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SHORT LENGTH SUPER HIPPO MOTOR ASSEMBLY

P. R. Scannell
W. A. Stephen

Chemical Systems Division
P. O. Box 358
Sunnyvale, CA 94088

February 1978

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Prepared for

Air Force Rocket Propulsion Laboratory
Director of Science and Technology
Air Force Systems Command
Edwards Air Force Base, CA 93523

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FOREWORD

This report was submitted by United Technologies/Chemical Systems Division, P.O. Box 358, Sunnyvale, CA 94086, under contract No. F04611-77-C-0027, job order No. 305909 JW with the Air Force Rocket Propulsion Laboratory, Edwards AFB, CA 93523.

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THOMAS L. KINSEL
Project Manager

CLARK W. HAWK
Acting Branch Chief

FOR THE COMMANDER

CHARLES R. COOKE, Director
Solid Rocket Division

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The short length HIPPO motor is a single cartridge version of the Super HIPPO high pressure ballistic test motor. The motor operates at pressures to 2,500 psi with propellant charge weights to 24,500 lb and is used to test rocket motor nozzles and components. This report summarizes the contract to design, fabricate, and install at AFRPL, including the first motor firing with a test nozzle for the Interim Upper Stage motor.

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ILLUSTRATIONS (Continued)

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1.0 INTRODUCTION

This report summarizes the design and development of the Short Length Super HIPPO workhorse solid rocket motor for testing of upper stage ballistic missile nozzle systems, propellant and insulation. The work was performed between 7 April 1977 and 3 November 1977 on contract No. F04611-77-C-0027. The Short Length Super HIPPO operates at pressure levels to 2500 psi and has 24500 lb propellant capacity.

The short length Super HIPPO (SLSH) completes the family of Super HIPPO workhorse test motors at AFRPL. The existing Super HIPPO motor has a 46,000-lb propellant capacity and the existing extended length Super HIPPO (ELSH) has an 89,000-lb propellant capacity. All three motors are of the same diameter and use interchangeable parts.

The Short Length Super HIPPO is installed in test area 1-52 at AFRPL/Edwards Air Force Base and shares spare parts and handling equipment with the Super HIPPO and ELSH motors which are installed in the High Thrust test area, 1-56.

The Short Length Super HIPPO (SLSH) motor consists of a cylindrical case which is pinned to flat plate closures. The closures are insulated by disks of asbestos phenolic and rubber. The propellant is loaded into 7-ft. diameter fiberglass cartridges identical to those used for the Super HIPPO and ELSH motors. A single propellant cartridge is used for the SLSH motor.

Detailed design analyses for this motor are presented in AFRPL TR-77-58, "Phase I Design and Analysis of Short Length Super HIPPO Motor Assembly." Background data on the related Super HIPPO and ELSH motors are available in AFRPL TR-77-24 "High Pressure Motors and Test Stand."

2.0 OBJECTIVE

The overall objective of this program was to design, fabricate, deliver, and demonstrate to AFRPL a single cartridge Super HIPPO type test motor capable of testing large scale nozzles at pressure levels up to 2,500 psig with a propellant capacity up to 24,500 lb. The addition of this motor to the Super HIPPO system provides the capability for efficient and realistic testing of components for upper stages of the next generation of ballistic missiles and launch vehicles.

3.0 SCOPE

The stated objectives of this program was accomplished in a three-phase program. Phase I consisted of design and analysis. Phase II consisted of fabricating the motor case, forward closure, clevis pins, and required motor hardware insulation. Phase III consisted of installation of the short length high pressure ballistic test motor at AFRPL, supporting hydrostatic proof testing, live motor assembly and checkout, and the first test firing.

4.0 TECHNICAL DISCUSSION

4.1 DESIGN AND ANALYSIS

4.1.1 Motor Design Description

The motor is a single propellant cartridge version of the Super HIPPO motor assembly as shown in CSD drawing C12413 and figure 4-1. The motor design is the same as that of the Super HIPPO and ELSH in that the case consists of a cylindrical barrel with flat plate end closures attached by double clevis pin joints. The motor case is approximately half the length of the Super HIPPO case to accommodate one cartridge-loaded propellant grain. The shear key attachments for nozzles or nozzle adapters are the same design as previously used on Super HIPPO and ELSH. The forward and aft insulators are the same as used on the Super HIPPO but with increased thickness on the rubber portion of the forward insulator to be compatible with the longer duration tests contemplated. The motor is ignited with a single C00631-07-01 igniter suspended into the propellant bore through the nozzle throat. The motor is capable of assembly using Super HIPPO/ELSH propellant grains. The motor case mates with and uses the existing Super HIPPO closures, insulation, cartridges, and seals, and is compatible with the following items:

Part No.	Item
C10120-01-01	Aft closure
C10277-XX-01	Forward insulation
C10280-01-01	Aft insulation
C10141-01-01	Straight pin
C10278-01-01	Spacer
C11479-0X-01	Loaded cartridge (typical)

The motor components manufactured on this program do not include propellant grains, igniters, nozzles, or insulated nozzle adapters. However, these items are shown on SLSH-IUS motor assembly drawing C12411 (figure 4-2) to provide a medium for defining installation requirements and to provide a motor assembly drawing for use with the IUS nozzle for the first motor test. A basic SLSH motor assembly drawing excludes the insulated nozzle adapter and nozzle,

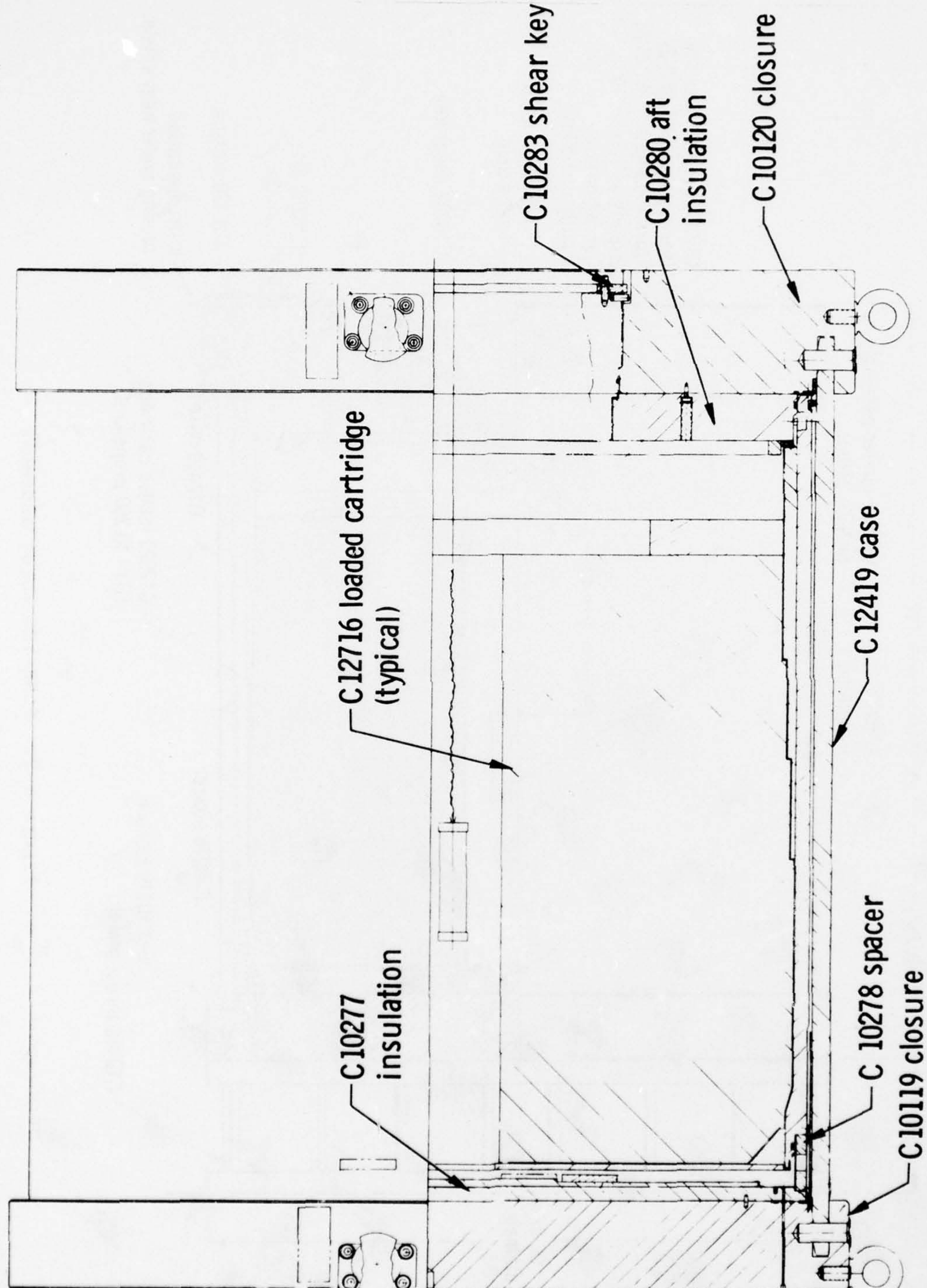

Figure 4-1. SLSH Motor Assembly

Sue 3

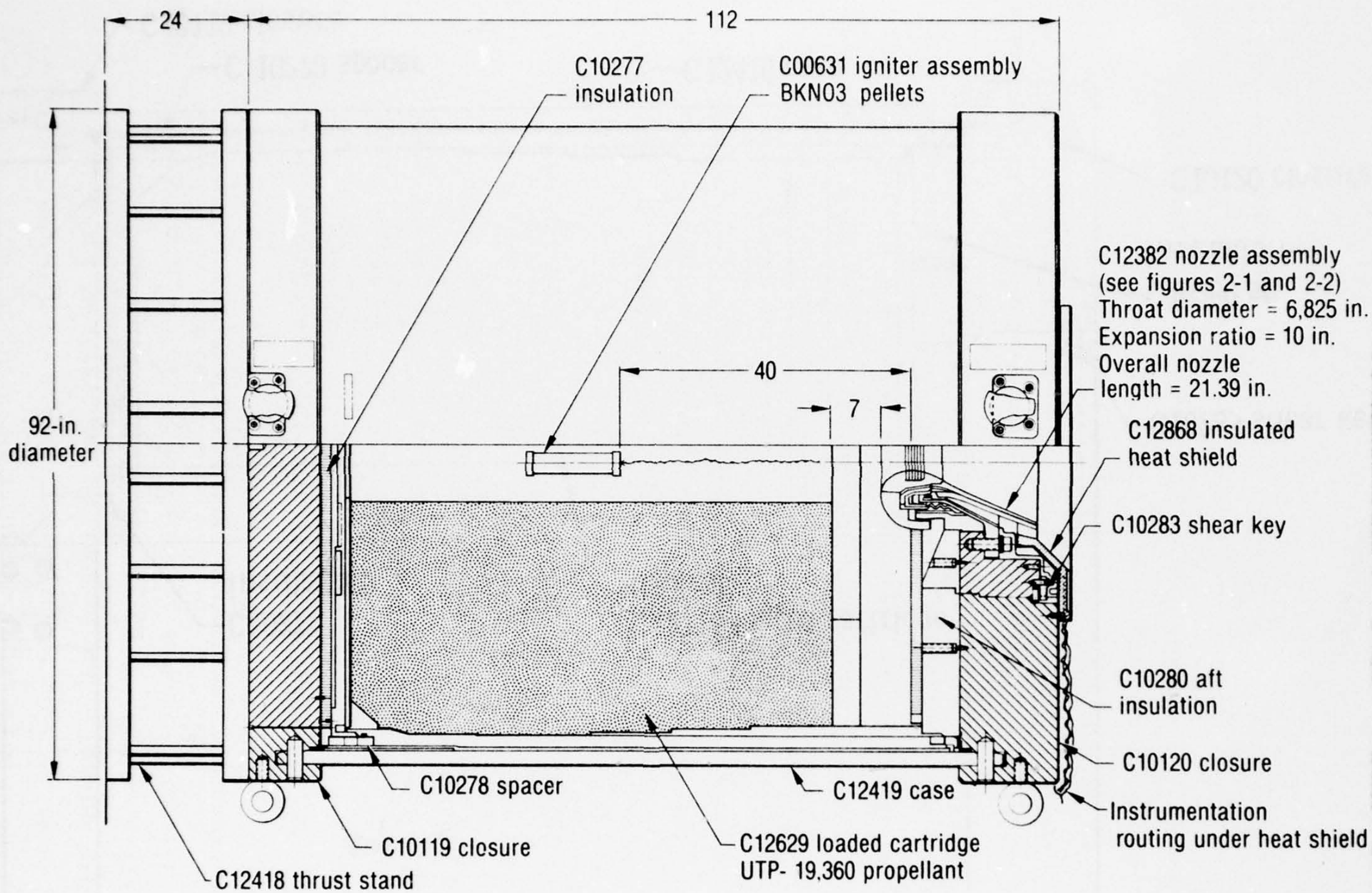

Figure 4-2. SLSH-IUS Motor Assembly

Sue 3

drawing C12413. The standard Super HIPPO with two propellant cartridges is shown in figure 4-3 for comparison.

The motor case is compatible with existing Super HIPPO handling equipment. The motor case is made of Government-furnished HY-130 steel and designed for a 5,000-psig burst strength and 2,500-psig MEOP with a safety factor of 2. The motor is capable of operating for 145 sec at 1,000 psi. The motor is adaptable to mounting to the Super HIPPO thrust stand or bolting to a simple thrust support. Motor design requirements are summarized in table 4-1.

The Super HIPPO propellant cartridge will fit directly into the case. The pressurization of the cavity outboard of the propellant grain cartridge works exactly as on Super HIPPO and ELSH; combustion gases flow under the propellant cartridge, through the holes in the C10278 spacer, and up along the walls. The O-ring seal between the aft insulator and the top of the propellant cartridge prevents through-flow of hot gases along the steel wall. The pressure drop down the propellant grain is considerably lower with this motor than with Super HIPPO or ELSH, so that there is less pressure drop behind the cartridge to cause a through-flow.

The motor insulation is made primarily of two materials, a hard asbestos phenolic material and silica-asbestos loaded Buna-N rubber (NBR). The asbestos phenolic is used for the aft insulator, the basic forward insulator, and the insulation plugs. The aft insulator bolts onto the closure, and the phenolic material is specified to provide structural stiffness. Similarly, the phenolic part of the forward insulator is held down by the weight of the propellant grain. The forward insulator also centers the bottom of the propellant grain in the motor case. A pin in the forward closure centers the forward insulator, and the grains center on a shoulder on the insulator. Insulation plugs protect the bolts which secure the insulation to the aft closure and they are retained by threads in the aft insulation. While not a part of this contract, a nozzle adapter was fabricated to adapt to the existing CHAR nozzle bolt flange. The insulator for this adapter was made of the same asbestos phenolic material and retained by similar bolts which are protected

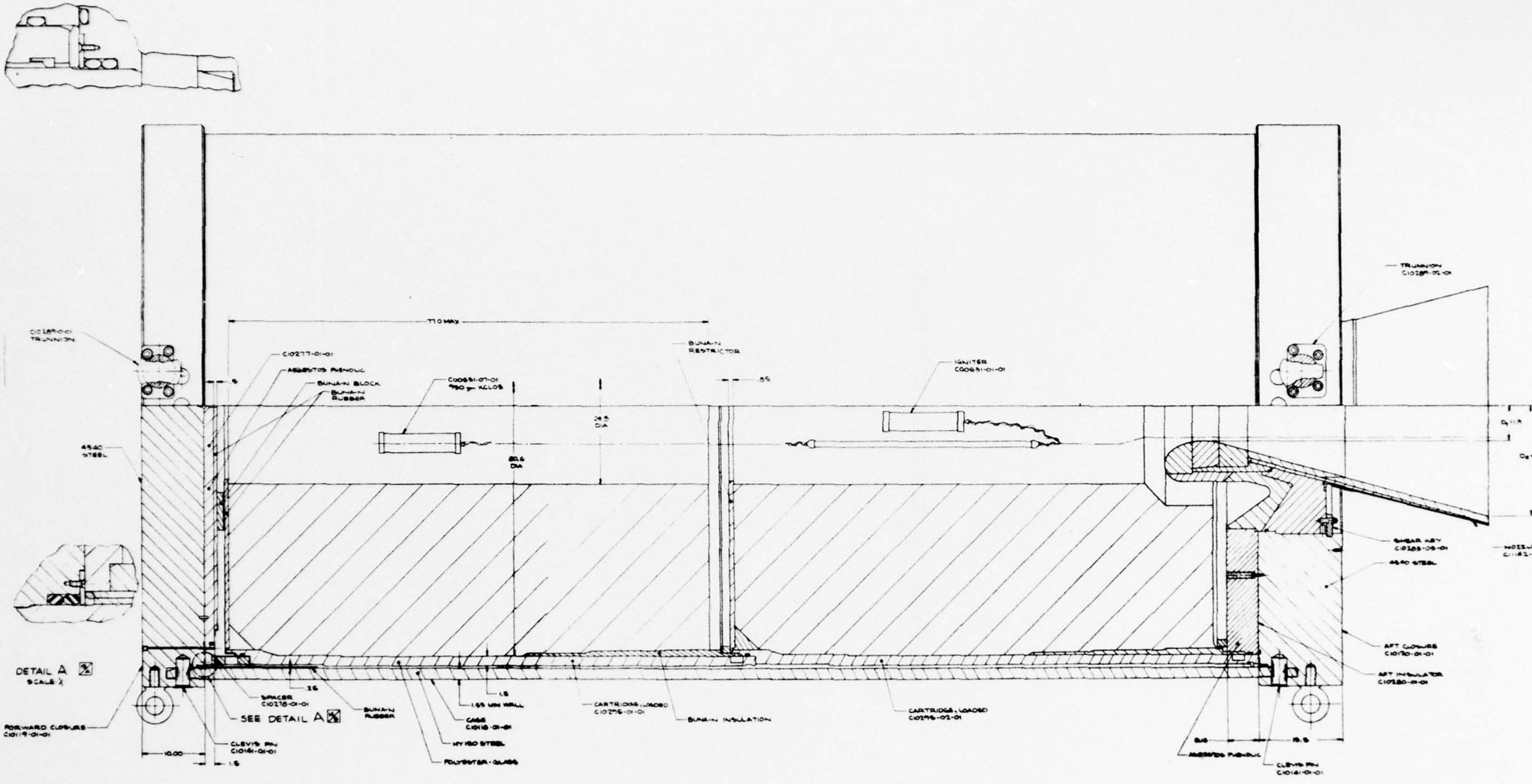

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Figure 4-3. High Pressure Ballistic Motor Assembly

TABLE 4-1. MOTOR DESIGN REQUIREMENTS AND CAPABILITIES

MEOP, psia	2,500
Minimum burst pressure, psia	5,000
Maximum propellant charge	24,500
Hydrostatic proof test, psia	3,750
Nozzle throat diameter capacity, in.	4 to 12
Movable nozzle deflection capacity, °	15
Case material	HY-130 steel
Case yield strength, psi	130,000
Demonstration test	
Nozzle throat diameter, in.	6.83
Nozzle expansion ratio	8.0
Nozzle half angle, °	15°
Chamber pressure, psi avg	590
Duration, sec	145
Ignition system	
Voltage, v	28
Time delay, sec	0.25

by similar insulation plugs. The interface between the adapter insulator and aft closure insulator contains a stagger joint to avoid direct radiation to the steel from the combustion gases. The stagger joint contains a cavity for placement of zinc chromate putty to control charging by hot gases.

The rubber insulation is used in areas where structural requirements of the insulation are for flexibility rather than for stiffness. The design of the rubber parts specifies tolerances wide enough to essentially eliminate machining. The parts can be laid up of green rubber sheets, cured, inspected, and shipped. Four rubber insulation items are used in addition to the forward restrictor and sidewall rubber of the cartridges: the forward insulator discs, the forward insulator blocks, the case wall insulation, and the aft insulator ring.

The forward insulator rubber discs are secured to the phenolic part of the forward insulator by a double-faced tape and protect the phenolic part (see figure 4-4). Thickness of rubber required depends on the test pressure, duration, and temperatures expected. The design height of the cartridge above the forward insulator phenolic portion will accept 3/4-in.-thick rubber with an additional thickness in the center port. The considerations are that (1) the char and erosion will be much deeper where the forward restrictor of the cartridge does not protect from the direct radiation from the core of combustion gases (i.e., under the grain the char and erosion will be lower); and (2) sufficient flow area must be provided between the forward restrictor of the cartridge and the forward insulator to allow flow of combustion gases for charging the cavity between the cartridge and case wall. The minimum flow area is defined by the product of the length of the inside perimeter of the restrictor and the vertical clearance from that perimeter to the forward insulator. Note that 1-1/2 in. of asbestos phenolic underlies the rubber sheet to protect the forward closure, so that underestimating the thickness of rubber required would not be catastrophic. The insulation was analyzed for 145-sec duration capability.

Rubber blocks are positioned and bonded on the forward insulator in a radial array to provide support for the forward insulator late in the firing after the grain has burned back and no longer supports the restrictor. The purpose is to keep the restrictor from sagging down onto the forward insulator, thereby sealing off the flow passage for charging gases into the cavity surrounding the propellant cartridge. These blocks were reduced in thickness from 1-in. on Super HIPPO/ELSH to 3/4-in. to allow greater forward insulator rubber thickness.

The gases which charge the cavity between the cartridge and the case would tend to impinge the steel case wall where they flow through the holes in the spacer, so a 1/4-in.-thick sheet of rubber is bonded to the inside of the case in this zone. The outside of the Super HIPPO propellant cartridge is reduced in diameter over the lower 18 in. to allow flow area for the gases

Sue 7

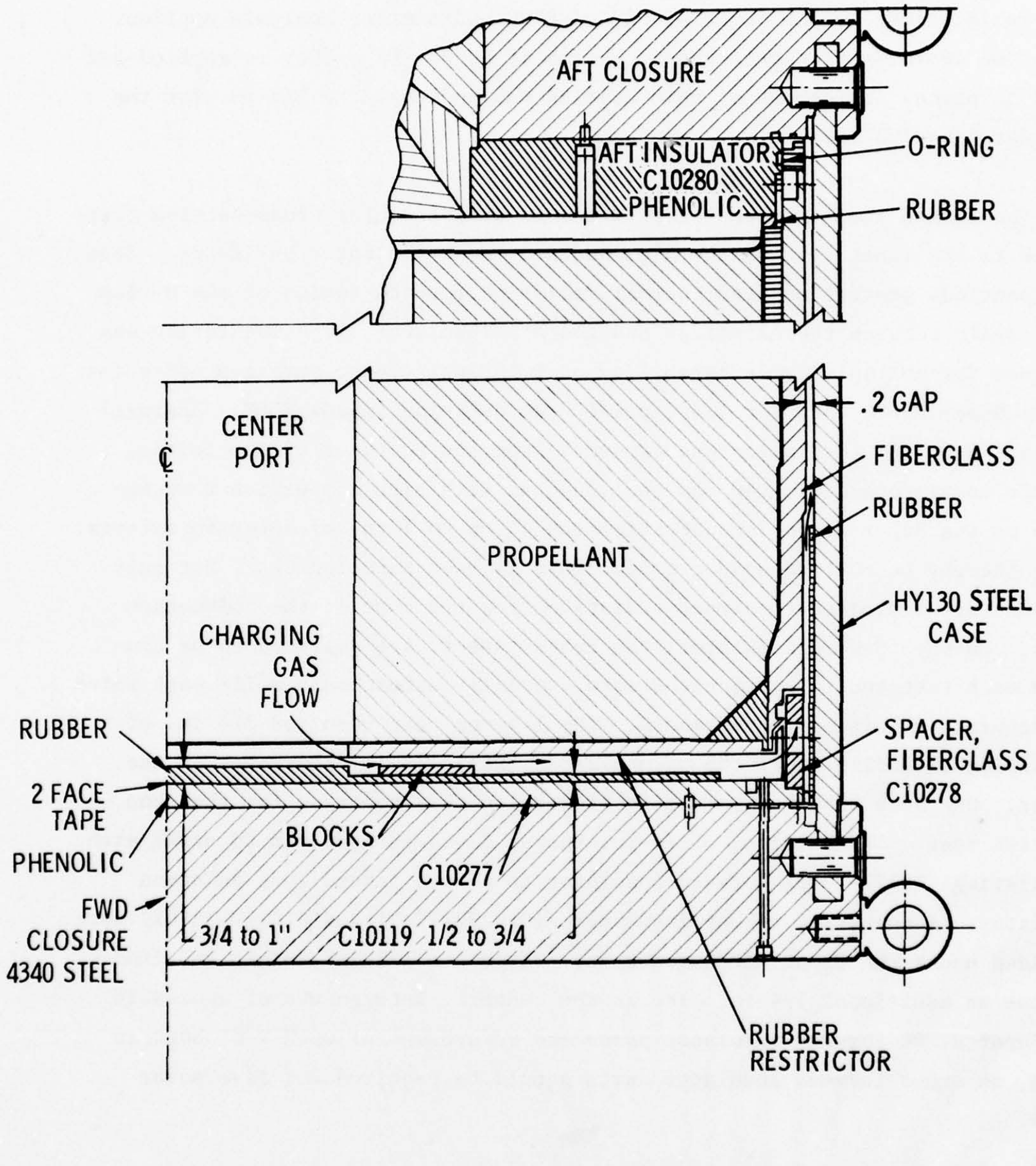

Figure 4-4. Installation Details

Sue 8

in the region where this rubber sheet is installed on the inside of the case wall. The nominal clearance between the case and cartridge is 0.2 in. unpressurized to allow for machining tolerances on these 7-ft-diameter components. This is identical to the Super HIPPO and ELSH and similar analysis applies. Above the 18-in.-wide rubber sheet, a coat of DC 93-104 rubber is applied and cured in place. Thickness of this coating was increased to 1/8 in. for the long duration IUS test.

The fourth item of rubber insulation is a rectangular cross-section ring bonded to the inner face of the aft insulator near the outer perimeter. This ring provides protection from thermal radiation for the region of the O-ring which seals between the cartridge and the aft insulator. The insulation was designed for multiple cycle capability at 1,500-psi/40-sec duration operation in the Super HIPPO, and for 1,400 psi/60-sec duration in the ELSH. Approximately 1/4-in. of insulation was consumed from the surfaces of the forward and aft insulators during 40 sec at 1,500 psi with high combustion temperatures on the Super Hippo demonstration test. Up to 1 in. of ablative material could thereby be charred and/or eroded in a 145-sec duration test, but only in those areas exposed to direct radiation from the core of the combustion gases. On the forward insulator, the rubber sheets are designed to be consumed each test and to protect the more expensive asbestos phenolic part which has accurate machining requirements. The 145-sec test required 3/4 in. of insulation extending under the grain plus an extra 1/4-in. thickness in the center. One such rubber disc was fabricated on this contract for the long duration test. In addition, a 1/4-in. rubber disc was provided to stack with an existing C10277-13-01 forward insulator to form a second long duration insulator. A number of rubber insulators (C10277-12-01 and C10277-13-01) were provided under the Super HIPPO contract. These are 1/2-in. thick, and item -13 has an additional 1/4-in. disc in the center. Between use of available new Super HIPPO forward insulator parts and refurbishment with V-61 between tests, no other forward insulator parts should be required for five motor tests.

One forward insulator phenolic part was fabricated to be reused for the five tests indicated.

The aft insulator, at 5.16 in. thick, provides ample insulation capacity for tests of 145-sec duration at 1,000 psi. However, one test at 145-sec duration and four tests at 60-sec duration would require two aft insulators. One aft insulator was fabricated and coated with 1-1/2 inches of V-61 insulation to provide the extra service life.

The new forward closure was made to the C10119 drawing using 4340 steel heat treated to a minimum ultimate strength of 125,000 psi. The closure is fully interchangeable with the existing Super HIPPO/ELSH C10119 forward closure with the exception of two new threaded holes which were added to the design for securing the closure to the SLSH thrust mount.

The IUS project nozzle adapter shown on figure 4-5, will physically fit the same nozzles as the CHAR motor flange; 4340 steel was specified for the adapter and the design was analyzed for 5,000-psi burst capability. The IUS hydrotest drawing provides for a configuration for testing the IUS/CHAR nozzle adapter, and a suitable hydroflange was designed and analyzed (figure 4-6). No provision was made for fabricating this flange under this contract.

A design layout was prepared to detail modifications required of the insulators to fire CHAR propellant cartridges in the SLSH motor, but detail fabrication drawings were not in the scope of this contract.

4.1.2 Design and Analysis Actions

Ten new drawings or new configurations and analyses were required for the SLSH motor.

A. The short barrel motor case design (C12419) is identical to the existing design for the Super HIPPO case except that the length is reduced by the maximum stacking length of one propellant grain, 81.19 in. The tolerance on the case length was reduced from the Super HIPPO version because closer dimensional control is possible with the shorter motor. The case length was also reduced by the amount of tolerance reduction.

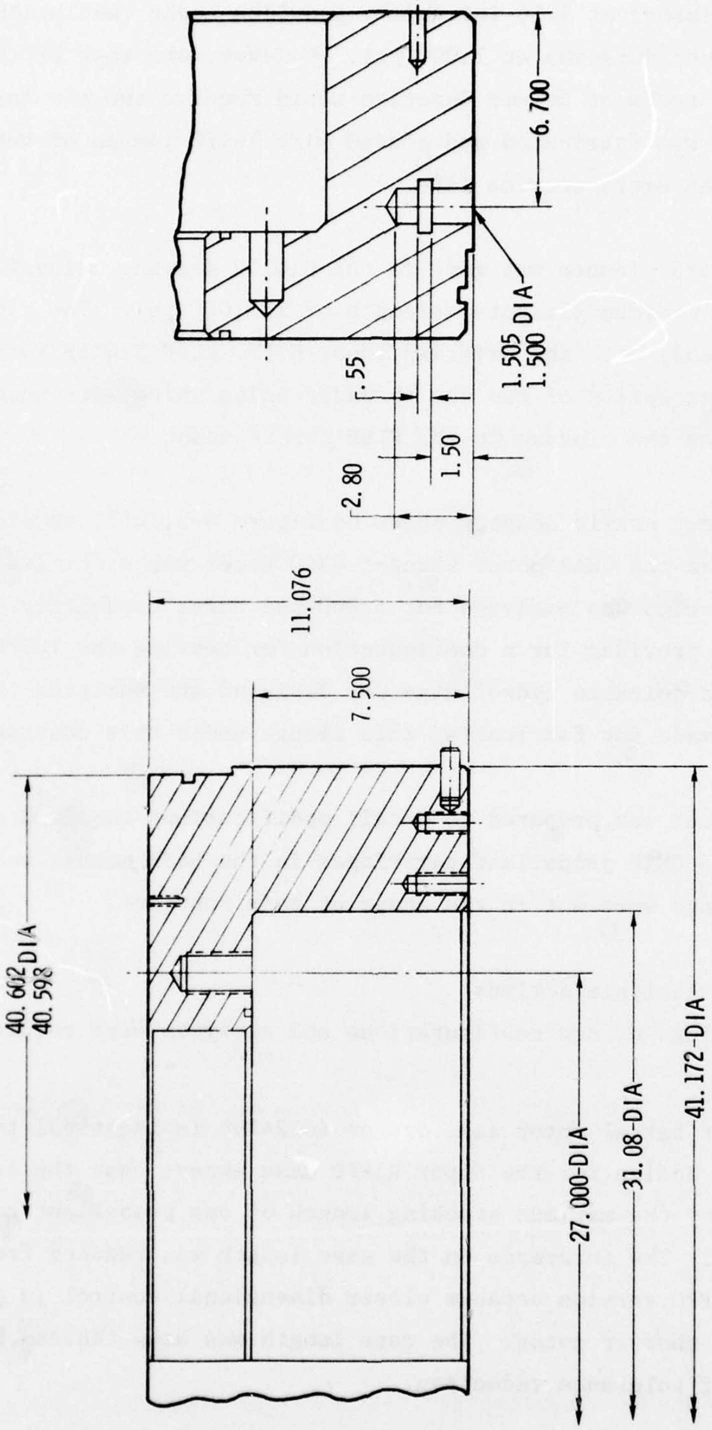

Figure 4-5. Nozzle Adapter

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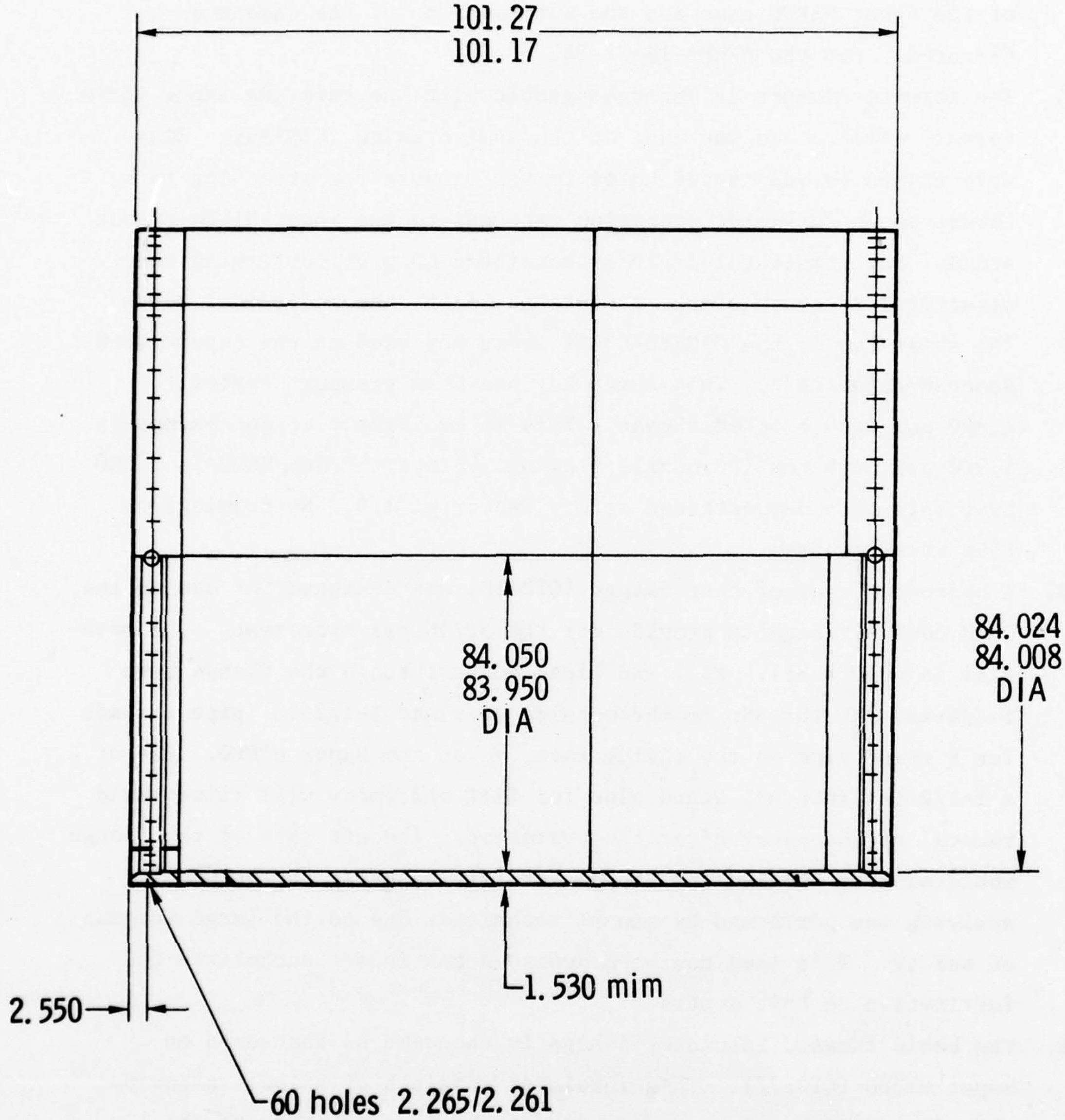

Figure 4-6. SLSH Motor Case

The material for the case was Government-furnished HY-130 steel as used in the Super HIPPO and ELSH motor cases. The structural analysis performed consisted of a finite element computer analysis of the Super HIPPO case and the interactions of the case and closures. See the AFRPL-TR-77-58.

B. The forward closure is interchangeable with the existing Super HIPPO forward closure and was made to the same drawing (C10119). ECOs were issued to add tapped holes to the closure for attaching to a thrust mount for motor operation external to the Super HIPPO thrust stand. New structural analysis consisted only of confirming the structural adequacy of the closure to accept the additional holes.

C. The shear key is the C10283-03-01 shear key used on the Super HIPPO demonstration test. This shear key has been pressure tested to 1,800 psi with blocked throat. This is equivalent to approximately 1,900 psi with the IUS nozzle flowing. Since the IUS MEOP is 1,000 psi, this is a demonstrated safety factor of 1.9. No drawings or ECOs were required.

D. A hydrostatic proof test flange (C12416) was designed for use on the CHAR nozzle flange to provide for the 3,750-psi hydrotest. The material is 4340 steel. Fill and bleed ports through the flange have 1-1/4-in. AND threads on the outside face and 1-1/2-in. pipe threads for a stand pipe on the inside face, as on the Super HIPPO. Use of a 1-1/2 in. internal stand pipe for fill and empty will allow rapid removal of the water after the hydrotest. The aft face of the flange would also be drilled and tapped for lifting eyes. Structural analysis was performed by manual techniques due to the large margins of safety. This item has been designed but is not authorized for fabrication on this contract.

E. The basic forward insulator design is the same as that used on Super HIPPO (C10277). This insulator consists of a lower asbestos phenolic portion which centers on a probe in the center of the forward closure and extends under the spacer which supports the cartridge. This part has accurate machining and flatness requirements and is fairly expensive. It is intended to be reused five or ten times, depending on test duration. The phenolic insulator is protected by a consumable rubber sheet insulator with no accurate machining requirements. The rubber part of the insulator is 1/2-in. thick for the Super HIPPO demonstration test of 40-sec at 1,500 psi. The rubber part of the ELSH unit is 3/4-in. thick at the center for 60-sec at 1,400 psi. The portion of the rubber under the shadow of the forward propellant grain can be much thinner. For this motor, additional configurations of insulator were added to the drawing: one that is 1-in. thick in the center and 3/4-in. thick further out, and one that is 1/4-in. thick over the full diameter to space up existing -13 insulators (ELSH) to 1-in. thick at the center. Also, a design change was added to allow fabricating the phenolic portion in two pieces, a small disc and a concentric ring. No structural analysis was required.

F. A hydrotest assembly drawing (C12420) was prepared similar to the Super HIPPO hydro assembly (C10286) with configurations for testing with the solid shear key, the notched shear key, and the IUS adapter. No new detailed analysis is contemplated, as the Super HIPPO analysis applies. The adapter was analyzed under the IUS program.

G. An alternate hydrotest assembly lists only SLSH components and excludes IUS unique parts (figure 4-7).

H. A loaded motor assembly drawing (C12411) was prepared essentially the same as Super HIPPO motor assembly C11167 but with the single-cartridge configuration and specifying the IUS nozzle, adapter, and grain. Analysis consisted of review and update of the gap charging analysis and thermal analysis for firing 145 sec at 1,000 psi. See figure 4-1.

I. The basic loaded motor assembly excludes the IUS insulated adapter and nozzle. While this is a general purpose workhorse motor, the insulation design assumes a forward restrictor, particularly beyond the 72-in. diameter. Any grain design which is not restricted on the forward face outboard of 50-in. diameter should be reviewed carefully.

J. The O-ring dimensions were standardized by use of common ID dimensions for close sizes and making the cross-section tolerances alike.

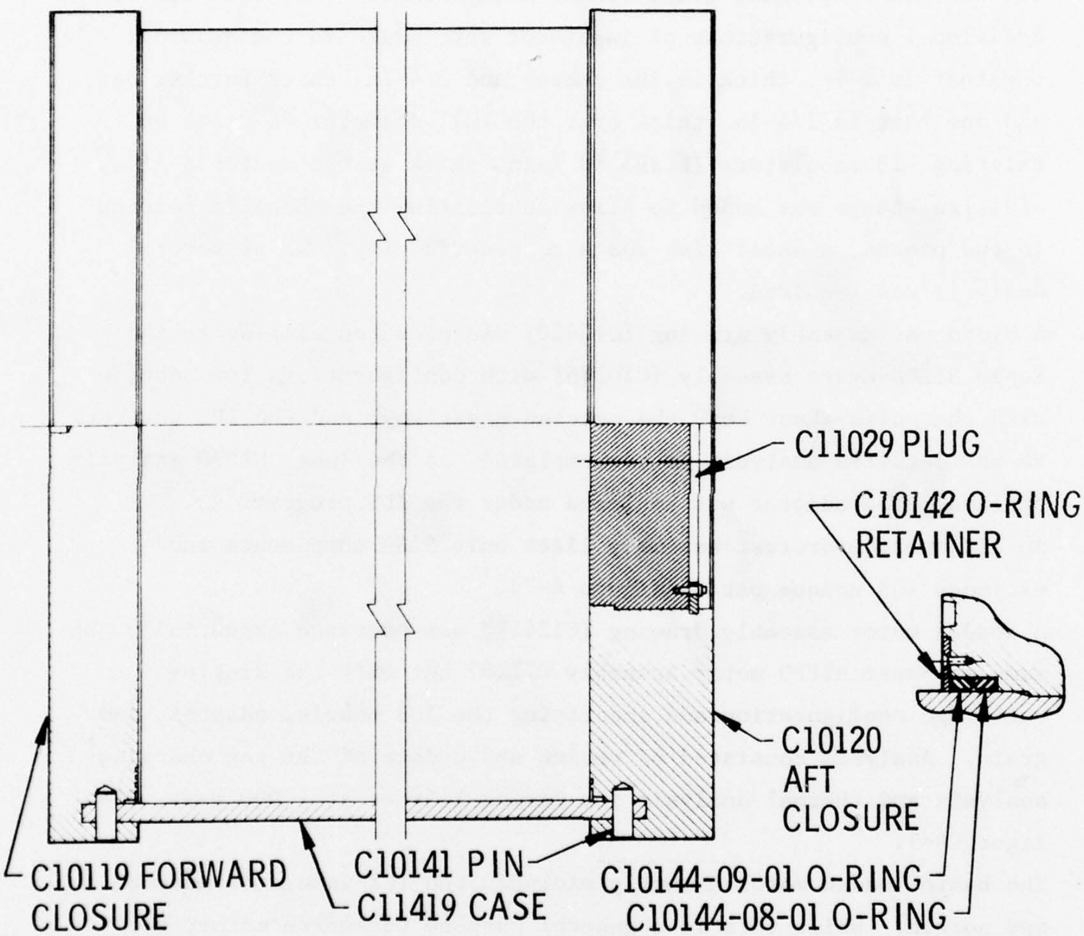

Figure 4-7. SLSH Hydro Assembly

Sue 15

Three sizes were deleted, leaving seven sizes (plus smaller standard units). The -1 is already obsolete, and the -3 and -5 sizes were also dropped. IDs will be standardized at 83.0/82.5, 78.5/78.0, 40.10/39.98, and 55.22/55.10 in. Cross-sections will be 0.515/0.485 in. in 90, 70, and 50 durometer, 0.575/0.545 in. in 70 durometer, and 0.289/0.269 in 70 durometer (Shore A). The sizes are shown in table 4-2.

K. A new thrust mount was designed for fabrication by the AFRPL weld shop. It has 3-in.-thick steel upper and lower plates and the uprights are welded of 2-in. steel plate. The design is intended to assume overloads to 10,000,000 lb should a closure fail. It also has some lateral capability should a nozzle fail asymmetrically. As designed, the lateral capability of the stand will accept the original Super HIPPO lateral force requirement of 81,000 lb when in combination with 300,000-lb axial force readily with the short length motor, marginally with the Super HIPPO motor. The limiting condition is the bolts holding the forward closure to the stand which are assumed to be 170,000-psi UTS Allen bolts (figure 4-8).

4.1.3 Drawing Numbers and Commonality with Super HIPPO and ELSH

Table 4-3 lists quantities of items supplied under this contract for the SLSH motor and indicates commonality of usage for Super HIPPO and ELSH testing. A complete list of Super HIPPO, ELSH, and SLSH drawings is included as table 4-4.

4.1.4 Performance and Capabilities

Figure 4-9 shows the duration capability of various nozzles from 4- to 20-in. throat. The very short and the very long durations are difficult to obtain because of burning rate limitations (0.2 to 1.5 in./sec at 1,000 psi) of available propellants. As a practical matter, a star grain of some manner would be recommended to test with the very large nozzles at high thrust so that conventional propellants would be used. This would reduce capacity somewhat.

TABLE 4-2. O-RING DIMENSIONS

No.	Test, lb	ID, in.	Cross-section	Shore A	Super HIPPO Quantity	ELSH Quantity	SLSH Quantity
C10144-10-01	35	78.5/78.0	0.515/0.485	50	1	1	1
C10144-09-01	35	83.0/82.5	0.575/0.545	70	2	3	2
C10144-08-01	35	83.0/82.5	0.515/0.485	90	2	3	2
C10144-07-01	15	55.22/55.10	0.289/0.269	70	-	1	-
C10144-06-01	35	78.5/78.0	0.515/0.485	70	3	7	2
C10144-04-01	15	40.10/39.98	0.289/0.269	70	1	-	1
C10144-02-01	15	78.5/78.0	0.289/0.269	70	3	3	3

NOTES:

In application, the -05s are replaced by -06s, the -03 is replaced by -02, and -01 is obsolete.

The use of only four ID values allows a simple layout board for controlling length (diameter) of all seven sizes for butt joining O-rings of linear stock.

In addition, color coding was added to mark 90 durometer stock red and 50 durometer stock yellow.

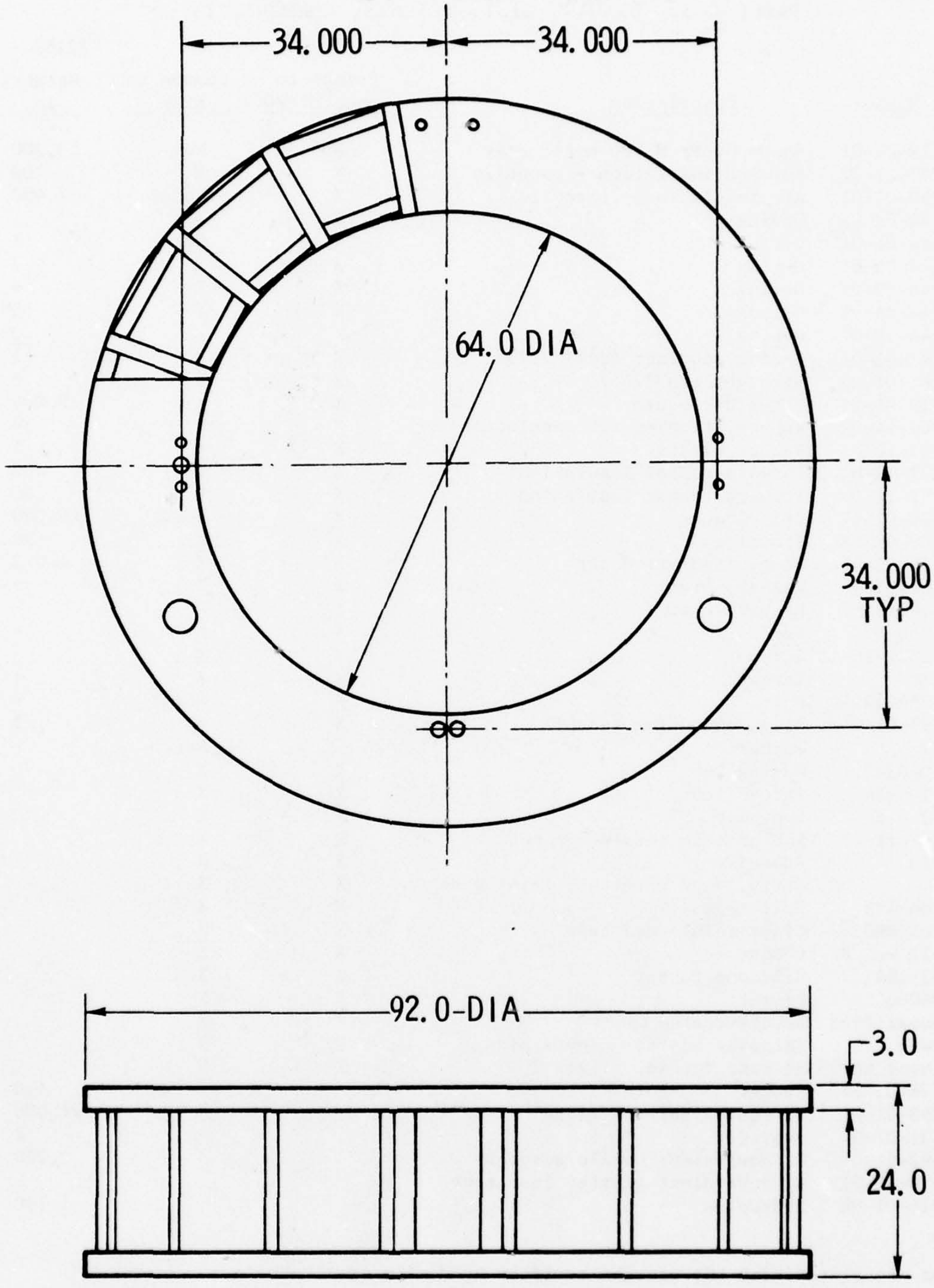

Figure 4-8. C12418 SLSH Thrust Mount

TABLE 4-3. DRAWING LIST, WEIGHTS, COMMONALITY

T2152

Part Number	Description	Common to Super HIPPO	Common to ELSH	Weight, lb
C12419-01-01	Short Super HIPPO motor case	No	No	13,200
C10277-11-01	Forward insulation - phenolic	X	X	700
C10280-01-01	Aft insulation - phenolic	X	No(a)	1,400
C10144-02-01	O-ring	X	X	1
C10144-04-01	O-ring	X	No(a)	1
C10144-05-01	O-ring	X	X	3
C10144-08-01	O-ring	X	X	4
C10144-09-01	O-ring	X	X	3
C10144-10-01	O-ring	X	X	3
C10142-01-01	O-ring retainer (set) 222351	X	X	21
C10141-01-01	Straight pin 224570	X	X	6
C10119-01-01	Forward closure	X	X	18,000
C11167-14-01	Rubber (ring on aft insulation)	X	X	30
C11167-12-01	Rubber blocks	X	X	1
C10277-14-01	Forward rubber insulation	X	X	400
C10277-15-01	Forward rubber insulation	X	X	150
C10120-01-01	Aft closure	X	No(a)	19,000
C10289-0X-0X	Trunnions	X	X	90
C10276-01-01	Plug, insulation aft	X	X	0.3
AN960-1616	Washer, flat	X	X	-
AN960-616	Washer, flat	X	X	-
MS51960-67	Screw	X	X	-
NAS 1351-16-14	Screw	X	X	-
AN6-10	Screw	X	X	-
MS21250-12016	Bolt	X	No(a)	-
C11199-01-01	Ring, centering (each)	X	X	3
WC-12	Washer	X	No(a)	-
MIL-G-4343	O-ring lub	X	X	
MIL-T-5544	Thread lub	X	X	
1 1/2 - 6	Eye bolt	X	X	
C11167-11-01	Rubber case insulation set	X	X	
EA 913	Adhesive	X	X	
---	Putty, zinc chromate, 1-in. wide	X	X	
Scotch 425	Foil tape	X	X	
Scotch 890	Glass reinforced tape	X	X	
No. 11 Wax 2	Cement	X	X	
DC 93-104	Silicone rubber	X	X	
DC 36060	Primer	X	X	
Devoseal 7565	Double-coated tape?	X	X	
PD 2493	Shipping box for clevis pins	X	X	
Lockbond No.55	Solvent for No. 11 wax 2	X	X	
C10278-01-01	Spacer			110
C10295-01-01	Or equivalent cartridge			26,000
C00631-07-01	Igniter			2
C12592-01-01	Or equivalent nozzle adapter			2,200
C12590-01-01	Or equivalent adapter insulator			
C12416-01-01	Hydroplug			1,100

(a) Items associated with aft closure could be used with small nozzle

(b) Use existing Super HIPPO item

(c) Provided by using program

TABLE 4-4. SUPER HIPPO DRAWING LIST

Size	Drawing	CH.	ECO	Title
E-3	C10118	C		Case, Motor - Super HIPPO
E-2	C10119	F	20505, 20619	Closure, Fwd - Super HIPPO
E-2	C10120	F		Closure, Aft - Super HIPPO
Q-1	C10121	N/C		Pin, Locating - Super HIPPO
C-1	C10141	N/C		Pin, Straight - Super HIPPO
E-1	C10142	N/C		O-Ring Retainer - Super HIPPO
Q-1	C10144	C	20492	O-Ring Packing - Super HIPPO
C-1	C10276	N/C		Plug, Insulation, Aft - Super HIPPO
Q-1	C10277	D		Insulator, Fwd - Super HIPPO
Q-1	C10278	C		Spacer, Cartridge - Super HIPPO
E-1	C10279	D		Cartridge, Insulated - Super HIPPO
E-1	C10280	B	20374 20494	Insulation, Outer-Aft Closure - Super HIPPO
E-1	C10283	B		Key, Lock, Adapter - Super HIPPO
J-1	C10286	B		Motor Assembly Hydrostatic Test Configuration - Super HIPPO
E-1	C10287	N/C		Plug, Nozzle, Hydrotest - Super HIPPO
E-1	C10289	C	20539	Trunnion Shaft - Super HIPPO
E-1	C10290	A		Adapter, Lifting - Case - Super HIPPO
E-1	C10291	N/C		Trunnion Base
E-1	C10292	N/C		Sling, 30,000 lb
C-1	C10293	A		Plug, Insulation
E-2	C10294	B		Cartridge Lift
E-2	C10295	C		Loaded Cartridge, Demo
E-1	C10297	A		Plug Nozzle Shell

TABLE 4-4. SUPER HIPPO DRAWING LIST
(Continued)

Size	Drawing	CH.	ECO	Title
E-1	C10299	A		Nozzle Assy 12.5" Sub
E-2	C10300	A		Nozzle Lift
E-1	C10712	N/C		Transport, Trailer, Modification Stage I - Super HIPPO
E-1	C10713	N/C		Transport Trailer, Closure - Super HIPPO
E-1	C10714	N/C		Transport Trailer, Cartridge - Super HIPPO
E-1	C10715	A		Transport Trailer, Handling Equip - Super HIPPO
C-1	C10741	N/C		Wrench, Spanner - Small Insulation Plug, Super HIPPO
C-1	C10742	N/C		Wrench, Spanner - Large Insulation Plug, Super HIPPO
E-1	C10761	N/C		Fixture, Leak Test - Super HIPPO
C-1	C10840	N/C		Pin Assy, Case Lift
E-1	C10849	N/C		Support, Trunnion
D-1	C00631	C		Igniter
	PD2492	B		Cartridge Pallet
	PD2493			Pin Box
D-1	C11007	C		Extended Super HIPPO Case Joint Ring
E-1	C11021	N/C	20461 20495	Insulator Aft
E-1	C11014	A		Adapter
E-1	C11015	A		Backup Key
	C11016	B		Key Shear
D-1	C11021	C		Insulation, Joint Ring
E-1	C11029	N/C		Plug, Aft Closure
E-3	C11125	B		Aft Case
E-2	C11126	D	20511	Closure

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TABLE 4-4. SUPER HIPPO DRAWING LIST
(Continued)

Size	Drawing	CH.	ECO	Title
J-1	C11142	A		Nozzle Assy
D-1	C11151	A		Stirrup Lifting
J-1	C11167	D	20496	Motor Assy
E-1	C11198	A		Test Fixture, Lock Key
D-1	C11199	N/C		Segmented, Ring, Centering
E-1	C11301	N/C		Lock Key, Test, Segmented
J-2	C11347	G	20378 20497	Motor Assy, Super HIPPO, Extended
D-1	C11369	N/C	20487	Insulation, Restrictor
J-1	C11374	C		Hydrostatic Test Assy, Super HIPPO, Extended
D-1	C11478	N/C		Restrictor, Aft
E-2	C11479	A	20159, 20377	Loaded Cartridge - Length - Super HIPPO
C-1	C12028	N/C		Clip, Retention, Shear Key
E-1	C12037	N/C		Shear Key - ELSH
	C12382	N/C	20550,20589 20628,20742	Nozzle Assy
	C12411	N/C		Assy - SLSH/IUS
	C12413	N/C		Loaded Motor Assy - SLSH
	C12416	N/C		Cover Hydro (Char)
	C12417	N/C		Hydro Assy - SLSH
	C12418	N/C	20643	Support, Case
	C12419	N/C		Case, Short Length
	C12420	N/C		Hydro Assy - SLSH
	C12590	N/C		Ins. Ring, Nozzle Adapter
	C12592	N/C	20349 20563	Ring Nozzle Adapter
	C12629	A	20735	Cartridge, Loaded, IUS
	C12716	A	20734	Cartridge Insulated, IUS
	C12742	N/C	20592	Ring, Backup
	C12868	N/C		Heat Shield

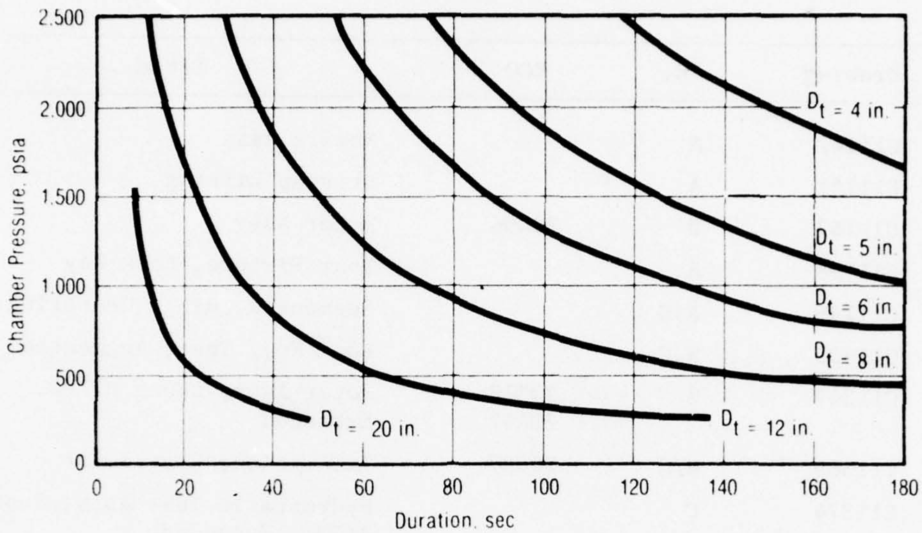

Figure 4-9. SLSH Duration as Chamber Pressure for Various Throat Diameters, 23,000-lb Propellant

Figure 4-10 shows thrust time capability for a single Super HIPPO grain with a maximum charge, using an optimum nozzle. Capabilities for some typical reduced charges are also shown.

Figures 4-11 and 4-12 show ballistic predictions for the first SLSH test with the IUS nozzle and propellant grain. Table 4-5 summarizes ballistic performance predictions for the IUS/SLSH.

Figure 4-13 shows the thrust time characteristics of the IUS/SLSH test with three thrust-time characteristics of the Super HIPPO and ELSH motors as orientation to the capabilities of the family of motors.

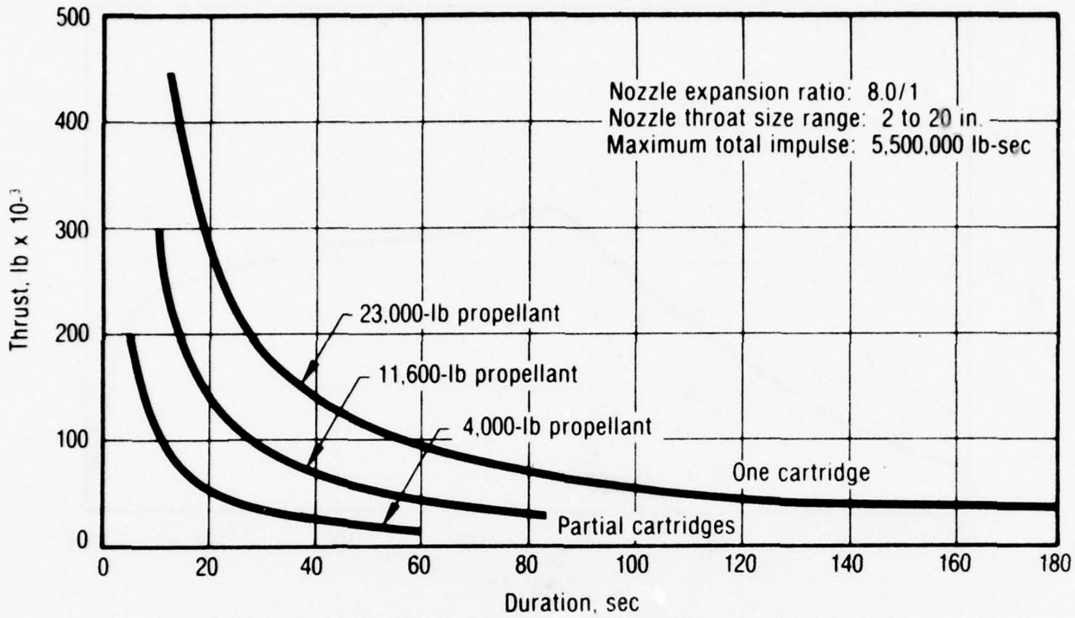

Figure 4-10. SLSH Thrust Time Capability

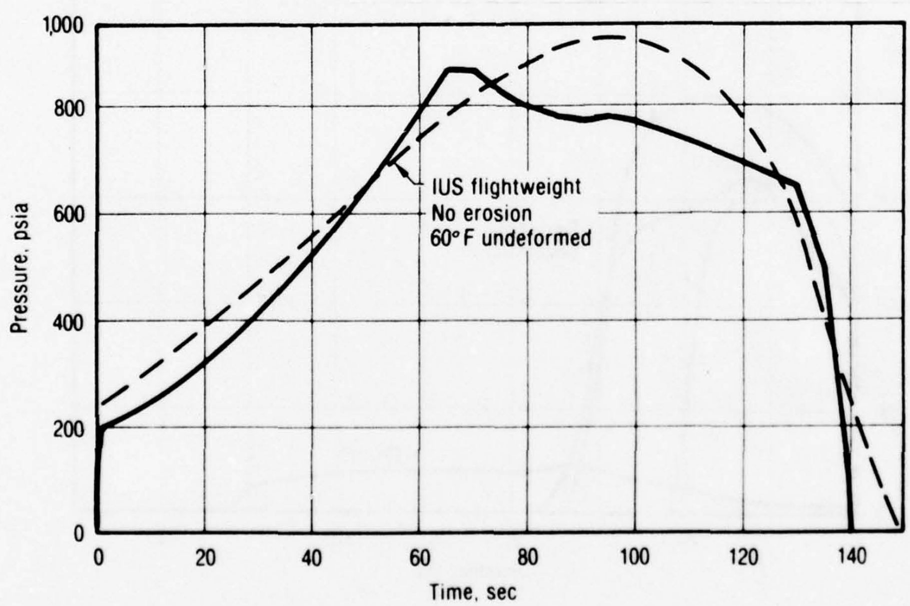

Figure 4-11. Ballistic Prediction for First SLSH Test

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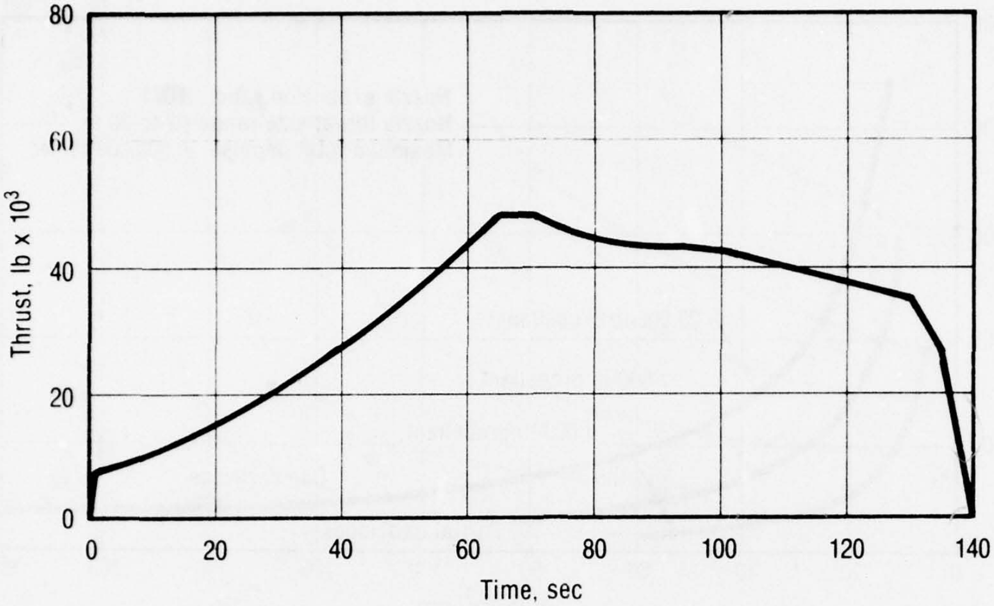

Figure 4-12. Ballistic Prediction for First SLSH Test

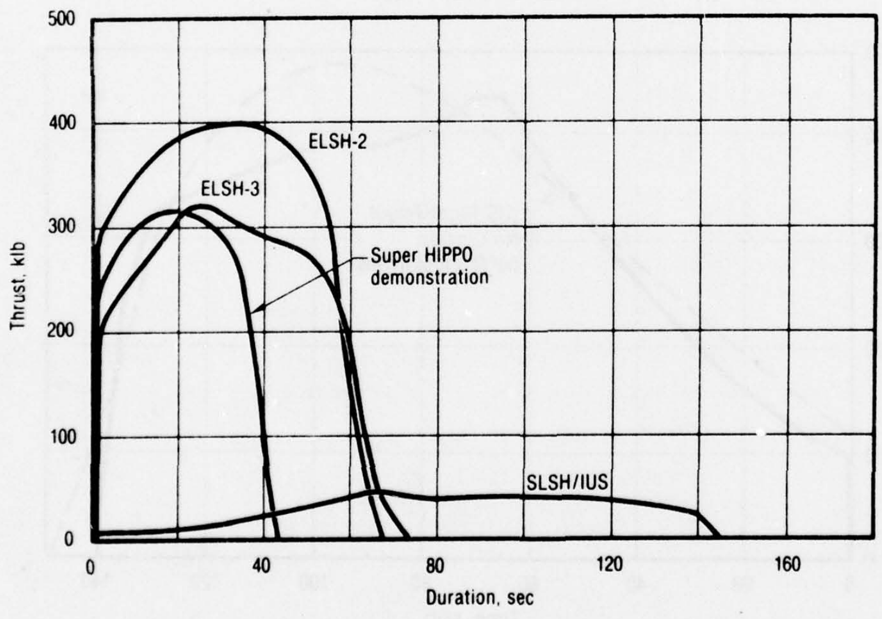

Figure 4-13. Thrust-Time Characteristics of Super HIPPO Tests

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TABLE 4-5. PREDICTED PERFORMANCE - FIRST SLSH TEST

Assumption	Value	
Propellant	UTP-19,360	
Burning rate at 600 psia, in./sec	0.237	
Pressure exponent	0.41	
Propellant weight, lb	19,949	
Propellant density, lb/in.^{3}	0.0635	
Characteristic velocity, ft/sec	5,000	
Initial throat diameter, in.	6.825	
Expansion ratio	8.0	
Nozzle efficiency	0.95	
Gamma	1.14	
Bore diameter, in.	15.5	
Grain length, in.	66	
Predicted Performance	**1 Mil/Sec Erosion**	**No Throat Erosion**
Web time, sec	143.4	139.3
Web time average chamber pressure, psia	564	608
Maximum chamber pressure, psia	818	869
Duration, sec	144.0	140.1

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4.1.5 Shear Key Design

The function of the shear key is to protect the motor case from failure by overpressure by failing at a low enough pressure to vent the gases in the motor case before case deformation becomes excessive. A shear key can be either general-purpose or for a specific test. A general-purpose key must not fail below the contractual MEOP of the motor of 2,500 psi. However, if a specific test were to have a considerably lower MEOP (e.g., 1,000 psi as on the IUS/SLSH test), the shear key could be allowed to fail at a much lower pressure (e.g., 1,500 psi). In any event, the key must fail at a low enough pressure to allow the nozzle-adapter assembly to accelerate out of the aft closure far enough to generate a gas flow area between the adapter and the closure. Since the closure is 13-in. thick and the insulator is 5-in. thick, the assembly must travel 18-in. before an appreciable area is generated. Presumably, whatever caused the case pressure to increase to the failure pressure of the key will cause continued pressure increase until this additional flow area is developed. Thus, the maximum pressure at which the shear key releases must be considerably below the 5,000-psi burst of the case to provide protection. The nature of the shear key is such that the force or pressure at failure cannot be predicted very accurately. The key is not loaded in shear, but in a combination of shear and bending. The amount of rotation and bending depends on the accuracy of machining, installation and on wear. The properties of the metal are also subject to variation. For these reasons, model tests were conducted on contract No. F04611-72-C-0023 (appendix D). Based on these tests, the C10283-03-01 was designed for use on the Super HIPPO demonstration test firing with an MEOP of 1,700 psi and an average throat diameter of 12-1/2 in. Analysis of the data from the shear key testing indicated that the 3-sigma lowest pressure at which this shear key would fail was 2,550 psi and the 3-sigma highest pressure was about 4,000 psi.

The IUS/SLSH motor assembly design specifies reuse of this same shear key for the test firing. At equal chamber pressures, the forces on the key are higher with the IUS nozzle (d_t = 7 in.) than with the demonstration test nozzle because of the smaller nozzle and thrust. The force on the shear key is equal to chamber pressure acting over the area of the closure to adapter seal (P_cA_a) minus thrust of the nozzle ($P_cA_tC_f$)

$$(F = P_cA_a - P_cA_tC_f = P_c (A_a - A_tC_f)$$

The ratio of force on the key with the IUS nozzle to that with the demonstration nozzle is:

$$R = \frac{F_{IUS}}{F_{demo}} = \frac{(A_a - A_{t_{IUS}} C_{f_{IUS}})}{(A_a - A_{t_{demo}} C_{f_{demo}})}$$

$$R = \frac{(40.6)^2 - (7)^2 (1.65)}{(40.6)^2 - (12.5)^2 (1.65)} = \frac{1567}{1390} = 1.127$$

Since the force on the shear key is higher for the same chamber pressure, the key will fail at a lower pressure. The theoretical lowest failure pressure is 2,550/1.127 = 2,260 psi. The theoretical highest failure pressure is 4,000/ 1.27 = 3,550 psi.

This shear key was hydrotested to 1,800 psi with a blind flange (i.e., no thrust). The force on the key during this hydrotest was higher than with the IUS nozzle flowing by the ratio $R = (40.6)^2/[(40.6)^2 - (7)^2\ 1.65] = 1.05$.

The equivalent IUS firing pressure was (1.05) 1,800 = 1,890 psi. The MEOP of the IUS test is 1,000 psi. Thus, a factor of safety of 1.89 has been demonstrated and the nozzle will not release inadvertently during the firing.

4.1.6 Acoustic Modes of SLSH Motor Combustion

Acoustic mode calculations were made on the SLSH motor for the ignition geometry. These calculations used a finite element NASTRAN model and are based on a sonic velocity of 41,200 in./sec. The calculations were limited to axial modes: no transverse oscillation effects were included. The frequencies of these modes are tabulated below.

Mode Number	Frequency, Hz
1	130.0
2	298.4
3	480.6
4	694.8
5	841.4
6	1,044.0

Examination of the acoustic pressure distributions shows that the cavities at both ends of the motor have a significant impact on the acoustic frequency. As the motor burns, their influence will diminish. Therefore, these frequencies will shift toward the classical organ pipe frequencies, i.e., $f = (41,200\ n)/(2L)$ Hz. For the fundamental ($n = 1$), this means the 130 Hz mode will approach 250 Hz. Hence, one can expect significant changes in the acoustic frequencies as the motor burns.

As far as the stand is concerned, it seems that little can be done to detune the stand frequencies from the motor acoustics. The large acoustic frequency changes will sweep across the stand frequency somewhere during the burn, no matter what the stand frequency is.

On the positive side, the chances of combustion instability driving the acoustics, and hence the stand, to destruction seem small. The acoustic driving of most aluminized HTPB propellants is low at these frequencies. The acoustic damping is usually sufficient to prevent these troubles.

The natural vibration frequencies are estimated at 150 Hz in lateral oscillation and 400 Hz in axial vibration. The amplitude expected is less than ±0.001 so that no interaction is expected.

4.1.7 Philosophy of Recycle of Insulation

The following paln is based upon the thermal analysis performed to predict insulation requirements for five firings similar to the demonstration firing (40 sec at 1,500 psi). Actual service life may vary as different propellants and duty cycles may be experienced. The components are discussed below starting at the nozzle and working forward.

4.1.7.1 Adapter Insulator

This item is considered as a portion of the nozzle. A new adapter insulator should be designed and fabricated for each nozzle to be tested. This is not in the scope of contract No. F04611-77-C-0027.

4.1.7.2 Aft Closure

The aft closure insulator is rated at five tests. One insulator and two sets of plugs (to protect the retaining screws) were provided. The capability for 145-sec duration tests at 800 psi is two tests. Since the cost of fabricating this part is quite high, even badly eroded insulators should not be discarded without project review to consider rework techniques.

The rectangular strip of rubber around the inside face of the aft insulator is bonded with EPON 913. This item should be replaced after each test.

4.1.7.3 Cartridge

The cartridge requires some refurbishment as a normal part of the reloading cycle. The forward restrictor of the cartridge is consumed on each firing. The rubber insulation inside the wall can be ground clean, patched locally with potting compound, and patched over larger areas with sheets of cured rubber. Eroded parts of the fiberglass surface can be built up with an epoxy-milled glass mixture. Sealing surfaces can be cleaned with surfacing resin. This refurbishment is a portion of routine reloading activities.

4.1.7.4 Cartridge Spacer

The cartridge spacer also requires periodic refurbishment. Since the spacer is returned with the cartridge on the shipping pallet, this refurbishment is included in the reloading or cartridge refurbishment contract.

4.1.7.5 Forward Insulator

The forward insulator consists of a large asbestos-phenolic disc which is expected to last 10 firings and smaller rubber discs which are replaceable after each test. The rubber discs are readily removable from the phenolic part, and are replaceable with two-face tape. Estimates of service life or thickness required for the rubber disc depend on the pressure, duration, and temperature of a test. The char rate is approximately 1/2 in./min at 1,000 psi. The diameter of the rubber was made large enough to protect the phenolic portion for extended service life. The rubber erodes deeply at the center and negligibly at the outer diameter.

Radial strips of rubber 3/4 by 1 by 6 in. are placed on the forward insulator to keep the forward restrictor from sagging onto the forward insulator. Additional strips are used for low-modulus propellant. Those are replaced each time.

4.1.7.6 Case Wall Insulation

A 1/4-in.-thick rubber insulator is bonded to the case wall to protect the steel locally where combustion gases enter the gap external to the cartridges. A spare rubber insulator will be provided. Replacement is by removal and rebonding new units.

Above the bonded-in rubber insulation, DC 93-104, a room curing silicone-base insulation rubber is installed. The short length motor insulation thickness is increased from 0.03 to 0.125 in. to accommodate the long durations. Refurbishment is by burnishing the rubber surface and applying additional coats of insulation. V-61 can also be used instead of DC 93-104.

4.1.8 Handling of SLSH Motor Components

4.1.8.1 Forward Closure (Weight ~18,000 lb)

The forward closure (C10119) has two trunnions (C10289) permanently attached. The centerline formed by these two trunnions is 5-1/2 inches offset from the center of gravity of the closure so that a third lift point is required. A 1-1/2-6 eyebolt provides the third point. The trunnions each have two journal sections: 2-in.-wide journals inboard for lifting hooks or stirrups and 6-in.-wide journals outboard for support in the trunnion base. The closure is lifted by use of the C10292 sling assembly using C11151 stirrups to attach to the 2-in. trunnion journals. A tag leg on the sling attaches to eyebolt.

The closure can be placed in the C10291 trunnion base using the C10849 support under the overbalance side. The stirrups become captive on the trunnions and must be disconnected from the C10292 sling. The closure can be inverted by attaching a crane hook to the 1-1/2 in. eyebolt and swinging it over the top. The crane must be capable of translation to keep the lift cable vertical so as to avoid putting horizontal loads into the trunnions.

The C10713 transport trailer has similar trunnion base supports and can be used for working on, inverting, and transporting of closures. The C10713 drawing contains instructions for positioning the support heads to level the closure.

The forward insulator is moved using the C10300 and three 1/2-13 eyebolts screwed into the threaded holes. The rubber portion of the forward insulator is moved manually.

4.1.8.2 Case (Weight ~13,000 lb)

The case is lifted by attaching a C10290 case lift adapter with four each of the C10840 pins. The C10290 adapter has journals identical to the C10289 trunnions. The case is lifted using the C10292 sling and the C11151 stirrups connected to the 2-in.-wide journals. The case should never be set on the concrete, but always on plywood or wood blocks to avoid scratching.

If the case is to be inverted, it is lowered onto another C10290 adapter and attached so that the adapters are parallel. The assembly is then lowered so that the wide journals of the lower case lift adapter engage the C10291 trunnion base. The case can then be lowered into a wooden cradle for storage or refurbishment. Care must always be taken to avoid scratching the O-ring surfaces inside the motor case. The lift adapters should be removed for any extended storage to avoid rust of the case. When lowering the case onto the closure, always use the 20,000-lb hydroset for smooth controlled engagement.

4.1.8.3 Aft Closure (Weight ~19,000 lb)

The aft closure has C10289 trunnions permanently attached exactly as the forward closure. It is handled in the same manner with the same fixtures. The aft closure is conveniently processed on the C10713 transport trailer. This allows the nozzle and closure subassembly to be put together inside a remote building to control sand, dust, and temperature. The preferred assembly sequence is to invert the closure for installation of the aft closure insulator, O-rings and retainers, then to rotate the closure upright for installation of the insulated nozzle adapter and/or nozzle. The nozzle/closure assembly can then be placed on the case as an assembly (using the hydroset).

4.1.8.4 Propellant Cartridge (Weight to 28,000 lb)

The propellant cartridges are shipped and stored on PD2492 shipping bases. The C10714 transport trailers will transport either CHAR or Super HIPPO grains on their respective bases. The propellant cartridges are lifted, loaded into motors, and removed from motors using the C10294 cartridge lift adapter. The lift adapter must be adjusted so the four lift points are locked, and engage the fiberglass by 1 ±1/8 in. The four safety latches must be engaged over the cartridge and pinned while lifting the propellant cartridge except for the final 2 ft of vertical travel while loading/unloading the cartridges in the motor case (see appendix E).

4.1.8.5 Miscellaneous

The handling equipment also includes C10741 and C10742 spanners for installing of insulation plugs, PD2493 clevis pin shipping containers, and a C11029 hydroplug for the C10120 aft closure during hydrotest. The C11198 shear key test fixture can be used to qualify new shear key samples.

4.1.8.6 Handling Equipment

Table 4-6 lists handling equipment and defines functions and weight of each item along with periodic load test requirements.

TABLE 4-6. HANDLING EQUIPMENT DESCRIPTION

Part Number	Quantity	Title and Function	Weight, lb	Load Test Required	Reference Figure No.
C10294-01-01	1	Adapter, Hoisting Cartridge. Transfer loaded cartridges from the delivery truck to the transport trailer and from the transport trailer to load the motor; offload the motor.	550	Yes	4-14
C10742	2	Wrench, Spanner, Large Insulation Plug. Installs and removes ablative plugs which cover the screws holding the insulation to the aft closure; comes in three different tang widths to accommodate machining differences on the plugs and effects of char and erosion.	1.3	No	
C10741	2	Wrench, Spanner, Small Insulation Plug. Same as C10742, but for the insulation plugs in the adapter and forward closure insulators.	0.3	No	
C10291-01-01	1	Trunnion Base - 30,000 lb. Provides support for inverting the adapter and the closures and for laying the case down; attaches to the pad floor.	1,700	Yes 50,000 lb	4-15
C10849-01-01	2	Support, Trunnion Base. Provides support for the off-balance load of the closures (the trunnions are deliberately mounted off center so that the closure will rest stably on three points); the supports butt to the base on either side of C10291 trunnion base;	175 base 75 head	Yes 6,000 lb, 2,000 lb	4-16

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TABLE 4-6. HANDLING EQUIPMENT DESCRIPTION
(Continued)

Part Number	Quantity	Title and Function	Weight, lb	Load Test Required	Reference Figure No.
C10849-01-01		height adjustments provide for the various closure conditions; the second support provides a safety head in case an unbalance situation should tip the closure the other way; one support must be removed for the operation of laying down the motor case (to install the rubber sheet at the charging gap).			
C10300-01-01	1	Lift Fixture - Nozzle. Attaches to the nozzle flange by three eyebolts to lift the nozzle; a cloth strap secures the nozzle from tipping; the unit will accommodate all contemplated nozzle designs; no inverting capability is provided for nozzles; this fixture is also used for lifting the forward insulator, the pin box, and the cartridge shipping cover.	125	Yes 8,400 lb	4-17
C10290-01-01	2	Adapter, Lifting, Case, 25,000 lb. Attaches to four of the pin holes in the case and provides trunnions to make the trunnion base and journals to mate the lifting hooks; two case lifting adapters are required to lay the case over on its side to to stand it up on end.	925	Yes 50,000 lb 11,900 ft-lb	4-18
C10840	8	Pin Assembly. Used to attach C1029[illegible] case lift adapters to case.	7.5	With C10290	

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TABLE 4-6. HANDLING EQUIPMENT DESCRIPTION
(Continued)

Part Number	Quantity	Title and Function	Weight, lb	Load Test Required	Reference Figure No.
C10292	1	Sling Assembly, 30,000 lb. Used to lift the case and closures.	275	Yes 60,000 lb	4-19
C11151	4	Stirrup. Two stirrups attach to C10290 sling for engagement of closure trunnions and case lift adapter.	125	Yes 30,000 lb	4-20
C10297-01-01	1	Plug Nozzle Shell. For hydrotest of 12.5 submerged nozzle shells.	500	No	
PD2492	2	Shipping Base - Loaded Cartridge.	600	No	
PD2493	3	Shipping Container - Clevis Pins.	40	No	
C10712	N/A	Transport Trailer - Mod Stage I. Provides for removing items from the basic Minuteman trailer in preparation for building up the Super HIPPO configurations.	N/A	N/A	
C10713-01-01	N/A	Transport Trailer - Closure. Provides trunnion bearing and outrigger supports similar to the C10291 trunnion base with the C10767 supports. Closures can be inverted in the trailer, but not with the larger nozzles installed; the larger nozzles would not cause excessive weight, but could hit on the frame.	N/A	Yes 2,000 lb 6,000 lb 50,000 lb	4-21

TABLE 4-6. HANDLING EQUIPMENT DESCRIPTION
(Continued)

Part Number	Quantity	Title and Function	Weight, lb	Load Test Required	Reference Figure No.
C10714-01-01	N/A	Transport Trailer - Cartridge. Will accept either Super HIPPO or CHAR motor cartridges (the skids under the CHAR motor shipping base must be cut down 1-1/2-in. each end to 96 in. overall); the Minuteman tiedown dogs are installed to engage the 4 by 4s of the shipping base, and the tiedown cables will transfer to mounting brackets on the trailer bed.	N/A	Yes 50,000 lb	
C10715-01-01	N/A	Transport Trailer - Handling Equipment. Four tabs on the front engage the lift probes of the cartridge lift fixture; cradles are provided to accept the adapter inverter and case lift fixture; four threaded ports provide tiedown for the leak check fixture; deck space is provided for the slings and pin boxes.	N/A	No	
C10289	8	Trunnion. Two trunnions are permanently attached by bolts to each closure and to the female clevis end of the aft case.	90 each	No	
N/A	2	Pin Puller. A Proto commercial slide hammer and shaft with adapter to 1/2-13 threads serves to pull the clevis pins.	N/A	No	
N/A	25	Eyebolts. Four eyebolt sizes are used: 1-1/2-6, 1-1/8-7, 1/2-13, and 3/4-10.	N/A	No	

TABLE 4-6. HANDLING EQUIPMENT DESCRIPTION
(Continued)

Part Number	Quantity	Title and Function	Weight, lb	Load Test Required	Reference Figure No.
C11198	1	Test Fixture, Lock Key.	N/A	No	
C11232	1	Hook, Joint Ring. For lifting insulated joint ring.	15	Yes 1,500 lb	4-22

1. Proof load only two opposing legs at any one time
2. Proof load with item 6 locked out and with items 56 and 59 rotated back.

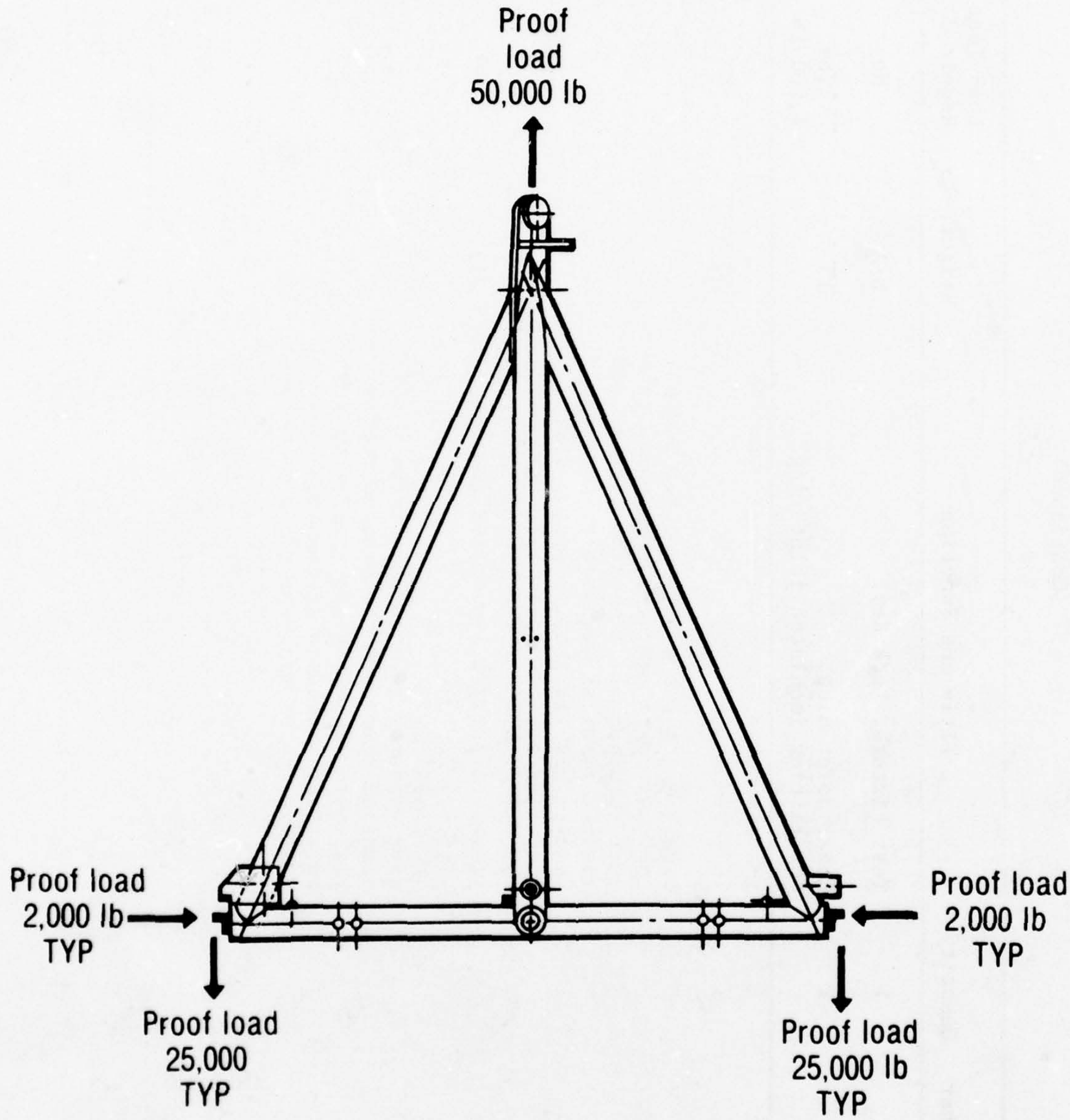


Figure 4-14. C10294 Cartridge Lift Adapter Load Test

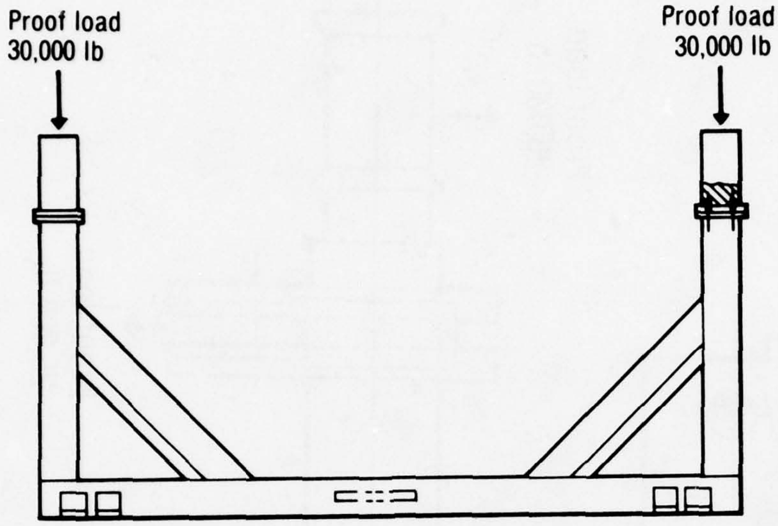


Figure 4-15. Proof Load Diagram - C10291 Trunnion Base and C10713 Closure Trailer

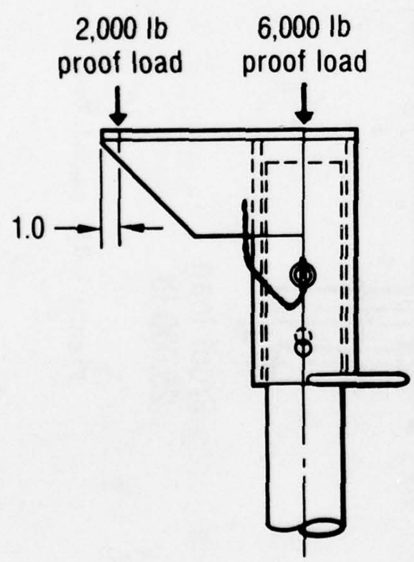


Figure 4-16. Proof Load Diagram — C10849 and C10713 Supports

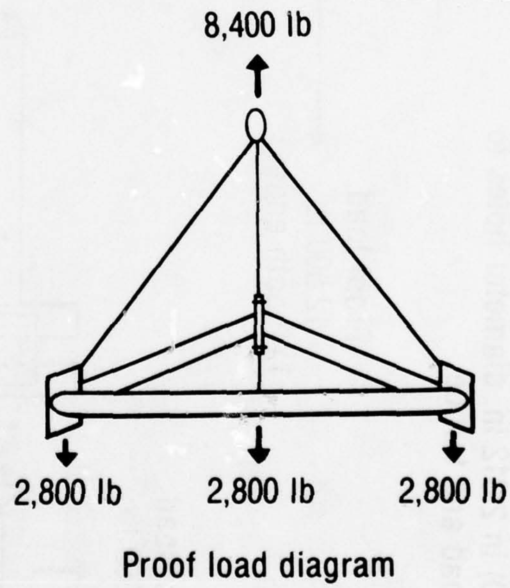


Figure 4-17. C10300 Nozzle Lift Adapter

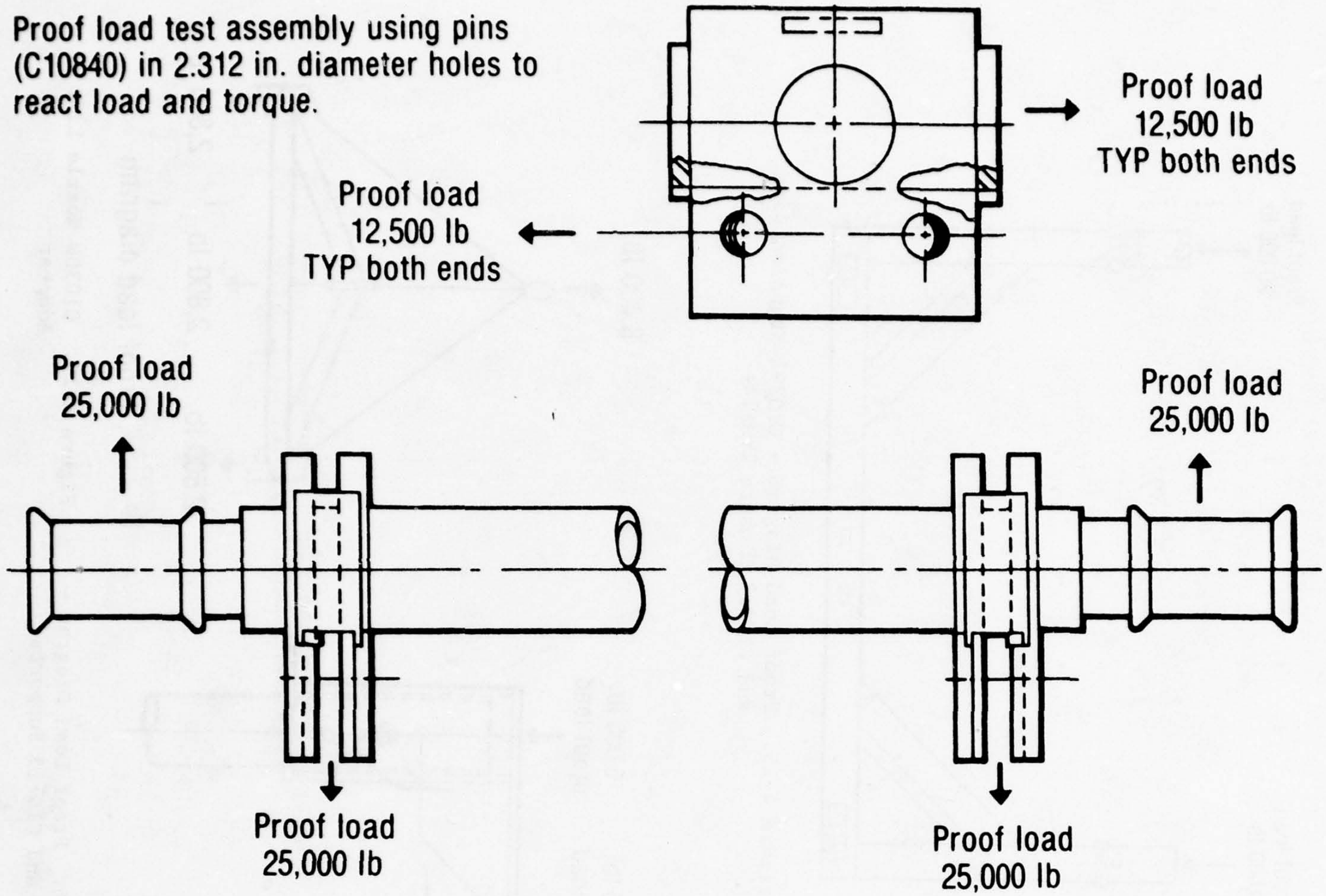


Figure 4-18. Load Test — Case Lifting Adapter, P/N C10290

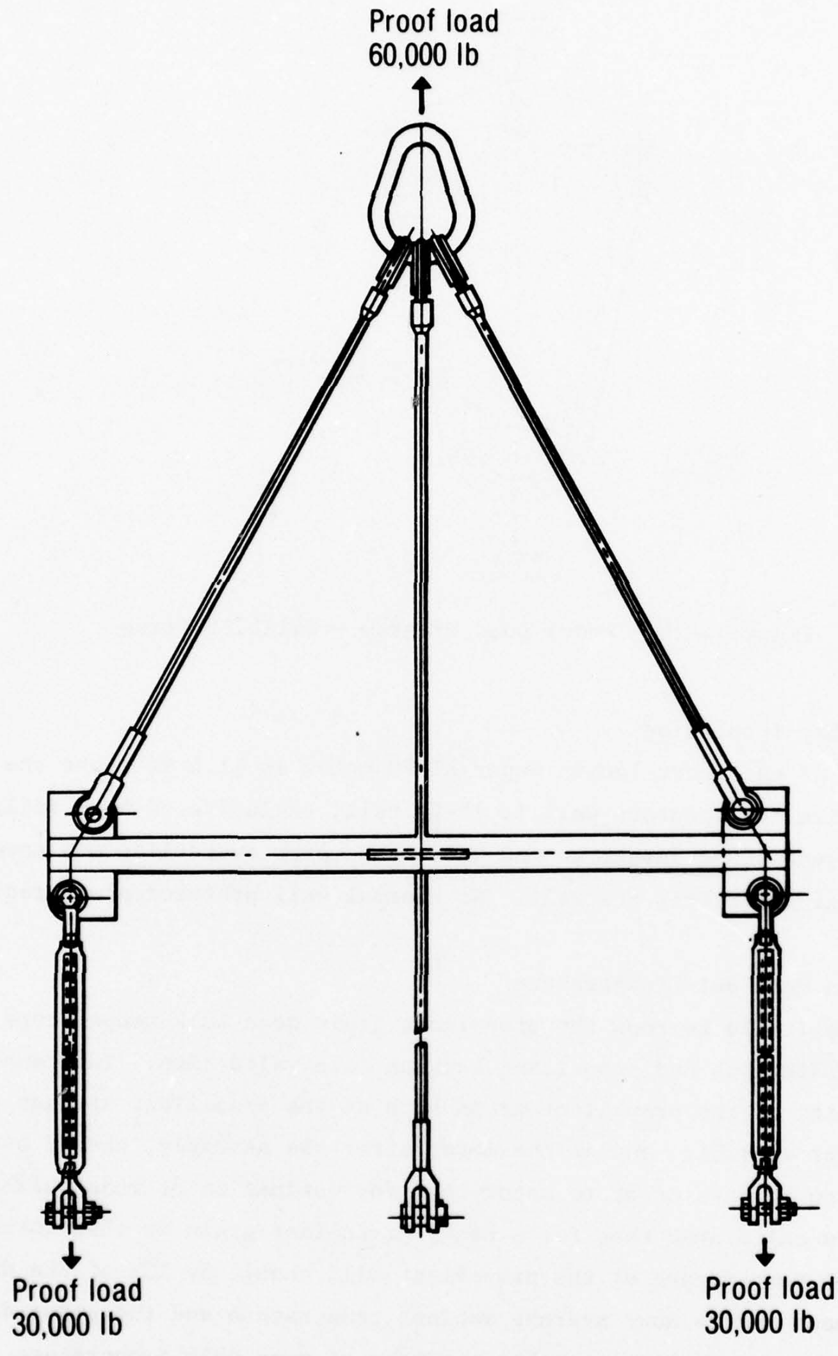


Figure 4-19. Proof Load Diagram — C10292 Sling Assembly

Sue 42

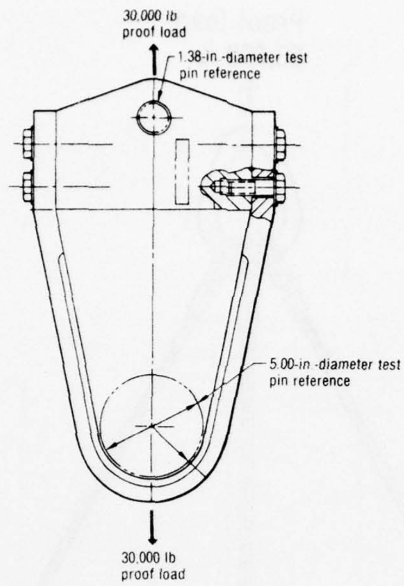


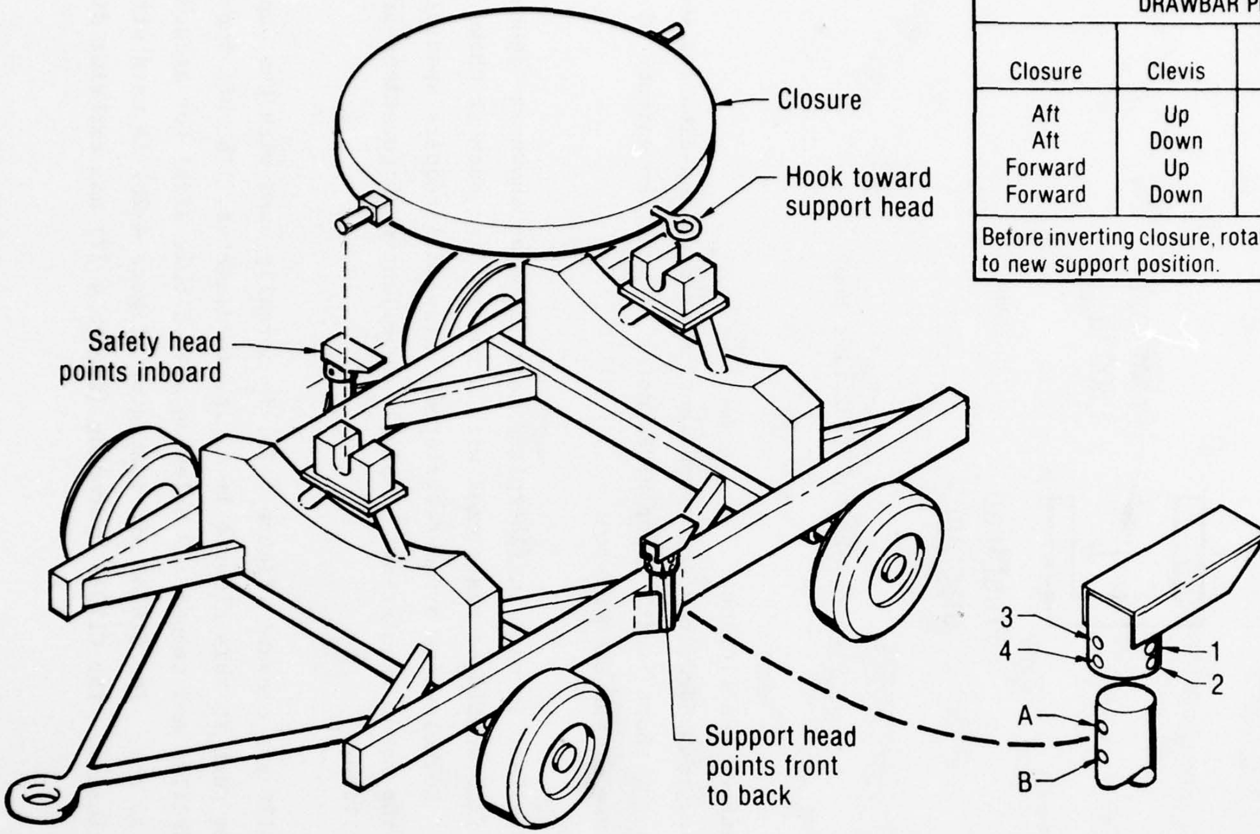
Figure 4-20. Proof Load Diagram — C11151 Stirrup

4.1.9 Test Bay Insulation

The top of the short length Super HIPPO motor is 11.4 ft above the thrust pad floor while the concrete wall is 25-ft tall, exclusive of hand railings. To avoid exhaust plume damage to the wall, the motor centerline was specified to be at least 11 ft from the wall. No thermal wall protection was required.

4.1.10 Grain Mean Bulk Temperature

It is desirable to know the propellant grain mean bulk temperature for ballistic predictions and propellant burning rate validation. The temperature in the vacinity of the propellant grain both at the propellant storage area prior to motor assembly, and at the motor after the assembly, should be measured for up to 30 days prior to motor test for estimation of mean bulk temperature. It was calculated that for a heavy propellant grain in this motor, that the mean bulk temperature of the propellant will change by 13% of the difference between the 24 hour average ambient temperature and the prior day's mean bulk temperature. A reasonable estimate of mean bulk temperature can be made with 10 days data.



DRAWBAR Pin Position			
Closure	Clevis	Support Head	Safety Head
Aft	Up	4-B	2-B
Aft	Down	3-A	1-A
Forward	Up	4-A	2-A
Forward	Down	3-A	1-A
Before inverting closure, rotate safety head 90° and pin to new support position.			

Figure 4-21. C10713 Closure Trailer

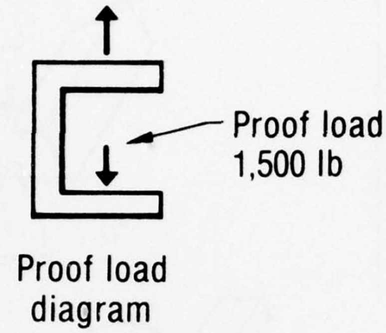


Figure 4-22. C11232 Lift Hook

4.1.11 Interface Descriptions

This paragraph describes the propellant cartridges and closures which can be used with the short length Super HIPPO motor for the convenience of persons considering use of the SLSH system.

The propellant is cast in fiberglass cartridges as shown in figure 4-23. The forward face should be restricted with a rubber disc such as shown in figure 4-24. Keyhole-type or nonrestricted grains will require special analysis of the motor insulation. Typical propellant configurations are shown on drawing C11479.

The C10120 aft closure (figure 4-25) is normally used with the Super HIPPO or SLSH. The port in this closure is 41 in. in diameter. The aft face of this closure is drilled and tapped (60 holes on a 46.5 bolt side) for attachment of TVC actuators, etc. The C10280 aft insulator (figure 4-26) is used with the C10120 aft closure. The C11029 hydroplug (figure 4-27) has exterior dimensions

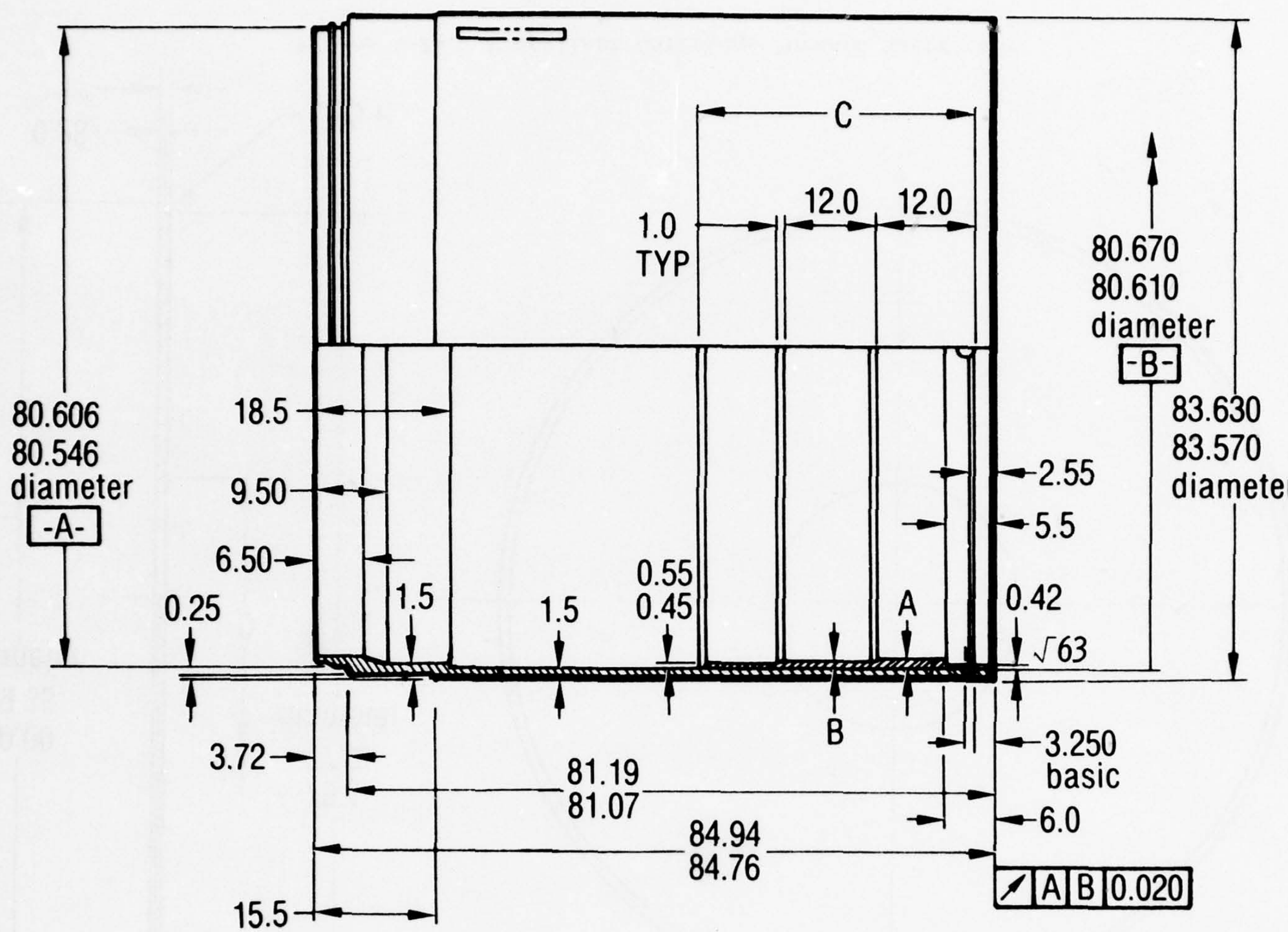


Figure 4-23. Super HIPPO Insulated Propellant Cartridge

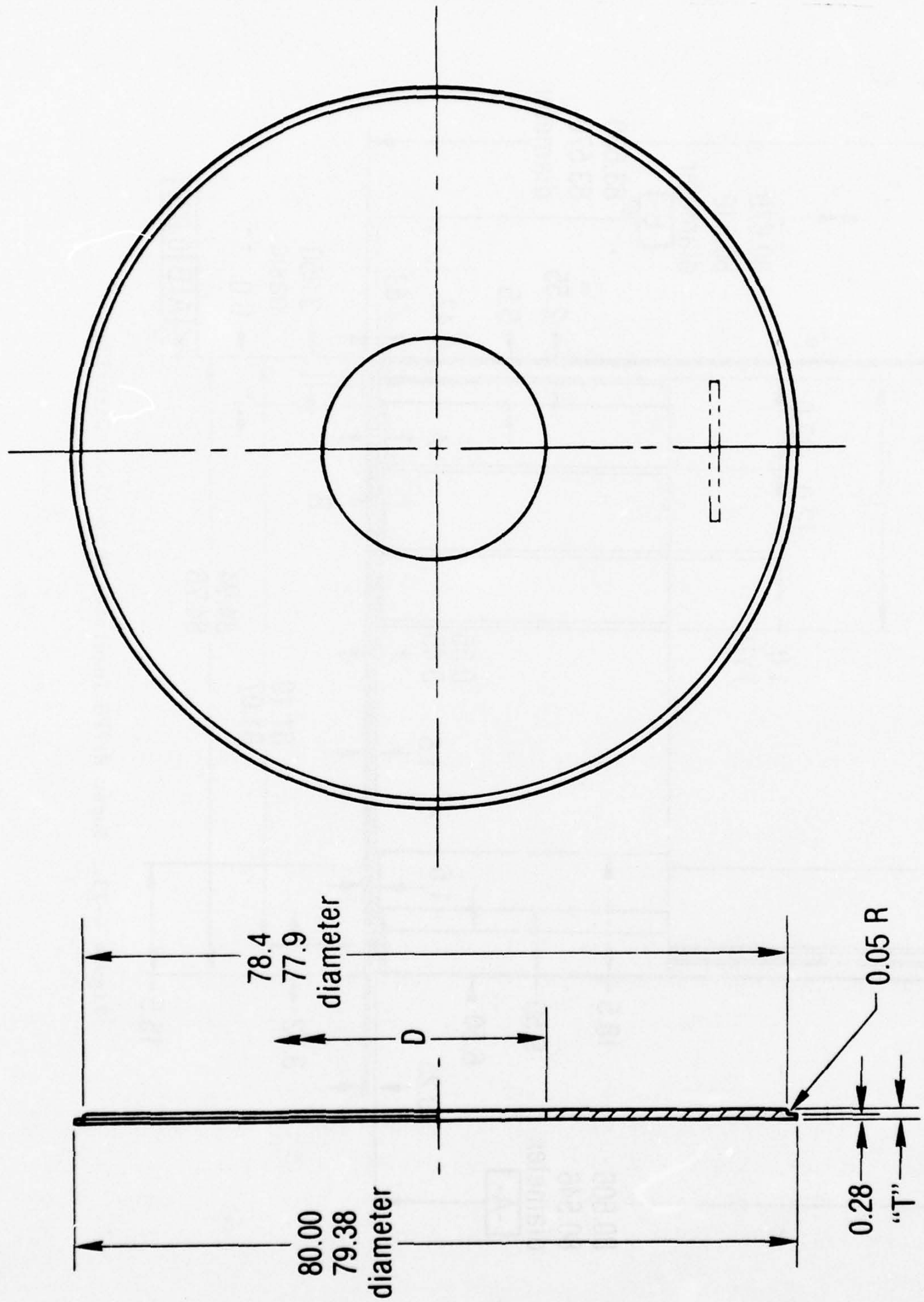


Figure 4-24. Propellant Cartridge Forward Restrictor

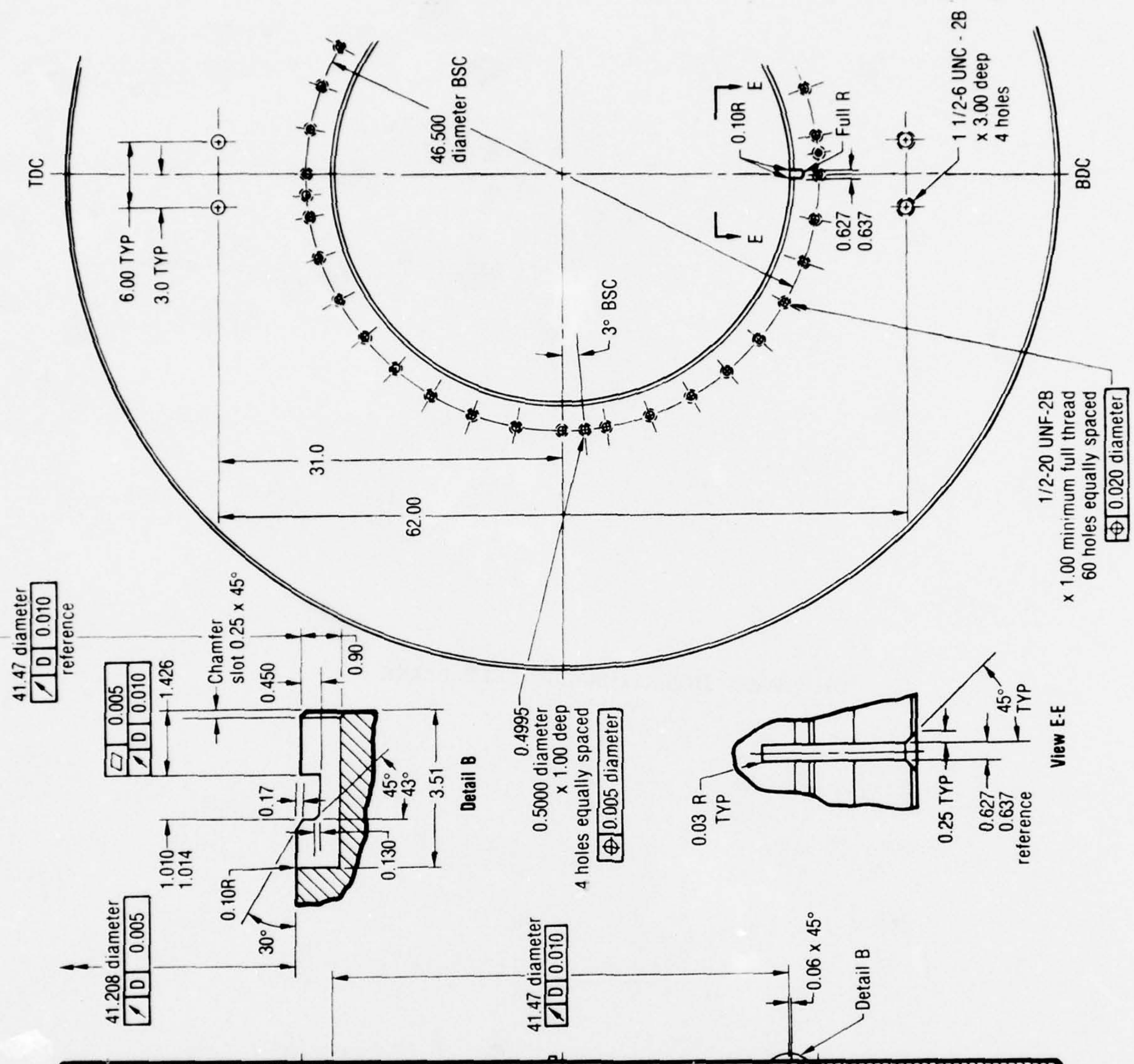


Figure 4-25. Super HIPPO Aft Closure Interface Dimensions

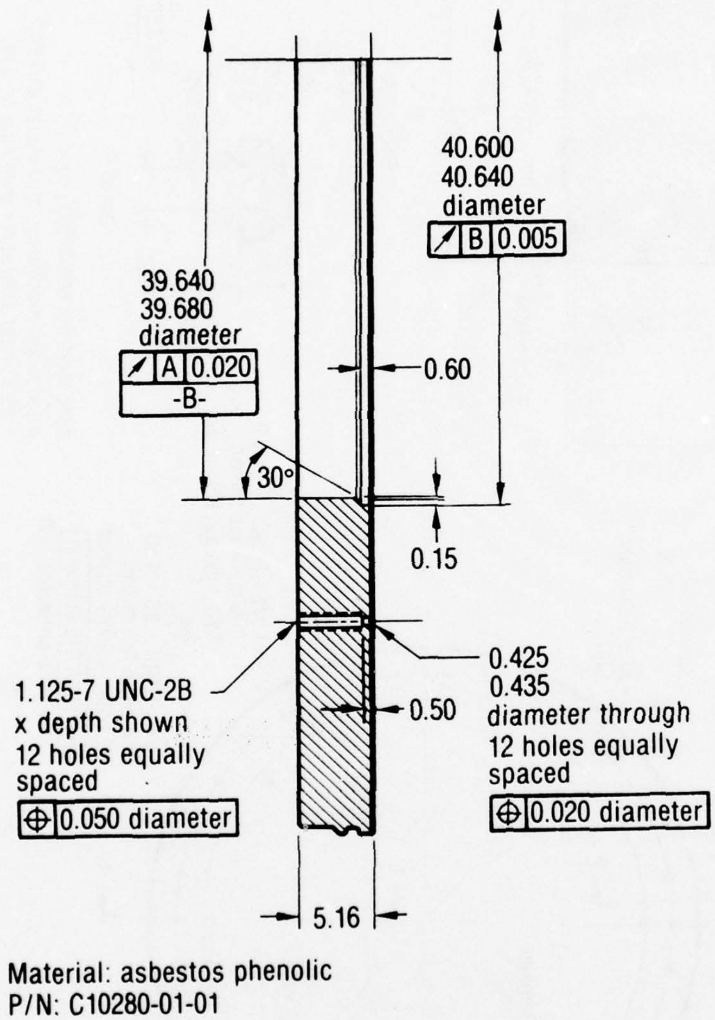


Figure 4-26. Aft Insulator for Use with Super HIPPO Aft Closure

Sue 50

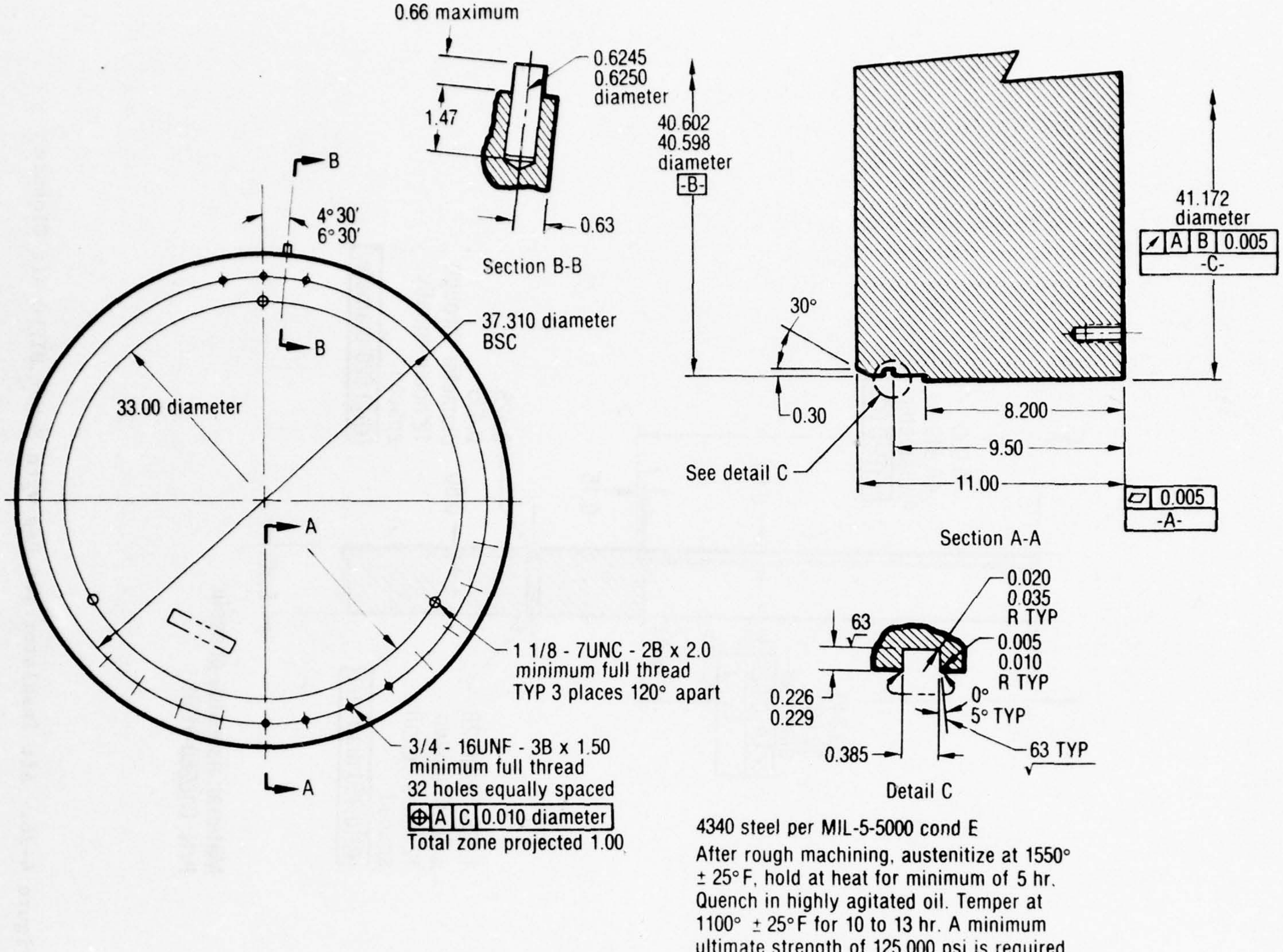


Figure 4-27. Nozzle Adapter to Mate Super HIPPO C10120 Aft Closure

as should be used for a nozzle or nozzle adapter for testing on the C10120 aft closure (figure 4-25). The nozzle will be retained by a shear key and assembled generally to the C11167 or C12413 assembly drawing.

Nozzles with larger flanges can be tested on the C11126 aft closure (figure 4-28), the port diameter is 55 in. The aft insulator for this closure is C11012 (figure 4-29). The nozzle is retained by a shear key and assembled per drawing C11347. Exterior dimensions of such a nozzle flange should be similar to C11014 (figure 4-30).

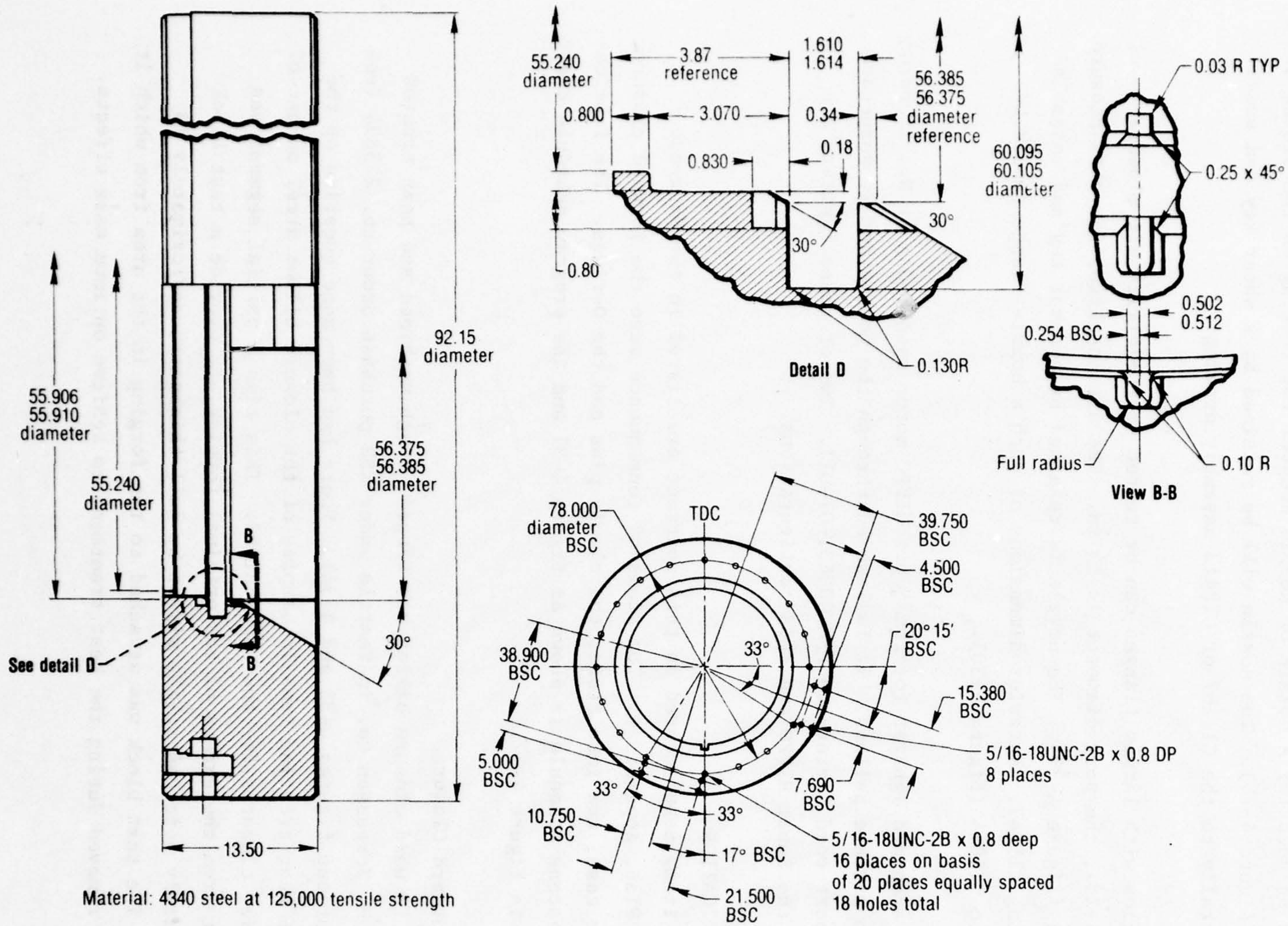
The standard igniter for the Super HIPPO motor uses 950 g of No. 2D boron potassium nitrate pellets. It is lowered through the nozzle and is suspended by a support cord (reference P/N C00631-07-01). Two of these igniters are used for the Super HIPPO and ELSH configurations.

4.2 FABRICATION

The items manufactured on this contract are listed in the Hardware Delivery Plan, Appendix A. The items of consequence were the forward closure, the motor case, the insulators, the clevis pins and the O-rings. The fabrication milestone schedule is shown as figure 4-31 and the program schedule chart is shown in figure 4-32.

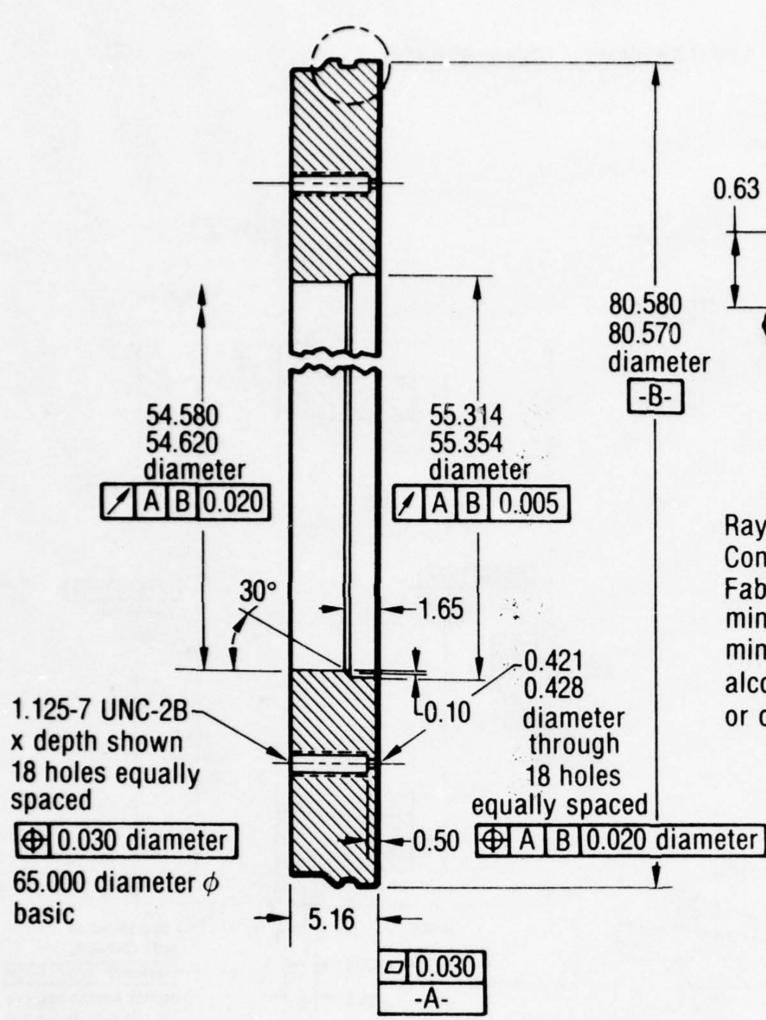
4.2.1 Forward Closure

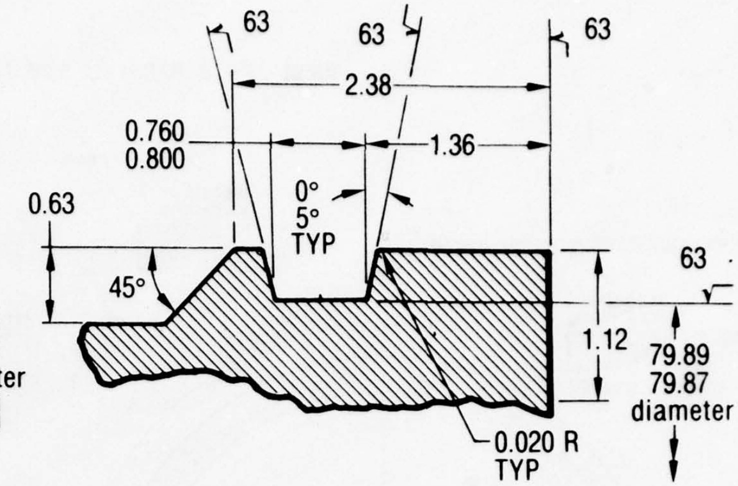
The forward closure billet was forged, rough machined and heat treated by Earle M. Jorgensen Co. in Seattle under CSD purchase order no. 225394 (see certifications figures 4-33 and 4-34). There had been some question on the method of heat treating tensile samples of the closure billet steel on one of the earlier closures for the Super HIPPO. This time a partial segment was flame cut from the excess of the original forging, to provide a test block approximately 5 inches at the widest by full thickness, approximately 13 inches. The test block was attached to the forging in the area from which it had been removed during the heat treatment to achieve optimum mass effects.



Material: 4340 steel at 125,000 tensile strength

Figure 4-28. ELSH Aft Closure Critical Details





Raybestos-Division of Raybestos-Manhattan, Inc., Stratford, Conn., code indent No. 81604 (or approved equivalent). Fabricate by molding at a pressure of 200 psi minimum. Density of cured part shall be 106 lb/ft 3 minimum. After final machining, visually inspect by alcohol-wipe test, no cracks, voids, inclusions or other discrepancies are allowed.

Material:
Asbesto phenolic
42 - RPD
Type 9617

Figure 4-29. Insulator, Aft Closure, ELSH

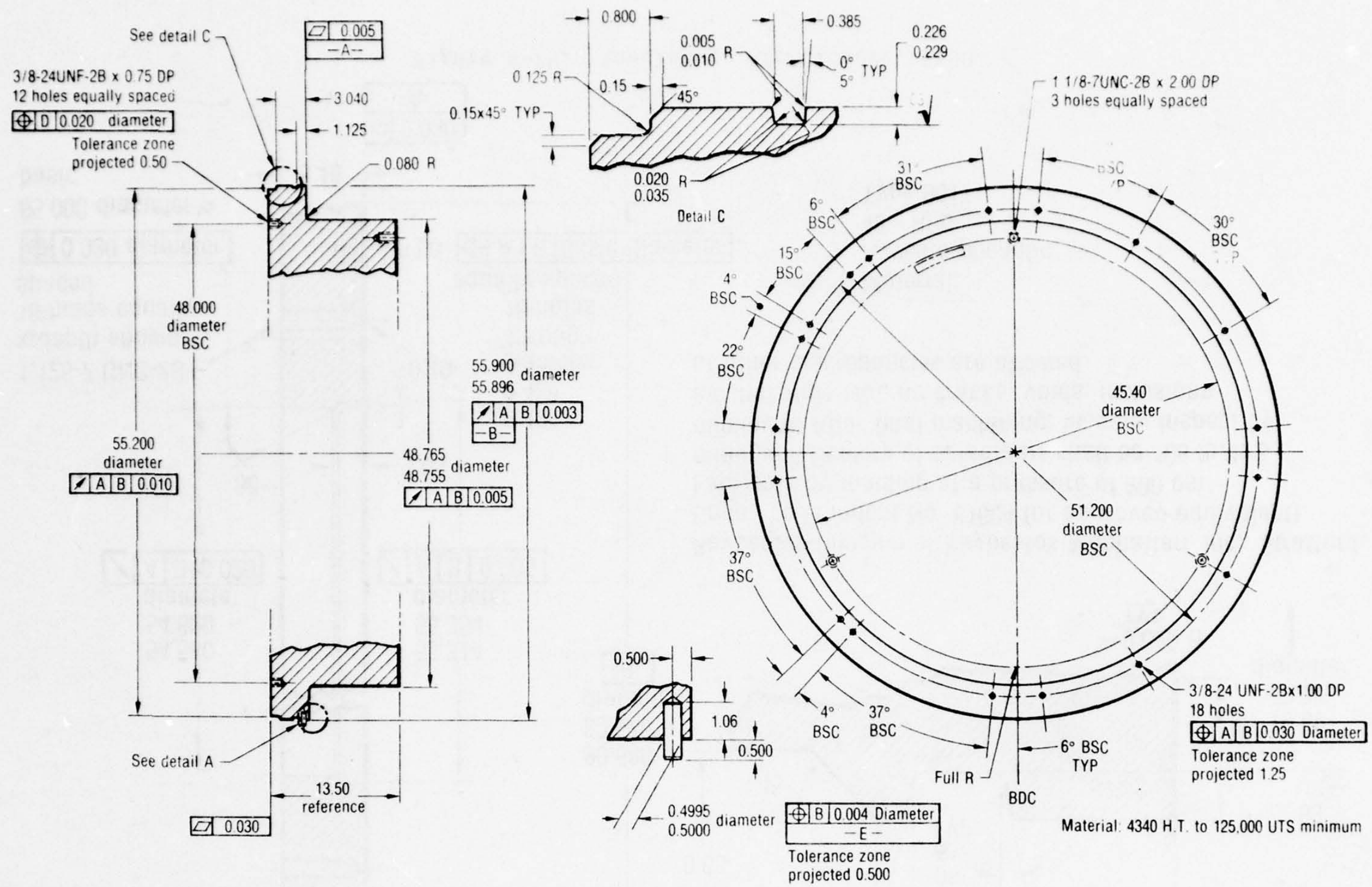


Figure 4-30. Adapter, Aft Closure Plug, ELSH

Item	Target	Actual
HY-130 Rolled to Cylinders	May 23	May 23
Design Review	June 6	June 10
All PO's Placed	June 30	June 24
Asbestos Sample Tests Complete	June 30	June 28
Case Girth Weld Complete	June 30	June 30
Misc. Items Reveived and Boxed	July 15	August 19
Closure Lathe Operations Complete	August 8	July 28
Match Drill Aft Closure	August 8	August 18
Ship Case	August 31	August 23
Motor Test	October 14	October 7

Figure 4-31. Target Milestone Chart — Accelerated Schedule
Short Length Super HIPPO

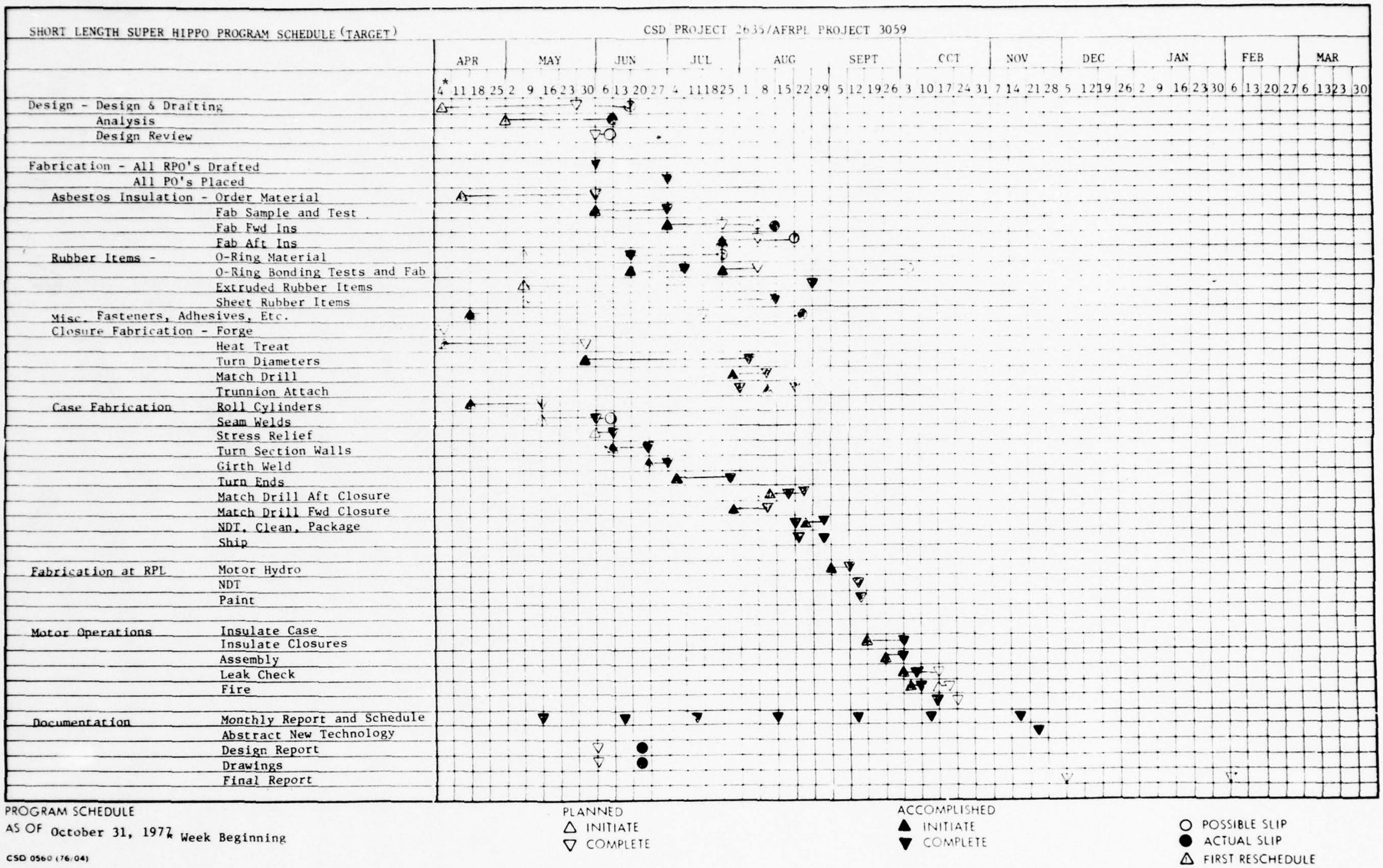


Figure 4-32. Program Schedule Chart

Review - Scannell

Advance Copy For Approval

EARLE M. JORGENSEN CO.

RECEIVED MAY 23 1977 PROCUREMENT

STEEL

FORGE DIVISION

8531 E. MARGINAL WAY SOUTH • PHONE 762-1100 (AREA 206)
MAILING ADDRESS: P. O. BOX 24026
SEATTLE, WASHINGTON 98124

CERTIFIED MATERIAL TEST REPORT

CUSTOMER

UNITED TECHNOLOGY CENTER
P O BOX 358
SUNNYVALE, CALIF

ATT: W R RICHEY

Date 5-16-77
Customer's Order No. S/C 225394
Our Invoice No. 9139 FS
Contract No.

HEAT NO.	MATERIAL	DESCRIPTION	SPECS.
17636	4340	1 PC ROUGH MACHINED TO FINISH 92.2" OD X 10.0" THK	MIL S 5000 COND E

CHEMICAL ANALYSIS

HEAT NO.	MATERIAL	C	MN	P	S	SI	NI	CR	MO	V	CU	SN			G/S
17636	4340	.39	.73	.013	.025	.28	1.79	.78	.22						
CHK ANAL		.40	.70	.012	.022	.26	1.70	.73	.22						

HARDENABILITY – ROCKWELL "C" IN 16th OF AN INCH

HEAT NO.	MATERIAL	1	2	3	4	5	6	8	10	12	14	16	20	24	28	32	HARDNESS BHN OR RC

MECHANICAL PROPERTIES

TEST NO.	HEAT NO.	MATERIAL	YIELD LBS./SQ. IN.	TENSILE LBS./SQ. IN.	ELONG. % 2 IN.	RED. OF AREA %	FRACTURE	BEND	MACRO	IMPACT
1-T	17636	4340	134,000	153,500	17.5	45.5	CUP		S1R1C1 T & B	

REMARKS: FREQUENCY/SEVERITY $\frac{.10}{.12}$

NORMALZIE	1650 DEG F	23 HRS
TEMPER	1275	16
QUENCH	1575	19
TEMPER	1125	15

INSPECTOR

SUBSCRIBED AND SWORN TO BEFORE ME

THIS ____________ DAY OF ____________ 19__

NOTARY PUBLIC—SEATTLE

WE CERTIFY THAT THE MATERIAL COVERED BY THIS REPORT HAS BEEN INSPECTED & TESTED IN ACCORDANCE WITH THE APPLICABLE REQUIREMENTS DESCRIBED HEREIN, AND TEST REPORTS ARE ON FILE SUBJECT TO EXAMINATION

EARLE M. JORGENSEN CO.

BY R L Kerwin

68

FORM 91-FS-1 F&H 10M 1-77

4.2-1

Figure 4-33. Certification Number 1

EARLE M. JORGENSEN CO.
STEEL
FORGE DIVISION
8531 E. MARGINAL WAY SOUTH • PHONE 762-1100 (AREA 206)
MAILING ADDRESS: P. O. BOX 24026
SEATTLE, WASHINGTON 98124

CERTIFICATE OF NON-DESTRUCTIVE TESTING

UNITED TECHNOLOGY CENTER
P O BOX 358
SUNNYVALE, CALIF

Date 5-18-77
Customer's Order No. S/C 225394
Our Invoice No. 9139 FS

MANUFACTURER: EARLE M JORGENSEN CO

MATERIAL 4340

SPEC. UTC GS-90402D DTD 10-25-64 & UTC E.C.O. 10293 SHT 1 OF 1 TO GRB (G33-01 C1 C AND B)

ASNT TC-1A

OPERATOR AL SCHLENKER

LEVEL II

DESCRIPTION OF ITEMS:	HEAT NO.
PC ROUGH MACHINED TO FINISH 92.2" OD X 10.0" THK	17636

EQUIPMENT: UM 771

ITEM	FREQUENCY	SEARCH UNIT	PULSE LENGTH VIDEO-IF	REJECT (ZERO SURPRESS)	SURFACE COND.	COUPLANT.
	2.25 MHZ	1" ACCUSCAN	MIN	OFF	MACH	OIL

REFERENCE STDS. & METHODS: CALIBRATED TO 5/64" FBH AND FIRST BACK REFLECTION TO 100% SCREEN HEIGHT. CONTACT.

RESULTS OF INSPECTION — COMMENTS:

ACCEPTABLE PER UTC SPEC GS-90402D DTD 10-25-64 AND UTC E.C.P. 10293 SHEET 1 OF 1 TO GRB (G33-01 C1 C & B).

TYPE OF INSPECTION

TEST CONDITIONS:

DESCRIPTION OF DEFECTS FOUND IF ANY:

SPEC.

OPERATOR

LEVEL

INSPECTED BY:

SUBSCRIBED AND SWORN TO BEFORE ME

THIS ______ DAY OF ______ 19 ____

NOTARY PUBLIC—SEATTLE

WE CERTIFY THE ABOVE TO BE IN ACCORDANCE WITH THE RECORDS CONTAINED IN OUR FILES
EARLE M. JORGENSEN CO.

BY R L Kerwin

FORM 91 FS - 3 FBH 8M 7-75

Figure 4-34. Certification Number 2

Sue 59

Tensile coupons were cut from the center of this test block. The values of 135 ksi yield, 153 ksi ultimate obtained on this heavy section are indicative that the 125 ksi minimum ultimate tensile strength was achieved in all areas.

Turning operations were performed by Oakland Machine Works in Oakland, Cal. The closure block was then match drilled for clevis pin holes with the motor case by Conseco in San Leandro, Cal, under CSD purchase order 225392.

4.2.2 Motor Case

The C12419-01-01 motor case steel started as three pieces — 2 purchased from US-Steel and one surplus to contract F04611-73-C-0023, the Super HIPPO contract. All three pieces were GFE and were provided at Allis Chalmers, Milwaukee. See Certifications, figures 4-35, 4-36, and 4-37. The steel used is HY-130 which is a high toughness steel developed by the Navy for submarine fabrication. The advantage of this steel is that is has high strength with low alloy levels, and it can be rolled and welded in the fully heat treated condition. Thus, the steel was delivered to Allis Chalmers, Milwaukee, as flat plates 2-1/4 and 2-1/2 inches thick, fully heat treated. Allis Chalmers rolled the plates to 83-1/2 inches I.D. under subcontract to Conseco/San Leandro and shipped to Conseco. Conseco completed manufacture and match drilling of the motor case under CSD purchase order 225392. See process flow sheets, figures 4-38 and 4-39. The first step was to seam weld the sectors into cylinders which could be finish machined to 84 inches I.D. The configuration of available HY-130 plate required that the two new pieces of HY-130 be rolled into 180° sectors with 2 seam welds, and the older (and longer) plate was rolled into a 360° sector requiring but one seam weld. This latter sector was used for the forward end of the case. See figure 4-40. Conseco had done the welding and fabrication on the Super HIPPO and ELSH motor cases, so that Conseco had already prepared welding and weld repair procedures, and had completed qualification welding under subcontract to CSD, Ref. Contract F04611-73-C-0023. The seam welds were made without incident and the cylinders were stress relieved. The stress relief cycle on the cylinder made of the

UNITED STATES STEEL CORPORATION

COUNTRY OF ORIGIN U.S.A. PAYABLE IN U.S. DOLLARS

	PURCHASE ORDER DATE	PURCHASE ORDER NO		
0000939179	09/21/76	F047007690050		
	USS CONTROL NO	USS ORDER NO		PAGE
	04802-1601	AL23525		
	TERMS	INVOICE DATE	INVOICE NO	
	30-1/2-10	02-17-77	163-19611	

PLEASE REFER TO THE ABOVE INVOICE NO. IN YOUR REMITTANCE

T 0- 0- 8 REMIT TO 004933396
S 1- 0- 0 PO BOX 36008M
I 1- 2- 0 PITTSBURGH, PA 15251

R 94

SOLD TO
U S GOVT AIR FORCE
ACCOUNTING & FINANCE OFFICER
AFFTC & ACF
EDWARDS AFB CALIF 935523

U S GOVT
ALLIS/CHALMERS MFG
1120 SOUTH 70TH
WEST ALLIS MILWAUKEE WISC 5321-
ATTN DEPT 8010/RUSSELL WHITE

SHIPPERS NO.	DATE SHIPPED	FROM	ROUTE CARRIER
075026	02/15/77	HOMESTEAD PA.	VIA AERO LOT 85237 PART 3 F

SHIP MODE	MINIMUM WEIGHT	FOB	VEHICLE IDENT	PREPAID COLLECT
LTL	0000M	MILL	CT18566 PA	C

Item No. / Description / Quantity / Unit Price / Amount

ARMOR PLATE HY-130 MIL-S-24371A DESCALED ONE COAT
PAINT ULTRASONIC INSP FOR SOUNDNESS AND THICKNESS

ITEM DESCRIPTION FT LENGTH IN
01 2-1/2 X 68 155
PRICE NUMBER 042-1791

HEAT-NO	PIECES	MARK-NO	FT. INCHES	POUNDS			
3P7117	1	0204903	155	7600			
3P7117	1	0204902	155	7600		CENTS/LB	
	2			15200	15200	78.4000	11916.80
			TOTAL				11916.80

SHIPMENT NO.ADA0001Z GOVT B/L K-3,631,110
INSPECTION GOVERNMENT SOURCE INSPECTION

CC SCHAEFER
Hill

71

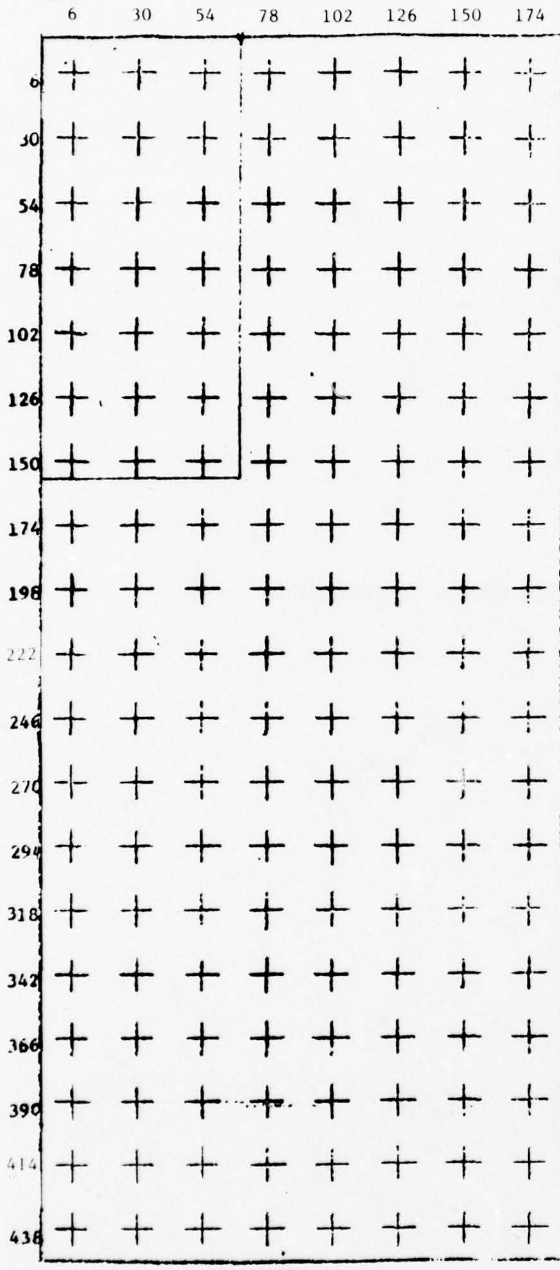
	PIECES	POUNDS
	2	15200
B/L		15200

DISC AMT 59.58 INVOICE AMT 11916.80

DAYS TO MATURITY OR DISCOUNT DATE RUN FROM DATE OF INVOICE

ORIGINAL of this invoice on BLUE paper. COPIES are on WHITE. "Goods or services which were produced or rendered in the United States covered by this invoice were produced or rendered in compliance with the requirements of the Fair Labor Standards Act of 1938, as amended."

Figure 4-35. Certification Number 3



U.S. STEEL CORPORATION
HOMESTEAD DISTRICT WORKS
PLATE ULTRASONIC INSPECTION REPORT

Mill Mark No.

Heat/Melt No. 3P7117

Slab/Plate No. 2204903

MATERIAL	LENGTH	WIDTH	GAGE
HY130	155	68"	2½"

SOUNDNESS DEFECTS - CLASS & LOCATION

flaw class *	dimension to: top end	dimension to: left side	flaw class *	dimension to: top end	dimension to: left side
NONE					

*KEY LBR = Lost Back Reflection (Reject)
XCL = Exceeds Calibration Level (Reject)
RBR = Reduced Bank Reflection (Record)
LCL = Less than Calibration Level (Record)

Soundness Satisfactory ☒ Refer Evaluation ☐

Remarks:
Special 1" scan - stamp side
No recordable indications

Specification/Procedure MIL-S-24371A

Instrument SPERRY Model UJ No.

Search Unit QUARTZ Size 1⅛" Frequency 2.25 MHZ

Inspector MC WILLIAMS Date 1/23/77

Reviewed by W. J. KONIE /Kd Date 1/23/77

FIGURE 4A

Figure 4-36. Certification Number 4

HT-2691

UNITED STATES STEEL CORPORATION

HOMESTEAD DISTRICT WORKS

ARMOR TEST REPORT

TB: 2-21-77

TEST REPORT NUMBER: 3283

U.S.GOVT. AIR FORCE
ACCOUNTING & FINANCE OFFICER-AFFTC & ACF
EDWARDS-AFB-CALIF. 935523

SPECIFICATION: MIL-S- 24371A
GRADE HY-130 DTD 8/21/75
MOD BY ORDER

INVOICE NUMBER: 163-19611
DATE SHIPPED: 2-17-77
CAR NUMBER:

CUSTOMER ORDER	MILL ORDER	ITEM	PLATE NUMBER	GAUGE	ENDS	MECHANICAL PROPERTIES: YIELD 0.2% OFFSET	TENSILE STRENGTH	ELONG % 2"	RED. AREA	FRACT	HEAT NUMBER
F0470075-90050	AL 23525				TT	133400	142800	19.0	66.0	-	
		01	0204903	2-1/2	TB	137400	141900	20.0	69.0	-	3P7117
					TT	138000	145000	17.0	68.0	-	
"	"	01	0204902	2-1/2	TB	138000	145000	17.0	64.0	-	3P7117

CHEMICAL COMPOSITION
L - Ladle; F & R - front & rear check analysis

LOC	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti
L	10	79	006	003	32	05	490	54	49	07	002
F	10	78	008	003	30	04	496	52	51	07	002
R	10	83	010	004	34	05	500	55	50	074	003

C/Transverse V-Notch Charpy Impact Test Results 0 & RT Deg F plts/Heat-** foot/pounds	HEAT TREATMENT (Deg C. is time at temperature; Deg F is total furnace time.) Temp° Quench Temper	Time in mts.	Coolant	BRINELL
CT-0-DEG. F. 78-79-79	902C 816C	120 120	W	277 **
CT-RT-DEG.F. 80-82-82	622C	120	A	293
CT-0-DEG. F. 73-68-62	902C 817C	120 120	T	293
CT-RT-DEG. F. 80-81-72	615C	165	E	293
			R	

** BRINELL HARDNESS VALUES.
FALL OUTSIDE THE RANGE SPECIFIED:
PRODUCT MEETS CHEMICAL & PHYSICAL PROPERTIES.

WE HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY.

M.W.MAXSON CHIEF METALLURGIST

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED, PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED, ULTRASONIC TESTING AND GAUGING (WHEN SPECIFIED) AND HEAT TREATMENT.

NOTE: ALL HEATS WITH LETTER P OR W ARE BASIC ELECTRIC FURNACE PRODUCED. ALL OTHERS ARE BASIC OPEN HEARTH MANUFACTURE, USING FULLY KILLED FINE GRAIN PRACTICE.

* IMPACTS ARE FROM THIS PLAT MECHANICAL PROPERTIES
#1 END - TRANSVERSE -TOP
#2 END - TRANSVERSE -BOT

Figure 4-37. Certification No. 5

BEST AVAILABLE COPY

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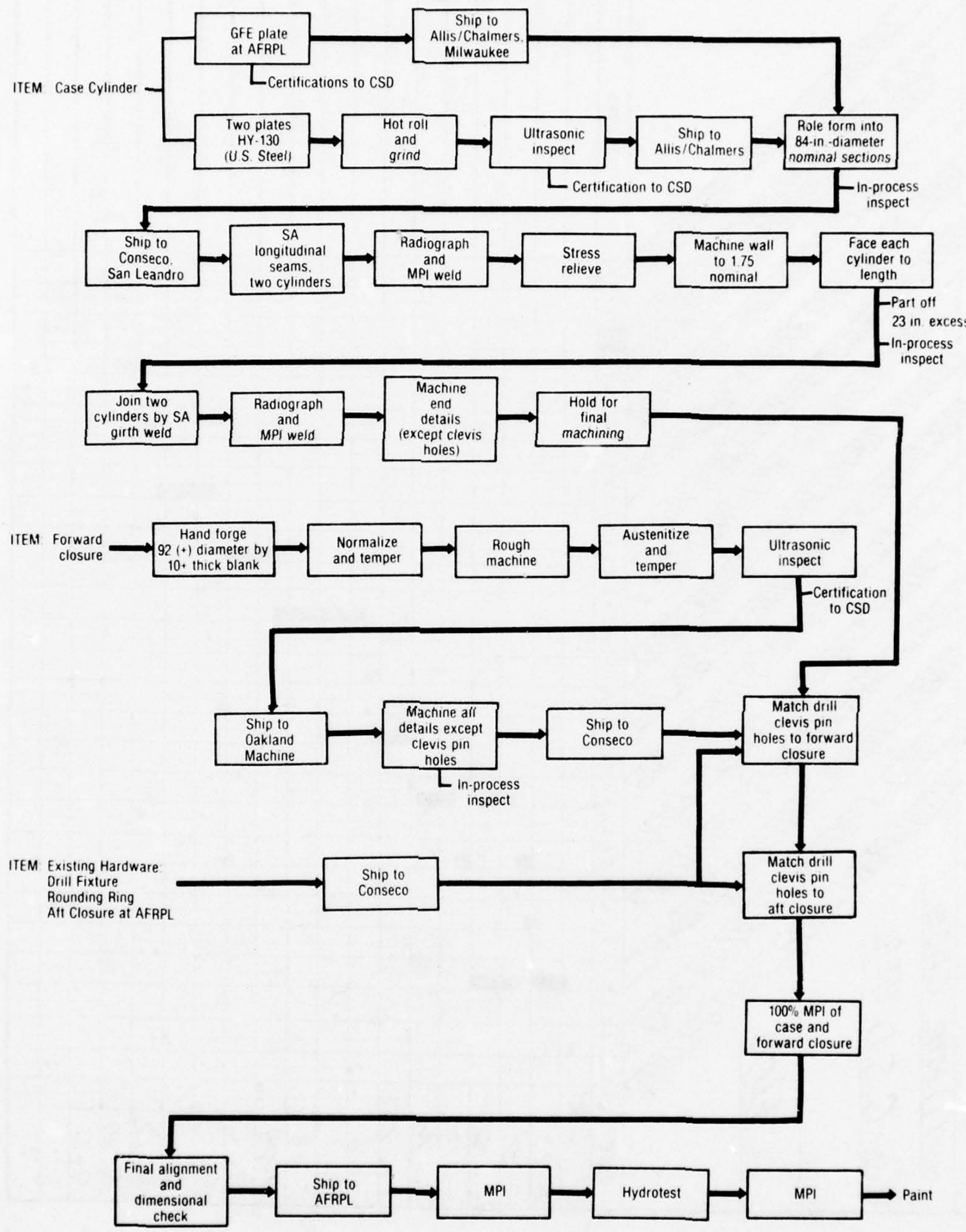

Figure 4-38. Case and Closure Fabrication Flow Sheet

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Sue 64

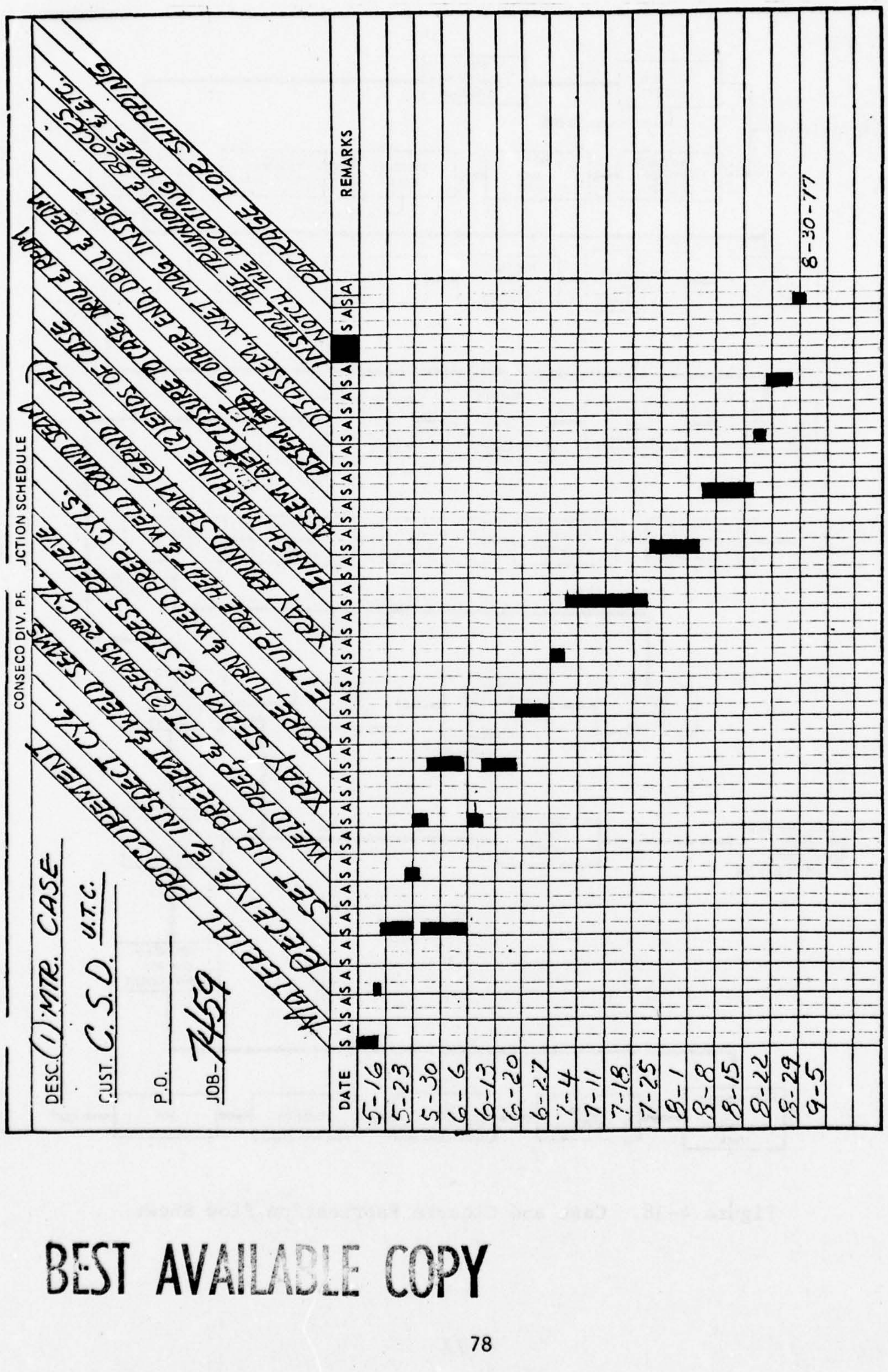


Figure 4-39. Case Flow Sheet

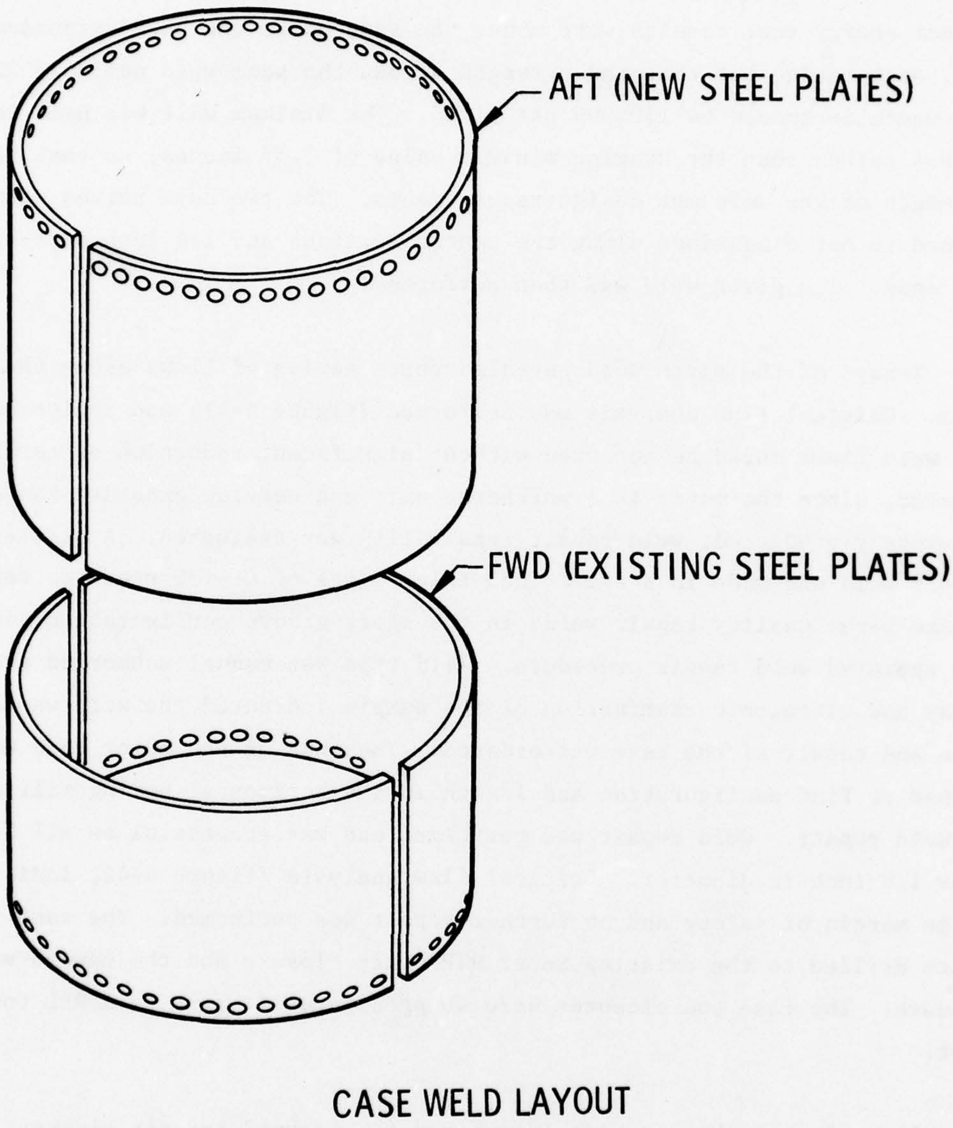


Figure 4-40. Case Weld Layout

two 180° sectors exceeded the intended 1025°F to 1075°F baud due to improper readout of the temperature recorder. Metallurgical tests of the weld tag ends indicated that the parent metal strength met the 130,000 yield, and Charpy impact energy test results were about the same as on the ELSH extension case, i.e. acceptable, but that the strength across the saem weld was only 120,000 psi where is should be 130,000 psi yield. The minimum wall was held to 1.7 inches rather than the drawing minimum value of 1.57 inches, so that the net strength of the weld met design requirements. The two case halves were turned to net dimensions along the center sections and 1/4 inch over-size near the ends. The girth weld was then performed.

X-rays of the girth weld revealed three series of flows along the root pass. Critical Flaw analysis was performed (figure 4-41) and indicated that the weld flaws could be accepted without significant reduction of service life. However, since the motor is a workhorse unit and service exposure cannot be accurately predicted, weld repair feasibility was evaluated. A simulated repair weld was made in a 2-1/2 inch thick plate of HY-130 steel to demonstrate X-ray quality repair welds in the short groove configurations using the approved weld repair procedure. Weld type was manual submerged arc. X-ray and ultrasonic examination of the sample indicated the weld was acceptable and repair of the case was ordered. The ends of the motor case were turned to find configuration and length in the horizontal boring mill prior to weld repair. Weld repair was performed and was successful on all but one flaw 1/8 inch in diameter. Critical flaw analysis (figure 4-42) indicated a large margin of safety and no further repair was performed. The case was match drilled to the existing Super HIPPO aft closure and the new forward closure. The case and closures were shipped bare of paint to AFRPL for hydro test.

The asbestos phenolic insulators for the forward and aft closures were made by American Polytherm in Sacramento. The insulators are made by laying up thin plies of asbestos impregnated with uncured phenolic resin. The assembly is

Available K_{ic} data determined from stress relieved HY-130 sub-arc welds shows values of 75 to 100 ksi $\sqrt{in.}$ which relates to R. T. Charpy impact values of 21 to 40 ft-lbs. Since the defects are in non-stress relieved welds with known higher toughness, i.e. Charpy = 55 ft-lbs, a K_{ic} value of 100 ksi $\sqrt{in.}$ is considered conservative for a fracture analysis of subject defects.

$$(a/Q)_{cr} \text{ @ proof} = \frac{K_{ic}^2}{\pi\sigma_{proof}^2} =$$

$$K_{ic} = 100 \text{ ksi } \sqrt{in.}$$

$$\sigma_{proof} = 105 \text{ ksi} \times \frac{t_{min}^{(1.6'')}}{t_{weld}^{(2.0'')}} = 84 \text{ ksi}$$

$$\therefore a/Q = \frac{1.42}{\pi} = 0.45\text{-inches;}$$ this value is conservative since defect axis is parallel to hoop stress direction.

X-ray has identified 3 defects, all slag inclusions, in the center girth weld.

(1) series of 5 interrupted inclusions over lengths of 3.5 inches and 5 inches x 0.015 wide.

(2) a circular spot 0.125" diameter.

(3) a 1-inch long x 0.200 wide inclusion.

UT longitudinal wave inspection from both sides locates the inclusions at the weld's mid-thickness.

Figure 4-41. Short Length Super HIPPO _ Weld Defects Fracture Mechanics Calculation

Analysis:

Flaw No. 1 — assume embedded crack with a (≈ 1/2 width) = 0.007 and length 5 inches (2c)

$$\therefore a/2c = \frac{0.007}{0.8} = 0.0015 \text{ or } Q = 0.8$$

$$a/Q = \frac{0.007}{0.8} = 0.009 <<< 0.45$$

Flaw No. 2 — assume embedded crack with a = 0.063" and length -0.125"

$$a/2c = 0.5; Q = 2.23$$

$$a/Q = \frac{0.063}{2.23} = 0.028 << 0.45$$

Flaw No. 3 — assume embedded crack with a = 0.100 and length = 1.00

$$a/2c = 0.1; Q = 0.8$$

$$a/Q = 0.125 << 0.45$$

Crack Propagation Probability:

Solve for K @ proof stress for existing flaw —

Flaw No. 1 $a/Q = 0.009$

$$\therefore K_{proof} = \sigma\sqrt{\pi a/Q} = 84\ (0.168) = 14{,}120 \text{ ksi } \sqrt{in.}$$

Flaw No. 2 $a/Q = 0.28$

$$K = 84\ (0.296) = 24{,}900 \text{ ksi } \sqrt{in.}$$

Figure 4-41. Short Length Super HIPPO — Weld Defects Fracture Mechanics Calculation (Continued)

Flaw No. 3 $a/Q = 0.125$

$$K = 84\ (0.63) = 52{,}600 \text{ ksi } \sqrt{\text{in.}}$$

There is no da/dN subcritical crack growth data available for this material, however, there is da/dN characteristics for D_6ac of toughness (K_{ic}) of 100 ksi $\sqrt{\text{in.}}$ These values are conservative since HY-130 has better crack resistance than

(1) for $\Delta K = 14{,}120$ ksi $\sqrt{\text{in.}}$, $da/dN = 1 \times 10^{-5}$ in./cycle

(2) $\Delta K = 24{,}900$ ksi $\sqrt{\text{in.}}$, $da/dN = 8 \times 10^{-5}$ in./cycle

(3) $\Delta K = 52{,}600$ ksi $\sqrt{\text{in.}}$, $da/dN = 1 \times 10^{-4}$ in./cycle

Condition (3) is worst case: 0.0001 in./cycle

Critical a/Q for flaw shape $a/2c = \frac{0.1}{1} = 0.1$ is

$$a/Q = \frac{0.9K_{ic}}{p^2} = 0.41 \qquad Q = 0.8$$

$$a = 0.32^{\text{in.}}$$

2c length = $3.2^{\text{in.}}$; therefore existing flaw of 0.100" half depth by $1^{\text{in.}}$ full length must grow by subcritical growth in repeated proof tests, 0.22" in depth and 2.2 inches in length. Since K increases with crack size G linear computation of $\frac{a}{dN}$ is invalid.

Several computations of ΔK vs flaw size change shows:

(a) after 1 cycle $a = 0.1001$

$2c = 1.0002$

$a/2c = 0.1$

$a/Q = 0.125$ $\underline{K_1 \text{ unchanged}}$

Figure 4-41. Short Length Super HIPPO — Weld Defects Fracture Mechanics Calculation (Continued)

(b)	2nd cycle	a	=	0.1002	
		2c	=	1.0004	
		a/2c	=	0.1002	
		a/Q	=	0.125	K_1 unchanged
(c)	3rd cycle	a	=	0.1003	
		2c	=	1.0006	
		a/2c	=	0.1002	
		a/Q	=	0.125	K_1 unchanged
(d)	4th cycle	a	=	0.1004	
		2c	=	1.0008	
		a/2c	=	0.1003	
		a/Q	=	0.125	K_1 unchanged
(e)	5th cycle	a	=	0.1005	
		2c	=	1.0001	
		a/2c	=	0.1004	
		a/Q	=	0.126	K_2 = 52,800 ksi $\sqrt{in.}$ growth rate unchanged
(f)	6th cycle	a	=	0.1006	
		2c	=	1.0012	
		a/Q	=	0.126	K_2 unchanged
(g)	7th cycle	a	=	0.1007	
		a/Q	=	0.126	K_2 unchanged

It is obvious from these calculations that many proof test cycles would be required before the flaw reached dangerous proportions.

Conclusion: The fracture analysis shows that the subject weld defects are not detrimental! The analysis technique has additional safeguards.

(1) flaws assumed to be continuous crack

(2) flaws assumed to oriented normal to principle stress. Actually flaw is in a 0 stress orientation.

(3) Full proof stress (3750) was used in calculations for subcritical growth. Actually the pressure cycles will be at MEOP of 2500.

Figure 4-41. Short Length Super HIPPO — Weld Defects Fracture Mechanics Calculation (Continued) ,

DISPOSITION:

Use as is based on fracture mechanics analysis which shows suitable margins.

ANALYSIS:

X-ray has identified a defect (slag inclusion or porosity) in the center girth weld. Dimensions are 1/8-in.-diameter as viewed from 90°, or 3/16-in. as derived from 45°. For a conservative analysis, assume defect is a continuous embedded crack with length equal to 3/16 (0.187 in.) and half depth (or) equal to 3/32 (0.094 in.). Using elastic fracture mechanics analysis, the critical stress required to propagate the assumed crack is as follows:

from NASA-8040:

$$\sigma_{cr} = \frac{K_{ic}}{\sqrt{\pi a/Q}}$$

Where: K_{ic} = plane strain toughness

a = flow 1/2 depth

Q = flow shape parameter

From CSD Report 2465 (FR)P K_{ic} for stress relieved HY-130 weld is 75 to 100 ksi $\sqrt{\text{in.}}$ which relates to Charpy value of 21 ft-lb to 40 ft-lb. Since the weld in question was not stress-relieved and has a Charpy value of 55 ft-lb, a K_{ic} value of 100 ksi $\sqrt{\text{in.}}$ is considered conservative. (Note: Non-stress relieved HY-130 GTA welds have typical K_{ic} values in excess of 150 ksi $\sqrt{\text{in.}}$)

With an (a) value of 0.094 in. and a length (2c) of 0.187 in.; a/2c = 0.5; and from 8040 Q for a/2c of 0.5 equals a worst case value of 2.2.

Solving for a/Q, $\frac{0.094}{2.2} = 0.043$

$$\therefore \text{ Solving for } \sigma_{cr} = \frac{K_{ic}}{\sqrt{\pi a/Q}} = \frac{100}{0.043} = \frac{100}{\sqrt{0.135}} = \frac{100}{0.368}$$

$$\sigma_{cr} = 272 \text{ ksi.}$$

Actual stress at proof test pressure = 105 ksi

$$\therefore \sigma_{cr}/\sigma_{proof} = \frac{272}{105} = +2.59 = \text{S.F.}$$

Figure 4-42. Girth Weld Flaw — HY-130 Steel, C12419 SLSH Case then heated while under pressure to effect a cure. A trial billet 5 inches thick by 15 inches diameter was cured first to prove the effectiveness of the proposed pressure-thermal cycle. This block was sectioned and examined for delaminations. None were found, and the closure insulators were laid up and cured. Shrinkage of the stock of plies proved greater than anticipated on the 5.16 inches thick aft-closure-insulator, and 1/4 inch of fiberglass had to be added on the closure side of the insulator.

The clevis pins are made of extruded 4340 steel rod. The extruding tends to form stringers which show up in the magnetic particle examination of the finished part. Ninety of 128 pins fabricated on the contract were rejected for these indications. Metallurgical tests confirmed the stringers were surface flaws and would not be detrimental because the pins are loaded in double shear.

The O-rings for the program were made from extruded rubber cord stock, butt welded by CSD and by RPL. Several lots of the cord stock were rejected for excessive surface flaws, and one lot of 90 durometer, 1/2 inch cross section cord stock would not bond. A layout board was fabricated for making up O-rings to proper length, and tests were conducted to demonstrate strength of the bonds.

The thrust mount was fabricated by the AFRPL weld shop to CSD drawing C12418.

4.3 DELIVERY AND INSTALLATION

The motor case was assembled into the C12417 hydro static test assembly configuration by AFRDL personnel at test stand 1-52 Pad C, and proof tested to 3750 psi. The motor was reconfigured to the C12420 hydro configuration to load test the shear-fail key at the nozzle adapter boss. Post hydro NDT revealed no flaws. The case and closure were painted by CSD.

The loaded motor configuration was insulated and assembled in TS1-52 Pad A by AFRPL test personnel. Configuration was per CSD drawing C12413 and C12411. The test nozzle was for the Interim Upper Stage under Boeing subcontract BAC P.C. 1-938002-9592 to CSD.

The IUS-Super HIPPO Nozzle configuration is shown in figure 4-43. This first Super HIPPO nozzle contained an integral throat and entrance section of advanced three-dimensional carbon/carbon (C/C) T-300 pan material, fabricated and densified by General Electric Co. The nozzle also included a movable TECHROLL® Joint and a short-length two-dimensional C/C rosette exit cone. The TECHROLL Joint was fabricated by CSD, with nozzle parts and assembly by Kaiser AEROTECH. The nozzle, fixed in the null position by a gib ring and exit cone restraint, was not vectored during the test. Initial throat diameter was 6.833 inches. The configuration of the motor is defined in appendix B.

The motor was successfully test fired on 7 October 1977. The firing ran 135.6 seconds web action time at an average chamber pressure of 596 psia. The motor and nozzle performed well during the test. The motor case and aft closure were at ambient temperature after the test.

Upon disassembly of the motor the phenolic portions of the forward and aft insulators were found to be damaged by force, not heat. The forward insulator had a radial fracture in the washer portion and the bond between the center disk and the washer portion was cracked. The breaks were free of soot, so the damage was post-test, when the nitrogen purge was turned on. The purge gas pressure lifted the forward insulator, cracked it, and lifted the cartridge. The zinc chromate putty between the top of the cartridge-fiberglass-wall and the aft closure was found to be squeezed out, confirming that the cartridge had been lifted.

Examination of the aft insulator revealed that 10 of the 12 bolts that hold the insulator to the closure had broken out the phenolic locally. There was a gap between the closure and the insulator, and this gap was free of soot. The hypothesis is that when the cartridge lifted up and fell back, the insulator was forced off. As a result of this problem, and noting that the

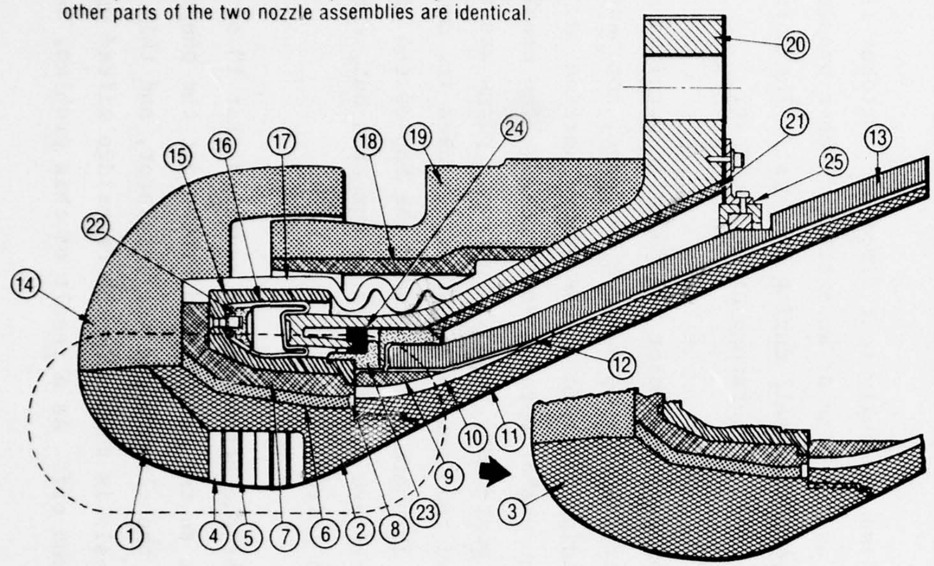


Figure 4-43. Nozzle Assembly IUS-SLSH

insulator is considerably thicker than required, the thickness of phenolic material under the bolt heads will be made thicker and longer bolts used, to strengthen this joint.

The aft insulator can be reworked by drilling and tapping a new set of holes, and potting the damaged ones. The forward insulator is probably not salvagable.

The char and erosion which occurred during the firing were light. Erosion rate of the forward insulator was approximately 1 mil per second. Char of the V-61 coating inside the aft closure was approximately 1/4 inch total, or 2 mils per second. Char and erosion to the motor case sidewall insulation were negligible. The propellant cartridge was in very good condition. The aft restrictor was still sound, char and erosion of the side wall rubber were low and the forward restrictor was sound and retained the original bore diameter.

Ballistic results shown in figure 4-44 and table 4-7 show good correlation between measured and predicted chamber pressure-time curves when the prediction is based on a 2% scale up of the average burning rates of propellant batches 750-6069-6071. This prediction also used the observed c* of 5,095 ft/sec, the adjusted ablation rate-time (figure 4-45) based on pre and post test throat diameters, and a 73°F propellant mean bulk temperature.

Figures 4-46, 4-47, 4-48 and 4-49 show motor assembly preparation, handling equipment and motor assembly.

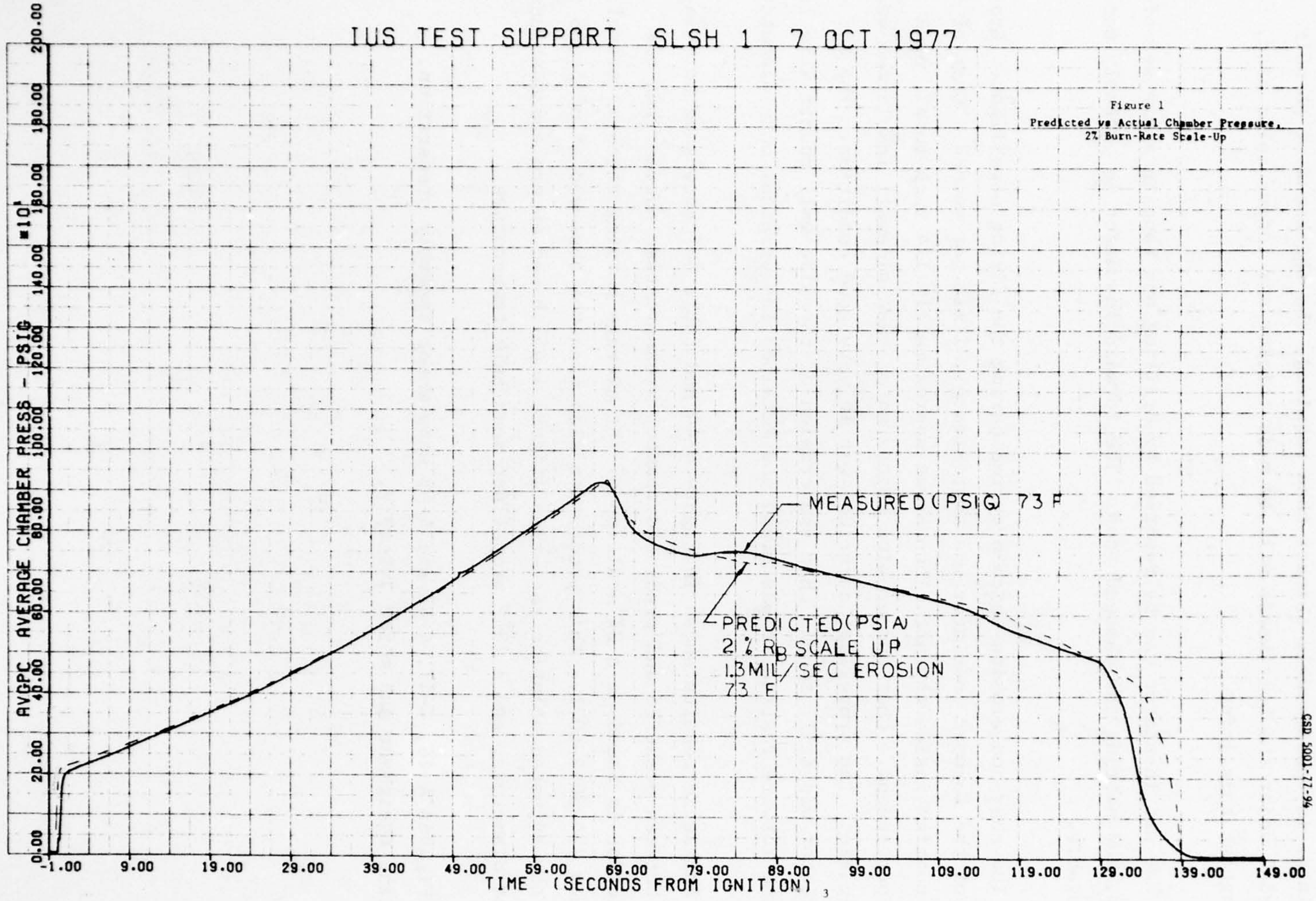


Figure 4-44. Predicted vs Actual Chamber Pressure, 2% Burn-Rate Scale-Up

TABLE 4-7. COMPARISON OF MEASURED AND POST TEST PREDICTED PERFORMANCE

	Super HIPPO Performance			
Parameter	750-6069 R_b 1.3 mils/sec Erosion	750-6069 R_b Erosion Starting at 40 sec	2% Burn Rate Scale Up 1.3 mils/sec Erosion	Measured 1.3 mils/sec Erosion
Propellant mean bulk temperature, °F	73	73	73	73
Action time, sec	141.9	140.9	138.5	135.6
Action time average chamber pressure, psia	569	574	584	596
Maximum chamber pressure, psia	916	948	930	936
Characteristic velocity, ft/sec	5095	5095	5095	5095
Initial throat diameter, in.	6.825	6.825	6.825	6.833
Final throat diameter, in.	6.825	7.193	7.193	7.193
Propellant weight, lb	19525	19525	19525	19525

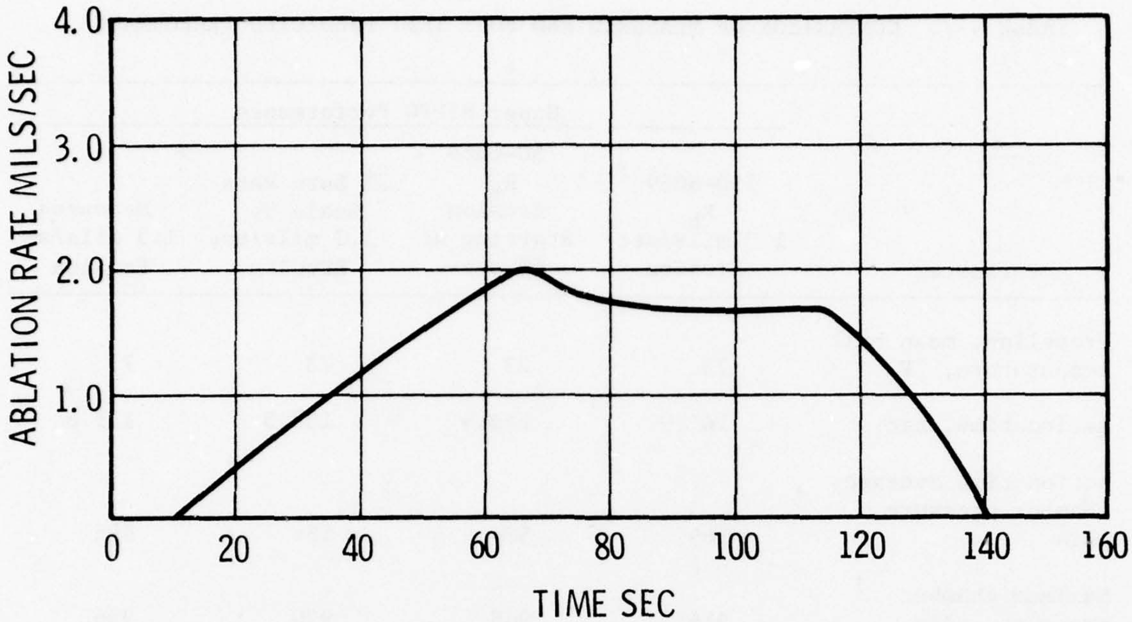
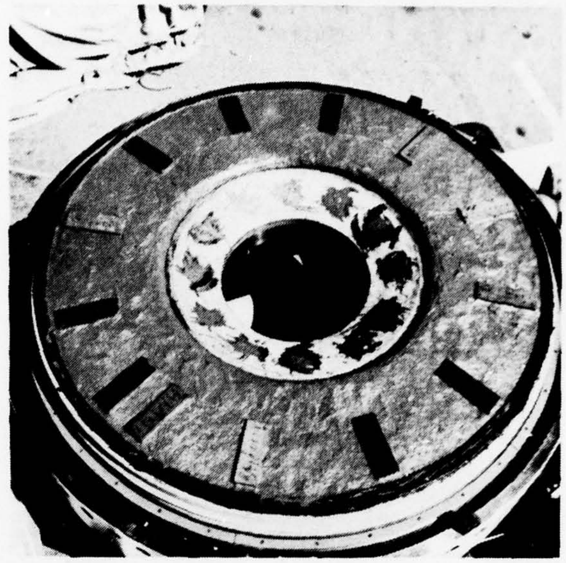


Figure 4-45. Adjusted Ablation Rate-Time Based On Super HIPPO ITE Pre and Post Throat Diameters and 84 In. Char Motor Extrapolation

Leak Check Flange



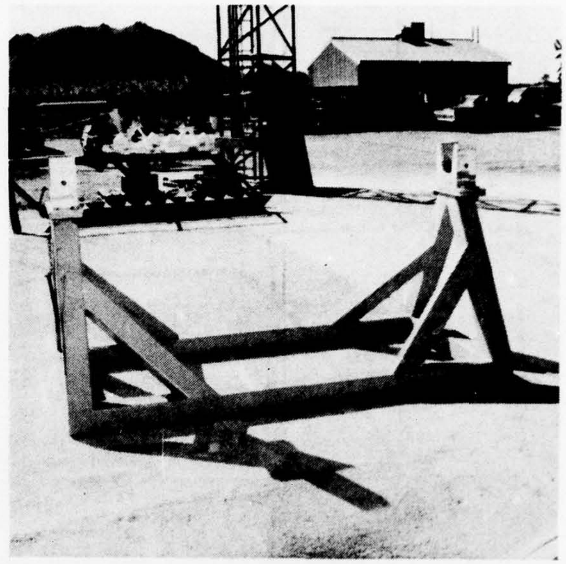
Insulated Aft Closure With Material Test Samples

Heat Shield

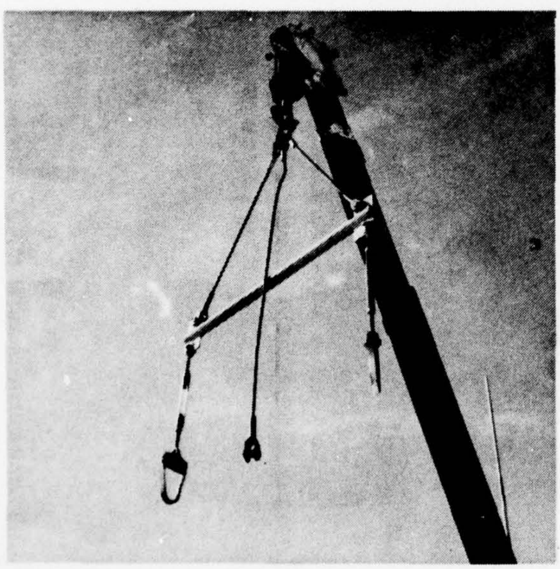
Insulated Heat Shield

Figure 4-46. Motor Assembly Preparations

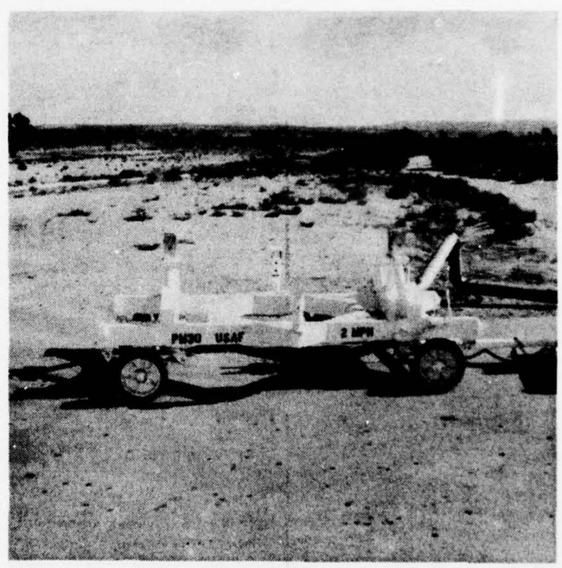
Care Lift Adapters



Trunnion Base

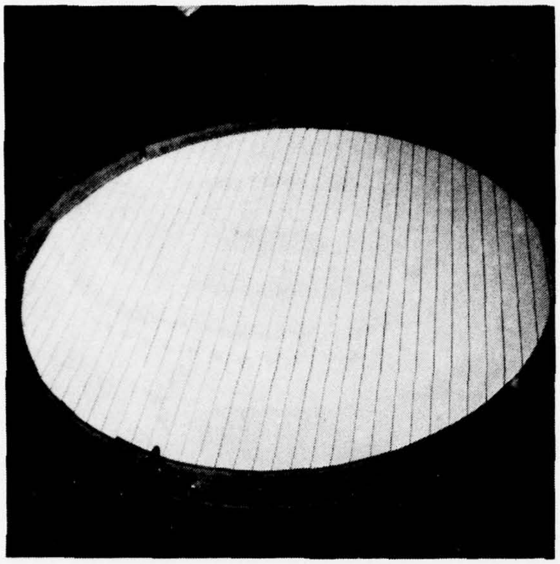


30,000 lb Sling



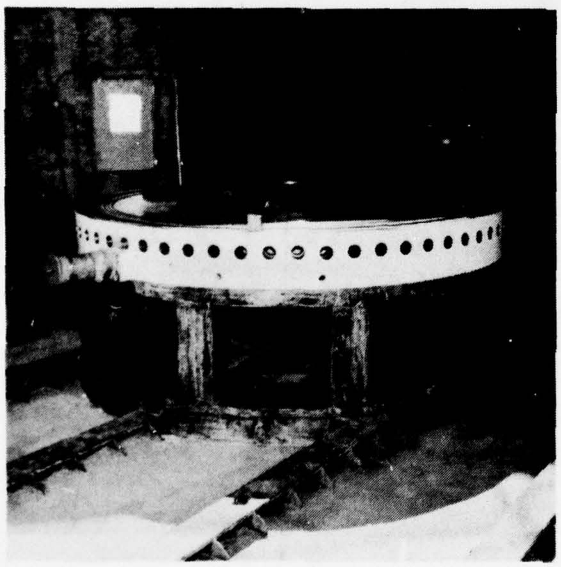
Closure Transport Trailer

Figure 4-47. Handling Equipment

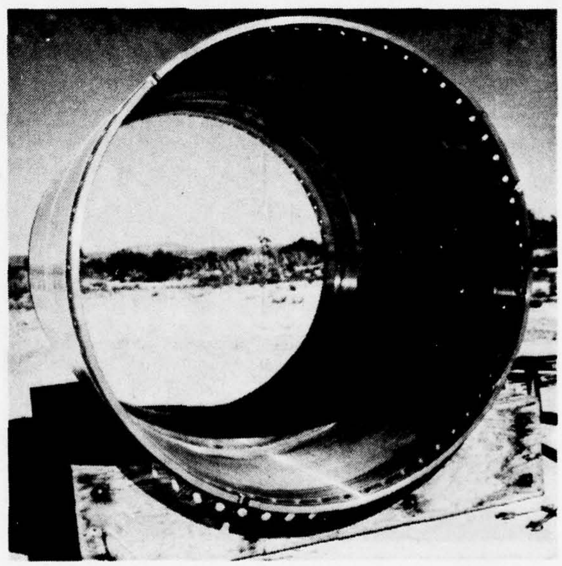


Forward Insulator with 2 Face Tape

Forward Insulator Assembly

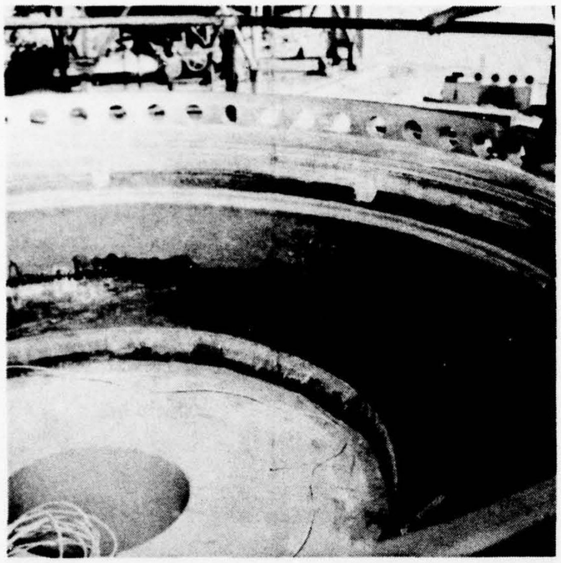


Forward Closure on Thrust Mount

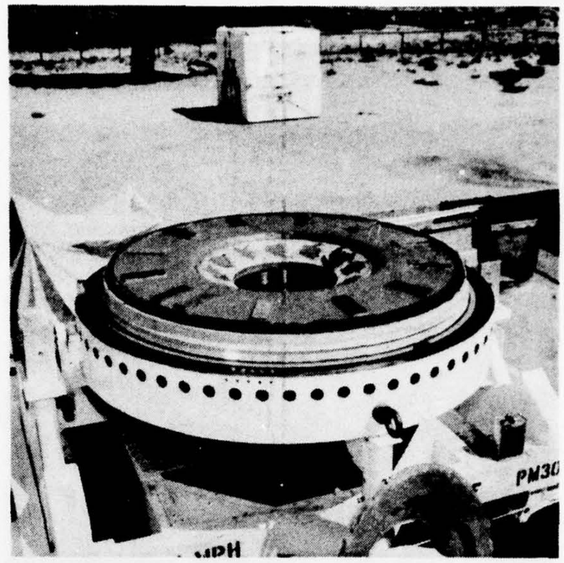


Motor Case Before Insulating

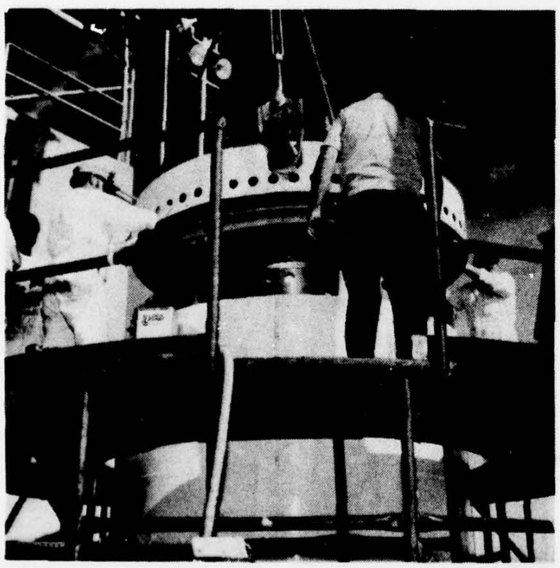
Figure 4-48. Motor Assembly Preparations



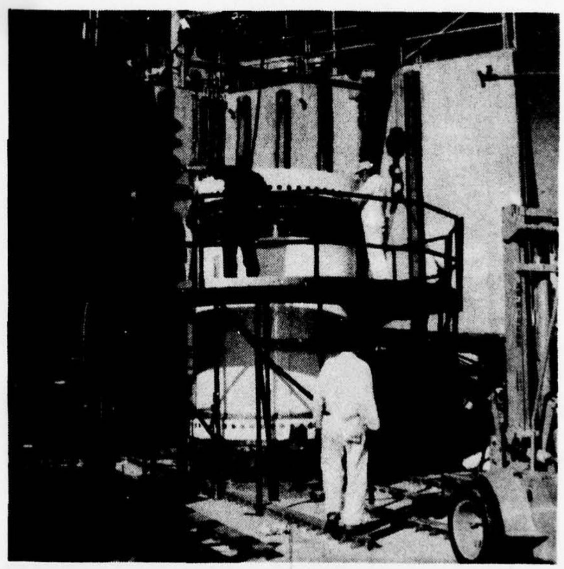
Propellant Cartridge in Motor



Aft Closure on Trailer



Closure Installation



Closure Installation

Figure 4-49. Motor Assembly

5.0 MAINTAINABILITY AND RELIABILITY

The SLSH motor is a shortened version of the Super HIPPO motor reported in AFRPL-TR-77-24. The design, fabrication and assembly problems encountered on the previous contract were solved and the solutions were then applied to this motor. The design of the motor was confirmed and the checkout firing for the motor performed as anticipated.

The motor has no moving parts and therefore maintainability is limited to care and maintenance of the components, such as pins and seal rings and environmental protection and storage.

Reliability of the motor will be demonstrated only after multiple firings have been made; however, the successful firings of SLSH, ELSH, and Super HIPPO conducted to date have demonstrated that inherent integrity of the design and the fabricated units.

6.0 SYSTEM SAFETY

During the engineering development phase of hardware design and fabrication a system safety analysis was performed. Paragraph 5.8.2.1 of MIL-STD-882 requires that a preliminary hazard analysis be performed as the initial analysis task during the acquisition of a system, and that "this analysis shall be imposed in performance or design specifications." The areas considered applicable are covered below:

A. Isolation of Energy Sources

Energy sources considered include the 24-v instrumentation voltage for the pressure transducers and excitation for strain gages. Electrical power for cameras, lights, TVC nozzle prime mover, motor ignition circuits, ac power outlets, and motorized cranes is outside the scope of this contract.

During motor loading operation, there is no active power from the thrust stand or motor system. Energy sources are diesel cranes and air driven power tools. No sparks eminate from these.

B. Fuels and Propellants

There are 25,000 lb of class II/ICC class B solid propellant in the grain. The distances between facilities at AFRPL in which the grains will be received, stored, and handled are considerably greater than required by AFM 127-100. Since these facilities were used by the Titan III program which involved considerably larger grains, these facilities are considered more than adequate for Super HIPPO.

C. System Environmental Constraints

Motor assembly operations should be conducted when the motor can be kept dry so the zinc chromate putty, adhesives, and lubricants will not become contaminated and fail to adhere. The nozzle throat should be plugged after motor assembly to keep foreign objects and materials out of the grain area.

D. Use of Explosive Devices and Their Hazard Constraints

The only device which could be considered as explosive is the igniter assembly. The igniter contains two squibs, U.S. Flare model 207A (appendix A, volume II). These squibs have seen extensive use in the missile field, including the CSD Titan III-C Stage 0 staging rocket motors. Handling live igniters at AFRPL is performed in accordance with procedures approved by the AFRPL test countdown committee and adequate safety precautions are observed.

E. Use of Pressure Vessels and Associated Plumbing, Fittings, Mountings, and Holddown Devices

The motor case is itself a pressure vessel. It is never pressurized to significant levels when personnel are in the area. The motor assembly includes an overpressure protection feature to release the nozzle in case of motor overpressure during a motor test and appropriate overload posts to absorb the reaction force are provided. The hydraulic plumbing and surge tanks are all provided by the Air Force.

F. Safe Operation and Maintenance of the System

Operations are conducted in accordance with the operations manual and the test countdown document.

G. Egress, Rescue, Survival, and Salvage

Egress is by open stairway with no confining doors or barriers. Rescue, survival, and salvage are by AFRPL established procedures.

H. Fire Ignition, Propagation Sources, and Protection

Few items are in the test area other than the propellant which will burn exothermically. Automobiles with catalytic converters are not allowed in the motor test area. Wild fire is not a concern as there is no combustible vegetation on the test pad.

I. Environmental Factors such as Equipment Layout and Lighting Requirements and Their Safety Implications in Manual Systems

The layout of the stand in the test bay, the access stairways to the working levels, the handling equipment, and handling carts were designed with ease and safety of operation in mind. Hooks and slings are devised so that the sling which attaches readily to provided attachment features has ample capacity for the weight of the part. Railings are provided on all elevated work areas.

J. Failsafe Design Considerations

The overpressure release feature for the nozzle is a failsafe design feature. The handling equipment is all designed with high factors of safety. The cartridge lift adapter uses a four-point pick rather than two or three so that failure of one support will not cause the cartridge to fall. The flexures in the load trains are pinned to provide a backup structure should the basic flexure fail.

K. Protective Clothing, Equipment, or Devices

Self-contained breathing apparatus was made available by the Air Force for rescue missions. The heat of the motor firing is too intense for protective clothing to be meaningful. Deluge systems for stand protection were considered, but the water tends to obscure the TVC plume in the motion pictures, thereby endangering test results.

L. Lightning and Electrostatic Protection

Electrostatic grounding straps are worn by all personnel in the vicinity of the live motor or live grains. Lightning protection is a facility consideration beyond the scope of the contract.

M. Human Error Analysis of Operator Functions, Tasks, and Requirements

Operating procedures are reviewed by CSD and AFRPL engineers and technicians to assure clear and unambiguous instruction.

AD-A053 042 UNITED TECHNOLOGIES CORP SUNNYVALE CALIF CHEMICAL SY--ETC F/G 21/8.2
SHORT LENGTH SUPER HIPPO MOTOR ASSEMBLY.(U)
FEB 78 P R SCANNELL, W A STEPHEN F04611-77-C-0027
UNCLASSIFIED CSD-2635-FR AFRPL-TR-77-91 NL

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APPENDIX A

HARDWARE ACCEPTANCE AND DELIVERY

PROJECT 2635

SHORT LENGTH SUPER HIPPO

HARDWARE ACCEPTANCE AND DELIVERY
PROJECT 2635
SHORT LENGTH SUPER HIPPO

Deliveries of hardware to AFRPL on Project 2635 (Contract F04611-77-C-0027) will be by commercial bill of lading in four shipments from four locations. The small items required for machining of the case and closure at Conseco will be accumulated at CSD, boxed as a group and sent to RPL from CSD. The aft closure and case will be shipped directly to AFRPL from Conseco in San Leandro. This shipment will include the return of Air Force Tooling and GFM provided for use on this program. In addition the trunnions which will be match drilled and bolted to the closure, the clevis pins which will be used to match drill the case to the closures, two PD2493 boxes and the o-ring retainers will be shipped from Conseco in this shipment (60,000 lb).

The other large items will be shipped directly from the manufacturing vendor. The C10277-11-01 and C10280-01-01 closure insulators from American Polytherm in Sacramento, and the rubber sheet stock items from a different vendor.

Covering DD 1149's should be cut for the shipments to transfer accountability. A single DD250 will be cut for all the hardware after completion of the case hydrotest and post test MPI at AFRPL. Acceptance will be at AFRPL.

Quality documentation to be forwarded to the Air Force project engineer, T. Kinsel via the CSD project engineer, Paul Scannell. Documentation to include specific objective evidence rather than certifications as much as practical. Quality please provide a spare quality package for project files for each shipment, either full size or on microfilm.

Table A-1 lists six categories for procurement and shipment. Table A-2 lists the items to be delivered.

TABLE A-1. PROCUREMENT AND SHIPPING CATEGORIES

Category	Description
A	Small items - accumulate in stores, box and ship to RPL 15 July.
B	Same as A, but delay procurement to allow maximum shelf life, and still make August 26 delivery to RPL.
C	Accumulate in Sunnyvale as appropriate, then ship to Conseco for use on motor fabrication. Ship directly from Conseco to RPL with case closure, tooling and GFM.
D	Drop ship to AFRPL.
G-XX	Group all items with same -XX identifier for combined procurement.
O	O-rings - purchase as extruded stock, bond into o-rings in materials lab, Sunnyvale.

Shipping Address

AFRPL
Material Branch/TEM
Bldg 8460
Edwards AFB, CA 93523

ATTN: T. Kinsel

Contract F04611-77-C-0027

CSD, Sunnyvale, CA.

TABLE A-2. PROJECT 2635 PROCUREMENT

Item	Category		Unit of Measure	Quan	Part Number	Description
1	C		Ea	1	C12419*	Short Super HIPPO motor barrel
2	D	G-01	Ea	1	C10277-11-01*	Forward insulation - phenolic
3	D	G-01	Ea	1	C10280-01-01*	Aft insulation - phenolic
4	O	G-02	Ea	10	C10144-02-01	O-ring
5	O	G-02	Ea	5	C10144-03-01	O-ring
6	O	G-02	Ea	5	C10144-04-01	O-ring
7	O	G-02	Ea	10	C10144-05-01	O-ring
8	O	G-02	Ea	10	C10144-08-01	O-ring
9	O	G-02	Ea	10	C10144-09-01	O-ring
10	O	G-02	Ea	5	C10144-10-01	O-ring
11	C	G-06	Ea	2	C10142-01-01	O-ring retainer (set) 222351
12	C		Ea	128	C10141-01-01	Straight pin 224570
13	C		Ea	1	C10119-01-01*	Forward closure
14	O	G-02	Ea	5	C11167-14-01	Rubber (ring on aft insulation)
15	O	G-02	Ea	12	C11167-12-01	Rubber blocks
16	D	G-03	Ea	1	C10277-14-01	Forward rubber insulation like C10277-12 but 1/4-in.-thick
17	D	G-03	Ea	1	C10277-15-01	Forward rubber insulation like C10277-13 but 3/4-in.-thick
18	C		Ea	2	C10289	Trunnions (1 ea of -01-02 & -01-01)
19	A	G-04	Ea	26	C10276-01-01*	Plug, insulation aft
20	C	G-05	Ea	50	AN960-1616	Washer, flat
21	A	G-05	Ea	50	AN960-616	Washer, flat
22	A	G-05	Ea	144	MS51960-67	Screw
23	C	G-05	Ea	20	NAS 1351-16-14	Screw
24	A	G-05	Ea	50	AN6-10	Screw
25	A	G-05	Ea	36	MS21250-12016	Bolt
26	A	G-06		8	C11199-01-01	Ring, centering (each)
27	A	G-05	Ea	72	WC-12	Washer
28	A		Gl	5	MIL-G-4343	O-ring lub (5 gl bucket, not tubes)
29	A		Cn	6	MIL-T-5544	Thread lub
30	C			2	1 1/2 - 6	Eye bolt
31	D	G-03		3	C11167-11-01	Rubber case insulation set
32	B		Gl	5	EA 913	Adhesive
33	B		Rl	50	---	Putty, zinc chromate, 1" wide

TABLE A-2. PROJECT 2635 PROCUREMENT
(continued)

Item	Category	Unit of Measure	Quan	Part Number	Description
34	A G-04		6	C10293-01-01*	Plug, insulation
35	A	Rl	10	Scotch 425	Foil tape
36	A	Rl	72	Scotch 890	Glass reinforced tape
37	B	Gl	10	No. 11 Wax 2	Cement
38	B	Lb	35	DC93-104	Silicone rubber
39	B	Gl	1	DC 3606D	Primer
40	A	Rl	10	Devoseal 7565	Double-coated tape
41	C	Ea	2	PD2493	Shipping box for clevis pins
42	B	Gl	4	Lockbond #55	Solvent for No. 11 Wax 2

APPENDIX B

FIRST IUS/SLSH FIRING

CONFIGURATION AND

DISCREPANCY SUMMARY

MOTOR COMPONENTS

CONTRACT F04611-77-C-0027

SLSH VMRR SUMMARY

P/N	PO	VMRR/IDR	Vendor	
C10141	223152	V020767	Inst. Mach	Clevis Pins Mag. Particle. Accept
C10277-11-01	233137	V016073	Am. Poly	Fwd. Ins. Phenolic Misc. Dim. - Rework
C10280	233137	V020043	Am. Poly	Aft Ins. Phenolic Misc. Dim. - Accept
C12419	225392	V020796	Conseco	Case - Finish at O-ring - Polish
C12419	225392	V020794	Conseco	O Size Pin Hole - Rework
C12419	225392	V020795	Conseco	Girth Weld X-ray - Rework
C12419	225392	V016907	Conseco	Low Charpy - Accept
C10144	231927	I042281	Porter	Scars - Accept
C10144	231927	I040345	Porter	Scars - Accept
C10289	233144	I042288	Oakland	A36 in lieu of 1020, false start - Accept

DISCREPANCIES - MOTOR ASSEMBLY

C12629 Cartridge	Aft Restrictor. After moving the cartridge from the RIS building to the test pad 1-52/A in strong sun, unbonds were noted between the aft restrictor item 7 and the sidewall rubber insulation and between the aft restrictor and the propellant. The sidewall debond extended 36 inches clockwise from BDC, 36 inches counter clockwise from BDC, and 58 inches intermittent counter clockwise from TDC. Max depth was one inch, nominal was 1/4 inch. The propellant unbond extended 24 inches clockwise and 24 inches counter clockwise from TDC. Max depth was 1/2 inch, nominal was 1/4 inch. Repair was by cutting AL60-9 restrictor back to solid bond, and potting with A1-227-70. Ref. IDR No. 042452.
C12629 Cartridge	Fwd. Barrier Ring. A fillet of V-61 one inch by 45° was applied between the item 8 forward barrier ring (silica asbestos rubber) and the (item 6) forward restrictor, also silica asbestos rubber. The fillet was added to provide additional thermal protection for the bond line between the forward restrictor and the barrier ring. Ref. IDR No. 042453.
C12629 Cartridge	Fwd. Restrictor. The bore of the item 6 forward restrictor was cut out to be flush with the propellant bore and forming a 30° half angle truncated cone, larger diameter down, to provide additional clearance for material test samples. Ref. IDR No. 042454.
C12411 Motor Assy	Material test samples were installed on the aft closure insulator and on the forward closure insulation. Ref. test plan CSD 5001-77-73.

C12411 Motor Assy	V-61 was potted 1-1/4 inches thick over the face of the aft insulator to facilitate rapid recycle for the second IUS/SLSH test. IDR No. 042455.
C12411 Motor	The 2-473 o-rings were butt jointed of .279 ± .019 Buna-N of 70 Shore A durometer in lieu of the Viton specified. Ref. IDR No. 042456. All other o-rings on the motor are Shore A - 70 Buna-N.
C12411 Motor Assy	One of the eight Allen bolts securing the motor to the thrust broke during torquing. Ref. IDR No. 042457. The other seven bolts were replaced with new bolts. It was not immediately possible to remove the broken bolt.
C12411 Case	Local unbonding occurred between the item 35 insulation sheet, 1/4 inch Buna-N, and the motor case at the lower or forward edge. Max. depth 1". EA 913 adhesive was injected into the crevice. Ref. IDR No. 042458.

CONFIGURATION FIRST IUS/SLSH FIRING

P/N	TITLE	CHANGE	ECOs
C12411	MOTOR ASSEMBLY	N/C	---
C10119	CLOSURE FORWARD	F	20505, 20619
C10120	CLOSURE AFT	F	
C10141	PIN STRAIGHT	N/C	
C10142	O-RING RETAINER	N/C	
C10144	O-RING PACKING	C	20492
C10278	SPACER CARTRIDGE	C	
C10277	INSULATOR FWD	D	
C10280	INSULATOR AFT	B	20374, 20494
C10276	PLUG, INSULATION, AFT	N/C	
C10283	KEY LOCK ADAPTER	B	
C10289	TRUNNION SHAFT	C	20539
C12868	HEAT SHIELD	N/C	---
C12419	CASE MOTOR	N/C	---
C12629	CARTRIDGE, LOADED	A	20735
C00631	IGNITER ASSY	C	20603
C11199	RING SEGMENT, CENTERING	N/C	
C12382	NOZZLE ASSEMBLY	A	---
C12590	INSULATION RING	N/C	
C12592	RING, NOZZLE ADAPTER	N/C	20349, 20563
C12742	RING BACK-UP	N/C	20592
C12418	ADAPTER THRUST STAND	N/C	20643
C12420	HYDRO ASSY	N/C	---
C12716	CARTRIDGE INSULATED	A	20734
C11369	INSULATION RESTRICTOR	N/C	20487

APPENDIX C

MOTOR ASSEMBLY PROCEDURE SLSH-105

APPENDIX C

MOTOR ASSEMBLY PROCEDURE SLSH-105

SLSH TESTING

General

No adaption has been made for mounting the SLSH motor in the Super HIPPO thrust stand so that it is fired bolted to a short mount (C12418) capable of assuming all thrust loads and providing access to the pressure transducer ports in the forward closure.

The SLSH motor is identical to the standard Super HIPPO except that the case length accepts only one grain. For assembly and processing, the bottom of the propellant grain is treated like a number one position grain, (i.e., it is taped to the C10278 spacer) and the aft end of the grain is treated like a number 2 position grain (i.e., the C11199 centering rings are attached, and two beads of zinc chromate putty are used). Also, for submerged nozzle tests the possibility of interference between the nozzle and the propellant must be considered for the grain. The general case SLSH motor, per C12413, interfaces with the test nozzle/insulation at the ID of the C10120 aft closure and C10280 aft insulator.

Forward Closure Subassembly

Forward Closure - Trunnion Subassembly

Motor Materials	No. Required
Alignment block, shoulder bolt, and roll pin	3 each
C10119-01-01 forward closure	1
C10289-01-01 trunnion	1
C10289-01-02 trunnion	1
AN960-1616 washers	16
NAS1351-16-44 screw	8
S276 1-1/2-6 eyebolt	1
MIL-T-5544 thread lub	AR

Support Materials	No. Required
Torque wrench, 500 ft-lb	1
Solvent, perchloroethane	AR

Assemble one each C10289-01-01 and C10289-01-02 trunnion shafts to C10119-01-01 forward closure using eight flat washers AN960-1616 and eight screws NAS1251-16-44. Clean bolts and threaded holes; lubricate with MIL-T-5544. Install the trunnion shafts and finger-tighten the bolts. Assure that bolts do not extend into the clevis groove by adding additional washers as required. Torque bolts to 450 ± 50 ft-lb. Install S-276 1-1/2-in. eyebolts (1-1/2-6 UNC-2A, 3-in. thread) 135^{o} from TDC in C10119-01-01 forward closure. Add washers under eyebolt shoulder as required to bring the plane of the eyebolt approximately coincident with the motor centerline. Install three alignment blocks with roll pins and shoulder bolts.

Install the C11151 stirrups on the turnbuckle legs of the 30,000-lb sling C10292, attach the sling to a crane. Position the stirrups in the 2-in.-wide journals of the trunnions, and pin the sling tag leg to the eyehook of the closure. *Test lift and adjust the turnbuckles to level the closure.*

Lower the closure onto the trunnion base with the eyehook toward the support head. Adjust the support head height to level the closure.

Subassembly of C10277-01-01 Forward Insulator

Motor Materials	No. Required
C10277-13-01 rubber disc	1
C10277-11-01 phenolic disc	1
C11347-14-01 rubber blocks	6
EA913 adhesive	AR
Scotch 425 foil tape	AR
DEVOSEAL-2-in.-wide two-face tape	AR
Zinc chromate putty	AR

Support Materials	No. Required
Solvent, 1,1,1-trichloroethane or suitable substitute	AR
Clean lint-free rags	AR
Sandpaper, 80- to 100-grit	AR
Scale, epoxy mixing containers, and stir rods	1 each

Visually inspect all motor materials for handling damage before assembly. All mating and sealing surfaces must be free of rust, pits, nicks, and scratches.

Keep the C10277-11-01 phenolic disc on a pallet during assembly for forklift transportation to the forward closure assembly area. Alcohol-wipe test the phenolic OD. Confirm no cracks or delaminations.

Clean the mating surfaces of the rubber and phenolic faces by lightly abrading with 80- to 100-grit sandpaper. Wipe down with solvent, and let solvent dry completely. Place the rubber disc on the phenolic and center it to ±1/8 in. Roll back a half-circle of the rubber and apply the two-face tape to the phenolic surface exposed. No wrinkles allowed. Remove the wax paper backing. Roll the rubber half-circle back into position and press it into place. Roll back the other half of the rubber disc and repeat two-face tape installation. Assure 80% minimum tape coverage of rubber at the phenolic interface. Press the rubber disc into place.

Solvent wipe the OD of the rubber disc plus 4 in. each way on the rubber and phenolic surfaces and let solvent dry.

Apply two layers of aluminum foil tape to hold down the edge of the rubber. Press tape into the corner carefully. Stagger overlap joints.

Coat phenolic surface from rubber to inner step with 1/8 inch of V-61 except in holes. Lay out the locations of the six C11347-14-01 rubber blocks (1 in. by 3/4 in. by 6 in.), butting the OD of the 28-in.-diameter raised zone for -13 rubber; bond 3/4 in. facedown. Lay out the location of any insulation test specimens. For testing with grains of 20-in. ID or smaller, put additional blocks radially inboard from the 28-in. zone. Bond 1 in. facedown (figure C-1).

Clean the mating surfaces of the C10277 rubber, the C11167-12-01 blocks, and the test specimens by abrading lightly with 80- to 100-grit sandpaper and solvent wipe. Mix 1 lb of EA913 adhesive per bonding instruction, 1 lb of part A to 0.12 lb of part B.

Apply EA913 to bonding surfaces of C11347-14-01 blocks, and to matching zones of C10277 rubber disc. Press blocks and samples into position on the C10277 rubber disc. Brush a fillet of epoxy along glue lines. Apply weights to provide contact pressure. Allow to set 24 hr. Four to seven days are required for EA913 to develop full strength at ambient conditions.

Insulated Forward Closure Subassembly

Motor Materials	No. Required
C10119-01-01 forward closure with trunnions	1
C10277-02-01 forward insulator subassembly	1
C10142-01-01 retainer (6 pieces)	1 set
MS51960-67 screw	36
MS16562-78 spring pin	1
C10119-12-01 steel pin (center guide)	1
C10144-02-01 O-ring	2
C10144-03-01 O-ring	1
1/4-in. AN plugs or instrumentation lines	2
MIL-T-5544 thread lub (thick black material)	AR
MIL-G-4343 grease (Dow)	AR
Zinc chromate putty, 1-in. -wide rolls	AR

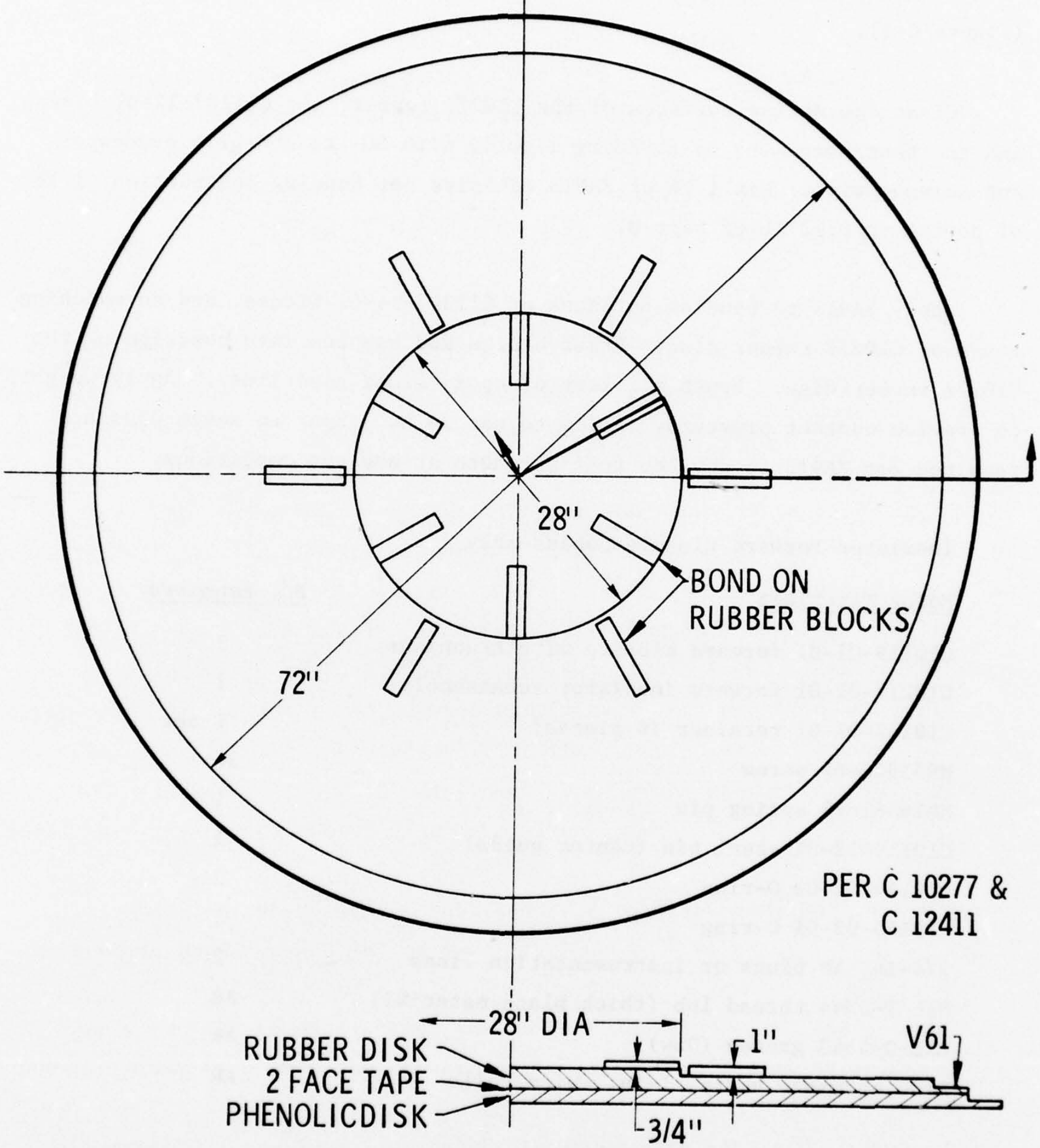

Figure C-1. Forward Insulator

Support Materials	No. Required
Solvent, perchloroethane or equivelant	AR
Rags	AR
C10300 sling	1
1/2-13 eyebolts	3
Twist drill, 1/4-in. diameter by 13-in. long	1

Cleaning

Position the closure in a clevis-up attitude. Clean the threaded holes, the O-ring grooves, the clevis groove, and the clevis pin holes. Clean the remainder of the metal parts. Visually inspect the closure and metal parts for handling damage. All sealing surfaces must be free of rust, pits, nicks, and scratches. Deburr as required with fine crocus cloth (No. 400).

Assure that the C10119-12-01 center guide is installed in the center hole of the closure and the MS16562-78 spring pin is installed 34 in. from center.

Retainer Installation

Lubricate the 36 MS51960-67 screws with MIL-T-5544 thread lub. Lubricate the underface of the C10142 retaining ring sectors and the O-ring glands with the MIL-G-4343 grease.

Assemble the sectors and secure with the screws. Torque the screws to 20 ± 5 in.-lb.

O-Ring Check

Inspect one each O-ring, -03-01, and two each -02-01. Inspect all over for nicks and cuts. Examine the butt joint bond by bending the O-ring 180^{o} at the joint with a 1-in. radius. Roll the section through 360^{o} and examine for discontinuities. Clean the forward closure. Lubricate the O-rings and install in the P_c gland groove. See figure C-2.

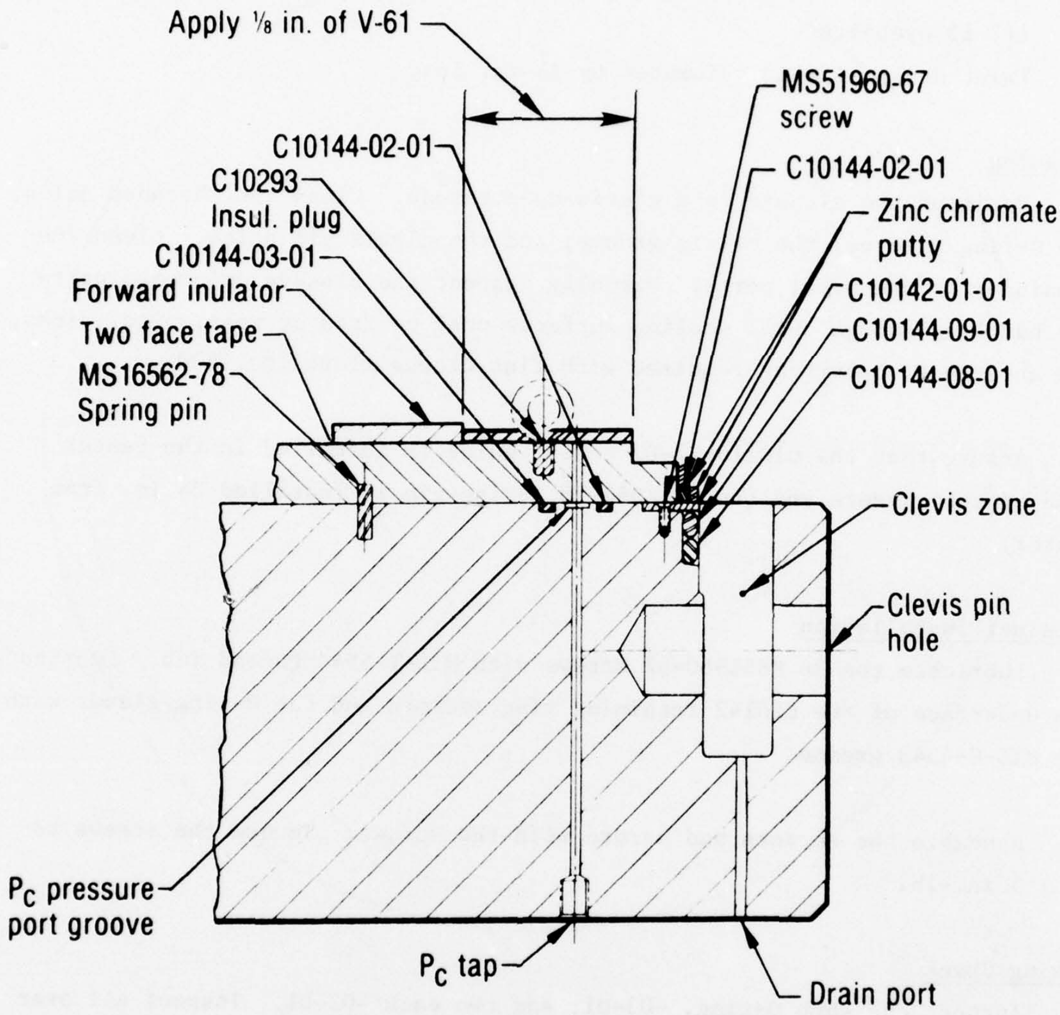

Figure C-2. Forward Closure Subassembly Super HIPPO

Install 1/2-13 eyebolts in the 3 threaded holes in the forward insulator.

Attach the C10300 sling assembly to the three eyebolts and lift the insulator subassembly. Align the insulator with the center guide and the alignment spring pin of the forward closure. Lower into position.

Assure that the two P_c tap holes align with holes through the insulator. Drill out phenolic if necessary with a long shank 1/4-in. twist drill. Install C10293 insulation plugs or zinc chromate putty in the three 1/2-13 threaded holes in the insulator.

Closure

Cover the closure as required to keep the clevis areas clean until assembly of the motor.

Insulated Case Preparation

Motor Materials	No. Required
C12419-01-01 case	1
C11347-13-01 rubber insulation, 18-in. wide	1 set
No. 11 wax 2 rubber cement (product No. 219)	AR
DC 36061 primer	AR
DC 93-104 silicone rubber	AR
Hillgard V-61 insulation	AR
Eastman 910	AR

Support Materials	No. Required
Solvent, grade ethanol or methanol	AR
Tape, 2 in., polyvinyl, pressure sensitive, Permical P-32 or 3M type 471	AR
Solvent, 1,1,1, trichloroethane, tetrechloroethylene, or perchloroethane	AR
Grit blast equipment	lot
16-silica grit	AR

Support Materials (Continued)	No. Required
Sandpaper, 80- to 100-grit	AR
Scale with 20-lb capacity	1
Lockbond No. [illegible] solvent (MEK base)	AR
C10290 case lift adapter	2
C10292 (30,000-lb sling)	1
C10291 trunnion base	1
Saddle block for case	1
Mobile crane - 25,000 lb at 40-ft high and 20-ft radius	1
C10840 pin assembly	8
White gloves	12
Polyethylene bags	12
Hand roller	2
Clean lint-free rags	AR
Solvent, acetone or MEK	AR
No. 400 crocus cloth	AR

Case Preparation

Support the motor case horizontally by the C10291 trunnion base and the wood saddle block using the C10290 case lift adapters, the C10840 pins, the C10292 sling, and the C11151 stirrups (see figures C-3 and C-4).

Cleaning

Clean the case ID and clevis pin holes with solvent wipe.

Visually inspect the clevis zone, O-ring sealing surface and clevis pin holes for handling damage. These areas must be free of rust, pits, nicks, and scratches. Deburr as required with fine crocus cloth (No. 400).

Scribe pencil lines 6.55 in. in from each end of the case around full circle. Apply two layers of polyvinyl tape from each pencil line to the ends of the motor case to mask the O-ring seal area during grit blast and to

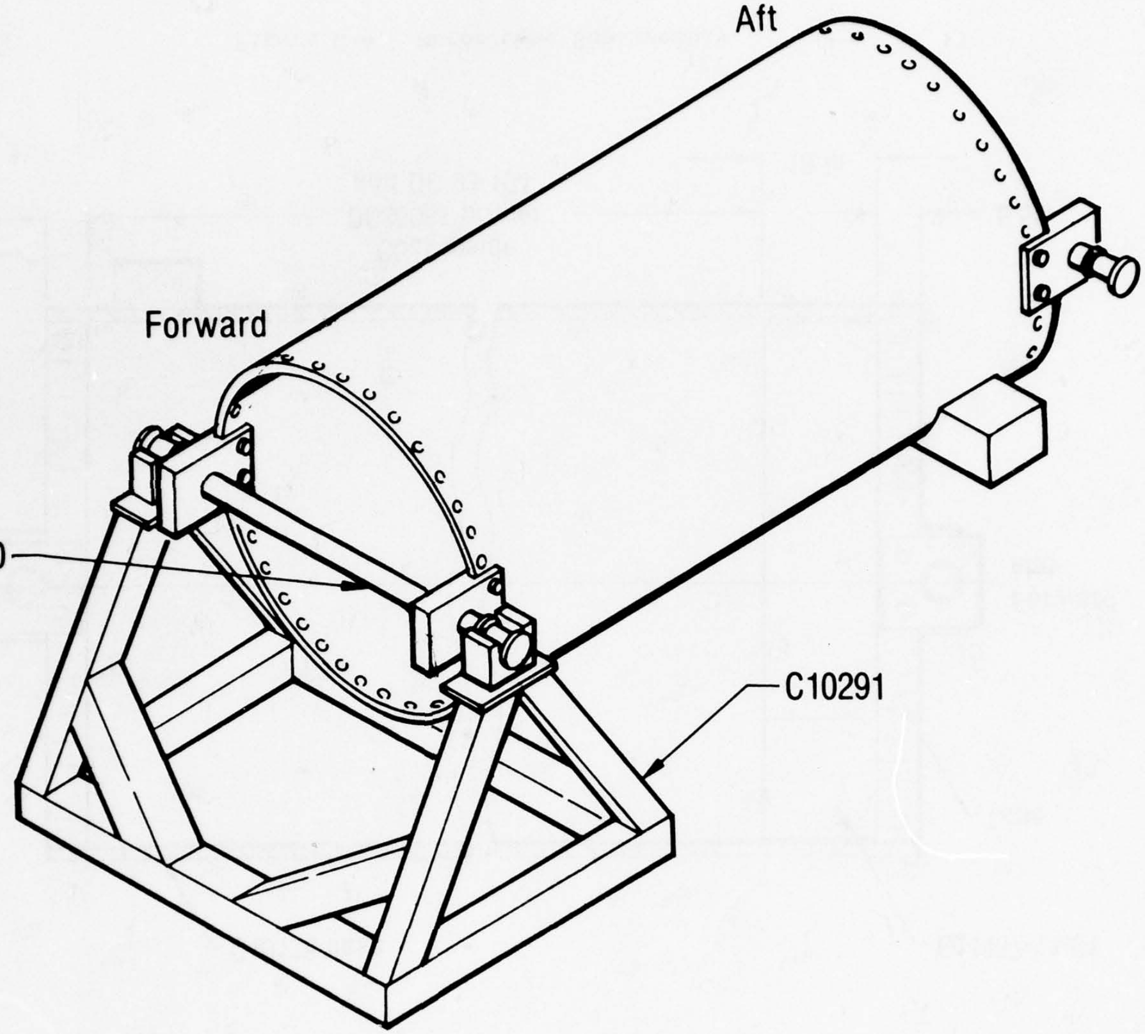

Figure C-3. Motor Case Ready for Insulation

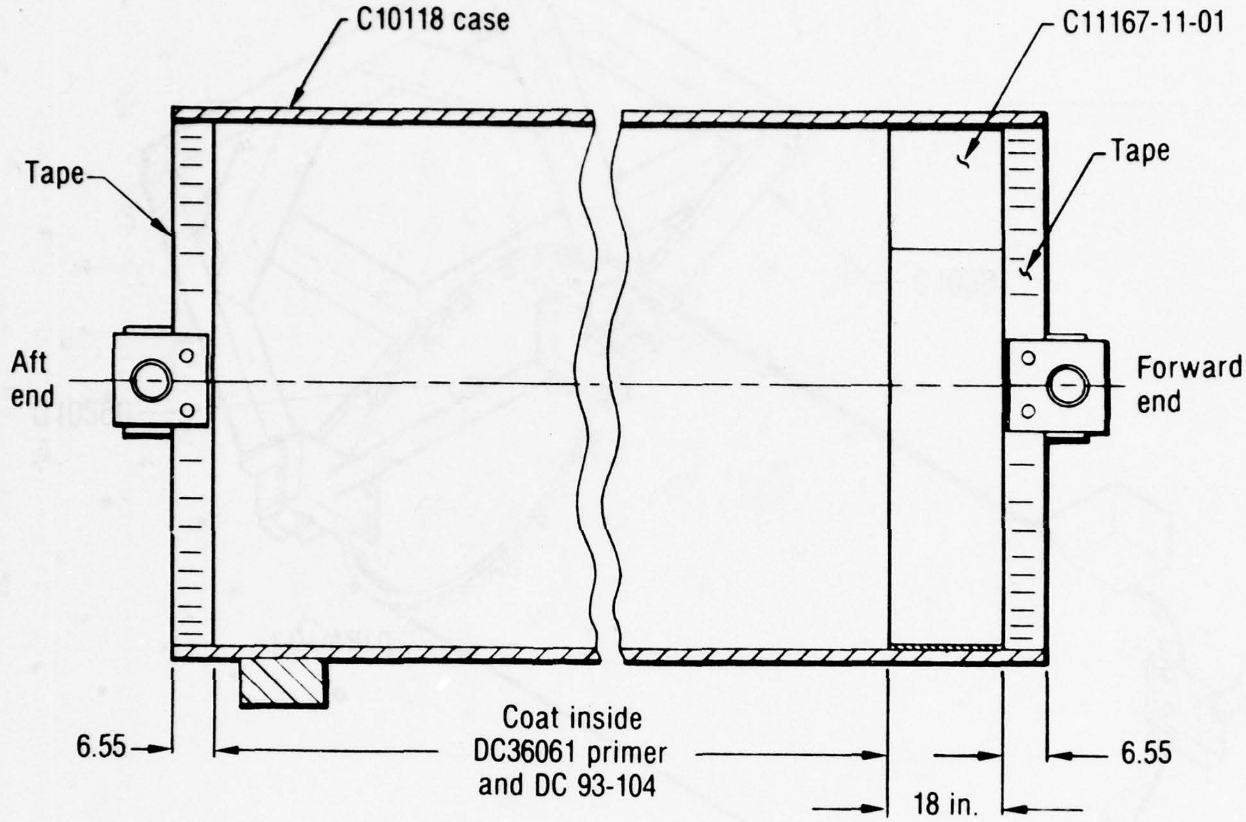

Figure C-4. Motor Case Subassembly

guide positioning of the C11347-13-01 rubber. Tape around the lift fixture to protect the case or support the case end on blocks and remove the lift adapter.

Lay out the C11347-13-01 rubber on paper for sandblasting (three pieces 1/4-in. thick by 18-in. wide by 88-in. long). Solvent wipe the rubber with 1,1,1 trichloroethane and allow to dry for 30 min before sand/grit blast.

Grit Blasting Case

Grit blast the rubber and the case ID with 40- to 60-Garnet grit or 16-silica grit at 50 to 120 psi.

Solvent wipe with 1,1,1 trichloroethane. No hands, shoes, or contaminated cloth on the bonding surface after blast and wipedown. To enter the case requires clean polyethylene bags tied about shoes; to handle bonding surfaces requires white gloves.

Rubber Sheet Installation

Fit-check two pieces of the 1/4-in. by 18-in. wide rubber sheet in the forward end of the case. Set the rubber-to-rubber joint at the low point; trim the rubber end as required to obtain a good fit. Keep rubber and case clean. Mark off the area of the case to be bonded with the two rubber pieces.

Lay the rubber out on the paper and brush a coat of No. 11 wax 2 rubber cement on the bonding zone of the case and to the rubber surface. Let dry for approximately 10 min.

Press the rubber into position; use a hand roller to roll out the bond. The cement bond should have handling strength immediately, with full strength in 3 days. Fit-check the remaining section of rubber sheet to the case and trim as required. If surfaces have become contaminated, abrade with 80- to 100-grit sandpaper, solvent wipe with 1,1,1 trichlorethane and let dry for 30 min. Brush No. 11 wax 2 rubber cement onto the rubber and steel bonding surfaces. Let the cement dry for approximately 10 min.

Press the two surfaces together; use a hand roller to roll out the bond. Clean up as required with Lockbond No. 55 solvent.

Allow the No. 11 wax 2 rubber cement to cure for 24 hr. Abrade areas of steel contaminated by cement and cement solvent with 80- to 100-grit sandpaper. If abrading is required on the O-ring surface for cleanup, use a No. 400 crocus cloth and rub in circumferential directions. Do not create axial direction scratches on O-ring surfaces.

Repair local areas of unbond of the rubber sheet to the case with Eastman 910. Pot any insulation voids and gaps at the joints with V-61.

DC36061 Primer

Alcohol wipe the contaminated area with No. 11 wax 2 rubber cement or with Lockbond No. 55. Allow alcohol to air dry for 30 min. Trichloroethane wipe and dry. Acetone wipe. Allow the cleaned surface to air dry at least 30 min.

Apply a thin coating of DC36061 primer to the case ID between the rubber and the far end tape by brushing or spraying. Avoid contaminating the rubber with the primer. Complete coverage should be attained with 1 to 2 pints of primer. The primed surfaces should be light pink in color. Air dry 1 hr minimum. Use clean polyethylene bags or equivalent over shoes to keep steel case clean.

DC93-104 Installation

Mix DC93-104 silicone rubber per manufacturing instructions using a mix ratio of 10 parts catalyst to 100 parts resin.

Brush or spray coat the primed surface with DC93-104 silicone rubber (thickness = 0.125 in.). Avoid contaminating the rubber with the DC93-104. Coverage shall be 55 to 65 ft^2/gal, approximately 8 gal to cover the case bore surface for SLSH

Cure the coating a minimum of 24 hr at ambient conditions. Remove the tape from the clevis areas and clean as required. Pot any gaps in the C11347-13-01 rubber sheet joints with V-61. Repair any voids in the DC93-104 [illegible]

Note - V-61 may be used instead of DC 36061 and DC 93-104.

Propellant Grain Preparation

Motor Materials	Materials
CC12629-01-01, S/N	1
Aluminum foil tape (Scotch 425 or equivalent)	AR
C10278-01-01 spacer	2
Zinc chromate	AR
Grease per MIL-G-4343	AR
C10144-05-01 O-ring	4
C11199-01-01 ring segments (4 pieces per set)	2 sets
Fiberglass reinforced tape (Scotch 890 or equivalent)	AR

Support	Materials
C10294 cartridge lift adaptor	1
Crane (25,000 lb at 10-ft radius)	1
A1227-70 potting compound	AR
Inspection gages	AR

CAUTION

In handling the loaded grains, do not allow personnel under the grains while weight of grain is supported by the lifting holes, i.e., by the lift adaptor.

Aft End Grain Preparation
Confirm P/N C12629-01-01, S/N .

Assure the grain is in a safe area for propellant. Remove the wooden and plastic covers, and the tape from the aft end of the grains. Remove the restraining cables.

Examine the exterior and aft ends of the cartridges for shipping damage. Inspect for unbonds at the rubber-to-fiberglass interface and the propellant-to-rubber interfaces of the propellant cartridges (see figure C-5). Pot any rubber unbonds or fiberglass delaminations with A1-227-70.

Examine the O-ring sealing surfaces on the ID of the fiberglass. Sand out any nicks or scratches with 100- to 200-grit sandpaper. Apply V-61 to smooth imperfections in the O-ring sealing surfaces as required. Sand out V-61 after cure.

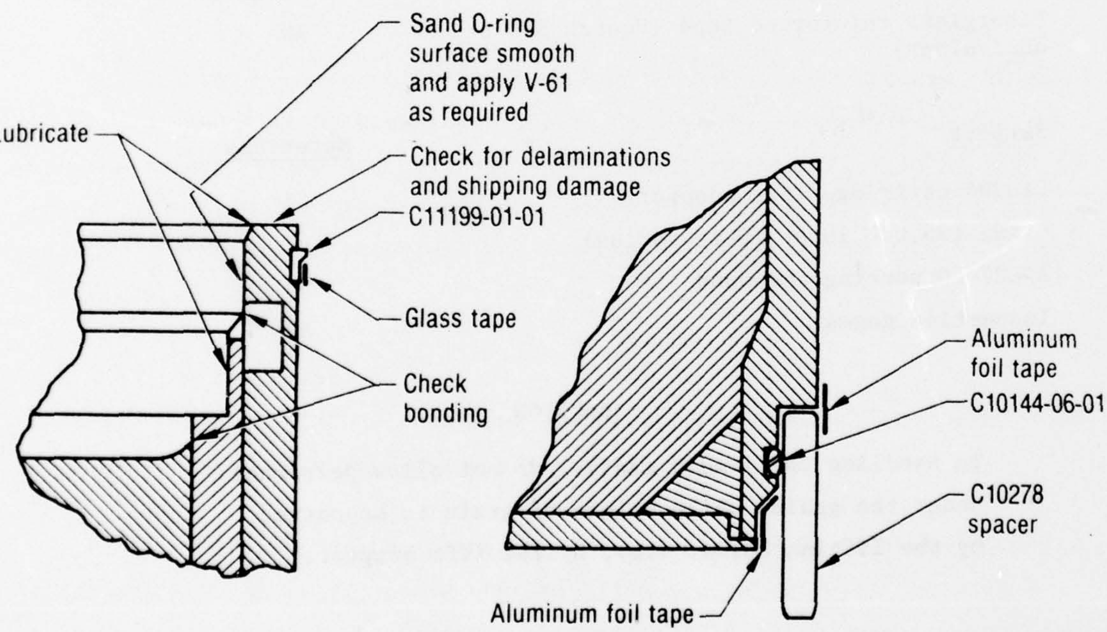

Figure C-5. Grain Processing

Forward End Preparation

Attach the C10294 cartridge lift to the grain. Roll the safety latches down and insert the drawbar pins (see RPL safety procedure).

Install the four centering ring segments (C11199) between the latches and tape them in place temporarily with fiberglass-reinforced tape. Lift the cartridge off the C10278 spacer.

Apply MIL-G-4343 lubricant to a C10144-06-01 and install in the O-ring groove. (NOTE: This O-ring is installed only to center the grain on the spacer.)

Apply two layers of foil tape from the lower edge of the cartridge toward the O-ring groove. Trim off any excess tape. Overlap any end joints in the first tape layer with the second layer. (The function of this tape is to protect the restrictor-to-fiberglass joint during test.) Center the second tape over the edges of the first tape.

Lower the grain back onto the spacer. Remove the lift adapter.

Wrap two plies of the fiberglass tape around the bottom of the centering rings.

Apply two layers of aluminum foil tape over the spacer-to-cartridge joint to assure good overlaps of ends and edges.

Replace the restraining cables for transportation to the test bay.

<u>Trimming Grain Forward Restrictor (if required)</u>

Attach the C10294 lift fixture to the grain cartridge (per grain lift procedure, revision A). Verify that the four lift pins are extended into the lift holes 1 in. (to the punch-mark) and the locking pin is engaged.

Lift the grain clear of the spacer ring. Position the spacer ring on steel saw horses or suitable blocking capable of supporting the grain weight (28,000 lb). Position the grain over the spacer and lower the grain until it just contacts the spacer/saw horses.

All unnecessary personnel should clear the area at this time.

Notify operations (32521) that grain restrictor trimming operations on the Super HIPPO grain is starting. Approved safety clothing should be used for this operation.

Trim the restrictor to within 0.2 to 0.4 in. of the propellant bore using mechanical cutters. Do not cut closer than 0.2 in. of the propellant. Cut in a manner which avoids putting a tensile load on the restrictor-to-propellant bond.

Trim and smooth the restrictor using an air driven rotary file or knife.

Inspect the propellant-liner-restrictor bondlines at the bore interface. Blend any debonds and pot with Al 227-70.

Notify operations (32521) that the grain restrictor trimming operation is complete for cartridge number.

Replace the grain on the shipping base and attach the four tiedowns and tighten the turnbuckles.

Aft Closure-Adapter Subassembly (IUS Unique, Drawing C12411-01-01)

General

The preferred aft closure assembly sequence is to install the IUS nozzle adapter in the aft closure, invert the closure, then install the adapter insulator and then the aft insulator. A blind flange is first installed on the nozzle port (CHAR configuration) for a 50-psi motor leak check, then the nozzle is installed. The clearance between the aft insulator and the adapter insulator is tight, so it is better to install both of these at the same time. The nozzle shell has enough clearance to the adapter bolts that there should be no problem letting the nozzle center on the adapter insulator.

Aft Closure - Trunnion Subassembly

Motor	Materials
C10120-01-01 aft closure	1
C10289-02-01 trunnion	1
C10289-02-02 trunnion	1
AN960-1616 washers	16
NAS1351-16-44 screw	8
S276 1-1/2-6 eyebolt	1
MIL-T-5544 thread lub	AR
Alignment blocks, roll pins, and shoulder bolts	3 each

Support	Materials
Torque Wrench, 500 ft-lb	1
C10291 trunnion base	1
C10849 support	2

Assemble one each of the C10289-02-01 and C10289-02-02 trunnion shafts to the C11126-01-01 aft closure using eight flat washers (AN960-1616) and eight screws (NAS1351-16-44). Clean bolts and threaded holes; lubricate with MIL-T-5544.

Install the shafts and finger-tighten the bolts. Make sure the bolts do not extend into the clevis groove; add additional washers as required. Torque to 450 ± 50 ft-lb.

Install S-276 1-1/2-in. eyebolts (1-1/2-6 UNC-2A, 3-in. thick) at 135° from TDC in the C11126-01-01 aft closure. Add washers under the eyebolt shoulder as required to bring the plane of the eyebolt approximately coincident with the motor centerline.

Install the C11151 stirrups on the turnbuckle legs of the 30,000-lb sling C10292, lift the sling to a crane and position the stirrups in the 2-in.-wide journals of the trunnions. Pin the sling tag leg to the eyehook of the closure Lower the closure onto the trunnion base with the eyehook toward the support head. Remove the sling by disconnecting the stirrups. Invert the closure to the clevis-down attitude.

Aft Insulator Subassembly

Motor	Materials
C10280-01-01 aft insulator	1
C12413-11-01 rubber strip (1.6- by 1.4- by 260-in.)	1 set
Insulation test samples	AR
EA913 epoxy adhesive	AR
C10276-01-01 insulation plugs	12

Support	Materials
Eastman 910 cement or Permabond 102	AR
Solvent	AR
Sandpaper, 80- to 100-grit	AR
Centering template	1
Rags	AR
Weights	AR
Epoxy weighing and mixing equipment	AR

Fit the 1.4 x 1.6 inch rubber strip around the OD of the bonding template. Cut ends to form the final joint so that a snug fit results. Assure the edge distance of 1.7 ± 0.1 in. from rubber OD to phenolic insulator OD will be met (reference C12413, zone 7B). NOTE: If insulation in propellant cartridge sidewall is less than 1.5-in.-thick, 1.7 dimension should be reduced accordingly.

Grind mating ends flat and true, abrade, solvent wipe, and bond with Eastman 910 (see figure C-6).

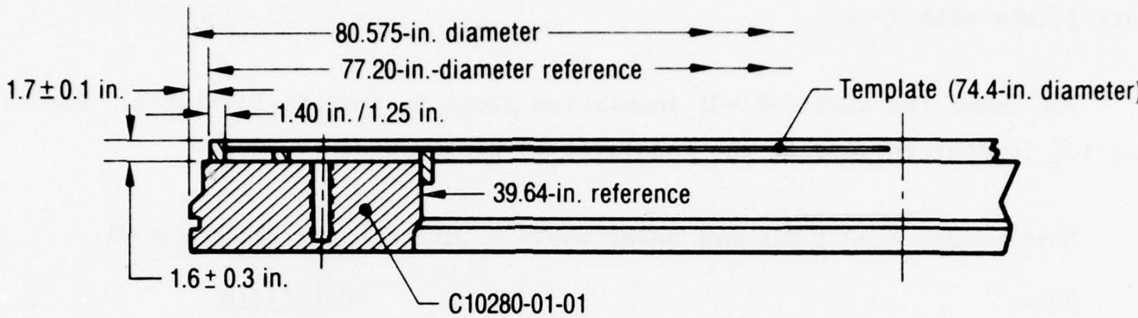

Figure C-6. Bonding Ring on Aft Insulator

Alcohol-wipe test the ID and OD of the C10280 aft insulator to inspect for unbonds. Use pure alcohol or highly volatile solvent. Wipe a heavy coat of alcohol or solvent on the exterior and interior surface; observe for delaminations or cracks. No cracks are allowed.

Fit-check the centering of the 12413-11-01 rubber ring just formed on the C10280-01-01 insulator using the bonding template. Shim as required. Wrap Parmacel tape on the template where required to prevent bonding. Check out the weights to be used to hold the rubber down after bonding.

Clean the mating surfaces of the C12413-11-01 rubber and the C10280-01-01 aft insulator by abrading lightly with 80- to 100-grit sandpaper.

Solvent wipe and let solvent dry for 30 min, minimum.

Mix 1 lb of EA913 adhesive per bonding instruction, 1 lb of part A to 0.12 lb of part B. Apply EA913 to bonding surfaces of C12413-11-01 rubber and to matching zones of C10280 aft insulation. Press into position using the template above. Brush a fillet of epoxy along glue lines. Apply weights to provide contact pressure.

After 24 hr, remove the weights. Four to seven days are required for EA913 to develop full strength at ambient conditions. Inspect EA913 bond-lines visually for unbond. No unbonds are allowed. Repair any voids in the butt joints with V-61.

Fit-check the C10276-01-01 insulation plugs in the aft insulator. Bottom tap the 1-1/8-7 threads in the insulator to clean up as required.

Nozzle Adapter-Aft Closure Subassembly - General, per C12413-01-01

Motor	Materials
C10120-01-01 aft closure with trunnions	1
C10283-03-01 shear key (notched)	1
MS21250-12016 bolts	32
WC-12 washer	64
C10144-04-01 O-ring	1
MIL-T-5544 thread lubricant	AR
MIL-G-4343 O-ring grease	AR
Nozzle Adapter C12 592	1

Support	Materials
Torque wrench, 360 ft-lb	1
Sling	AR

Place the closure in a clevis-down attitude and level.

Clean the shear key groove and seal surfaces of the closure and nozzle. Rub out any axial scratches in the sealing surfaces using circumferential strokes with No. 400-crocus cloth. Clean the shear key bolts and washers.

Examine the surface of the C10144-04-01 O-ring for surface blemishes. Bend the bonded joint into a 1-in. radius and roll through 360^{o}. No voids, cracks or unbonds are allowed. Lubricate the O-ring lightly with O-ring grease and install on the nozzle adapter. Lift the nozzle adapter on the

C10300 sling and adjust to level. Lower the nozzle adapter into the closure with the indexing pin aligned to the slot in the closure.

Install the section of the shear key with the indicated face up and with match numbers on the sectors adjoining. Lubricate the bolt threads. Install two washers on each bolt with the bevels facing away from each other. Install the bolts and number the bolts holes 1 through 32. Torque to 120 to 170 ft-lb in the first pass and to 335 ± 25 ft-lb on the second pass. Torque sequence is: 1, 17, 9, 25, 4, 21, 13, 29, 6, 22, 14, 30, 4, 20, 12, 28, 8, 24, 2, 18, 10, 26, 16, 32, 7, 23, 15, 31, 3, 19, 11, 27.

Insulated Aft Closure Subassembly (per C12411, IUS)

Motor	Materials
Adapter-aft closure subassembly	1
C12590-01-01 adaptor	1
2-473 Viton O-ring	1
C10276-01-01 insulation plug	12
AN6-10 screw	12
AN960-1616 washer	12

Adaptor Insulation Installation

Position the adapter aft closure subassembly in the clevis-up attitude.

Lubricate the 2-473 O-ring with O-ring lubricant and place it in the groove in the face of the adapter. Place three threaded guides in the three equally-spaced holes in the face of the adapter. Use 3/8-24 threaded rod at least 8 in. long. Install 1-1/8-7 eyebolts in three of the threaded holes in the face of the adapter insulator.

Attach the C10300 sling assembly to the three eyebolts and lift the insulator onto the adapter. Remove the guide rods.

Lubricate the 12 AN6-20 screws with MIL-T-5544 thread lubricant, add the AN960-616 washers and install in the twelve holes. Assure the insulator is centered. Fix the insulator as required.

Bring all 12 bolts up finger tight, then tighten each bolt in sequence, 1/4 turn. Repeat until the insulator compresses the O-ring and the insulator is flat against the adapter after the aft closure insulator has been fitted and bolted finger tight. Torque the AN6-20 screws to 15 to 20 ft-lb.

Insulated Aft Closure Assembly

<u>Motor</u>	<u>Materials</u>
C10120-01-01 aft closure adapter subassembly	1
C10280-01-01 aft insulator subassembly	1
C10276-01-01 insulation plug	12
C10142-01-01 retainer (six pieces)	1 set
MS51960-67 screw	36
AN960-616 washer	12
AN6-20 screw	12
C10144-05-01 (or -06-01) O-ring	1
C10144-10-01 O-ring	1
Thread lub per MIL-T-5544 (thick black material)	AR
Grease per MIL-G-4343 (Dow)	AR
Zinc chromate putty	AR

<u>Support</u>	<u>Materials</u>
3/8-24 x 8-in. threaded stock guides	3
Solvent	AR
Rags	AR
C10300 sling	1
1-1/8-7 eyebolts	3
C10742 insulation plug tool	1
Graphite tape	AR

Cleaning

Clean the threaded holes, O-ring grooves, clevis groove, and clevis pin holes. Clean the remainder of the metal parts (see figure C-7). All sealing surfaces must be free of rust, pits, nicks, and scratches. Deburr as required with fine crocus cloth (No. 400).

Examine the aft insulator for damage. Check for delaminations in the insulator ID and OD, and for unbonds at the rubber-phenolic bondline. Check bondlines of any material test samples; pot with V-61 as required. Alcohol-wipe test the cylindrical surfaces of the C10280 insulator.

Retainer Installation

Lubricate the 36 MS51960-67 screws with MIL-T-5544 thread lub. Lubricate the underface of the C10142 retaining ring sectors and the O-ring glands with the MIL-G-4343 grease. Assemble the C10142 retaining ring sectors and secure with the MS51960-67 screws. Torque the screws to 20 ± 5 in.-lb.

O-Ring Check

Inspect one of the C10144-10-01 O-rings. Inspect all over for nicks and cuts. Examine the butt joint bond by bending the O-ring 180^{o} at the joint with a 1-in. radius. Roll the section through 360^{o} and examine for discontinuities. Install 1-1/8-7 eyebolts in three of the threaded holes of the aft insulator subassembly.

Install the three threaded guides in three equally spaced threaded holes at the 65-in.-diameter bolt circle on the aft closure. Use a 3/8-24 threaded rod at least 8 in. long. Attach the C10300 sling assembly to the three eyebolts and lift the insulator subassembly. Level as required using the turnbuckles of the sling. Align the insulator and lower into position for fit check. Start the 12 AN6-20 bolts with washers in the matching holes of the aft closure. If necessary, file the insulator to fit the bolts. Remove the insulator.

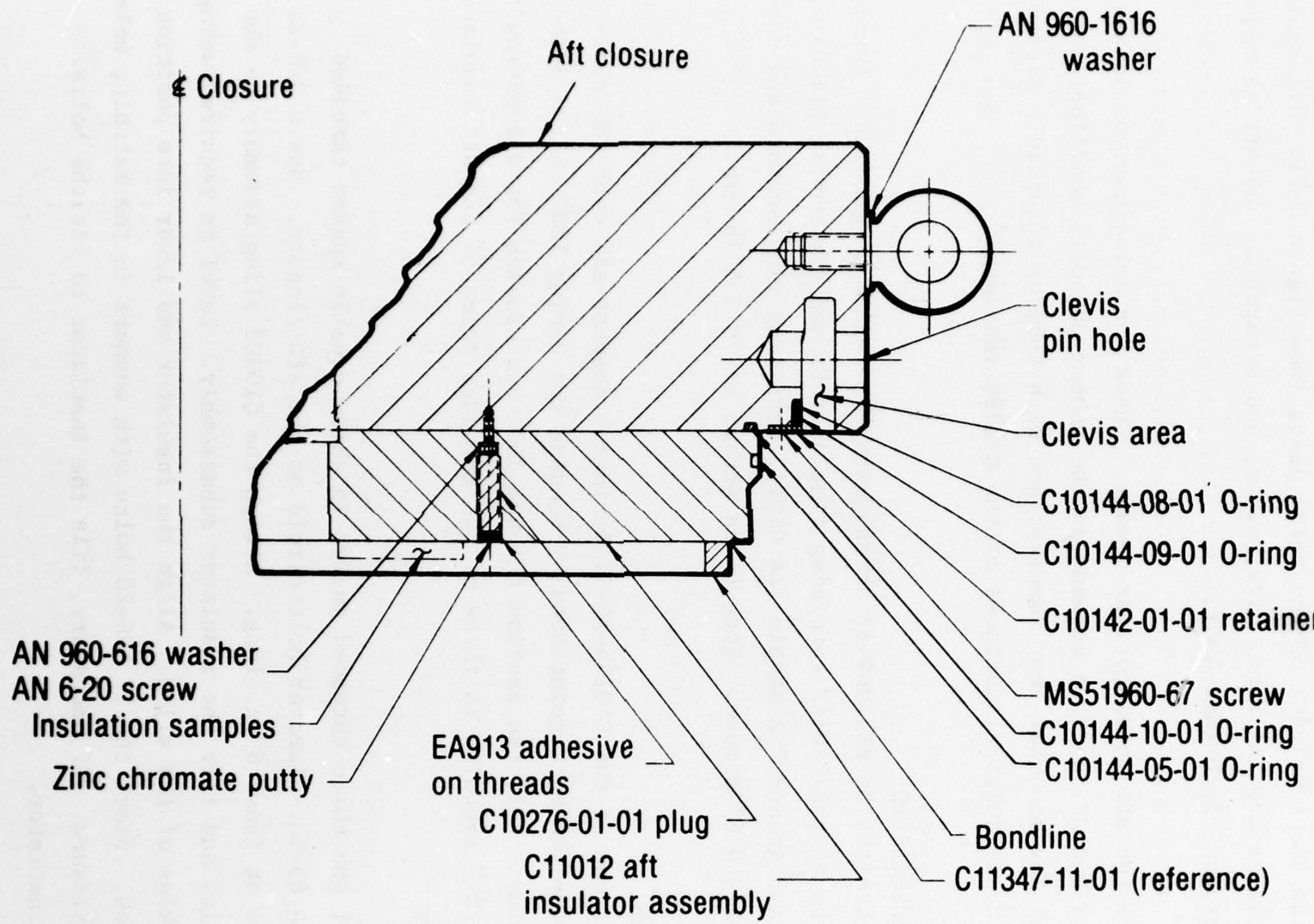

Figure C-7. Aft Closure Subassembly

Install a bead of zinc chromate putty (normally 0.25 to 0.35 in. in diameter) on the step of the nozzle (adapter insulator) just above the closure. See figure C-8. In order to size the amount of putty required, place 0.35-in.-diameter balls of putty on the nozzle step three places around. Lubricate the putty with O-ring lubricant and lower the insulator in place. Remove the insulator and measure the putty thickness. Remove the putty and lubricant. Install a bead of putty 0.1 in. larger in diameter than the above thickness.

Closure-to-Insulator O-Ring Installation

Apply a light coat of MIL-G-4343 grease in the O-ring groove which is on the forward face of the closure inboard of the retainer. Lubricate the C10144-10-01 O-ring lightly with MIL-G-4343 grease and install it in the groove. Assure that this is the soft 50 durometer "A" O-ring.

Align the insulator and lower into position. Remove the sling, the eyebolts, and the guides.

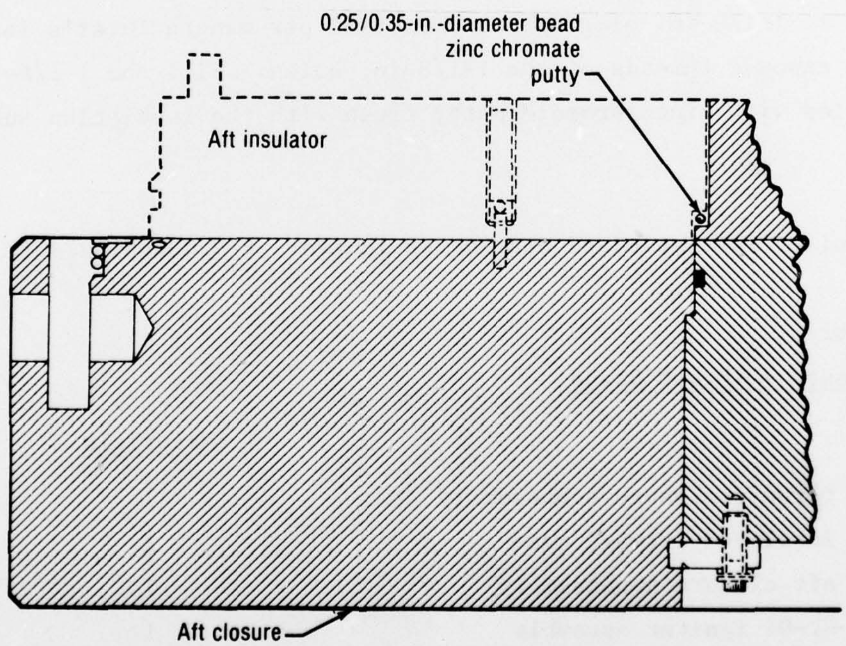

Figure C-8. Putty-on-Nozzle Step

Clean the 24 C10276 insulation plugs and the 12 matching threaded holes in the aft insulator and the adapter insulator with perchloroethane.

Clean 12 AN6-20 screws and AN960-616 or MS20002006 washers. Lubricate screw threads and underhead. Install the screws and washers finger-tight.

Tighten each bolt in sequence 1/4 turn. Repeat until the insulator compresses the -10 O-ring and the insulator is flat against the closure. Torque the AN6-20 screws to 15 to 20 ft-lb.

Prepare 24 1/2-in.-diameter balls of zinc chromate putty and drop one in each of the 1-1/8-7 threaded holes. Install the C10276 plugs in the 1-1/8-7 threaded holes. Wrap the plug threads with graphite tape as required to obtain a secure threaded fit. Use a C10742 wrench. Plugs should recess two turns below the insulation surface.

Solvent wipe and abrade the exposed threads in the aft insulator at each of the 24 1-1/8-in. plug holes. Mix V-61 per manufacturer's instructions and pot the exposed threads of the 1-1/8-in. holes. Fill the 1-1/8-in.-diameter holes with zinc chromate putty flush with the insulation surface.

Igniter

The igniter is a standard char motor igniter, P/N C00631-07-01.

Motor Assembly

Forward Closure - Thrust Stand

Motor	Materials
C10119 forward closure subassembly	1
C12419 insulated forward case	1
C10120 aft closure subassembly	1
C00631-07-01 igniter assembly	1
C10141 pins	120
Zinc chromate putty	AR

Motor (Continued)	Materials
MIL-G-4343 O-ring lubricant	AR
MIL-T-5544 thread lub	AR

Support	Materials
Solvent, Isopropyl alcohol	AR
Rags	AR
C10292 sling	1
C11151 stirrups	4
C10290 case lift adaptor	2
C10840 pins	8
C10291 trunnion base	1
Saddle for case	2
Mobile crane (25,000 lb at 20-ft radius and 60-ft elevation, with hydraset capability)	1
Torque wrenches	AR

Forward Closure Installation

The forward closure must be in a clevis-up attitude. Lift forward closure with C11151 stirrups on turnbuckle legs of the C10292 30,000-lb sling.

Adjust turnbuckles to level closure. Lower the forward closure to the stand with TDC oriented toward the guide pin in the thrust stand. Support closure weight from the crane until the bolts are all started into the closure.

Lubricate four capscrews 1 in. (8 x 4 in.) and four capscrews 1.25 in. (7 x 5 in.) with MIL-T-5544 thread lub and install through the thrust stand into the closure finger tight. Lower the closure and remove the sling and stirrups.

Torque the 1-1/4-in. capscrew to 625 ft-lb and the 1-8 capscrews to 287 ft-lb.

Case Installation

Check the forward closure and motor case for general cleanliness, damage in the seal area, and adequacy of MIL-G-4343 lubricant on the sealing surface at the case forward end and the closure clevis O-rings. A light but continuous coating is desired.

Clean, examine and lubricate one each C10144-08 and -09 O-rings and install. Assure the 1/2 inch hard rubber O-ring is below, and the 9/16 softer O-ring above.

Lift the motor case to the upright position with C10292 lift, C11151 stirrups, and C10290 case lift adapter. Assure the lift is level; use turnbuckles to adjust it as necessary. Using the crane, lift the case off the trunnion base, lower the case to the pad, and unpin the bottom case lift adaptor. Clean, deburr, and lubricate as required in the lift-hidden area of the forward case joint.

Position the case on the forward closure. TDC points toward T.S. 1.56. Lubricate the clevis pins lightly with MIL-T-5544 lub. Install sixty pins. WARNING: Assure that threaded end of pin is out. Apply two layers of aluminum foil tape over the pins. Unpin and remove the case lift adapter. Clean, inspect and lubricate in the adaptor-hidden zones of aft case clevis.

Case to Forward Closure Putty

Lower a ladder into the case being careful not to dislodge the forward insulation.

Install a 0.25-in.-diameter bead of zinc chromate putty under the C12413-13-01 rubber insulator as shown in figure C-9.

Clean and inspect a C10144-02-01 O-ring for damage, nicks, or cuts. Bend the O-ring 180^{o} with a 1-in. radius at butt joint. Roll the section through 360^{o} and examine for discontinuities. Insert the O-ring into the

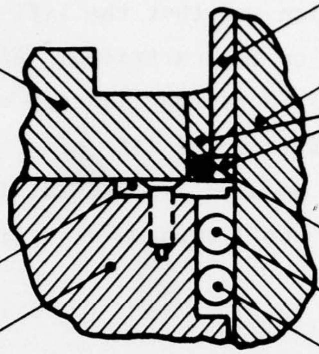

Figure C-9. Putty at Forward Insulator

crevice between the forward insulator and the case insulation rubber (C12413-13-01) until the O-ring rests on the C10142 retainer adjacent to the putty beneath the rubber. Work zinc chromate putty into 0.2-in.-diameter ropes and force into the clevis on top of the -02-01 O-ring until the crevice is full. Remove the ladder.

Grains

Arrival of Grains to Test Area

Place the test areas in General AMBER condition.

Grains on the Test Pad

Place the test stand in a local RED condition.

Forward Case Grain Installation

Confirm that preparation operations have been completed on the grain. Confirm seal number is correct. Move grain transport trailer to motor area. Remove wood covers, plastic covers, and tiedown cables.

Make a final check of propellant bondlines on grain for transport damage.

Lift and position the C10294 lift fixture over cartridge of grain. Assure safety grips are in the UP position and that the lift pins are all retracted. Lower lift fixture into position on the cartridge. Align index on fixture with groove on top face of cartridge. (Note that fixture must be at rest on cartridge to be properly aligned.) Extend the lift pins into the fiberglass cartridge. Verify lift pins are engaged 1 ± 1/8 in. into cartridge holes. The pin is punch-marked at 1 in. Roll down safety grips over outside of cartridge and insert locking pins.

CAUTION

Do not allow personnel under the grains while the weight of the grain is supported by the lifting holes, i.e., by the lift adaptor.

Lift the cartridge over a safety support and re-examine the lower propellant bondline.

Lift the cartridge center over the motor and begin to lower. When the lift fixture is 1 to 2 ft above the top of the motor case, remove the safety grip locking pins and roll the safety latches back. Continue lowering. Assure the safety latches move far enough back not to scratch the case ID.

Lower the cartridge into position. Be careful the spacer on the bottom of the cartridge does not hang up on the step of the forward insulator.

Distance from the top of the forward cartridge to the top of the case should be 6.20 to 6.50 in. when the cartridge is down. Record distance at TDC ________ and BDC ________ .

Lift the cartridge back out and inspect the forward sidewall rubber sheet in the case and the DC93-104 rubber on the case ID. Repair any damage.

Reset the cartridge. Retract lift pins until all four clear the cartridge lift holes. Remove lift fixture.

Examine the case O-ring sealing surface, particularly near the ends of the four centering ring arcs on the grain. Burnish out any axial scratches with No. 400 crocus cloth, rubbing in a circumferential direction.

Build a zinc chromate putty bead on the aft face of the aft cartridge with 1-in.-wide putty strips until the top of the putty is 6.0 ± 0.1 in. down from the top of the case. Record this distance eight places around. See figure C-10.

1.	___________	4.	___________	7.	___________
2.	___________	5.	___________	8.	___________
3.	___________	6.	___________		

The putty should extend from the steel case inward 1 in. and should not extend inboard of the bevel on the fiberglass cartridge.

Measure the thickness "F" of the aft insulator outboard of the square cross-section rubber ring eight places around and determine minimum value.

1.	___________	4.	___________	7.	___________
2.	___________	5.	___________	8.	___________
3.	___________	6.	___________	Minimum	___________

Add 6.0 to $F_{minimum}$: E = _________ +6.0 = _________ ±0.1.

Build a zinc chromate bead on the lower rubber step on the rubber insulation in the cartridge 1/2 in. wide until distance to top of case equals E above. Measure this value eight places around.

1.	___________	4.	___________	7.	___________
2.	___________	5.	___________	8.	___________
3.	___________	6.	___________		

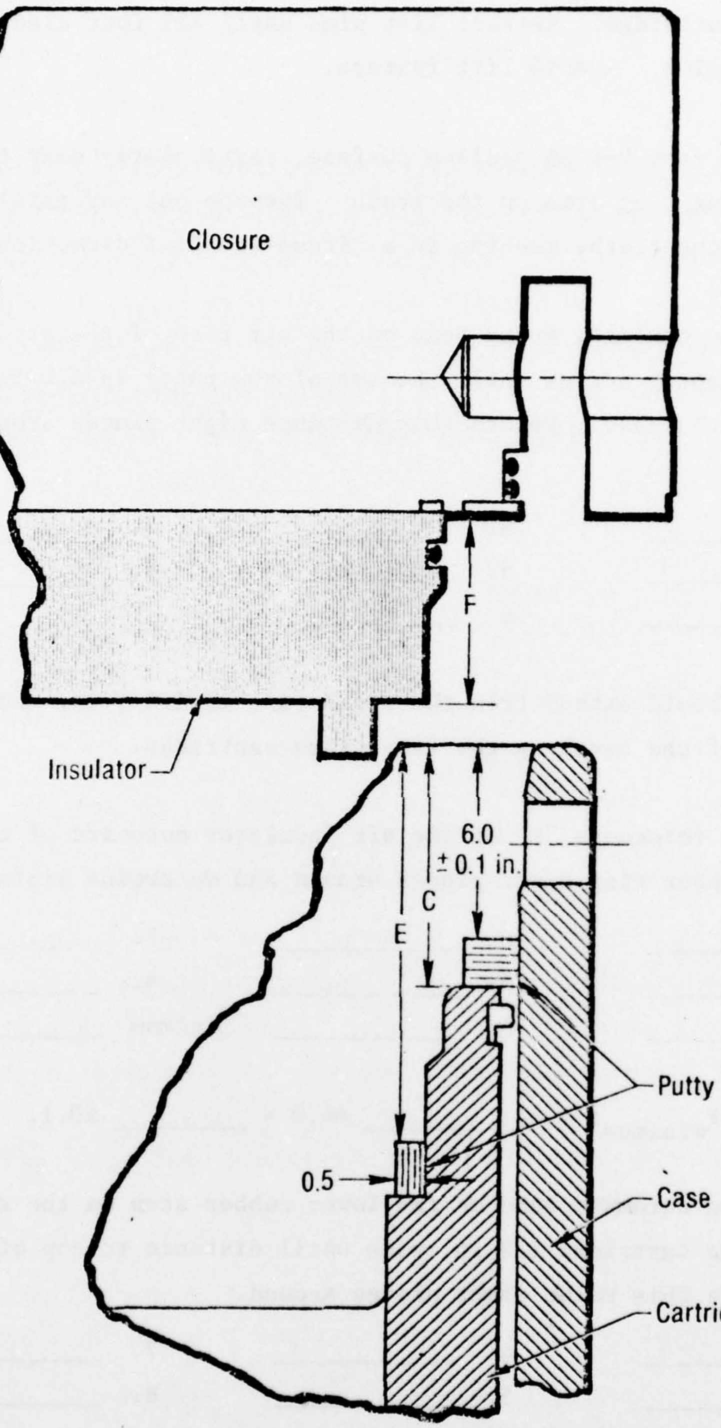

Figure C-10. Putty on Propellant Cartridge

Coat the zinc chromate putty lightly with O-ring lubricant for fit-check.

Aft Closure Assembly

Remove the grain transport and bring up the closure transport trailer with the aft closure in the clevis-up attitude.

Assure that the aft closure subassembly procedures have been completed, clean, examine and lubricate C10144-05/06-01 O-ring. Install it on the aft insulator. Clean, examine and lubricate a C10144-09-01 and -08-01 O-ring. Install in the groove on the closure with smaller O-ring farther into clevis.

Rotate the closure to clevis-down attitude. Using the crane and the C10292 sling with C11151 stirrups on turnbuckle legs, lift the aft closure; level aft closure using turnbuckles.

Lift the aft closure and lower carefully onto motor case. Lower slowly to assure proper alignment of the aft insulator into the cartridge and to allow time for excess zinc chromate putty to flow into cavities.

Apply MIL-T-5544 and fit-check three clevis pins equally spaced to assure the closure is fully seated. Keep threaded end out.

Remove the pins and the aft closure and examine the putty for even deformation and the mating area for damage. Repair the putty and remove lubricant from putty and aft closure insulator with denatured alcohol. Retain O-ring lubricant on the O-ring.

Replace the aft closure. Apply MIL-T-5544 and install 60 C10141 clevis pins. Apply two layers of aluminum foil tape over pins. Place the test area in a general GREEN condition.

PNEUMATIC MOTOR LEAK CHECK

Inspect a 2-473 Viton O-ring, lubricate with MIL-G-4343 and place it in the O-ring groove on the adapter. Clean the CHAR hydro-plate and lower onto the adaptor. Clean 25 socket head capscrews 1-1/2-6 x 4, Allen or Unbrako, only, and MS209002-24 24 washers. Lubricate the threads of the capscrews with MIL-T-5544. Install the bolts with washers and number them 1 through 24. Torque to 300 to 350 ft-lb. Torque sequence: 1, 13, 7, 19, 4, 16, 10, 22, 2, 14, 8, 20, 5, 17, 11, 23, 3, 15, 9, 21, 6, 18, 12, 24.

Connect GN_2 lines to the flare connections in the hydroflange.

Tape over the gaps between the closures and the case, and the two drain holes in the forward closure.

Pressurize the motor to 50 psig. Record time and exact pressure. Close off all GN_2 feed valves. Time _______ Pressure _______ psig.

Soap-bubble check at the shear key joint, both case-closure joints, the mid-case joint, the drain holes, and the P_c lines.

Record time and pressure every 10 min to evaluate pressure decay rate at which motor should stabilize, then show no loss for 30 min.

Time	Pressure	Decay rate last 10 min	Average decay rate since start, psi/min
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______
_______	_______	_______	_______

Time	Pressure	Decay rate last 10 min	Average decay rate since start, psi/min
________	________	________	________
________	________	________	________
________	________	________	________
________	________	________	________
________	________	________	________

Depressurize and remove the hydroflange.

Nozzle Installation

Motor Materials	No. Required
C12382-01-01 nozzle assembly	1
C12868-01-01 heat shield	1
1-1/2-12 x 4.0-in. SOC HD capscrew, Allenoy	24
MS20002-C24 washer	24
2-473 Viton A O-ring	1
1/2-20 UNF 2A x 1.0 capscrew	20
AN960 -816 (1/2-in. washer)	20
DC93-058 silicone rubber	6 gal
V-61 Gengard	7 gal
MIL-G-4343 O-ring lubricant	AR
MIL-T-5544 thread lub	AR

Support Materials	No. Required
5/8-11 eyebolts	3
C10300 lift adaptor	1
Perchloroethane solvent	AR
Crocus paper, 80 to 100	AR
Parmacel tape	AR
Torque wrenches	AR

Heat Shield Preparation

Fit-check the heat shield to the closure.

Abrade the heat shield all over to provide a good bonding surface. Solvent wipe with perchloroethane or equivalent and let air-dry for 30 min. Coat the underface of the heat shield with Parmacel tape to prevent sticking of V-61. Mask off the 20 bolt holes, and apply a 1-in.-thick coat of V-61 to the outside face of the heat shield, with buildup to 1-1/2-in. thick at the minimum diameter. This should require 6 to 7 gal of V-61.

Nozzle Installation

Clean the flange faces of the nozzle and the adaptor, the 24 each 1-1/2-12 capscrews and washers, and the bore of the nozzle port in the adaptor.

Install a 0.25-in.-diameter bead of zinc chromate putty in the bore of the adaptor immediately above the adaptor insulator. Smooth the putty out so that it does not protrude inboard of the port in the insulator.

Clean and inspect a 2-473 O-ring. Lubricate lightly with MIL-G-4343 and install in the groove on the adaptor.

Install three eyebolts (5/8-11) in the nozzle flange. Attach a three-legged sling with triangular spreader, i.e., C10300, and test lift the nozzle. Level as required. Keep the sling lines clear of the exit cone. Dress the instrumentation cables up and tape them temporarily. Lower the nozzle into the adaptor. Install 24 1-1/2-12 capscrews with washers. Remove the sling and eyebolts. Torque the 1-1/2-in. capscrews to 1,000 to 1,100 ft-lb in three passes: 300 to 350 ft-lb, 700 to 750 ft-lb, and 1,000 to 1,100 ft-lb. Number the bolts 1 through 24 and torque in the following sequence: 1, 13, 7, 19, 4, 16, 10, 22, 2, 14, 8, 20, 5, 17, 11, 23, 3, 15, 9, 21, 6, 18, 12, 24.

Insulation

Abrade the nozzle flange and outboard to the face of the aft closure. Solvent-wipe with perchloroethane or equivalent.

Dress the instrumentation wires in two or three bundles to fit the channels of the heat shield. Fit-check the heat shield to the closure and wires. Remove the heat shield. Tape the wires in place with adhesive tape.

Coat the area from inside of the nozzle flange to the aft face of the aft closure with a 1/2-in. minimum thickness of DC93-058 silicone rubber. Check by template that the rubber will not interfere with the heat sheild. Lower the heat sheild into place and install the 20 each 1/2-20 bolts with washers. Torque to 70 to 90 ft-lb. Coat the bolts with 1-1/2 inches zinc chromate putty.

Igniter

Check and install the igniter per standard CHAR procedures.