x 14 gage Gripsteel Surface Armor (or equal).

Bonding of Fondu Fyre to metal plates will be accomplished by using shear resistant studs and 3/4 in. x 14 gage Gripsteel Surface Armor (or equal).

DATA SHEET 8 (concl)

Acceptances - The owner's representative will witness Fondu Fyre application and inspect the finished work for inclusions of rebound, sags, or sloughing. Hollow spots will be detected by sounding with a hammer. Imperfections discovered will be cut out and replaced with sound material at no additional cost to the owner.

Before final acceptance, the builder will furnish the owner's representative with copies of reports on all tests performed.

3.3 Behavior Prediction

Considerable work has been done to enable the prediction of the behavior of candidate deflector coating materials (Ref 1 and 2). The work encompassed the effects of liftoff acceleration, solid rocket motor aluminum content, and chamber pressure on deflector erosion and was verified by a scale effects investigation. The tests to determine effects of liftoff acceleration revealed that deflector erosion is approximately inversely proportional to the square root of liftoff acceleration expressed in nozzle diameters per sec^2. Evaluations of the effect of SRM aluminum content showed that erosion was not proportional to aluminum content but was greatest where the amount of aluminum in the propellant was optimum from a specific impulse standpoint. The chamber pressure investigation (Ref 2), which was based on very limited data, revealed that erosion was proportional to chamber pressure squared. This indication was entirely unsuspected and could not be explained on the basis of theoretical considerations. The relationship was adopted, however, to provide a conservative approach to erosion prediction. The scale effects investigation involved the correlation of full-scale Titan IIIC data obtained from the first launch with scale model data. Figure 12 is a deflector erosion prediction nomograph that summarizes the results of the work done in Ref 1 and 2.

Resistance to erosion should not be the only deflector coating characteristic considered when selecting a coating or predicting the behavior of a coating. During the investigations of Ref 1 several candidate coatings had a tendency to spall (H-W Special Mix 13-65, Fondu Fyre XB-1, and Portland cement; Fig. 13 thru 16) and some required more care in curing than others (e.g., Fondu Fyre XB-1; Fig. 17). In addition, some coatings performed more poorly when fired on a second time than they did the first time (Fondu Fyre WA-1 and Portland cement; Fig. 18). These factors must be weighed in light of the specific application. Unfortunately, only a small amount of quantitative data are available and there is little in the way of a quantitative approach that can be taken in weighing the factors.

3.4 Maintenance and Refurbishment Methods

While different coatings require different refurbishment techniques, most manufacturers of coatings recommend that the following steps be taken:

1) Remove loose scale by wire brushing and/or sandblasting;

2) Wash down deflector and allow to dry;

3) Spread epoxy in the area to be refurbished;*

4) Apply wet mix over the epoxy using the Gunite process or by packing the mix firmly in place;

5) Smooth the refurbished area and cure using a very light water spray or mist. Curing compounds aren't generally permitted. Curing should proceed for a period of no less than 24 hr.

3.5 Cost Data

The following cost data were submitted by manufacturers of candidate deflector coating materials and reflect the cost of large-quantity purchases. The data should be used as cost indicators only since the time a purchase is made, the shipping location, and the total quantity of material needed have a strong influence on the ultimate purchase price. No attempt has been made to provide cost data for all currently-available candidate coating materials, but rather to provide enough information to allow preliminary cost estimates.

Coating Manufacturer	Coating	Cost ($/ton)
Harbison-Walker, Fulton, Mo.	Extra Strength Castable	115
	Extra Strength Castable LI	125
	Harcast ES	210
	Special Mix 13-65 Fused Silica Castable	300
The Pryor Giggey Co., Whittier, Calif.	Fondu Fyre WA-1	107
	Fondu Fyre XB-1	370
Ideal Cement	Portland Cement Mix	20

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*A Fondu Fyre WA-1 deflector was refurbished by simply packing wet Fondu Fyre mix in the area to be refurbished under pressure without first coating the deflector with an epoxy. Model tests involving this deflector revealed the adequacy of this technique. A second Fondu Fyre WA-1 deflector was refurbished using an epoxy bonding agent consisting of Epon 828, Versamid 140, phenol glycidyl ether (PGE), and Fondu Fyre WA-1 from which aggregate had been screened. This second refurbishment procedure was also adequate (Ref 1).

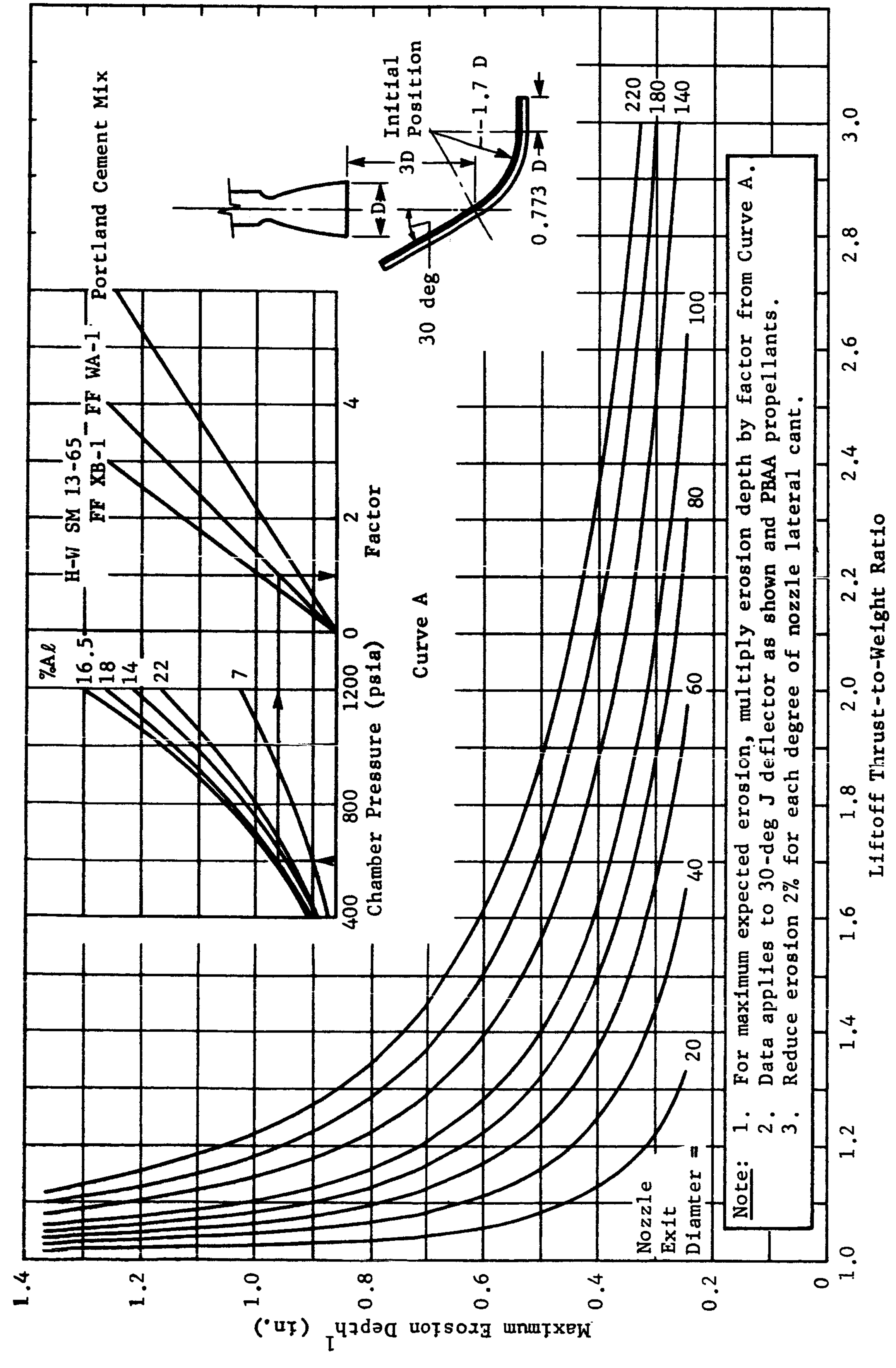
Installation Cost

The cost of installing a deflector coating is dependent on variables such as current labor costs, the type of installation, the kind and cost of reinforcing material used, etc. Data available are meager and conflicting and are presented here only to put on record the items that must be considered in deflector coating cost estimates. The data given represent actual costs of two NASA deflector coating installations.

The NASA job at Complex 37 had a total installed cost, including all materials, of $384 per ton of Fondu Fyre WA-1. The cost of welding the gripsteel and applying Fondu Fyre ran about $6.00 per sq ft. Two-thirds of the labor was on welding the gripsteel to the deflector.

The sound suppression test stand at MSFC had a sheet steel deflector to which 1-in. steel grip plates were welded and a 3-in. coating of Fondu Fyre WA-1 was applied via the Gunite process. The cost breakdown per sq ft for coating the deflector was as follows:

Steel Grip Plate	$0.79
Fondu Fyre WA-1	3.27
Application Cost	2.20
Consultant Cost	0.92
	$7.18



Note: 1. For maximum expected erosion, multiply erosion depth by factor from Curve A.
2. Data applies to 30-deg J deflector as shown and PBAA propellants.
3. Reduce erosion 2% for each degree of nozzle lateral cant.

Fig. 12 Deflector Erosion Prediction Nomograph

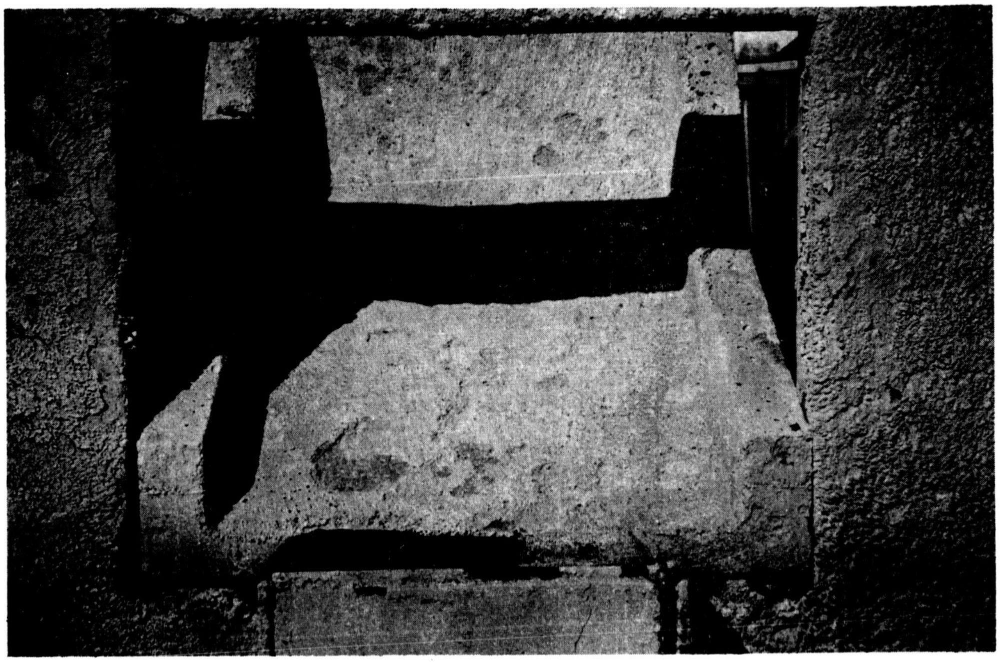


Fig. 13 Spalled H-W Special Mix 13-65 after a Firing

Fig. 14 Spalled Fondu Fyre XB-1

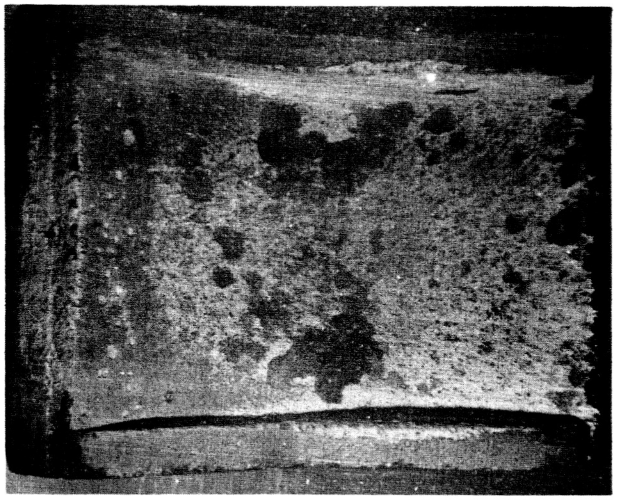


Fig. 15 Spalled Portland Cement

Fig. 16 Spalled Concrete on Southeast Corner of AGE Building, ETR Complex 40

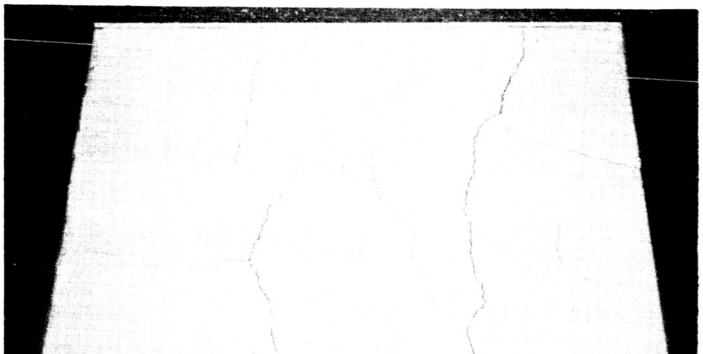
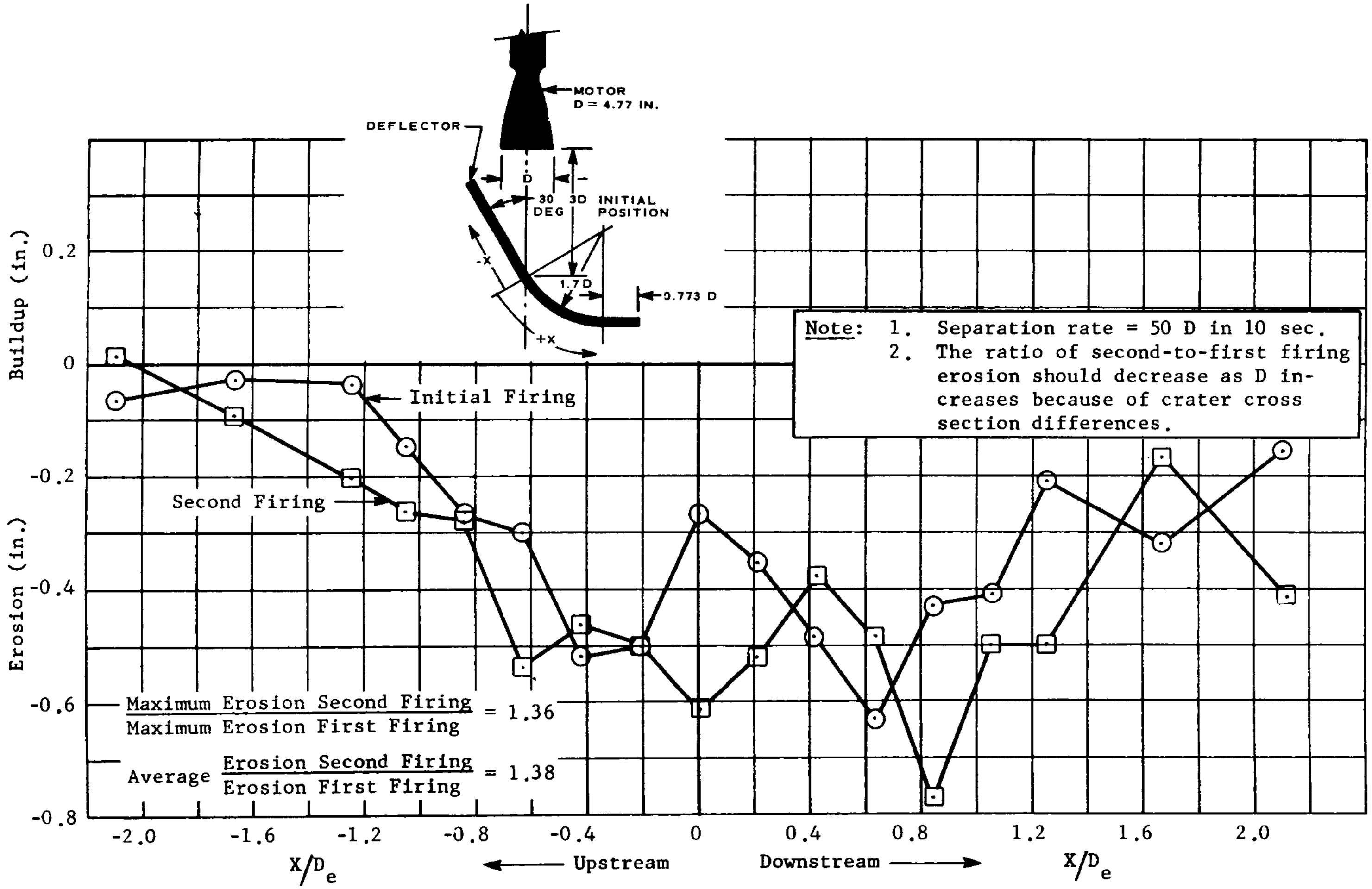


Fig. 17 Fondu Fyre XB-1 Deflector (Cracked during Cure)



Note: 1. Separation rate = 50 D in 10 sec.
2. The ratio of second-to-first firing erosion should decrease as D increases because of crater cross section differences.

$$\frac{\text{Maximum Erosion Second Firing}}{\text{Maximum Erosion First Firing}} = 1.36$$

$$\text{Average } \frac{\text{Erosion Second Firing}}{\text{Erosion First Firing}} = 1.38$$

Fig. 18 Effect of Successive Firings on the Centerline Erosion of a Fondu Fyre WA-1 Deflector

4.0 THERMAL PROTECTIVE COATINGS

4.1 Criteria for Use

Steel structures on or near a rocket launch pad are frequently exposed to the exhaust gas environment. Generally these structures see no more than the fringes of the rocket motor exhaust plume and are more than able to stand up under the temperatures and pressures encountered. However, there are launch situations during which ground winds cause the missile to drift close to the structures and immerse them well within the exhaust plume. Without some kind of thermal protection, thermal stresses, buckling, and perhaps even structural failures would occur. Work in Ref 1 indicated that if a steel structure remained at least 1.5 nozzle exit diameters laterally from the centerline of an exhaust plume, it would probably not be damaged during launch provided the space vehicle separated at least 50 nozzle exit diameters from the pad in 10 sec. This separation rate corresponds to a liftoff thrust-to-weight ratio equal to 1.25 for a 100-in. nozzle, 1.50 for a 200-in. nozzle, etc. At lower liftoff rates or where drift brings the space vehicle closer than 1.5 nozzle exit diameters to the steel structure, some type of thermal protection is in order.

4.2 Desired Characteristics

A low density coating is especially desirable for application to structures on large mobile launchers. The Saturn V mobile launcher, for instance, is difficult enough to move without the added weight of thermal protective coating material. Protective coatings should be viscous and set rapidly so as not to sag when applied to vertical surfaces. They should be easy to apply and should adhere firmly to underlying surfaces. Some contemporary coatings cost $14/sq ft to apply excluding the materials cost. An easier method of application would substantially reduce this figure.

Any coating selected should have a high resistance to thermal and acoustic shock as well as the high temperature erosive environment of an aluminized SRM. It would, of course, be unacceptable if it continued to burn after the space vehicle left the pad or if it did not impede the conduct of heat to the underlying structure. Compatibility with exhaust residue from the booster and any liquid propellants that might be used is another requirement. These chemicals should not be hypergolic upon contact with the coating or cause it to deteriorate. The coating should weather well and it should be semielastic so as not to crack if the underlying structure is temporarily deformed. It should be easy to refurbish locally and should be inexpensive.

4.3 Relative Performance

Two classes of materials have been used in actual practice as thermal protective coatings -- epoxies and silicones. The epoxies char on the surface and are ablators. The char has good emittance characteristics and is porous thus permitting a certain amount of surface cooling by transpiration. Silicones do not char unless the organic portion contains phenyl groups. The epoxies have proven to be slightly better than the silicones on the basis of small-scale tests.

A large number of off-the-shelf thermal protective coatings were screened during the SPREE program (Ref 1) and several were singled out as superior. These were Dynatherm E-300, Dow Corning Q90-006, and Martyte. Martyte is manufactured and sold by Presstite Division of Interchemical Corp. Dynatherm E-300 and Martyte are ceramic impregnated epoxies and Dow Corning Q90-006 is a silicone. Dynatherm E-300 features an asbestos fiber filler and a glasseous ceramic filler that softens and retains some of the char for future launches. It has additional transpiration formulated in the coating in the form of subliming inorganic oxides. Dow Corning Q90-006 contains iron oxide that is a good emitter of infrared radiation and thereby offers additional cooling.

The coatings evaluated during the SPREE tests were ranked according to volume loss during simulated liftoff. Dynatherm E-300 performed best of the three top contenders on this basis followed by Dow Corning Q90-006 and Martyte. Other coatings evaluated are listed below (not in the order of relative performance).

Dow Corning Q20-103

Dow Corning Q30-121

Dow Corning Q93-019

General Electric RTV 511

General Electric RTV 757 (foamed)

Raytheon RPR 2138

Fuller Fulblate 878 Type I
Fuller Fulblate 878 Type II
Fuller 190 J-4
Fuller Korblate II-190-L
Raytheon RPR 2141
Raytheon RPR 2156

In addition to the listed coatings, many others were evaluated before the selection of Martyte for the Titan IIIC integrated transporter launcher (ITL). Martyte has performed well as a thermal protective coating in actual usage on this launcher and in particular on the ITL umbilical masts.

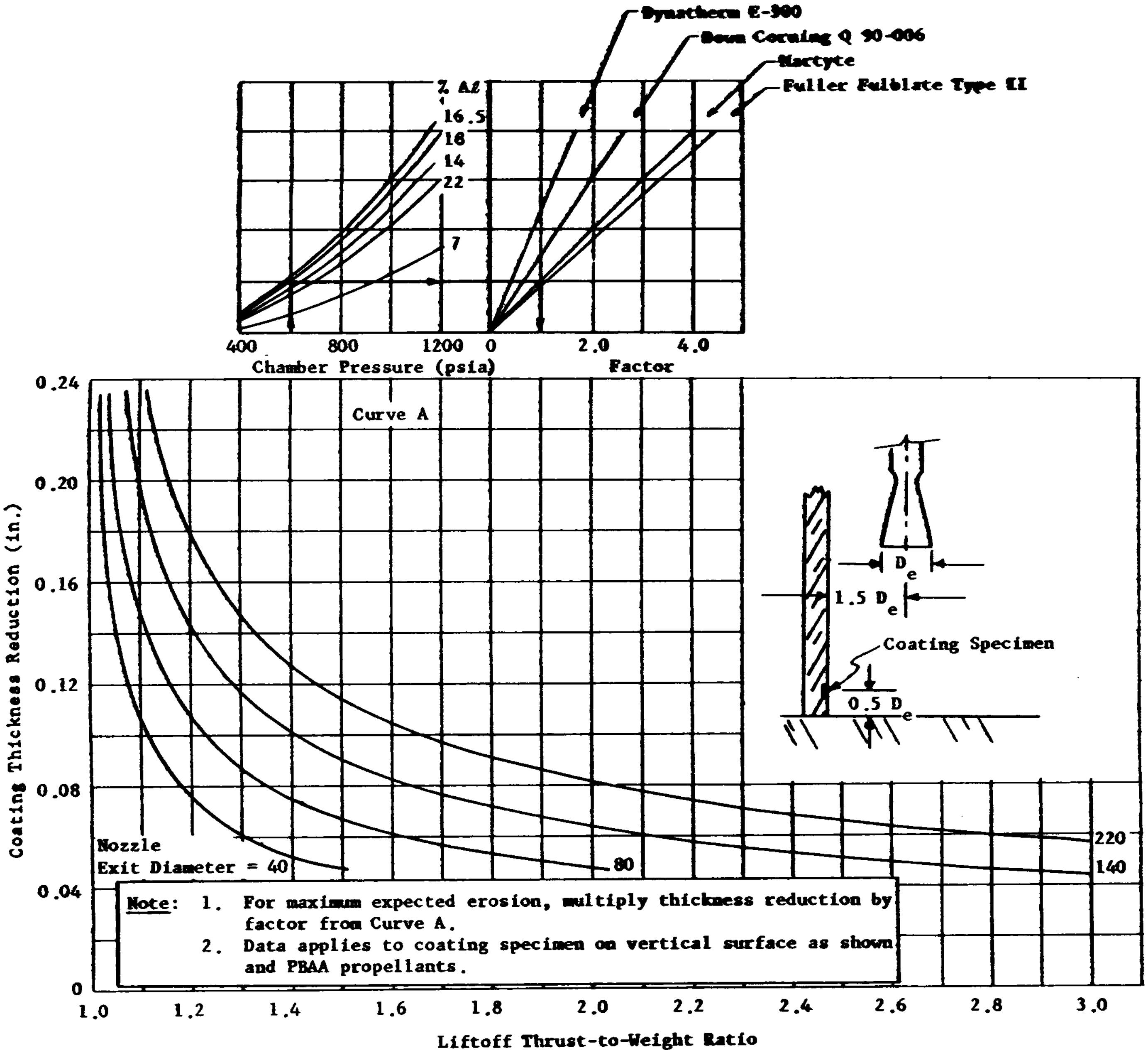
The cost of the three top contending coatings were about the same. Specific costs for large quantity purchases would have to be negotiated with the manufacturers for ranking purposes. Dynatherm E-300 and Martyte were more easily applied than Dow Corning Q90-006 and it is reported that Dynatherm is attempting to develop a gun to simplify the applicability of E-300. The specific gravities of Dynatherm E-300, Dow Corning Q90-006, and Martyte are, respectively, 1.2, 1.48, and 1.5.

4.4 Behavior Prediction

The data shown in Fig. 19 were developed from SPREE test results and give a basis for predicting the reduction in thickness of four protective coatings during launch. The nomograph applies only to coated vertical surfaces 1.5 nozzle exit diameters distant from the centerline of a single, uncanted rocket motor. The data can be applied to almost any size vehicle having a liftoff thrust-to-weight ratio of 1.0 to 3.0 and SRM chamber pressures to 1200 psi.

4.5 Cost Data

No attempt has been made to compile thermal protective coating cost data. Many of the coating costs reflect research and development amortizations and are not representative of actual material costs. Manufacturer's cost data are extremely flexible based on the quantity of material purchased. A certain ceramic impregnated epoxy, for instance, sells for $70/gal. A reasonable cost for the resin would be $6/gal. and $0.60/lb for the ceramic filler. An 11 lb kit of Dow Corning Q90-006 was purchased for SPREE testing for $54.50.



Note: 1. For maximum expected erosion, multiply thickness reduction by factor from Curve A.
2. Data applies to coating specimen on vertical surface as shown and PBAA propellants.

Fig. 19 Thermal Protective Coating Erosion Prediction Nomograph

5.0 GLOSSARY OF TERMS

D	Nozzle exit diameter
Epon 828	A product of Shell Chemical Company
PBAA	Polybutadiene acrylic acid
P_c	Rocket motor aft end chamber pressure
PCE	Pyrometric Cone equivalent
Phenol Glycidyl Ether	A product of Shell Chemical Company
q	Heating rate, Btu/ft^2-sec
SRM	Solid Rocket Motor
T_t	Exhaust Plume Stagnation Temperature
UTC	United Technology Corporation
Versamid 140	A product of General Mills
ΔP	Stagnation pressure minus atmospheric pressure; in supersonic flow, stagnation pressure refers to the pressure behind a normal shock
ϵ	Nozzle expansion ratio, $\frac{\text{exit area}}{\text{throat area}}$

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