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STUDY OF MONOPROPELLANTS FOR ELECTROTHERMAL THRUSTERS

DESIGN AND FABRICATION TASK SUMMARY REPORT

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One Space Park
Redondo Beach, Calif. 90278

JANUARY 1974

INTERIM REPORT

FOR PERIOD MAY - JULY 1973

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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Prepared under the direction of C. K. Murch, Program Manager

16. Abstract

The objective of the "Study of Monopropellants for Electrothermal Thrusters" program is to determine the feasibility of operating small thrust level electrothermal thrusters with monopropellants other than MIL-grade hydrazine. The work scope includes analytical study, design and fabrication of demonstration thrusters, and an evaluation test program wherein monopropellants with freezing points lower than MIL-grade hydrazine are evaluated and characterized to determine their applicability to electrothermal thrusters for spacecraft attitude control.

Five demonstration thrusters were fabricated to determine the feasibility of operation with monomethylhydrazine, Aerozine-50, 77 percent hydrazine-23 percent hydrazine azide, and TRW formulated mixture of hydrazine monopropellants (MHM) consisting of 35 percent hydrazine-50 percent monomethylhydrazine-15 percent ammonia. The thruster design was based on the Electrothermal Hydrazine Thruster (EHT) developed by TRW for NASA/GSFC on NASA Contract No. NAS5-11477[1]. The present thruster is designed to produce a steady-state thrust level of 0.344 N at 1.724×10^6 N/m^2 feed pressure. Vacuum specific impulse goals were set at 1961 N-s/kg steady-state and 1716 N-s/kg pulsed-mode (0.050 second to steady state)

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PREFACE

The objective of the "Study of Monopropellants for Electrothermal Thrusters" program is to determine the feasibility of operating small thrust level electrothermal thrusters with monopropellants other than MIL-grade hydrazine. The work scope includes analytical study, design and fabrication of demonstration thrusters, and an evaluation test program wherein monopropellants with freezing points lower than MIL-grade hydrazine are evaluated and characterized to determine their applicability to electrothermal thrusters for spacecraft attitude control.

Five demonstration thrusters were fabricated to determine the feasibility of operation with monomethylhydrazine, Aerozine-50, 77 percent hydrazine-23 percent hydrazine azide, and TRW formulated mixture of hydrazine monopropellants (MHM) consisting of 35 percent hydrazine-50 percent monomethylhydrazine-15 percent ammonia. The thruster design was based on the Electrothermal Hydrazine Thruster (EHT) developed by TRW for NASA/GSFC on NASA contract number NAS5-11477[1]. The present thruster is designed to produce a steady-state thrust level of 0.344 N at 1.724×10^6 N/m^2 feed pressure. Vacuum specific impulse goals were set at 1961 N-s/kg steady-state and 1716 N-s/kg pulsed-mode (0.050 second to steady state).

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LIST OF FIGURES

1.0 INTRODUCTION

This report summarizes the design and fabrication of demonstration thrusters in support of the "Study of Monopropellants for Electrothermal Thrusters" program. The design requirements, design rationale and fabrication methods are included in this report.

2.0 DESIGN

2.1 DESIGN OBJECTIVES

The thruster design was based on the Electrothermal Hydrazine Thruster (EHT) developed by TRW for NASA/GSFC on NASA Contract No. NAS5-11477. The upgraded design and performance requirements are listed below.

1. Thrust: 0.344 ± 0.0267N at 1.724 MN/m^2 nominal feed pressure
2. Vacuum specific impulse: 1961 N-s/kg steady state
   (goals) 1716 N-s/kg pulsed-mode
3. Pulse duration: 0.050 second to steady state
4. Pulse mode duty cycle: that typical for attitude control including "wheel dump"
5. Holding power: 5 watts maximum
6. Nominal voltage: 24 to 32 vdc
7. Maximum steady state on-time: 30 hours
8. Total number of pulses: 3×10^5
9. Weight: to be determined
10. Size: to be determined

The specific impulse values have been designated as program goals rather than a firm requirement.

2.2 DESCRIPTION OF DESIGN

The original electrothermal hydrazine thruster (EHT) upon which the present thruster is based is shown in Figure 1. The EHT design was modified by replacing the braze joint between the thrust chamber and nozzle with a threaded screen pack sleeve arrangement. This design, as illustrated in Figure 2, provides significant cost savings in thruster fabrication and will greatly implement performance optimization during the Evaluation Test Program. The design provides for

1. Component interchangeability
2. Changes in screen pack geometry
3. Changes in characteristic chamber length, L*, by varying the screen pack length or nozzle section length, or both
4. Nondestructive inspection, analysis, and cleaning of internal thruster components.

The additional thrust chamber and nozzle block mass associated with the threaded design will reduce the thruster's performance somewhat and increase the times required to reach holding and steady-state temperatures. These losses will be small and will not significantly affect the performance characterization tests performed in this feasibility study.

2.3 THRUSTER COMPONENTS

The thruster solenoid valve to be used during the Evaluation Test Program is the Wright Components, Inc. Model No. 15650 valve. This valve was successfully used on NASA/GSFC contract No. NAS5-11477. The injector-to-valve seal is accomplished by a Teflon compression sleeve.

Two 10.2 cm long by 0.114 cm diameter sheathed Aerorod heater elements are used to heat the thrust chamber and nozzle. These heater elements are sized to maintain holding temperatures in excess of 540°C for sea-level operation during portions of the Evaluation Test Program phase. Thruster insulation is provided by wrapping layers of Microquartz felt around the thrust chamber.

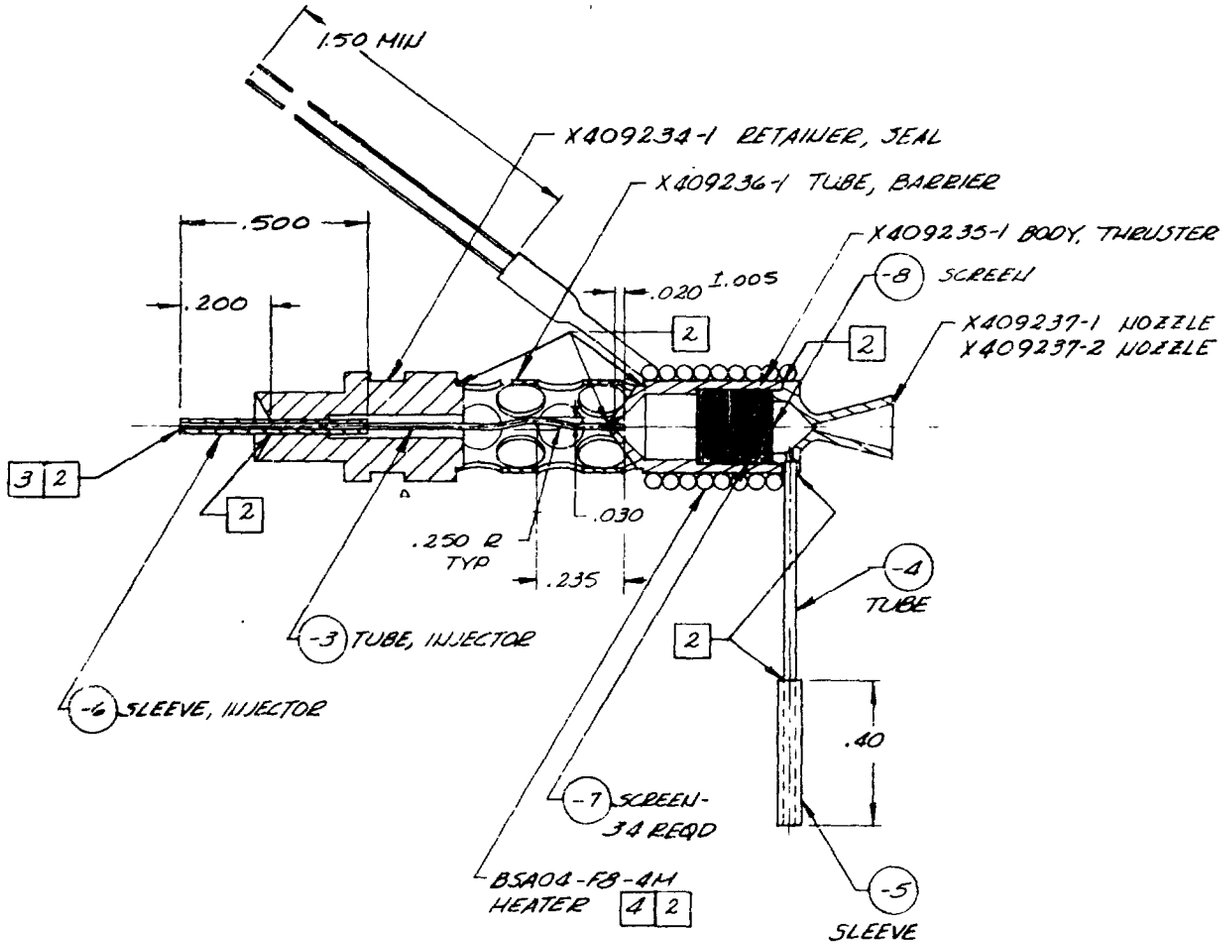

Figure 1. Electrothermal Hydrazine Thruster

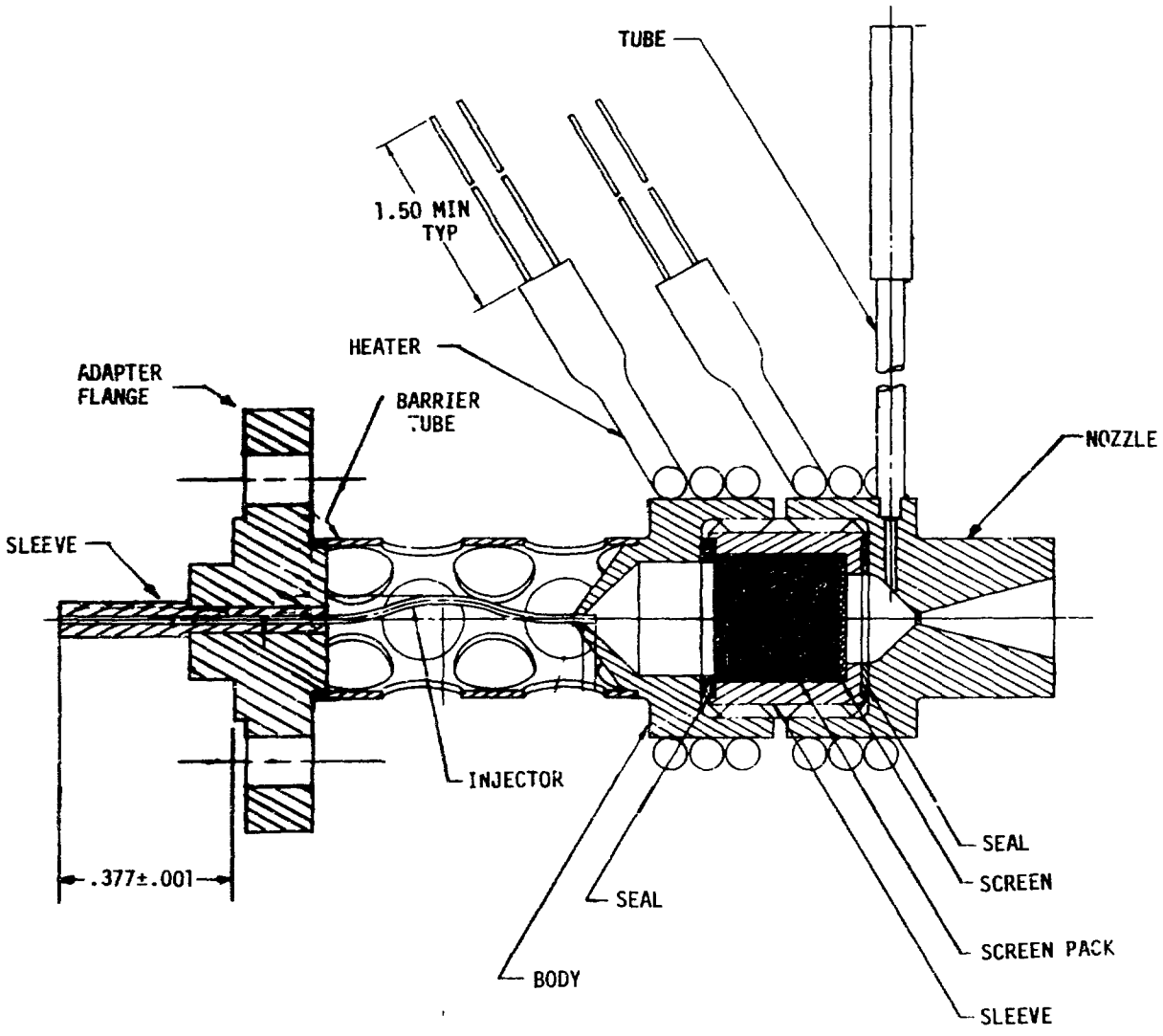

Figure 2. Monopropellant Demonstration Thruster

The nozzle is of standard convergent-divergent design with an area ratio of 50. The throat diameter is 0.046 cm. The screen pack sleeve is sized to accept 0.51 cm diameter platinum screens. The initial s[illegible] length is 0.51 cm. The chamber head end has a 90° included angle a[illegible] a tapered wall thickness to limit heat transfer to the injector. The thrust chamber - screen pack - nozzle seals are of thin h[illegible]rdened copper.

The thruster is mated to the Wright Components, Inc. valves through a 0.025 cm thick thermal barrier tube and adapter flange.

Engineering drawings for the various demonstration thruster components are included in Appendix A.

3.0 FABRICATION

3.1 THRUSTER COMPONENTS

The fabricated components for five thrusters are shown in Figure 3. Included are the nozzle, screen pack sleeve, body, barrier tube, valve adapter flange and gasket seals. An assembled but not brazed view of the demonstration thruster configuration is presented in Figure 4. The injector tube and two heating elements are missing from Figure 4. All parts were fabricated from Haynes alloy L605 (Haynes 25) with the exception of the adapter flange (Type 304 stainless steel) and the gasket seals (No. 102 copper).

The injector tubes were fabricated from Haynes 25 tubing (0.0356 cm OD by 0.0152 cm ID). All injectors were built with a thermal relief bend rather than a complete loop. The chamber end of the injector was trimmed square and deburred on a jeweler's lathe.

The heater elements were wound in one layer on a mandrel slightly smaller than the outer diameter of the thruster body.

The screen packs were fabricated from 52 mesh platinum gauze and 40 mesh Haynes 25. The platinum screens (60) were punched and pre-compressed by the tooling shown in Figure 5. A single Haynes 25 screen was used as a

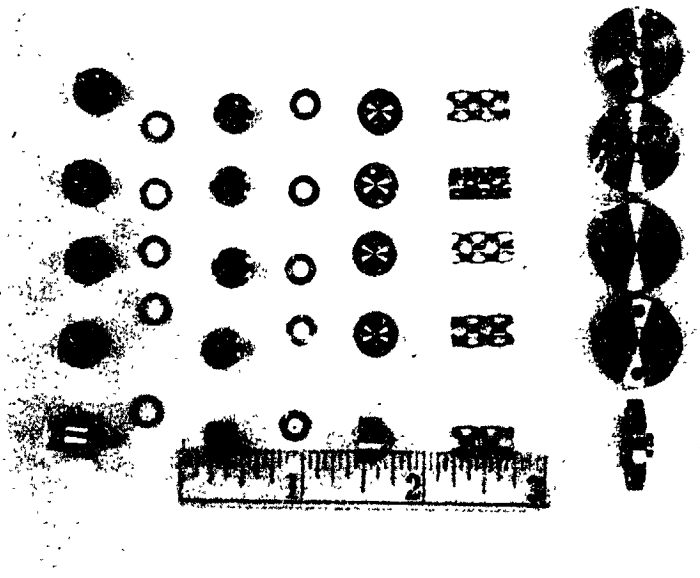

Figure 3. Demonstration Thruster Components

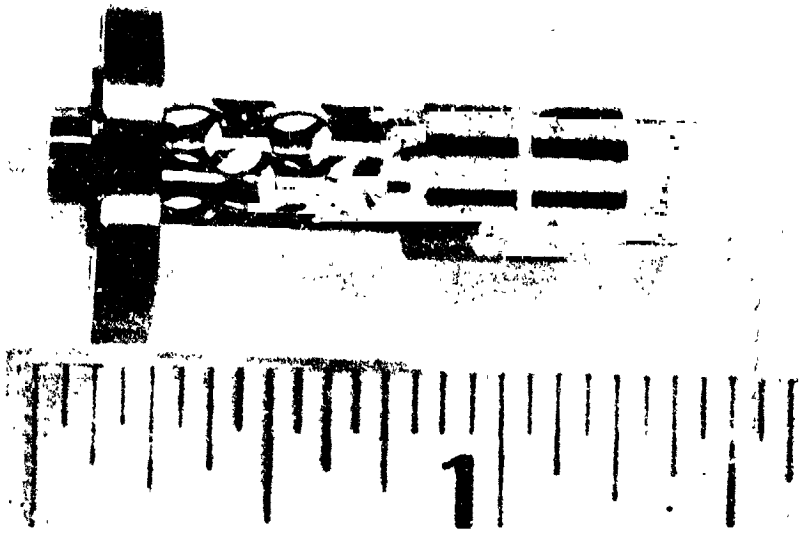

Figure 4. Demonstration Thruster Configuration

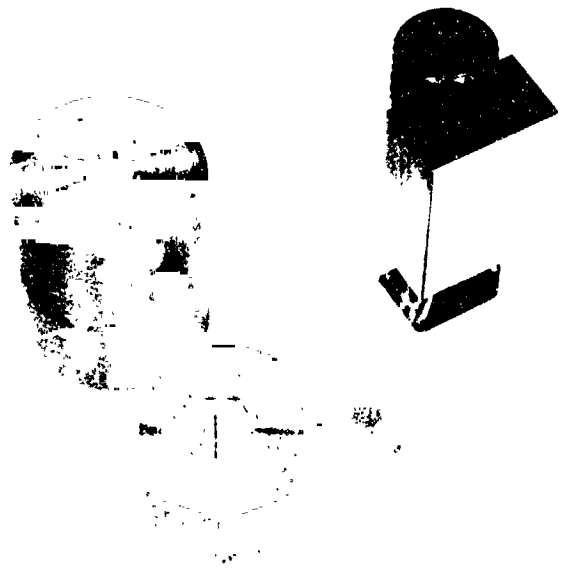

Figure 5. Screen Forming Tooling

retainer for the platinum screen pack. The Haynes 25 retainer was inserted into the screen pack sleeve towards the nozzle end of the thruster. The compacted platinum screen pack was then transferred directly from the compression die into the sleeve.

The split-chamber design allowed the thruster to be assembled in one high-temperature braze cycle. Nicrobraze alloy 21C was used for the entire assembly. A brazed thruster is shown in Figures 6 and 7 as dissassembled and assembled views.

4.0 NEW TECHNOLOGY

The modular design of the monopropellant demonstration thruster described in Section 2.2 of this report has resulted in substantial fabrication cost savings and will enhance technical efforts during the Evaluation Test Program phase. The design is novel in electrothermal hydrazine thruster technology.

5.0 PROGRAM FOR THE EVALUATION TEST TASK

A detailed plan for the Evaluation Test Task of the Study of Monopropellants for Electrothermal Thrusters was submitted as Appendix B of the Analytical Task Summary Report[2].

6.0 CONCLUSIONS

The fabricated thruster assemblies will allow the rapid evaluation and characterization of monopropellants with freezing points lower than MIL-grade hydrazine. The design permits changes in the internal thrust chamber geometry in order to accommodate the different combustion characteristics of the monopropellants to be used during the Evaluation Test Task of this program.

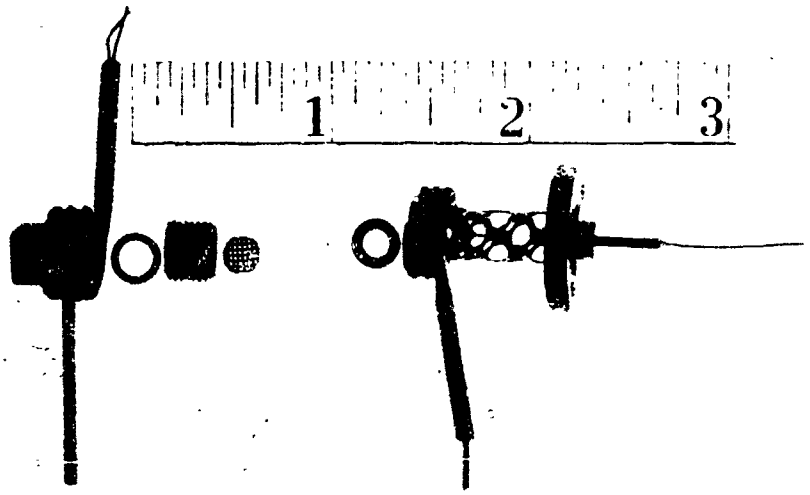

Figure 6. Disassembled Demonstration Thruster

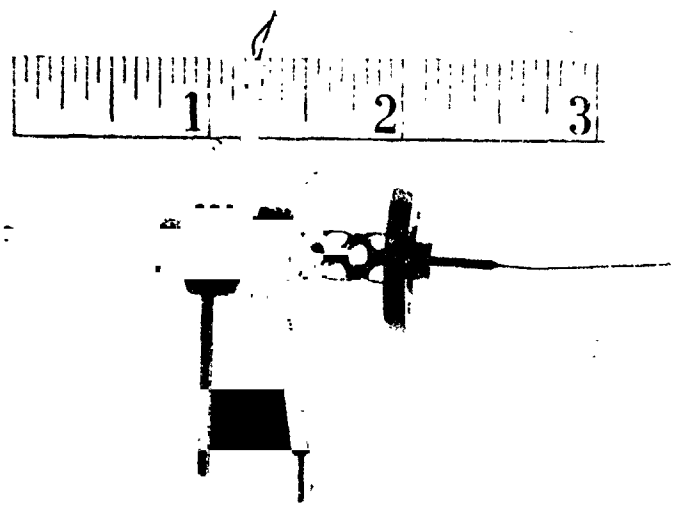

Figure 7. Assembled Demonstration Thruster

7.0 REFERENCES

1. Monopropellant Hydrazine Resistojet, Engineering Model Fabrication and Test Task Summary Report, TRW Document 20266-6024-RO-00, March 1973.

2. J. D. Kuenzly and Rein Grabbi, Study of Monopropellants for Electrothermal Thrusters, Analytical Task Summary Report, TRW Document 22409-6010-RU-00, December 1973.

APPENDIX A

A complete set of monopropellant demonstration thruster drawings is included in this appendix.

(1)	Gasket	X412586-1
(1)	Gasket-Screen Pack	X412582-1
(1)	Body, Monopropellant Demonstration Thruster	X412581-1
(1)	Sleeve-Threaded, Monopropellant Demonstration Thruster	X412579-1
(1)	Nozzle, Monopropellant Demonstration Thruster	X412578-1
(1)	Tube, Barrier-EHT	X409236-1
(60)	Screen	X412580-15
(1)	Screen	X412580-14
(1)	Sleeve	X412580-13
(1)	Tube	X412580-12
(1)	Tube	X412580-11
(1)	Plate, Seal-EHT	X409383-1
(1)	Seal, Tube-EHT	X410563-1
(1)	Sleeve, Injector	X409240-9

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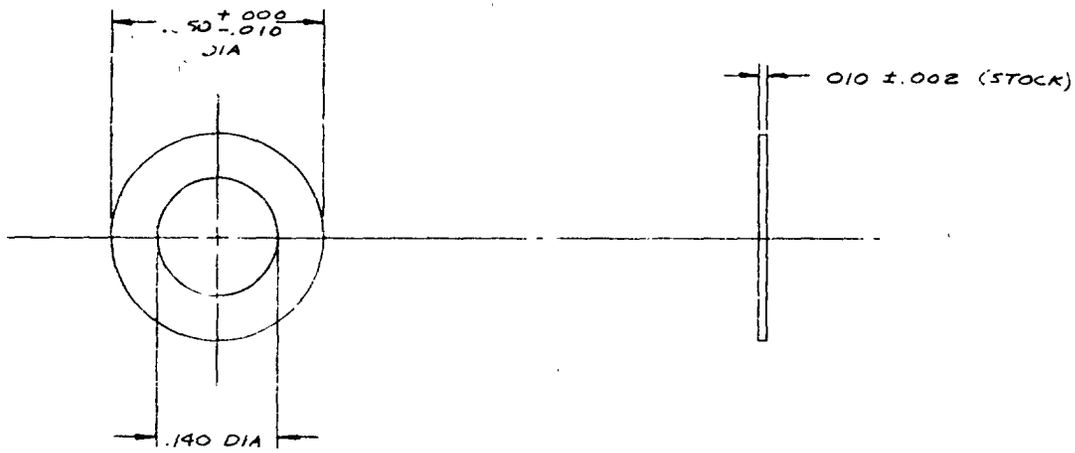

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X412586

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UNDER .514	+.008 -.005	.391 THRU .750	+.005 -.005
.514 THRU .125	+.004 -.004	.751 THRU 1.000	+.008 -.005
.126 THRU .250	+.005 -.004	1.000 THRU 2.000	+.012 -.001
.251 THRU .500	+.006 -.004	OVER 2.000	+.015 -.010

ON DECIMAL DIMENSIONS: .XXX ± .010; .XX ± .05; .X ± .1

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GASKET,

SIZE	CODE IDENT NO.	
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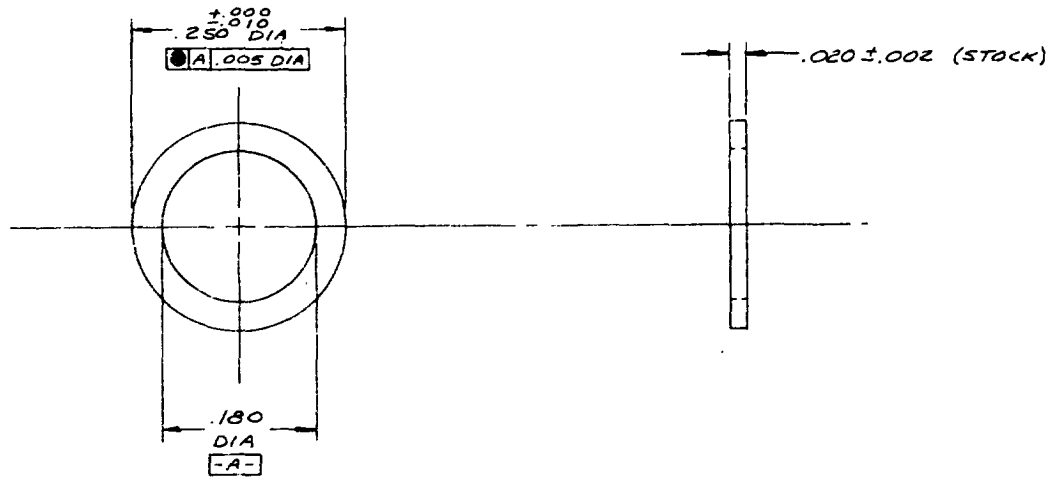

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7. PARENTHETICAL DATA IS FOR REFERENCE ONLY.

TOLERANCES

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ON DECIMAL DIMENSIONS:
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ON ANGULAR DIMENSIONS:
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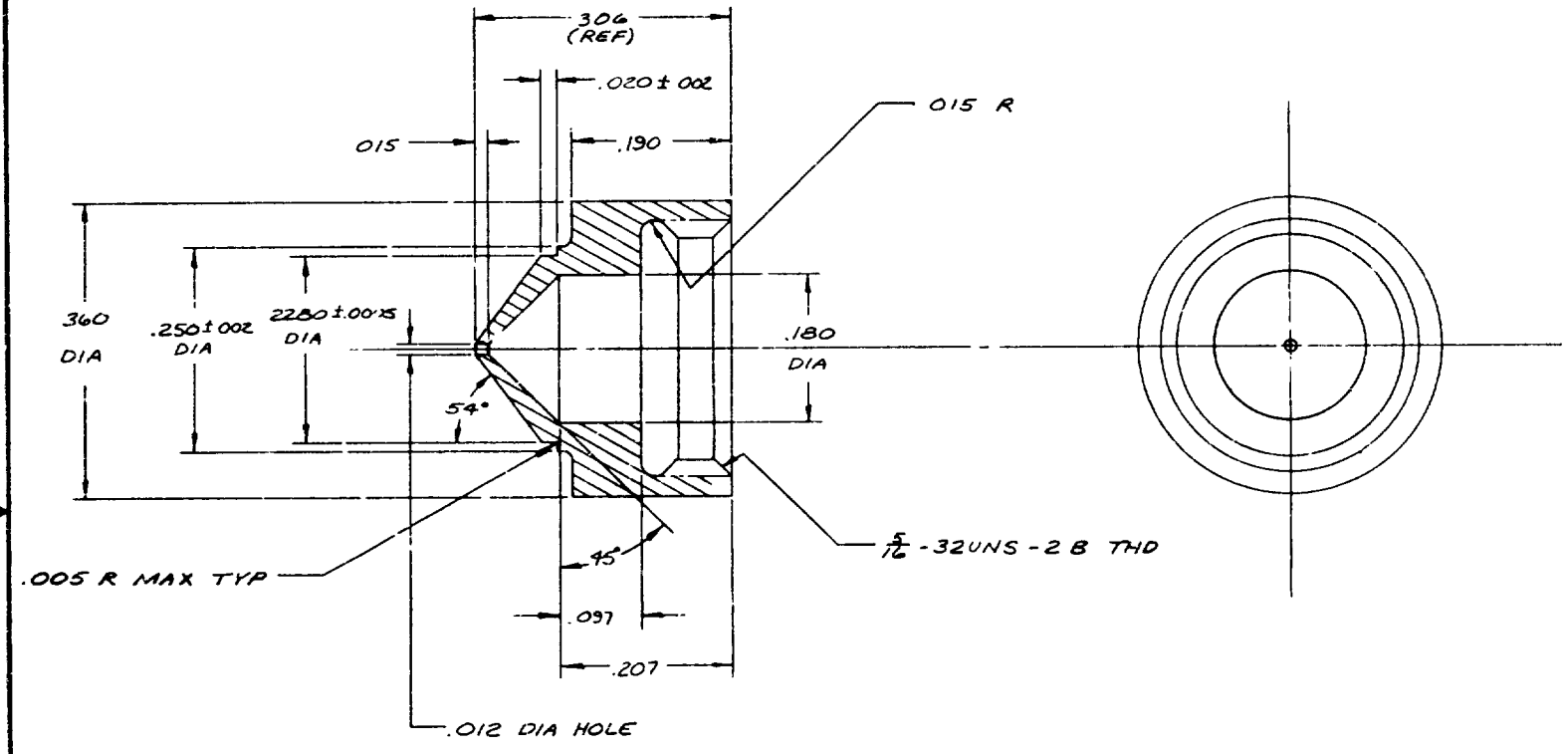

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.251 THRU .500	+.005 −.002	OVER 2.000	+.015 −.002

ON DECIMAL DIMENSIONS: .XXX ± .010; .XX ± .03; .X ± .1

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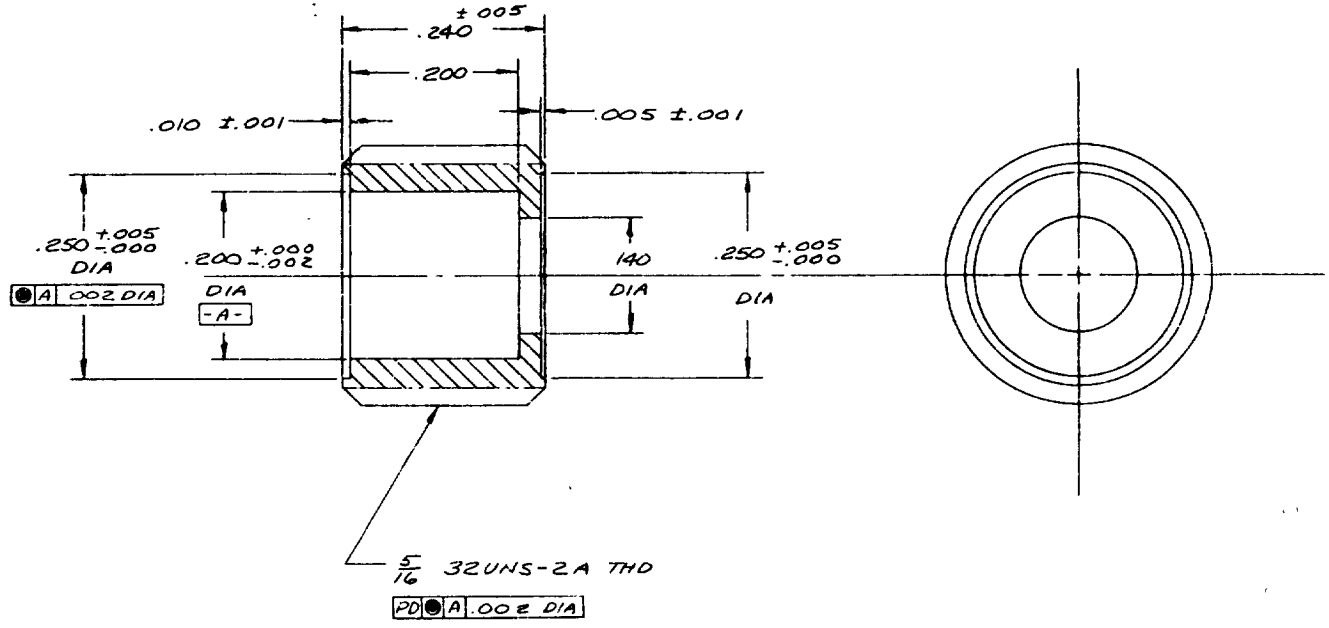

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TOLERANCES

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SLEEVE - THREADED, MONOPROPELLANT DEMONSTRATION THRUSTER

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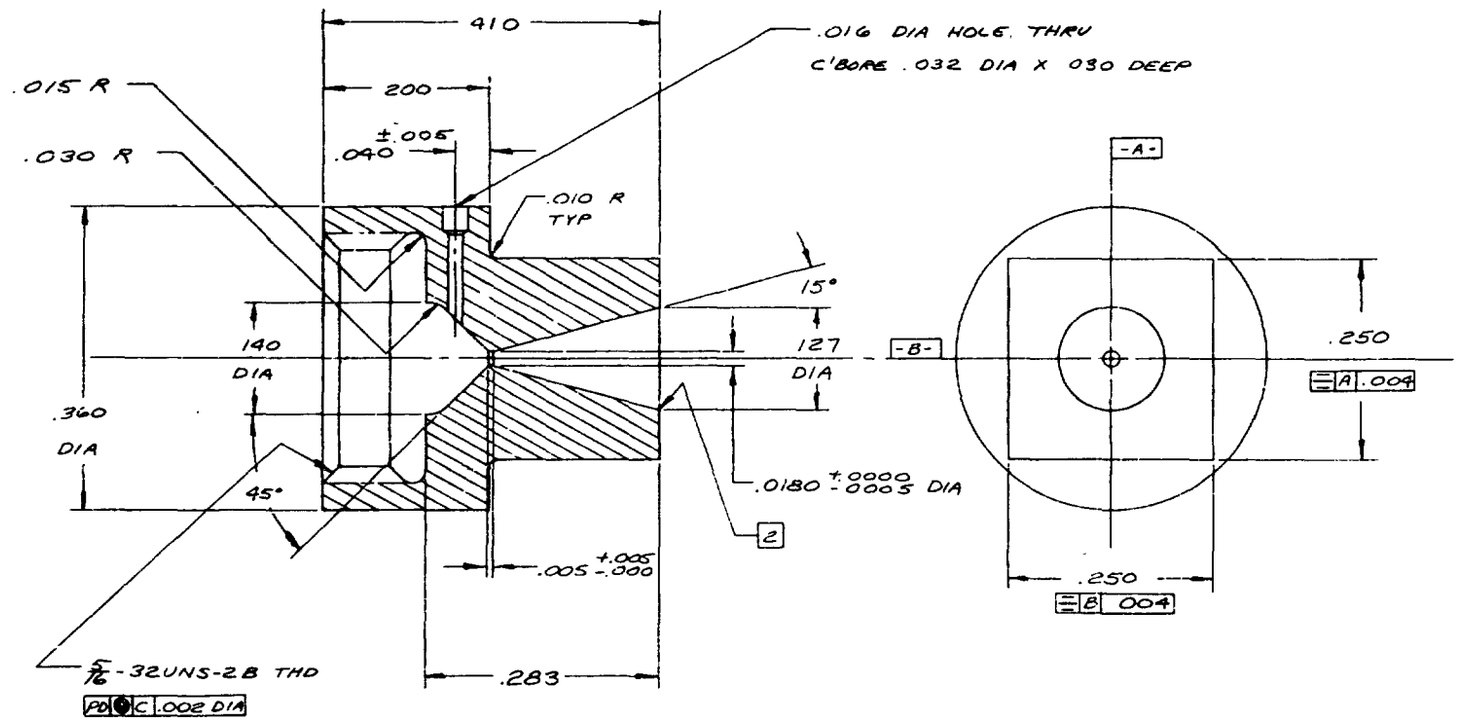

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6. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
7. PARENTHETICAL DATA IS FOR REFERENCE ONLY.

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LOCATING ± 0°30'
FORMED ± 2°
CHAMFERS ± 5°

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NOZZLE - MONOPROPELLANT DEMONSTRATION THRUSTER

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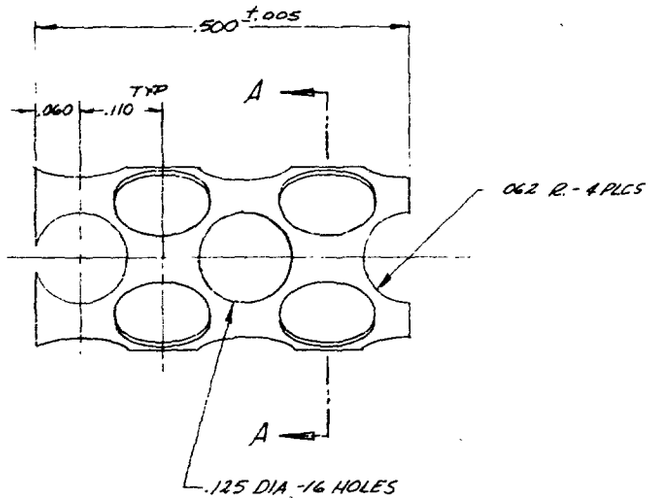
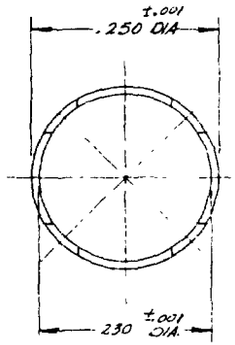
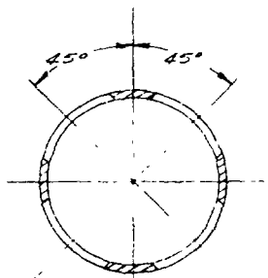
X412578

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED







SECT A-A

X409236

CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
	-1	TUBE, BARRIER	L-605 (HAYNES 25) BAR	AMS 5759		

PARTS LIST

QTY REQD PER ASSY CONFIGURATION

FINISH

HEAT TREAT

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES
3. SURFACE TEXTURE SHALL BE 125/
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA.	FROM	THRU	TOL.
TOLERANCES ON DECIMAL DIMENSIONS:	UNDER	.040	+.003 -.000
.XXX ± .005	.040	.125	+.004 -.000
.XX ± .02	.125	.250	+.005 -.000
.X ± .1	.251	.500	+.005 -.000
TOLERANCES ON ANGULAR DIMENSIONS: MACHINED & LOCATING ± 0°30' FORMED ± 1° CHAMFERS ± 5°	.501	.750	+.006 -.000
	.751	1.000	+.007 -.000
	1.001	2.000	+.012 -.000
	OVER	2.001	+.015 -.000

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	J. UGERSOU	12 DEC 1991
CHECKED		
STRUCTURES		
MAT'L & PROCESS		
CLASS	C.R. Hunter	2/22/93
SUPERVISOR	C.L. Hurst	4/23/93
OTHER APPROVALS		

THE FOLLOWING ECO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

TUBE, BARRIER - EHT

SIZE	CODE IDENT NO.	
C	11982	X409236

SCALE 1/1 SHEET

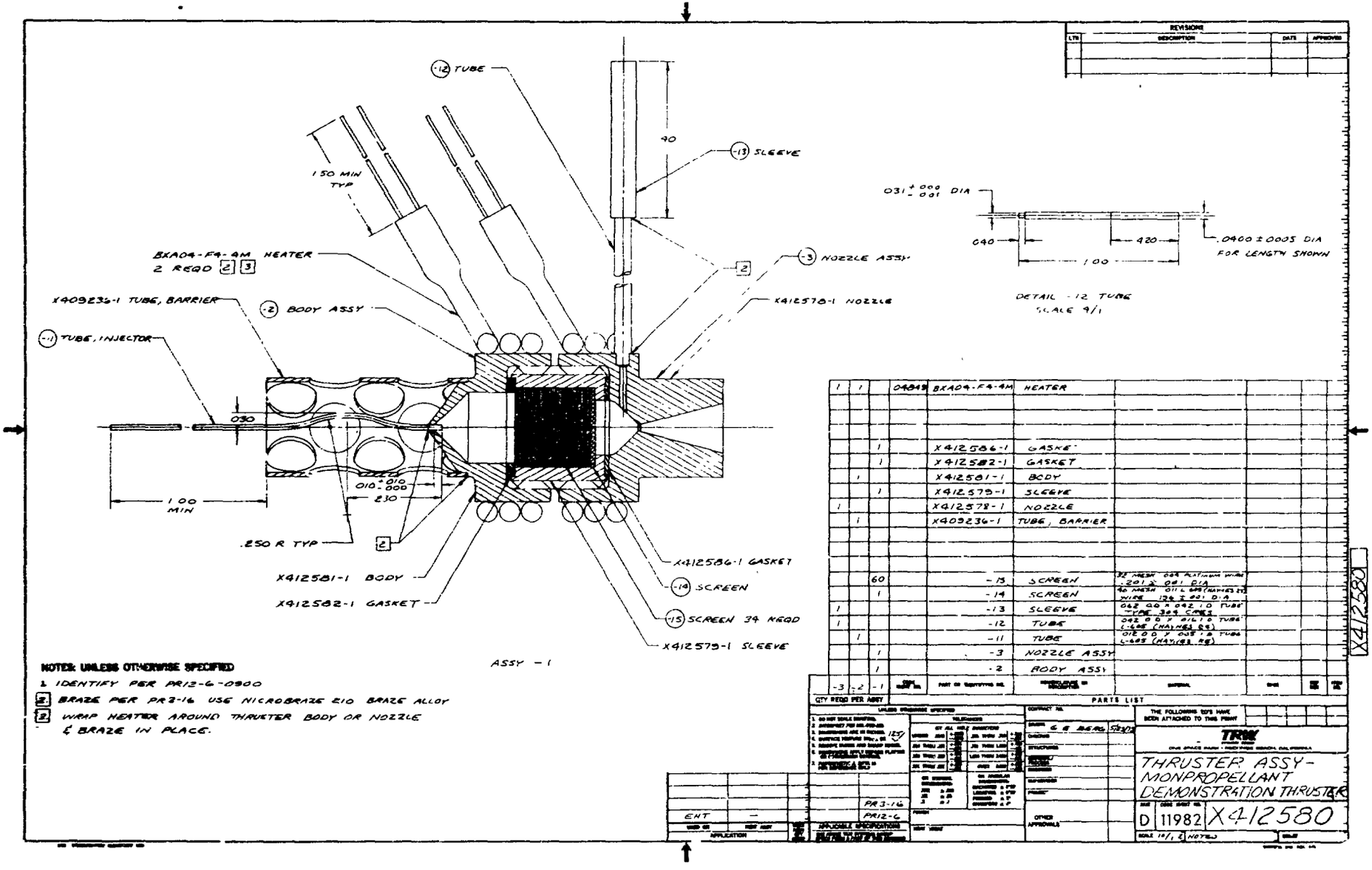
1. IDENTIFICATION MARKING PER PR 12-6-0900
TYPE _____ CLASS _____
PART NUMBER _____

NOTE: UNLESS OTHERWISE SPECIFIED

USED ON	NEXT ASSY	NEXT ASSY QTY REQD
EHT	X409240	1(-1)
APPLICATION		

APPLICABLE SPECIFICATIONS
THE BRUNSWICK SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

12-6



REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

QTY REQD PER ASSY								
-3	-2	-1						
1	1		04849	BXA04-F4-4M	HEATER			
		1		X412586-1	GASKET			
		1		X412582-1	GASKET			
	1			X412581-1	BODY			
		1		X412579-1	SLEEVE			
1				X412578-1	NOZZLE			
	1			X409236-1	TUBE, BARRIER			
		60		-13	SCREEN	32 MESH .009 PLATINUM WIRE .201 ± .001 DIA		
		1		-14	SCREEN	40 MESH .011 L .698 (MAYHEW) .172 WIRE .124 ± .001 DIA		
1				-13	SLEEVE	.062 .00 x .042 .10 TUBE -TIME 321 CRES		
1				-12	TUBE	.062 O.D. x .015 I.D. TUBE L.495 (MAYHEW) 64		
	1			-11	TUBE	.012 O.D. x .008 I.D. TUBE L.689 (MAYHEW) 98		
		1		-3	NOZZLE ASSY			
		1		-2	BODY ASSY			

PARTS LIST

NOTES: UNLESS OTHERWISE SPECIFIED

1. IDENTIFY PER PR13-6-0900
2. BRAZE PER PR3-16 USE NICROBRAZE 210 BRAZE ALLOY
3. WRAP HEATER AROUND THRUSTER BODY OR NOZZLE & BRAZE IN PLACE.

ENT	—
APPLICABLE SPECIFICATIONS	PR3-16
	PR12-6

THE FOLLOWING SDS HAVE BEEN ATTACHED TO THIS PRINT

TRW

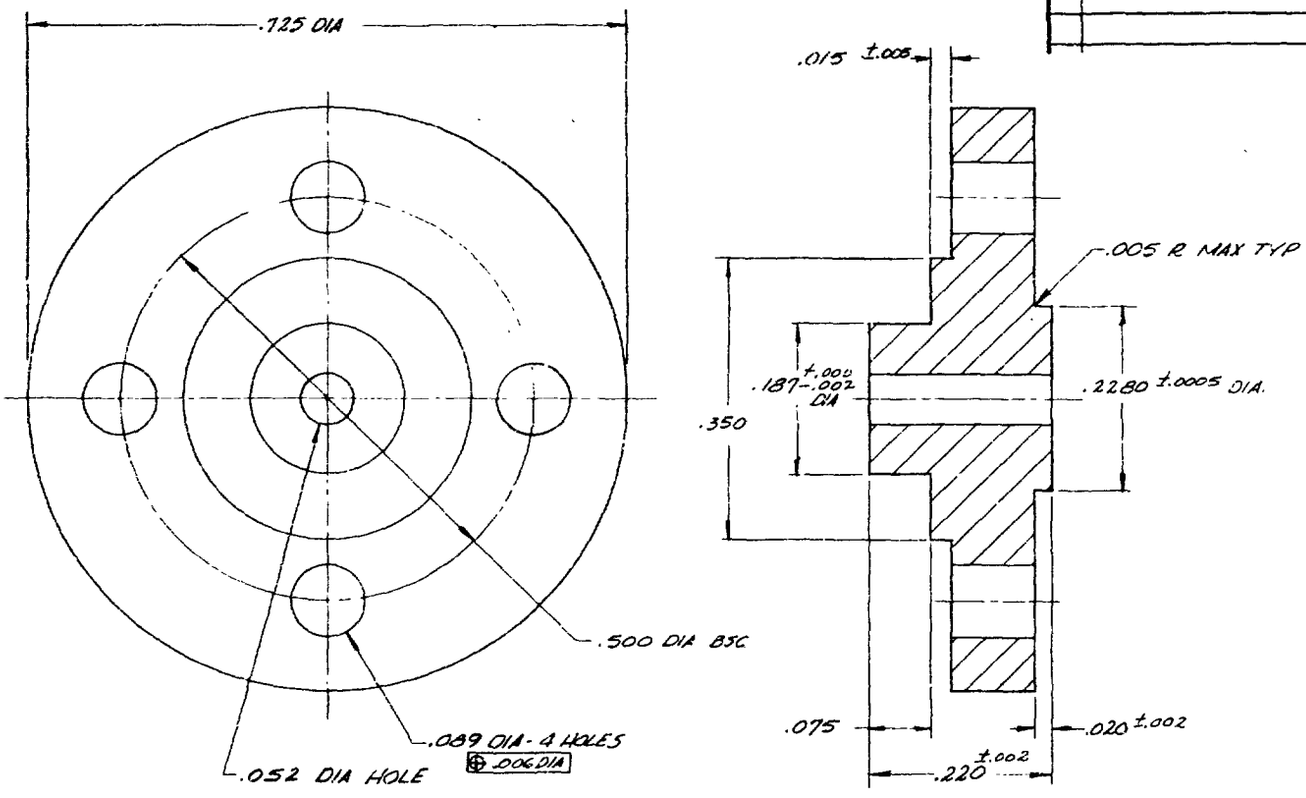
THRUSTER ASSY-MONPROPELLANT DEMONSTRATION THRUSTER

SIZE	CODE IDENT NO.	DRAWING NO.
D	11982	X412580

SCALE 10/1, 2 NOTED

X412580

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



X409383

CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC.	REF DES	ITEM NO.
	-1	SEAL R	TYPE 304 CRES BAR	AMS5759		

PARTS LIST

QTY REQD PER ASSY CONFIGURATION			
EHT	X009240	(-1)	PR 12-6
USED ON	NEXT ASSY		APPLICABLE SPECIFICATIONS
APPLICATION			THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

1. IDENTIFICATION MARKING PER PR 12-6-0900
TYPE _____ CLASS _____
PART NUMBER _____
NOTE: UNLESS OTHERWISE SPECIFIED

FINISH

HEAT TREAT

UNLESS OTHERWISE SPECIFIED
1. INTERPRET PER MIL-STD-100.
2. DIMENSIONS ARE IN INCHES.
3. SURFACE TEXTURE SHALL BE 125/ MAX
4. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.
5. REMOVE BURRS & SHARP EDGES

TOLERANCES - ALL HOLE DIA		
FROM	THRU	TOL.
UNDER .0469		+.0020 -.0000
.0469	.125	+.0050 -.0000
.126	.250	+.0050 -.0000
.251	.500	+.0050 -.0000
.501	.750	+.0050 -.0000
.751	1.000	+.0050 -.0000
1.001	2.000	+.0050 -.0000
OVER 2.000		+.0050 -.0000

TOLERANCES OR DECIMAL DIMENSIONS:
.XXX ± .010
.XX ± .03
.X ± .1

TOLERANCES ON ANGULAR DIMENSIONS:
MACHINED & LOCATING ± 0°30'
FORMED ± 2°
CHAMFERS ± 1°

DO NOT SCALE DRAWING

CONTRACT NO.

DRAWN	J. WINGERSON	21 DEC 1971
CHECKED		
STRUCTURES		
MAT'L & PROC. SPEC		
STRESS		
SUPERVISOR		

OTHER APPROVALS

THE FOLLOWING ECP'S HAVE BEEN ATTACHED TO THIS PRINT

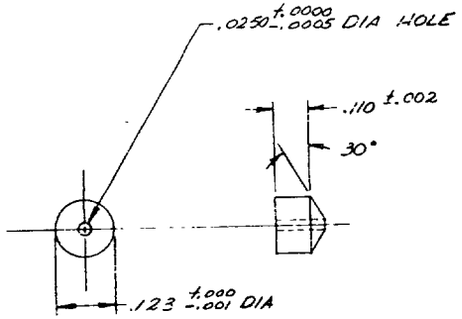
TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

PLATE, SEAL - EHT

SIZE	CODE IDENT NO.	
C	11982	X409383

SCALE 1/1 SHEET

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



X410563

NOTES: UNLESS OTHERWISE SPECIFIED

1. IDENT. MARKING PER DR 12-6-0900

ITEM NO.	QTY REQD PER ASSY	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPEC	RE DES
-1	1		SEAL	TEFLON ROD	MIL R 19468		

PARTS LIST

UNLESS OTHERWISE SPECIFIED

1. DO NOT SCALE DRAWING.
2. INTERPRET PER MIL STD-100.
3. DIMENSIONS ARE IN INCHES. (25)
4. SURFACE TEXTURE SMALL 80
5. REMOVE BURRS AND SHARP EDGES.
6. DIMENS THIS APPLY BEFORE PLATING OR CO CROSION COATING.
7. PARENTHETICAL DATA IS FOR REFERENCE ONLY.

TOLERANCES

ON ALL HOLE DIAMETERS

UNDER .0149	+.0020 −.0005	.501 THRU .750	±.002 −.001
.014 THRU 125	+.004 −.001	.751 THRU 1.000	+.013 −.007
.126 THRU .250	+.005 −.001	1.001 THRU 2.000	+.013 −.001
.251 THRU .500	+.005 −.001	OVER 2.000	+.015 −.005

ON DECIMAL DIMENSIONS
XXX ± .010
XX ± .03
X ± .1

ON ANGULAR DIMENSIONS
MACHINED ± 0°30'
LOCATING ± 0°30'
FORMED ± 2°
CHAMFERS ± 5°

FINISH

HEAT TREAT

CONTRACT NO.

DRAWN	J. WINGERSON	9/5/72
CHECKED		
STRUCTURES		
MATERIAL/ PROCESS		
ENGINEER	[signature]	9/5/72
SUPERVISOR	[signature]	9/5/72
PROJECT		

OTHER APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SEAL, TUBE EHT

SIZE	CODE IDENT NO.	
C	11982	X410563

SCALE NONE SHEET

USED ON	NEXT ASSY	NEXT ASSY QTY REQD
EHT		1(-1)

APPLICATION

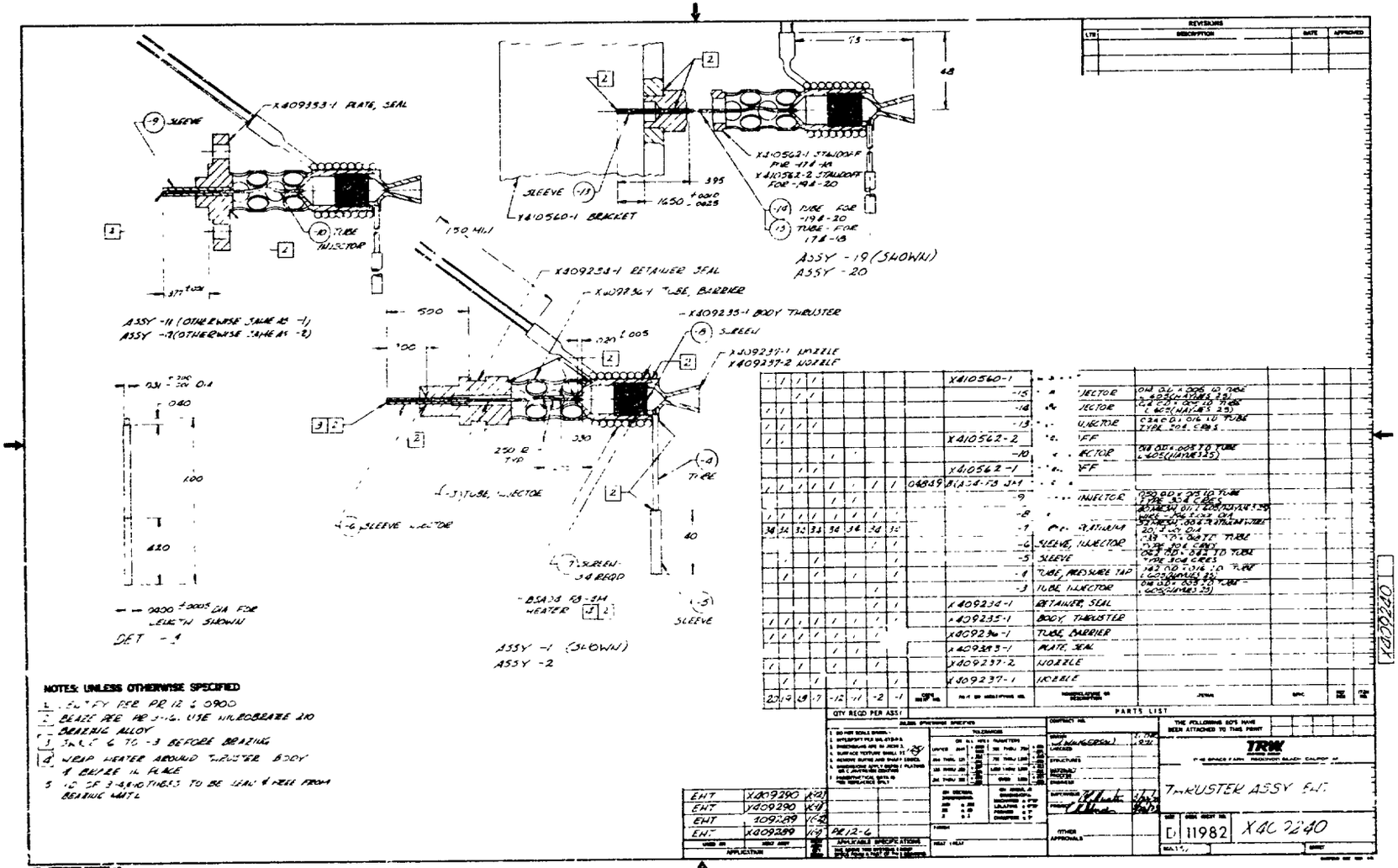
APPLICABLE SPECIFICATIONS

DR 12-6

THE ABOVE TRW SYSTEMS GROUP SPECS FORM A PART OF THIS DRAWING

SYSTEMS 3400 REV 9-71

20


X409393-1 PLATE, SEAL
SLEEVE
TUBE INJECTOR
ASSY -11 (OTHERWISE SAME AS -1)
ASSY -12 (OTHERWISE SAME AS -2)
DET - 1
X410560-1 BRACKET
SLEEVE
X410562-1 STANDOFF FOR -17 & -18
X410562-2 STANDOFF FOR -19 & -20
TUBE FOR -19 & -20
TUBE FOR -17 & -18
ASSY -19 (SHOWN)
ASSY -20
X409234-1 RETAINER SEAL
X409236-1 TUBE, BARRIER
X409235-1 BODY THRUSTER
SCREEN
X409237-1 NOZZLE
X409237-2 NOZZLE
TUBE, INJECTOR
SLEEVE INJECTOR
SCREEN 34 REQD
BRAZE FOR HEATER
SLEEVE
ASSY -1 (SHOWN)
ASSY -2
REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
NOTES: UNLESS OTHERWISE SPECIFIED
1. ELTFY PER PR 12-6 0900
2. BRAZE PER PD 3-16. USE NICROBRAZE 210
3. BRAZING ALLOY
4. JOIN 6 TO -3 BEFORE BRAZING
5. WRAP HEATER AROUND THRUSTER BODY 4 BRAZE IN PLACE
6. ID OF 3 & 4 TO BE CLEAN & FREE FROM BRAZING MATL
PARTS LIST
QTY REQD PER ASSY
DRAWING
TRW
THRUSTER ASSY E.M.
SIZE
D
CAGE IDENT NO.
11982
X40 2240
SHEET
EHT X409290 X21
EHT Y409290 Y21
EHT 409289 169
EHT X409289 169
PR 12-6
USED ON
APPLICATION
NEXT ASSY