Chart Industries, Inc. PROCESS SYSTEMS DIVISION

WESTBOROUGH, MA 01581					ENGINEERING	NO: V095-1-005
THERMAL / VACUUM TECHNOLOGY GROUP					CALCULATIONS	Page 1 of 4
REV	DEO#	DATE	BY:	CHECK	TITLE: **Structural Design Criteria**	
0		02/29/00	RDC	DMcW		
1		4/14/00	RDC	DMcW		
2	0029	3/19/01	RDC	DMcW		
					BY: R. D. Ciatto	DEPT: C/S
PROJECT: SOFIA MIRROR COATER NASA AMES					PROJECT NO: V59095	

PURPOSE: Establish structural design criteria.

METHOD: Review NASA Statement of Work and extract applicable requirements.

ASSUMPTIONS: N/A

INPUTS: N/A

REFERENCE: RFO-37014, SOW, 10/4/99, Statement of Work

CALCULATIONS:

see Attachments

CONCLUSIONS: The Structural Design Criteria conforms to project requirements.

NOTES:

Revision History

Rev.	Comments	Date
0	Initial Issue	March, 2000
1	Change allowable stress per client comments. Changed Viton to Buna	April, 2000
2	Include requirement for positive pressure.	March, 2001

SOFIA VACUUM VESSEL
STRUCTURAL DESIGN CRITERIA

Design Code for Vessel: ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1, 1998 Edition through 1999 Addenda.

Design Code for Support Legs, Head Support Frame and Platform: AISC Manual of Steel Construction, Allowable Stress Design, Ninth Edition.

Internal Vacuum = -14.7 psig

Positive Internal Pressure = 0.10 psig for vacuum chamber. This is the design pressure per UG-21 of the ASME Code.

Design Temperature = 70° F. Assumed environmental temperature ranges from -20°F to 100°F

Mechanical Loads:

Weight
Unbalanced Vacuum Loads - N/A for vessel design

Seismic Acceleration: Per Uniform Building Code, UBC-94.

Seismic Zone: 4
Importance Factor: 1.0

Shipping Acceleration

Vertical Accel = 1G
Horizontal Accel = .5G

Pressure Boundary Material = ASTM SA240, Type 304 stainless steel for shells, heads, nozzles and shell attachments (brackets) for primary mirror assembly. Other specification numbers and product forms of Type 304 may be used for miscellaneous pressure parts. External reinforcing pads shall be A516 Gr 70 carbon steel plate.

Structural Steel for Head Support Legs and Platform: ASTM A36 shapes and plate and/or A500 Gr B tube steel.

Platform Live Load: 488 kg/m^2 = 100 psf

Vacuum Vessel Basic Stress Limits (Section VIII, Div. 1):

Type 304 ss

Design Condition
S = 20.0 ksi at 70° F for membrane stress
1.5S = 30.0 ksi at 70° F for membrane + bending stress

Design + Seismic Condition
1.2S = 24.0 ksi at 70° F for membrane stress
1.2(1.5S) = 36.0 ksi at 70° F for membrane + bending stress

WRC 107 Local Stress Limits for Primary Mirror Assembly Shell Attachments to Vessel

Type 304

Design Condition
1.5 S = 30.0 ksi at 70°F for primary membrane + primary bending stress.
3.0 S = 60.0 ksi at 70°F for combined primary + secondary stress.

Design + Seismic Condition
1.2(1.5S) = 36.0 ksi at 70° F for primary membrane + primary bending stress.

O-Ring Seal Material: Buna (1/2 in.)

Stress Limits for Supports: See AISC Code for allowable stresses.

Allowable base plate pressure on concrete foundation: 1500 psi for normal load condition.

Chart Industries, Inc. PROCESS SYSTEMS DIVISION

WESTBOROUGH, MA 01581					ENGINEERING	NO: V095-1-009
THERMAL / VACUUM TECHNOLOGY GROUP					CALCULATIONS	Page 1 of 12
REV	DEO#	DATE	BY:	CHECK	TITLE:	
0	0002	4/24/00	RDC	DMcW		
1	0009		RDC		**Chamber Support Legs**	
2						
					BY: R. D. Ciatto	DEPT: 744
PROJECT: SOFIA MIRROR COATER NASA AMES					PROJECT NO: V59095	

PURPOSE: Design chamber support legs in accordance with structural design criteria (SDC).
Ensure that legs meet requirements for weight, including 5000 lb. mirror assembly and UBC-94 seismic loads.

METHOD: A Chart Industries proprietary spread sheet computer program is used to implement code design rules and compute local compressive stresses at top of support legs.

ASSUMPTIONS: N/A

INPUTS: Internal vacuum = -14.7 psig. Positive internal pressure = 0 psig.
Design temperature = 100°F for allowable stress.
Weights from V095-1-006, Pressure Boundary

REFERENCE: V095-1-005, Structural Design Criteria.
Dwg. V095-5-200, sheet 2, Vacuum Vessel Details.

CALCULATIONS:

see Attachments.

CONCLUSIONS: The chamber support legs conform to project requirements.
Chamber dimensions preclude overturning during an earthquake and anchors are not subjected to tension.
Therefore, anchors were selected for horizontal shear only. Two Hilti Kwik Bolt II expansion anchors (1 in. ϕ x 4 ½ embedment) will be used at each support leg.

NOTES: The program uses UBC-97 for seismic design. The resulting seismic acceleration is greater than that required by UBC-94. Output attached includes empty weight with top head attached; the load case with the head removed was also run and the results are the same.

Revision History

Rev.	Comments	Date
0	Initial Issue	April, 2000
1	Complete revision incorporating new dimensions.	September, 00
2	Primary punching shear stress in head at top of leg included, p. 3 10 & 11.	April, 01

Seismic Design Acceleration

Per UBC-94, Par. 1630,

Fp = Z Ip Cp Wp

Z = .40 for Zone 4	(Table 16-I)
Ip = 1.00	(Table 16-K)
Cp = .75	(Table 16-O)

Per Par 1630.20, Cp is doubled for a non-rigid structure, i. e. period, T > .06 sec. Assume T > .06 sec.

=> Cp = 1.50

Fp = .40 x 1.00 x 1.5 Wp
= .60 Wp

But, equipment is laterally self-supporting at ground level.

=> Cp = 2/3 x 1.5 = 1.00

Fp = .40 Wp

Check Par. 1632

V = Z I C W/Rw (par. 1628)

C = 2.75	(max. value)
Rw = 3	(min. value)

V = .4 (1.00) (2.75) W/3
= .37W < .40 W

∴ Use Fp = .40 W

Lateral seismic acceleration is .40G.

Note: The Chart spreadsheet program utilizes UBC-97 and uses an acceleration factor of .44G.

Only primary stresses are evaluated for earthquake loads. This ensures that structural integrity is maintained. The earthquake bending moments at the top of the support legs are evaluated for primary stress in the head. Resulting stresses are secondary except for the direct punching shear stress, which is evaluated on page 10 and 11. Section VIII, Div. 1, which is a thickness code, does not require evaluation of secondary stress. Secondary stresses resulting from seismic events will cause some plastic straining that will act to absorb earthquake energy.

Vessel Weights

Vessel full w/ mirror and top head:	32822 lb.	(V095-1-006)
Subtract top head:	5283	(V095-1-008)
Subtract mirror assembly	5000	
	=====	
Vessel empty	22539 lb.	

Review of Dwg. V095-5-200, Sheet 1, shows that the mirror assembly C. G. is located at about 2/3 of the height of the vessel. Since the spreadsheet program assumes that all weight is at the 2/3 elevation, it will give a conservative result for overturning due to lateral seismic acceleration.

Vessel Anchors

From the following output, there is no uplift on anchors. Select Hilti Kwik Bolt II, 1” diam. with 4 ½” embedment.

Max shear force $V_{max} = 3.47$ k

$< V_{all} = 8.1$ k

PROGRAM NAME "LEG20300.WK3" (SHEET B), RESULTS OF VERTICAL TANK JACKET, LEG AND BOLT DESIGN PROGRAM. (FOR VERTICAL TANKS TO 1997 UBC)

THIS CALCULATION INCORPORATES PORTIONS OF THE FOLLOWING CODES......

1. ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIV 1, 1998 EDITION

2. UNIFORM BUILDING CODE, 1997 EDITION

3. AISC MANUAL OF STEEL CONSTRUCTION, NINTH EDITION, 1989.

GENERAL INPUT DATA.. 1997 UBC

TANK ID NUMBER		N/A		
WT full	Wtf	32.80	(KIPS)	
WT empty (KIPS)	Wte	22.50	(KIPS)	
OVERALL TANK HT	Ht	15.700	(FT)	
BASE TO TK BTTM	Hb	0.08	(FT)	
DIAMETER OF TK	Dtnk	13.250	(FT)	
JACKET THICKNESS	Tjct	0.625	(IN)	(LOWEST COURSE ONLY)
JCKT YLD STRESS	Yjct	30.00	(KSI)	(ASME S A-240 TP304)
BTTM HEAD THICK.	Hdt	0.563	(IN)	
LEG FIXITY(KL/R)	FL	2.00	(AISC TABLE C-C2.1)	
AVERAGE LEG LNTH	Lave	25.56	(IN)	
LEG YIELD STRESS	YLDL	36.00	(YLD STRESS, KSI)	
JACKET MOD OF E	E	29600	(KSI)	
CM OF LEG	(DIMENSIONLESS)	0.85	(AISC SECTION H1)	

GUSSET WIDTH @ TANK	GWT	12.000	(IN)	
GUSSET THICKNESS	GT	0.750	(IN)	
WRAPPER WIDTH	WRW	24.000	(IN)	
WRAPPER THICKNESS	WRT	0.750	(IN)	
FILLET SIZE ON WRAPPER	Dw	0.500	(IN)	
FILLET SIZE ON GUSSETT	Dg	0.500	(IN)	
BOLT CIRCLE RAD.	RBC	6.10	(FT)	
NO. BOLTS/LEG	N	2	(ASTM A-36 ANCHOR BOLTS, W THREADS IN SHEAR PLANE)	
BOLT DIAMETER EACH	D	1.00	(IN)	
BOLT TENS ALLOW	SIGMAT	19.10	(KSI)	(AISC TABLE I-B. P. 4-3, FOR A-36 CAST IN PLACE)
BOLT SHEAR ALLOW	SIGMAS	9.90	(KSI)	(AISC TABLE I-D. P. 4-5, FOR A-36 CAST IN PLACE)
BASE PLATE SIZE	BPL	14.50	(IN)	ASSUMED SQUARE
BASE PLATE THICK.	BPLT	1.00	(IN)	
CONCRETE STRENGTH	f'c	4000	(PSI)	

SEISMIC DESIGN INPUT	(97 UBC)			zone factor ------------
SEISMIC ZONE	(0,1,"2A,"2B,3,4)	4	(TABLE 16-I)	0.40
IMPORTANCE FACT.	I	1.25	(TABLE 16-K)	
STRESS RED. FACT.	Sr	1.40	(UBC SECTION 1612.3.2)	

WIND DESIGN INPUT 1997 UBC SECTION 1616 TO 1620............................

WIND SPEED	(MPH)	0	(FIG 16-1)
EXPOSURE	(B,C OR D) D		(SECTION 1616) OR CUSTOMER SPEC.
EXPOSURE FACTOR	(CE)	1.73	(TABLE 16-G , BASED ON HEIGHT AT TOP OF TANK)
OCCUP CATEGORY	(Iw);(1 or 1.15)	1.15	(TABLE 16-K)

GENERAL INTERMEDIATE CALCULATIONS.................................

PROJECTED AREA		208.03	(FT^2)
2/3 HEIGHT OF TK	HTS	10.49	(FT)
HORIZ CG OF TK	(FT);(X DIR)	5.29	(MEASURED FROM LEG 1 BOLT CL)
HORIZ CG OF TK	(FT);(Y DIR)	3.05	(MEASURED FROM LEG 1 BOLT CL)

SEISMIC INTERMEDIATE CALCULATIONS.....................................

SEISMIC COEFF.	Ca	0.44	(TABLE 16-Q, FOR DEFAULT PROFILE Sd)
REDUNDANCY FACT.	R	2.20	(TABLE 16-P, VERTICAL TANK)
EQUIV. G LEVEL	G	0.4464	
SEIS BASE SHEAR (TANK FULL)	VSF	14.64	(KIPS)
SEIS BASE SHEAR (TANK EMPTY)	VSE	10.04	(KIPS)

WIND INTERMEDIATE CALCULATIONS.....................................

PRESSURE COEF	(Cq)	0.80	(TABLE 16-H) FOR ROUND TANKS
WIND PRESSURE	(Qs)	0.00	(TABLE 16-

F)

WIND BASE SHEAR	(VW)	0.00	(KIPS)	

DETERMINATION OF GREATEST BASE SHEAR ....

GREATEST SHEAR FORCE	(Vmax)	14.64	(KIPS)	SEISMIC GOVERNS

FOR OVERTURNING FROM WIND OR SEISMIC WHICHEVER GOVERNS....

AT THE LOWEST COURSE OF THE JACKET...............

MAX COMPRESSIVE STRESS IN JACKET (TANK FULL, W/VACUUM) (w/3/4 REDUCTION FOR WIND OR SEISMIC)	1.040	OK <=	8.90	KSI	V095-1-006
MAX COMP STR IN JACKET @ TOP OF LEG	2.321	OK <=	8.90	KSI	Pressure included

FOR THE SUPPORT LEG...................................

MINIMUM RADIUS OF GYRATION	3.61	INDIVIDUALLY
TOTAL IXX	1825.66	GLOBALLY
TOTAL IYY	1825.66	GLOBALLY

		max w/full tank	leg/dir	max w/empty tank
		--------------- ------- ---- --------------		
BASE SHEAR LEG 1	X DIR (KIPS)	3.85	LEG 1/X	2.64
BASE SHEAR LEG 2	X DIR (KIPS)	6.93	LEG 2/X	4.76
BASE SHEAR LEG 3	X DIR (KIPS)	3.85	LEG 3/X	2.64
BASE SHEAR LEG 1	Y DIR (KIPS)	5.91	LEG 1/Y	4.05

BASE SHEAR LEG 2	Y DIR (KIPS)	2.83	LEG 2/Y	1.94	
BASE SHEAR LEG 3	Y DIR (KIPS)	5.91	LEG 3/Y	4.05	
		-------	---------	-------	
MAXIMUM BASE SHEAR FORCE (KIPS) IN ANY DIRECTION		6.93	@ LEG 2/X	4.76	
OVERTURNING MOMENT ABOUT XX AXIS W/AXIS THRU LEG1/LEG3 BOLT CL (FT KIPS)		190.33	LL+DL or 3/4(LL+DL+WL or SL) whichever governs		
OVERTURNING MOMENT ABOUT YY AXIS W/AXIS THRU LEG1 BOLT CL (FT KIPS)		245.29	LL+DL or 3/4(LL+DL+WL or SL) whichever governs		
MAX VERTICAL REACTION ABOUT X AXIS (KIPS) (DOWNWARD FORCE)		20.79	@ LEG 2	(INCLUDES 3/4 REDUCTION ON FORCE IF WIND OR SEISMIC GOVERNS)	
MAX VERTICAL REACTION ABOUT Y AXIS (KIPS) (DOWNWARD FORCE)		10.93	@ LEG 1 OR LEG 3		(INCLUDES 3/4 REDUCTION IF WIND OR SEISMIC GOVERNS)

LEG
CHARACERISTICS...
....

MAXIMUM MOMENT AT LEG TOP (IN-K) ASSUMING PARTIAL FIXITY AT BASE		99.68	@ LEG 2/X	W/ 3/4 REDUCTION ON MOMENT FOR WIND OR SEISMIC
VERTICAL DOWN FORCE TO USE (KIPS)		20.79	@ LEG 2	(INCLUDES 3/4 REDUCTION ON FORCE
FOR THIS TANK, THE GREATEST FORCE	IS		@ LEG 2	
QA	STIFFENED REDUCTION FACTOR	1.0000		
Q	OVERALL REDUCTION FACTOR	0.9964		
COMPUTED AXIAL STRESS	(KSI)	0.770	BASED ON WHOLE CROSS SECTION AT TOP	
COMPUTED BENDING STRESS (ON OUTER ROLLED ELEMENT)	(KSI)	0.707	BASED ON WHOLE CROSS SECTION AT TOP	

COMBINED STRESS (ON OUTER ROLLED ELEMENT)	(KSI)	1.476	BASED ON WHOLE CROSS SECTION AT TOP
Cc'		127.63	AISC EQUATION (A-B5-11)
KL/R RATIO		14.14	THE LARGEST VALUE OF ANY LEG
FA ALLOW	(KSI)	20.871	AISC EQUATION (A-B5-11)
FB ALLOW	(KSI)	21.521	AISC APPENDIX B B5 2. a.
KL/RXX		14.14	
F'E XX		762	AISC SECTION H1

FOR THE LEG EVALUATION BASED ON COMPRESSION AND BENDING....................

INTERACTION 1	AISC EQ. H1-1	0.15	<= 1 OK
INTERACTION 2	AISC EQ. H1-2	0.17	<= 1 OK

PRIMARY PUNCHING SHEAR STRESS IN HEAD AT TOP OF LEG

LEG MOMENT OF INERTIA ABOUT STRONG AXIS, Ixx		353	IN^4	FROM SPREAD SHEET PROGRAM
DISTANCE FROM N/A TO TIP OF GUSSET, Hy		10.25	IN.	
MOMENT AT TOP OF LEG FROM ABOVE		99.68	IN-K	
BENDING STRESS AT TIP OF GUSSET	M*Hy/Ixx	2.89	KSI	
DIRECT STRESS FROM ABOVE		.77	KSI	
TOTAL AXIAL STRESS AT TIP OF GUSSET NORMAL TO HEAD, ft		3.66	KSI	
GUSSET THICKNESS	GT	0.750	(IN)	

FORCE PER IN. AT TIP OF GUSSET NORMAL TO HEAD, P = ft*GT	2.75 K/IN			
BTTM HEAD THICK. Hdt	0.563 IN			
PRIMARY PUNCHING SHEAR STRESS IN HEAD AT TIP OF GUSSET, fv = p/(2*Hdt)	2.44 KSI < 12 KSI		This value it low. The allowable stress is taken at ½ S= 20 ksi. An increase of factor of 1.2 is applied per UG-23(d).	

DETERMINATION OF WELD PROPERTIES AND WELD STRESSES AT THE TOP OF LEG... (LEG BENT ABOUT LOCAL X AXIS OF LEG)

MINIMUM SECTION MODULUS OF WELD	41.49	IN^3		
TOTAL WELD AREA AT TOP OF LEG	24.00	IN^2		
WELD STRESS FROM COMPRESSIVE LOADS	0.87	KSI		
WELD STRESS FROM MOMENT AT LEG TOP	2.40	KSI		
WELD STRESS FROM HORIZ. SHEAR FORCES	0.29	KSI		
SRSS OF WELD STRESSES	3.28	KSI	OK <=	14.50

DETERMINATION OF BOTTOM HEAD THICKNESS..............

MINIMUM THICKNESS OF BOTTOM HEAD (BASED ON GUSSETT FILLET SIZE REQ,D)	0.438	IN	OK <=	0.563

DETERMINATION OF BASE PLATE SIZE...(BASED ON COMPRESSIVE STRESSES IN CONCRETE)

BASE PLATE SURFACE AREA	210	IN^2
BASE PLATE SURFACE SECTION MODULUS	508.10	IN^3
CONCRETE COMP. STRESS FROM P LOADS	0.099	KSI
CONCRETE COMP. STRESS FROM M	0.065	KSI

LOADS

TOTAL CONCRETE COMP. STRESS	0.164	KSI	OK <=	1.800

FORCES AND MOMENTS REQ'D FOR THE FOUNDATION DESIGN.................

TOTAL BASE SHEAR FORCE AT WORST LEG (K)	6.93	@ LEG 2/X	(ACTUAL MAX FORCE, NO REDUCTION FOR WIND OR SEISMIC)
MAXIMUM COMPRESSIVE FORCE ON WORST LEG (K)	20.79	@ LEG 2	(INCLUDES 3/4 REDUCTION ON FORCE
MAXIMUM BENDING MOMENT @ BASE PLATE (IN-K)	33.23	@ LEG 2/X	W/ 3/4 REDUCTION ON MOMENT FOR WIND OR SEISMIC (75% OF MOMENT @ TOP OF LEG, 25% @ BASE OF LEG)
MAX NET UPLIFT FORCE PER BASE PLATE (K)	0.00	@ LEG 2 W/TANK FULL	(ACTUAL MAX FORCE, NO REDUCTION FOR WIND OR SEISMIC)

AT THE BOLT LEVEL FOR UPLIFT AND SHEAR FORCES...........			leg/dir ---------	
MAX BOLT SHEAR FORCE (TANK FULL)	3.47	KIPS	@ LEG 2/X	
MAX BOLT SHEAR FORCE (TANK EMPTY)	2.38	KIPS	@ LEG 2/X	
MAX BOLT SHEAR STRESS (TANK FULL)	4.41	KSI, OK	@ LEG 2/X	W/ 1/3 INCREASE
MAX BOLT SHEAR STRESS (TANK EMPTY)	3.03	KSI, OK	@ LEG 2/X	W/ 1/3 INCREASE
MAX UPLIFT FORCE PER BOLT ABOUT XX AXIS (TANK FULL)	NO UPLIFT	KIPS	@ LEG 2 W/TANK FULL	
MAX UPLIFT FORCE PER BOLT ABOUT XX AXIS (TANK EMPTY)	NO UPLIFT	KIPS	@ LEG 2 W/TANK EMPTY	
MAX UPLIFT FORCE PER BOLT ABOUT YY AXIS (TANK FULL)	NO UPLIFT	KIPS	@ LEG 1 OR 2 W/TANK FULL	
MAX UPLIFT FORCE PER BOLT	NO UPLIFT	KIPS	@ LEG 1 OR 2 W/TANK EMPTY	

ABOUT YY AXIS
(TANK EMPTY)

MAX TENSION STRESS PER BOLT (ANY DIRECTION, TANK FULL)	0.00	OK <	25.47	KSI	W/ 1/3 INCREASE
MAX TENSION STRESS PER BOLT (ANY DIRECTION, TANK EMPTY)	0.00	OK <	25.47	KSI	W/ 1/3 INCREASE
MAX INTERACTION SHEAR AND TENSION STRESS (TANK FULL)	0.000	< = 1.333, OK			W/ 1/3 INCREASE
MAX INTERACTION SHEAR AND TENSION STRESS (TANK EMPTY)	0.000	< = 1.333, OK			W/ 1/3 INCREASE

DETERMINATION OF BASE PLATE THICKNESS...(BASED ON UPLIFT FORCES ON BOLTS)

BASE PLATE THICKNESS REQ'D	0.000	IN	OK <=	1.000	THICKNESS USED

Chart Industries, Inc. PROCESS SYSTEMS DIVISION

WESTBOROUGH, MA 01581					ENGINEERING	NO: V095-1-010
THERMAL / VACUUM TECHNOLOGY GROUP					CALCULATIONS	Page 1 of 55
REV	DEO#	DATE	BY:	CHECK	TITLE:	
0		4/24/00	RDC	DMcW	**Head Support Frame**	
1						
					BY: R. D. Ciatto	DEPT: 744
PROJECT: SOFIA MIRROR COATER NASA AMES					PROJECT NO: V59095	

PURPOSE: Design head support frame in accordance with structural design criteria (SDC).
Ensure that frame meets requirements for supporting weight of head including UBC-94 seismic load condition.

METHOD: The STAAD computer program for structural design is used for this calculation.

ASSUMPTIONS: N/A

INPUTS: Design temperature = 100°F for allowable stress.
Weights from V095-1-008, Head Lifting Lugs.

REFERENCE: V095-1-005, Structural Design Criteria
Dwg. V095-5-202, Top Head Storage Platform.
Research Engineers, Yorba Linda, CA, STAAD Release 2.0

CALCULATIONS:

see Attachments.

CONCLUSIONS: The head support frame conforms to project requirements.

NOTES:

Revision History

Rev.	Comments	Date
0	Initial Issue	April, 2000
1	Update geometry. Apply head load directly to columns.	September, 00

Loads & Load Combinations

1. Selfweight

2. Head Weight

Reaction on each of 3 brackets: 1.5 x 5283/3 = 2642 lb. (V095-1-008)
Impact factor of 1.5 is included. This load is applied at top of posts, nodes 5, 10 & 15.

3. Seismic X-direction

Acceleration = .40G (V095-1-009). Structure with head is assumed to be non-rigid per UBC-1630.
For head W = 5283 lb.
Force at top of each post: Fx = .40 x 5283/3 = 704.4 lb.

Since the lateral load is applied 4 in. above the beam centerline, a moment is added.

Mz = -4 x 704.4 = -2817.6 in-lb.

This load case includes acceleration of structure selfweight.

4. Seismic X without head but with selfweight of structure.

5. Seismic Z-direction

Same as 3 but in Z-direction. Mx = 2817.6 in-lb.

6. Seismic Z without head but with selfweight of structure.

<u>Load combinations</u>

7. 1 + 2 Selfweight + head weight.

8. 1 + 2 + 3 Selfweight + head weight + seismic X acceleration. Load 2 divided by 1.5 to eliminate impact factor during seismic acceleration.

1 + 2 x (1/1.5) + 3

9. 1 + 2 + 5 Selfweight + head weight + seismic Z acceleration. Load 2 divided by 1.5 to eliminate impact factor during seismic acceleration.

1 + 2 x (1/1.5) + 5

Concrete Expansion Anchors

To determine if any leg of the support structure is subjected to tensile forces the support reactions in the following STAAD output were reviewed. Only the above load cases and combinations that include structure weight are applicable. These are load cases:

1, 4, 6, 7, 8 & 9.

Review of support reactions for these load cases determined that seismic overturning forces are not great enough to cause anchor tension.

For shear, the maximum shear force is

V = 1269 lb.

at node 11 for load case no. 8.

There are 3 anchors at each base plate. The shear per anchor is:

V = 1269/3 = 423 lb.

For 5/8 in. Hilti Kwik Bolt II, the allowable shear force is

Vall = 3330 lb. per anchor (Hilti Product Tech. Guide/2000).

Therefore, these anchors will be used with a minimum embedment of 2 ¾ in.

STAAD output is given on the following sheets.

```
****************************************************
*                                                  *
*           STAAD/Pro STAAD-III                    *
*           Revision 2000                          *
*           Proprietary Program of                 *
*           RESEARCH ENGINEERS, Inc.               *
*           Date=    SEP 12, 2000                  *
*           Time=    10:17:33                      *
*                                                  *
*      USER ID: Chart Process Systems              *
****************************************************
```

```
 1. STAAD SPACE SOFIA HEAD SUPPORT FRAME
 2. START JOB INFORMATION
 3. JOB NAME SOFIA
 4. JOB CLIENT NASA AMES
 5. JOB NO V59095
 6. JOB PART SUPPORT FRAME
 7. ENGINEER NAME RDC
 8. ENGINEER DATE 25-APR-00
 9. END JOB INFORMATION
10. INPUT WIDTH 79
11. UNIT INCHES POUND
12. JOINT COORDINATES
13. 1 0 0 0; 2 0 30.5 0; 3 0 61 0; 4 0 91.5 0; 5 0 112.69 0; 6 0 0 156.86
14. 7 0 30.5 156.86; 8 0 61 156.86; 9 0 91.5 156.86; 10 0 112.69 156.86
15. 11 135.849 0 78.43; 12 135.849 30.5 78.43; 13 135.849 61 78.43
16. 14 135.849 91.5 78.43; 15 135.849 112.69 78.43; 16 0 112.69 38.43
17. 17 0 112.69 76.86; 18 0 112.69 115.29; 19 33.2825 112.69 19.215
18. 20 66.565 112.69 38.43; 21 99.8475 112.69 57.645; 22 33.9622 112.69 137.253
19. 23 67.9245 112.69 117.645; 24 101.887 112.69 98.0375
20. MEMBER INCIDENCES
21. 1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 6 7; 6 7 8; 7 8 9; 8 9 10; 9 11 12; 10 12 13
22. 11 13 14; 12 14 15; 13 5 16; 14 5 19; 16 16 17; 17 17 18; 18 18 10; 19 19 20
23. 20 20 21; 21 21 15; 22 10 22; 23 22 23; 24 23 24; 25 24 15
24. MEMBER PROPERTY AMERICAN
25. 1 TO 12 TABLE ST PIPS80
26. 13 14 16 TO 25 TABLE ST TUB80303
27. UNIT INCHES KIP
28. CONSTANTS
29. E 29000 MEMB 1 TO 14 16 TO 21 22 TO 25
30. POISSON 0.3 MEMB 1 TO 14 16 TO 21 22 TO 25
31. DENSITY 0.000283 MEMB 1 TO 14 16 TO 21 22 TO 25
32. ALPHA 6E-006 MEMB 1 TO 14 16 TO 21 22 TO 25
33. UNIT INCHES POUND
34. SUPPORTS
35. 1 6 11 PINNED
36. MEMBER OFFSET
37. 4 8 12 END 0 -4 0
38. PRINT ALL
```

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 2

JOINT COORDINATES

COORDINATES ARE INCH UNIT

JOINT	X	Y	Z
1	0.000	0.000	0.000
2	0.000	30.500	0.000
3	0.000	61.000	0.000
4	0.000	91.500	0.000
5	0.000	112.690	0.000
6	0.000	0.000	156.860
7	0.000	30.500	156.860
8	0.000	61.000	156.860
9	0.000	91.500	156.860
10	0.000	112.690	156.860
11	135.849	0.000	78.430
12	135.849	30.500	78.430
13	135.849	61.000	78.430
14	135.849	91.500	78.430
15	135.849	112.690	78.430
16	0.000	112.690	38.430
17	0.000	112.690	76.860
18	0.000	112.690	115.290
19	33.283	112.690	19.215
20	66.565	112.690	38.430
21	99.848	112.690	57.645
22	33.962	112.690	137.253
23	67.924	112.690	117.645
24	101.887	112.690	98.037

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 3

MEMBER INFORMATION

MEMBER	START JOINT	END JOINT	LENGTH (INCH)	BETA (DEG)	RELEASES
1	1	2	30.500	0.00	
2	2	3	30.500	0.00	
3	3	4	30.500	0.00	
4	4	5	17.190	0.00	
5	6	7	30.500	0.00	
6	7	8	30.500	0.00	
7	8	9	30.500	0.00	
8	9	10	17.190	0.00	
9	11	12	30.500	0.00	
10	12	13	30.500	0.00	
11	13	14	30.500	0.00	
12	14	15	17.190	0.00	
13	5	16	38.430	0.00	
14	5	19	38.431	0.00	
16	16	17	38.430	0.00	
17	17	18	38.430	0.00	
18	18	10	41.570	0.00	
19	19	20	38.431	0.00	
20	20	21	38.431	0.00	
21	21	15	41.571	0.00	
22	10	22	39.216	0.00	
23	22	23	39.216	0.00	
24	23	24	39.216	0.00	
25	24	15	39.216	0.00	

MATERIAL PROPERTIES.

ALL UNITS ARE - POUN INCH

MEMBER	E	G	DEN	ALPHA
1	28999998.0	11153845.0	0.28299999	0.00000600
2	28999998.0	11153845.0	0.28299999	0.00000600
3	28999998.0	11153845.0	0.28299999	0.00000600
4	28999998.0	11153845.0	0.28299999	0.00000600
5	28999998.0	11153845.0	0.28299999	0.00000600
6	28999998.0	11153845.0	0.28299999	0.00000600
7	28999998.0	11153845.0	0.28299999	0.00000600
8	28999998.0	11153845.0	0.28299999	0.00000600
9	28999998.0	11153845.0	0.28299999	0.00000600
10	28999998.0	11153845.0	0.28299999	0.00000600
11	28999998.0	11153845.0	0.28299999	0.00000600
12	28999998.0	11153845.0	0.28299999	0.00000600
13	28999998.0	11153845.0	0.28299999	0.00000600
14	28999998.0	11153845.0	0.28299999	0.00000600
16	28999998.0	11153845.0	0.28299999	0.00000600
17	28999998.0	11153845.0	0.28299999	0.00000600
18	28999998.0	11153845.0	0.28299999	0.00000600
19	28999998.0	11153845.0	0.28299999	0.00000600
20	28999998.0	11153845.0	0.28299999	0.00000600
21	28999998.0	11153845.0	0.28299999	0.00000600
22	28999998.0	11153845.0	0.28299999	0.00000600
23	28999998.0	11153845.0	0.28299999	0.00000600
24	28999998.0	11153845.0	0.28299999	0.00000600
25	28999998.0	11153845.0	0.28299999	0.00000600

MEMBER PROPERTIES. UNIT - INCH

MEMB	PROFILE	AX/ AY	IZ/ AZ	IY/ SZ	IX/ SY
1	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
2	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
3	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
4	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
5	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
6	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
7	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
8	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
9	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
10	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
11	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
12	ST PIP S80	8.40	72.50	72.50	145.00
		5.04	5.04	16.81	16.81
13	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
14	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
16	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
17	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
18	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
19	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
20	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
21	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
22	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
23	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20
24	ST TUB 80303	3.89	29.60	6.30	17.30
		3.00	0.75	7.40	4.20

25	ST	TUB 80303	3.89	29.60	6.30	17.30
			3.00	0.75	7.40	4.20

```
 SOFIA HEAD SUPPORT FRAME                               -- PAGE NO.    6


MEMBER PROPERTIES. UNIT - INCH
-----------------

MEMB   PROFILE              AX/          IZ/          IY/         IX/
                            AY           AZ           SZ          SY



SUPPORT INFORMATION (1=FIXED, 0=RELEASED)
-------------------
UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

JOINT   FORCE-X/   FORCE-Y/   FORCE-Z/   MOM-X/   MOM-Y/   MOM-Z/
          KFX        KFY        KFZ       KMX      KMY      KMZ

   1       1          1          1         0        0        0
               0.0        0.0        0.0      0.0      0.0      0.0
   6       1          1          1         0        0        0
               0.0        0.0        0.0      0.0      0.0      0.0
  11       1          1          1         0        0        0
               0.0        0.0        0.0      0.0      0.0      0.0


************ END OF DATA FROM INTERNAL STORAGE ************


 39. LOAD 1 SELFWEIGHT
 40. SELFWEIGHT Y -1
 41. LOAD 2 HEAD WEIGHT
 42. JOINT LOAD
 43. 5 10 15 FY -2642
 44. LOAD 3 SEISMIC X
 45. JOINT LOAD
 46. 5 10 15 FX 704.4 MZ -2817.6
 47. SELFWEIGHT X 0.4
 48. LOAD 4 SEISMIC X W/0 HEAD W/ SELFWEIGHT
 49. SELFWEIGHT X 0.4
 50. SELFWEIGHT Y -1
 51. LOAD 5 SEISMIC Z
 52. JOINT LOAD
 53. 5 10 15 FZ 704.4 MX 2817.6
 54. SELFWEIGHT Z 0.4
 55. LOAD 6 SEISMIC Z W/O HEAD W/ SELFWEIGHT
 56. SELFWEIGHT Z 0.4
 57. SELFWEIGHT Y -1
 58. LOAD COMB 7 WEIGHT INCLUDING HEAD
 59. 1 1.0 2 1.0
 60. LOAD COMB 8 WEIGHT + SEISMIC X
 61. 1 1.0 2 0.67 3 1.0
 62. LOAD COMB 9 WEIGHT + SEISMIC Z
 63. 1 1.0 2 0.67 5 1.0
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    SOFIA HEAD SUPPORT FRAME                                   -- PAGE NO.    7

    64. PERFORM ANALYSIS



           P R O B L E M   S T A T I S T I C S
           -----------------------------------

     NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS =    24/   24/    3
     ORIGINAL/FINAL BAND-WIDTH =   14/    4
     TOTAL PRIMARY LOAD CASES  =    6, TOTAL DEGREES OF FREEDOM =   135
     SIZE OF STIFFNESS MATRIX =    4050 DOUBLE PREC. WORDS
     REQRD/AVAIL. DISK SPACE =  12.07/   51.1 MB,  EXMEM =   53.2 MB


  ++ Processing Element Stiffness Matrix.              10:17:33
  ++ Processing Global Stiffness Matrix.               10:17:33
  ++ Processing Triangular Factorization.              10:17:33
  ++ Calculating Joint Displacements.                  10:17:33
  ++ Calculating Member  Forces.                       10:17:34


    65. LOAD LIST 1 TO 9
    66. PARAMETER
    67. CODE AISC
    68. KZ 2 MEMB 1 TO 12
    69. KY 2 MEMB 1 TO 12
    70. LY 112.69 MEMB 1 TO 12
    71. LZ 112.69 MEMB 1 TO 12
    72. LY 156.86 MEMB 13 14 16 TO 25
    73. LZ 156.86 MEMB 13 14 16 TO 25
    74. UNL 112.69 MEMB 1 TO 12
    75. UNL 156.86 MEMB 13 14 16 TO 25
    76. TRACK 1 MEMB 1 TO 14 16 TO 25
    77. PRINT MAXFORCE ENVELOPE NSECTION 4 LIST 1 TO 14 16 TO 25
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SOFIA HEAD SUPPORT FRAME -- PAGE NO. 8

MEMBER FORCE ENVELOPE

ALL UNITS ARE POUN INCH

MAX AND MIN FORCE VALUES AMONGST ALL SECTION LOCATIONS

MEMB		FY/ FZ	DIST DIST	LD LD	MZ/ MY	DIST DIST	LD LD	FX		DIST	LD
1	MAX	694.54	0.00	3	417.85	30.50	1				
		23.73	0.00	1	723.70	30.50	1	3073.06	C	0.00	7
	MIN	-13.70	30.50	1	-20741.06	30.50	3				
		-1059.12	0.00	5	-31860.74	30.50	5	1828.32	T	30.50	5
2	MAX	665.54	0.00	3	835.71	30.50	1				
		23.73	0.00	1	1447.41	30.50	1	3000.56	C	0.00	7
	MIN	-13.70	30.50	1	-40597.63	30.50	3				
		-1030.11	0.00	5	-62837.11	30.50	5	1828.32	T	30.50	5
3	MAX	636.53	0.00	3	1253.56	30.50	1				
		23.73	0.00	1	2171.11	30.50	1	2928.05	C	0.00	7
	MIN	-13.70	30.50	1	-59569.55	30.50	3				
		-1001.11	0.00	5	-92928.83	30.50	5	1828.32	T	30.50	5
4	MAX	607.54	0.00	3	1489.07	17.19	1				
		23.73	0.00	1	2578.99	17.19	1	2855.55	C	0.00	7
	MIN	-13.70	17.19	1	-69872.54	17.19	3				
		-972.00	0.00	5	-109497.87	17.19	5	1828.32	T	17.19	5
5	MAX	694.53	0.00	3	10048.17	30.50	9				
		315.73	0.00	3	9629.67	30.50	3	4029.53	C	0.00	9
	MIN	-329.45	30.50	9	-20740.88	30.50	3				
		-1082.84	0.00	9	-32584.43	30.50	9	1055.55	T	30.50	3
6	MAX	665.54	0.00	3	20096.37	30.50	9				
		315.73	0.00	3	19259.32	30.50	3	3957.02	C	0.00	9
	MIN	-329.45	30.50	9	-40597.58	30.50	3				
		-1053.84	0.00	9	-64284.31	30.50	9	1055.55	T	30.50	3
7	MAX	636.53	0.00	3	30144.45	30.50	9				
		315.74	0.00	3	28889.13	30.50	3	3884.51	C	0.00	9
	MIN	-329.44	30.50	9	-59569.55	30.50	3				
		-1024.87	0.00	9	-95100.05	30.50	9	1055.54	T	30.50	3
8	MAX	607.56	0.00	3	35807.14	17.19	9				
		315.72	0.00	3	34316.41	17.19	3	3812.01	C	0.00	9
	MIN	-329.38	17.19	9	-69872.40	17.19	3				
		-995.88	0.00	9	-112078.04	17.19	9	1055.55	T	17.19	3
9	MAX	1268.81	0.00	8	0.07	0.00	8				
		0.00	0.00	3	0.09	0.00	5	4312.31	C	0.00	8

	MIN	0.00	30.50	2	-38256.33	30.50	8				
		-512.25	0.00	9	-15181.19	30.50	9	0.00	C	30.50	5
10	MAX	1239.78	0.00	8	0.00	0.00	2				
		0.00	0.00	3	0.02	30.50	3	4239.80	C	0.00	8
	MIN	0.00	30.50	2	-75627.76	30.50	8				
		-483.24	0.00	9	-29477.69	30.50	9	0.00	C	30.50	5
11	MAX	1210.81	0.00	8	0.07	0.00	5				
		0.00	0.00	7	0.28	0.00	3	4167.30	C	0.00	8
	MIN	0.00	30.50	2	-112115.30	30.50	8				
		-454.26	0.00	5	-42890.08	30.50	9	0.00	T	30.50	5
12	MAX	1181.84	0.00	8	0.25	0.00	5				
		0.02	0.00	3	0.29	17.19	8	4094.79	C	0.00	8
	MIN	0.00	17.19	2	-132290.52	17.19	8				
		-425.16	0.00	9	-50058.45	17.19	9	0.00	T	17.19	5
13	MAX	86.34	0.00	8	8111.95	0.00	8				
		34.54	0.00	4	552.16	38.43	4	15.82	C	0.00	1
	MIN	-1218.89	38.43	5	-95597.55	0.00	5				
		0.00	38.43	2	-790.52	0.00	9	410.89	T	38.43	3
14	MAX	86.34	0.00	1	1782.69	0.00	1				
		8.66	0.00	4	790.61	0.00	9	206.12	C	38.43	8
	MIN	-1055.55	38.43	3	-85953.66	0.00	3				
		-34.95	0.00	5	-279.44	38.43	6	373.07	T	0.00	5
16	MAX	44.03	0.00	8	6329.35	0.00	3				
		17.62	0.00	8	903.88	38.43	4	15.82	C	0.00	1
	MIN	-1218.89	38.43	5	-49478.20	0.00	9				
		0.00	38.43	2	-403.18	0.00	5	410.89	T	38.43	3
17	MAX	1.73	0.00	4	44928.30	38.43	5				
		10.08	0.00	9	903.88	0.00	4	32.06	C	38.43	6
	MIN	-1259.47	38.43	9	-3515.57	0.00	9				
		-16.23	38.43	4	-15.81	0.00	5	410.89	T	38.43	3
18	MAX	0.00	0.00	3	97380.17	41.57	9				
		10.08	0.00	9	790.56	41.57	9	50.32	C	41.57	6
	MIN	-1305.23	41.57	9	-855.42	0.00	1				
		-34.54	41.57	4	-456.29	41.57	3	410.89	T	41.57	3
19	MAX	44.04	0.00	7	4524.75	38.43	5				
		0.20	0.00	4	621.98	0.00	8	220.67	C	38.43	8
	MIN	-1055.55	38.43	3	-46110.35	0.00	8				
		-20.29	0.00	5	-775.02	38.43	6	364.70	T	0.00	5
20	MAX	1.73	0.00	7	35744.00	38.43	3				
		9.09	38.43	6	465.45	0.00	4	235.25	C	38.43	8
	MIN	-1096.13	38.43	8	-6423.86	0.00	8				
		-16.84	38.43	3	-811.59	19.22	6	356.19	T	0.00	5
21	MAX	0.00	0.00	2	81406.72	41.57	8				
		24.94	41.57	6	0.01	41.57	5	251.43	C	41.57	8

```
 SOFIA HEAD SUPPORT FRAME                                       -- PAGE NO.   10

    MIN  -1141.90  41.57    8    -855.44   0.00    7
           -26.00  41.57    8    -912.79  41.57    8    347.70 T   0.00    5

22  MAX    695.78   0.00    9   44100.27   0.00    9
             0.09  39.22    3     790.49   0.00    9    388.93 C   0.00    9
    MIN  -1055.54  39.22    3  -85953.41   0.00    3
           -34.95   0.00    9    -622.02  39.22    8      0.00 C  39.22    2

23  MAX    652.61   0.00    9   18418.23   0.00    5
             8.73  39.22    8       0.00  39.22    1    380.43 C   0.00    9
    MIN  -1055.55  39.22    8  -45316.30   0.00    8
           -19.99   0.00    5    -783.28  39.22    6      0.00 C  39.22    2

24  MAX    609.43   0.00    5   38229.79  39.22    3
            17.36  39.22    3      62.59  39.22    3    371.73 C   0.00    9
    MIN  -1098.72  39.22    8  -30137.97  39.22    9
            -5.04   0.00    9    -813.66   9.80    6      0.00 C  39.22    2

25  MAX    609.44   0.00    5   81406.60  39.22    8
            26.00  39.22    8     912.78  39.22    8    362.93 C   0.00    9
    MIN  -1141.89  39.22    8  -53280.62  39.22    5
             0.00  39.22    2    -684.90   0.00    6      0.00 C  39.22    2


********** END OF FORCE ENVELOPE FROM INTERNAL STORAGE **********


 78. CHECK CODE MEMB 1 TO 14 16 TO 25
```

```
   SOFIA HEAD SUPPORT FRAME                                -- PAGE NO.   11




                     STAAD-III CODE CHECKING - (AISC)
                     ***********************




 ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

 MEMBER     TABLE       RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX            MY             MZ       LOCATION
 =======================================================================


     1  ST  PIP S80       PASS     AISC- H2-1         0.093        5
                    1828.32 T          0.00      33284.38      30.50

  -----------------------------------------------------------------------
 | MEM=     1, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     2  ST  PIP S80       PASS     AISC- H2-1         0.175        5
                    1828.32 T          0.00      65722.71      30.50

  -----------------------------------------------------------------------
 | MEM=     2, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     3  ST  PIP S80       PASS     AISC- H2-1         0.254        5
                    1828.32 T          0.00      97316.26      30.50

  -----------------------------------------------------------------------
 | MEM=     3, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     4  ST  PIP S80       PASS     AISC- H2-1         0.297        5
                    1828.32 T          0.00     114749.96      17.19

  -----------------------------------------------------------------------
 | MEM=     4, UNIT KIP-INCH,  L=  17.2  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     5  ST  PIP S80       PASS     AISC- H1-3         0.115        9
                    3957.02 C          0.00      34098.54      30.50
```

```
 -----------------------------------------------------------------------
| MEM=     5, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
| KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
| FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
 -----------------------------------------------------------------------

     6  ST  PIP S80       PASS     AISC- H1-3         0.198         9
                   3884.52 C          0.00       67352.34       30.50

 -----------------------------------------------------------------------
| MEM=     6, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
| KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
| FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
 -----------------------------------------------------------------------
```

```
   SOFIA HEAD SUPPORT FRAME                                  -- PAGE NO.   12


 ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

 MEMBER     TABLE       RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX            MY             MZ       LOCATION
 =======================================================================

      7  ST  PIP S80       PASS     AISC- H1-3        0.279         9
                     3812.01 C         0.00      99763.26       30.50

  -----------------------------------------------------------------------
 | MEM=     7, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

      8  ST  PIP S80       PASS     AISC- H1-3        0.323         9
                     3771.15 C         0.00     117659.00       17.19

  -----------------------------------------------------------------------
 | MEM=     8, UNIT KIP-INCH,  L=  17.2  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

      9  ST  PIP S80       PASS     AISC- H1-3        0.128         8
                     4239.80 C         0.00      38256.33       30.50

  -----------------------------------------------------------------------
 | MEM=     9, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     10  ST  PIP S80       PASS     AISC- H1-3        0.221         8
                     4167.30 C         0.00      75627.76       30.50

  -----------------------------------------------------------------------
 | MEM=    10, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     11  ST  PIP S80       PASS     AISC- H1-3        0.312         8
                     4094.79 C         0.00     112115.30       30.50

  -----------------------------------------------------------------------
 | MEM=    11, UNIT KIP-INCH,  L=  30.5  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------
```

```
    12  ST  PIP S80       PASS     AISC- H1-3         0.362         8
                    4053.93 C          0.00     132290.52       17.19

  -----------------------------------------------------------------------
 | MEM=    12, UNIT KIP-INCH,  L=  17.2  AX=  8.40  SZ=  16.8  SY=  16.8 |
 | KL/R-Y=  76.7  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 23.76 |
 | FTZ= 23.76  FCY= 23.76  FTY= 23.76  FA= 15.71  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

    13  ST  TUB 80303     PASS     AISC- H2-1         0.607         5
                      34.49 T       -790.52     -95597.55        0.00
```

```
   SOFIA HEAD SUPPORT FRAME                                 -- PAGE NO.   13

 ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

 MEMBER     TABLE       RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX            MY             MZ       LOCATION
 =======================================================================

  -----------------------------------------------------------------------
 | MEM=    13, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     14  ST  TUB 80303     PASS     AISC- H1-3         0.547         3
                     175.64 C        456.33     -85953.66        0.00

  -----------------------------------------------------------------------
 | MEM=    14, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     16  ST  TUB 80303     PASS     AISC- H2-1         0.314         9
                       1.77 T       -403.18     -49478.20        0.00

  -----------------------------------------------------------------------
 | MEM=    16, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     17  ST  TUB 80303     PASS     AISC- H1-3         0.286         5
                      16.19 T        371.55      44928.30       38.43

  -----------------------------------------------------------------------
 | MEM=    17, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     18  ST  TUB 80303     PASS     AISC- H1-3         0.619         9
                      50.26 C        790.56      97380.17       41.57

  -----------------------------------------------------------------------
 | MEM=    18, UNIT KIP-INCH,  L=  41.6  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     19  ST  TUB 80303     PASS     AISC- H1-3         0.301         8
                     206.01 C        621.98     -46110.35        0.00
```

```
 -----------------------------------------------------------------------
| MEM=    19, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
| KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
| FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
 -----------------------------------------------------------------------

    20  ST  TUB 80303     PASS     AISC- H1-3         0.230         3
                     219.43 C        -22.28       35744.00       38.43

 -----------------------------------------------------------------------
| MEM=    20, UNIT KIP-INCH,  L=  38.4  AX=  3.89  SZ=   7.4  SY=   4.2 |
| KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
| FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
 -----------------------------------------------------------------------
```

```
   SOFIA HEAD SUPPORT FRAME                                  -- PAGE NO.   14



 ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

 MEMBER     TABLE        RESULT/   CRITICAL COND/     RATIO/     LOADING/
                           FX            MY            MZ       LOCATION
 =======================================================================


     21  ST  TUB 80303     PASS     AISC- H1-3         0.526         8
                      251.43 C       -912.79      81406.72       41.57

  -----------------------------------------------------------------------
 | MEM=    21, UNIT KIP-INCH,  L=  41.6  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     22  ST  TUB 80303     PASS     AISC- H1-3         0.547         3
                      175.64 C       -456.36     -85953.41        0.00

  -----------------------------------------------------------------------
 | MEM=    22, UNIT KIP-INCH,  L=  39.2  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     23  ST  TUB 80303     PASS     AISC- H1-3         0.296         8
                      206.09 C       -622.00     -45316.30        0.00

  -----------------------------------------------------------------------
 | MEM=    23, UNIT KIP-INCH,  L=  39.2  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     24  ST  TUB 80303     PASS     AISC- H1-3         0.246         3
                      220.45 C         62.59      38229.79       39.22

  -----------------------------------------------------------------------
 | MEM=    24, UNIT KIP-INCH,  L=  39.2  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------

     25  ST  TUB 80303     PASS     AISC- H1-3         0.526         8
                      251.09 C        912.78      81406.60       39.22

  -----------------------------------------------------------------------
 | MEM=    25, UNIT KIP-INCH,  L=  39.2  AX=  3.89  SZ=   7.4  SY=   4.2 |
 | KL/R-Y= 123.3  CB=  1.00  YLD= 36.00  ALLOWABLE STRESSES:  FCZ= 21.60 |
 | FTZ= 21.60  FCY= 21.60  FTY= 21.60  FA=  9.81  FT= 21.60  FV= 14.40   |
  -----------------------------------------------------------------------
```

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79. PRINT MEMBER STRESSES LIST 1 TO 14 16 TO 25
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SOFIA HEAD SUPPORT FRAME -- PAGE NO. 15

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
1	1	.0	51.3 C	0.0	0.0	51.3	2.7	4.7
		1.00	42.7 C	43.0	24.9	92.4	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	0.0	0.0	125.7	137.8	62.6
		1.00	125.7 T	572.8	1233.7	1485.9	132.1	62.6
	4	.0	33.7 C	0.0	0.0	33.7	26.4	4.1
		1.00	25.1 C	37.3	215.3	243.6	20.7	4.1
	5	.0	217.7 T	0.0	0.0	217.7	62.6	210.1
		1.00	217.7 T	1895.2	572.8	2197.5	62.6	204.4
	6	.0	20.8 C	0.0	0.0	20.8	6.1	34.6
		1.00	12.2 C	289.8	55.5	307.3	6.1	28.8
	7	.0	365.8 C	0.0	0.0	365.8	2.7	4.7
		1.00	357.2 C	43.0	24.9	406.9	2.7	4.7
	8	.0	136.4 C	0.0	0.0	136.4	135.1	57.9
		1.00	127.8 C	529.8	1208.9	1447.6	129.3	57.9
	9	.0	44.4 C	0.0	0.0	44.4	59.9	205.4
		1.00	35.8 C	1852.1	548.0	1967.2	59.9	199.7
2	1	.0	42.7 C	43.0	24.9	92.4	2.7	4.7
		1.00	34.1 C	86.1	49.7	133.5	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	572.8	1233.7	1485.9	132.1	62.6
		1.00	125.7 T	1145.6	2414.9	2798.5	126.3	62.6
	4	.0	25.1 C	37.3	215.3	243.6	20.7	4.1
		1.00	16.4 C	74.5	378.0	401.7	14.9	4.1
	5	.0	217.7 T	1895.2	572.8	2197.5	62.6	204.4
		1.00	217.7 T	3737.7	1145.7	4127.0	62.6	198.6
	6	.0	12.2 C	289.8	55.5	307.3	6.1	28.8
		1.00	3.5 C	527.0	110.9	542.1	6.1	23.1
	7	.0	357.2 C	43.0	24.9	406.9	2.7	4.7
		1.00	348.6 C	86.1	49.7	448.0	2.7	4.7
	8	.0	127.8 C	529.8	1208.9	1447.6	129.3	57.9
		1.00	119.1 C	1059.5	2365.1	2710.7	123.6	57.9
	9	.0	35.8 C	1852.1	548.0	1967.2	59.9	199.7
		1.00	27.1 C	3651.6	1096.0	3839.7	59.9	193.9
3	1	.0	34.1 C	86.1	49.7	133.5	2.7	4.7
		1.00	25.4 C	129.1	74.6	174.5	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	1145.6	2414.9	2798.5	126.3	62.6
		1.00	125.7 T	1718.4	3543.4	4063.7	120.5	62.6

4	.0	16.4 C	74.5	378.0	401.7	14.9	4.1
	1.00	7.8 C	111.8	488.0	508.5	9.2	4.1
5	.0	217.7 T	3737.7	1145.7	4127.0	62.6	198.6
	1.00	217.7 T	5527.7	1718.5	6006.3	62.6	192.9

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 16

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	6	.0	3.5 C	527.0	110.9	542.1	6.1	23.1
		1.00	5.1 C	711.6	166.4	735.9	6.1	17.3
	7	.0	348.6 C	86.1	49.7	448.0	2.7	4.7
		1.00	339.9 C	129.1	74.6	489.1	2.7	4.7
	8	.0	119.1 C	1059.5	2365.1	2710.7	123.6	57.9
		1.00	110.5 C	1589.3	3468.8	3926.0	117.8	57.9
	9	.0	27.1 C	3651.6	1096.0	3839.7	59.9	193.9
		1.00	18.5 C	5398.5	1643.9	5661.8	59.9	188.2
4	1	.0	25.4 C	129.1	74.6	174.5	2.7	4.7
		1.00	20.6 C	153.4	88.6	197.7	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	1718.4	3543.3	4063.7	120.5	62.6
		1.00	125.7 T	2041.2	4156.2	4756.1	117.3	62.6
	4	.0	7.8 C	111.8	488.0	508.5	9.2	4.1
		1.00	2.9 C	132.8	526.9	546.3	5.9	4.1
	5	.0	217.7 T	5527.7	1718.5	6006.3	62.6	192.9
		1.00	217.7 T	6513.2	2041.4	7043.3	62.6	189.6
	6	.0	5.1 T	711.6	166.4	735.9	6.1	17.3
		1.00	10.0 T	792.5	197.6	826.7	6.1	14.1
	7	.0	339.9 C	129.1	74.6	489.1	2.7	4.7
		1.00	335.1 C	153.4	88.6	512.2	2.7	4.7
	8	.0	110.5 C	1589.3	3468.8	3926.0	117.8	57.9
		1.00	105.6 C	1887.8	4067.6	4590.0	114.6	57.9
	9	.0	18.5 C	5398.6	1643.9	5661.8	59.9	188.1
		1.00	13.6 C	6359.8	1952.8	6666.5	59.9	184.9
5	1	.0	51.3 C	0.0	0.0	51.3	2.7	4.7
		1.00	42.7 C	43.0	24.9	92.4	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	0.0	0.0	125.7	137.8	62.6
		1.00	125.7 T	572.8	1233.7	1485.9	132.0	62.6
	4	.0	33.7 C	0.0	0.0	33.7	26.4	4.1
		1.00	25.1 C	37.3	215.3	243.6	20.7	4.1
	5	.0	217.7 C	0.0	0.0	217.7	62.6	210.1
		1.00	217.7 C	1895.2	572.8	2197.5	62.6	204.4
	6	.0	81.8 C	0.0	0.0	81.8	11.5	44.0
		1.00	73.2 C	375.9	105.2	463.6	11.5	38.2
	7	.0	365.8 C	0.0	0.0	365.8	2.7	4.7
		1.00	357.2 C	43.0	24.9	406.9	2.7	4.7
	8	.0	136.4 C	0.0	0.0	136.4	135.1	57.9
		1.00	127.8 C	529.8	1208.9	1447.6	129.3	57.9
	9	.0	479.7 C	0.0	0.0	479.7	65.4	214.8

		1.00	471.1 C	1938.2	597.7	2499.3	65.4	209.1
6	1	.0	42.7 C	43.0	24.9	92.4	2.7	4.7
		1.00	34.1 C	86.1	49.7	133.5	2.7	4.7

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 17

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	572.8	1233.7	1485.9	132.1	62.6
		1.00	125.7 T	1145.6	2414.9	2798.5	126.3	62.6
	4	.0	25.1 C	37.3	215.3	243.6	20.7	4.1
		1.00	16.4 C	74.5	378.0	401.7	14.9	4.1
	5	.0	217.7 C	1895.2	572.8	2197.5	62.6	204.4
		1.00	217.7 C	3737.7	1145.7	4127.0	62.6	198.6
	6	.0	73.2 C	375.9	105.2	463.6	11.5	38.2
		1.00	64.6 C	699.2	210.3	794.7	11.5	32.5
	7	.0	357.2 C	43.0	24.9	406.9	2.7	4.7
		1.00	348.6 C	86.1	49.7	448.0	2.7	4.7
	8	.0	127.8 C	529.8	1208.9	1447.6	129.3	57.9
		1.00	119.1 C	1059.5	2365.1	2710.7	123.6	57.9
	9	.0	471.1 C	1938.2	597.7	2499.3	65.4	209.1
		1.00	462.4 C	3823.8	1195.4	4468.7	65.4	203.3
7	1	.0	34.1 C	86.1	49.7	133.5	2.7	4.7
		1.00	25.4 C	129.1	74.6	174.5	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	1145.6	2414.9	2798.5	126.3	62.6
		1.00	125.7 T	1718.4	3543.4	4063.7	120.5	62.6
	4	.0	16.4 C	74.5	378.0	401.7	14.9	4.1
		1.00	7.8 C	111.8	488.0	508.5	9.2	4.1
	5	.0	217.7 C	3737.7	1145.7	4127.0	62.6	198.6
		1.00	217.7 C	5527.7	1718.5	6006.3	62.6	192.9
	6	.0	64.6 C	699.2	210.3	794.7	11.5	32.5
		1.00	55.9 C	969.9	315.5	1075.9	11.5	26.7
	7	.0	348.6 C	86.1	49.7	448.0	2.7	4.7
		1.00	339.9 C	129.1	74.6	489.1	2.7	4.7
	8	.0	119.1 C	1059.5	2365.2	2710.7	123.6	57.9
		1.00	110.5 C	1589.3	3468.8	3926.0	117.8	57.9
	9	.0	462.4 C	3823.8	1195.4	4468.7	65.4	203.3
		1.00	453.8 C	5656.8	1793.1	6388.0	65.4	197.6
8	1	.0	25.4 C	129.1	74.6	174.5	2.7	4.7
		1.00	20.6 C	153.4	88.6	197.7	2.7	4.7
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	125.7 T	1718.4	3543.4	4063.7	120.5	62.6
		1.00	125.7 T	2041.2	4156.2	4756.1	117.3	62.6
	4	.0	7.8 C	111.8	488.0	508.5	9.2	4.1
		1.00	2.9 C	132.8	526.9	546.3	5.9	4.1
	5	.0	217.7 C	5527.6	1718.5	6006.3	62.6	192.9

	1.00	217.7 C	6513.3	2041.3	7043.4	62.6	189.6
6	.0	55.9 C	969.9	315.5	1075.9	11.5	26.7
	1.00	51.1 C	1099.3	374.8	1212.5	11.5	23.5
7	.0	339.9 C	129.1	74.6	489.1	2.7	4.7
	1.00	335.1 C	153.4	88.6	512.2	2.7	4.7

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	8	.0	110.5 C	1589.3	3468.8	3926.0	117.8	57.9
		1.00	105.6 C	1887.8	4067.6	4590.0	114.6	57.9
	9	.0	453.8 C	5656.8	1793.1	6388.0	65.4	197.6
		1.00	448.9 C	6666.7	2129.9	7447.6	65.4	194.4
9	1	.0	51.3 C	0.0	0.0	51.3	5.4	0.0
		1.00	42.7 C	0.0	49.7	92.4	5.4	0.0
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	251.3 C	0.0	0.0	251.3	246.3	0.0
		1.00	251.3 C	0.0	2225.9	2477.2	240.6	0.0
	4	.0	86.5 C	0.0	0.0	86.5	49.8	0.0
		1.00	77.9 C	0.0	428.9	506.9	44.0	0.0
	5	.0	0.0 C	0.0	0.0	0.0	0.0	101.6
		1.00	0.0 C	903.0	0.0	903.0	0.0	95.9
	6	.0	51.3 C	0.0	0.0	51.3	5.4	24.1
		1.00	42.7 C	193.8	49.7	242.7	5.4	18.3
	7	.0	365.8 C	0.0	0.0	365.8	5.4	0.0
		1.00	357.2 C	0.0	49.7	406.9	5.4	0.0
	8	.0	513.4 C	0.0	0.0	513.4	251.7	0.0
		1.00	504.7 C	0.0	2275.6	2780.3	246.0	0.0
	9	.0	262.0 C	0.0	0.0	262.1	5.4	101.6
		1.00	253.4 C	903.0	49.7	1157.8	5.4	95.9
10	1	.0	42.7 C	0.0	49.7	92.4	5.4	0.0
		1.00	34.1 C	0.0	99.4	133.5	5.4	0.0
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	251.3 C	0.0	2225.9	2477.2	240.6	0.0
		1.00	251.3 C	0.0	4399.1	4650.4	234.8	0.0
	4	.0	77.9 C	0.0	428.9	506.9	44.0	0.0
		1.00	69.3 C	0.0	805.3	874.6	38.3	0.0
	5	.0	0.0 C	903.0	0.0	903.0	0.0	95.9
		1.00	0.0 C	1753.4	0.0	1753.4	0.0	90.1
	6	.0	42.7 C	193.8	49.7	242.7	5.4	18.3
		1.00	34.1 C	335.0	99.4	383.5	5.4	12.6
	7	.0	357.2 C	0.0	49.7	406.9	5.4	0.0
		1.00	348.6 C	0.0	99.4	448.0	5.4	0.0
	8	.0	504.7 C	0.0	2275.6	2780.3	246.0	0.0
		1.00	496.1 C	0.0	4498.5	4994.7	240.2	0.0
	9	.0	253.4 C	903.0	49.7	1157.8	5.4	95.9
		1.00	244.8 C	1753.4	99.4	2001.0	5.4	90.1
11	1	.0	34.1 C	0.0	99.4	133.5	5.4	0.0
		1.00	25.4 C	0.0	149.1	174.6	5.4	0.0

2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
	1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
3	.0	251.3 C	0.0	4399.1	4650.5	234.8	0.0
	1.00	251.3 C	0.0	6519.8	6771.1	229.0	0.0

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	4	.0	69.3 C	0.0	805.3	874.6	38.3	0.0
		1.00	60.7 C	0.0	1129.0	1189.6	32.5	0.0
	5	.0	0.0 T	1753.4	0.0	1753.4	0.0	90.1
		1.00	0.0 T	2551.2	0.0	2551.2	0.0	84.4
	6	.0	34.1 C	335.0	99.4	383.5	5.4	12.6
		1.00	25.4 C	423.5	149.1	474.4	5.4	6.8
	7	.0	348.6 C	0.0	99.4	448.0	5.4	0.0
		1.00	339.9 C	0.0	149.1	489.1	5.4	0.0
	8	.0	496.1 C	0.0	4498.6	4994.7	240.2	0.0
		1.00	487.5 C	0.0	6668.9	7156.4	234.5	0.0
	9	.0	244.8 C	1753.4	99.4	2001.0	5.4	90.1
		1.00	236.2 C	2551.2	149.1	2791.7	5.4	84.4
12	1	.0	25.4 C	0.0	149.1	174.6	5.4	0.0
		1.00	20.6 C	0.0	177.1	197.7	5.4	0.0
	2	.0	314.5 C	0.0	0.0	314.5	0.0	0.0
		1.00	314.5 C	0.0	0.0	314.5	0.0	0.0
	3	.0	251.3 C	0.0	6519.8	6771.1	229.1	0.0
		1.00	251.3 C	0.0	7691.9	7943.2	225.8	0.0
	4	.0	60.7 C	0.0	1129.0	1189.6	32.5	0.0
		1.00	55.8 C	0.0	1288.3	1344.1	29.3	0.0
	5	.0	0.0 T	2551.2	0.0	2551.2	0.0	84.4
		1.00	0.0 T	2977.6	0.0	2977.6	0.0	81.1
	6	.0	25.4 C	423.5	149.1	474.4	5.4	6.8
		1.00	20.6 C	450.2	177.1	504.4	5.4	3.6
	7	.0	339.9 C	0.0	149.1	489.1	5.4	0.0
		1.00	335.1 C	0.0	177.1	512.2	5.4	0.0
	8	.0	487.5 C	0.0	6668.9	7156.4	234.5	0.0
		1.00	482.6 C	0.0	7869.0	8351.6	231.2	0.0
	9	.0	236.2 C	2551.2	149.1	2791.7	5.4	84.4
		1.00	231.3 C	2977.6	177.2	3214.2	5.4	81.1
13	1	.0	4.1 C	0.0	240.9	245.0	28.8	0.0
		1.00	4.1 C	0.0	97.6	101.7	14.7	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	105.6 T	108.6	855.3	1069.6	0.0	46.0
		1.00	105.6 T	129.9	855.3	1090.9	0.0	23.5
	4	.0	8.6 T	107.1	360.7	476.4	28.8	46.0
		1.00	8.6 T	131.5	22.2	162.2	14.7	23.5
	5	.0	8.9 T	188.2	12918.6	13115.7	406.3	13.4
		1.00	4.5 T	96.0	6588.6	6689.1	406.3	13.4
	6	.0	4.8 T	185.6	1570.0	1760.4	28.2	13.2
		1.00	0.5 T	94.6	1021.2	1116.3	42.3	13.2
	7	.0	4.1 C	0.0	240.9	245.0	28.8	0.0

	1.00	4.1 C	0.0	97.6	101.7	14.7	0.0
8	.0	101.6 T	108.6	1096.2	1306.4	28.8	46.0
	1.00	101.6 T	129.9	757.7	989.2	14.7	23.5
9	.0	4.8 T	188.2	12677.7	12870.7	377.5	13.4
	1.00	0.4 T	96.0	6686.2	6782.7	391.6	13.4

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 20

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
14	1	.0	4.1 C	0.0	240.9	245.0	28.8	0.0
		1.00	4.1 C	0.0	97.6	101.7	14.7	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	45.2 C	108.6	11615.4	11769.2	351.9	11.4
		1.00	48.9 C	148.1	6133.5	6330.5	351.9	0.1
	4	.0	2.7 C	107.1	1387.3	1497.1	20.5	11.6
		1.00	6.4 C	147.7	957.4	1111.5	34.6	0.3
	5	.0	95.9 T	188.2	5718.6	6002.7	203.1	46.6
		1.00	93.7 T	64.6	2553.6	2711.9	203.1	27.1
	6	.0	11.3 T	185.6	560.8	757.6	0.3	46.5
		1.00	9.1 T	66.5	455.7	531.3	13.8	27.0
	7	.0	4.1 C	0.0	240.9	245.0	28.8	0.0
		1.00	4.1 C	0.0	97.6	101.7	14.7	0.0
	8	.0	49.2 C	108.6	11374.5	11532.3	323.1	11.4
		1.00	53.0 C	148.1	6231.1	6432.2	337.2	0.1
	9	.0	91.8 T	188.2	5477.7	5757.8	174.4	46.6
		1.00	89.7 T	64.6	2651.2	2805.4	188.5	27.1
16	1	.0	4.1 C	0.0	97.6	101.7	14.7	0.0
		1.00	4.1 C	0.0	216.5	220.5	0.6	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	105.6 T	129.9	855.3	1090.9	0.0	23.5
		1.00	105.6 T	213.7	855.3	1174.6	0.0	0.9
	4	.0	8.6 T	131.5	22.2	162.2	14.7	23.5
		1.00	8.6 T	215.2	96.6	320.4	0.6	0.9
	5	.0	4.5 T	96.0	6588.6	6689.1	406.3	13.4
		1.00	0.2 T	3.8	258.6	262.5	406.3	13.4
	6	.0	0.5 T	94.6	1021.2	1116.3	42.3	13.2
		1.00	3.9 T	3.7	252.7	260.3	56.4	13.2
	7	.0	4.1 C	0.0	97.6	101.7	14.7	0.0
		1.00	4.1 C	0.0	216.5	220.5	0.6	0.0
	8	.0	101.6 T	129.9	757.7	989.2	14.7	23.5
		1.00	101.6 T	213.7	638.8	954.1	0.6	0.9
	9	.0	0.5 T	96.0	6686.2	6782.7	391.6	13.4
		1.00	3.9 T	3.8	475.1	482.7	405.7	13.4
17	1	.0	4.1 C	0.0	216.5	220.5	0.6	0.0
		1.00	4.1 C	0.0	115.6	119.7	13.5	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	105.6 T	213.7	855.3	1174.6	0.0	0.9
		1.00	105.6 T	142.6	855.3	1103.5	0.0	21.6

4	.0	8.6 T	215.2	96.6	320.4	0.6	0.9
	1.00	8.6 T	144.1	4.2	156.9	13.5	21.6
5	.0	0.2 T	3.8	258.6	262.6	406.3	13.4
	1.00	4.2 T	88.5	6071.4	6164.0	406.3	13.4

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 21

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	6	.0	3.9 C	3.7	252.7	260.3	56.4	13.2
		1.00	8.2 C	87.2	735.5	830.9	70.5	13.2
	7	.0	4.1 C	0.0	216.5	220.5	0.6	0.0
		1.00	4.1 C	0.0	115.6	119.7	13.5	0.0
	8	.0	101.6 T	213.7	638.8	954.1	0.6	0.9
		1.00	101.6 T	142.6	739.7	983.9	13.5	21.6
	9	.0	3.9 C	3.8	475.1	482.7	405.7	13.4
		1.00	8.2 C	88.5	5955.8	6052.5	419.8	13.4
18	1	.0	4.1 C	0.0	115.6	119.7	13.5	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	105.6 T	142.6	855.3	1103.5	0.0	21.6
		1.00	105.6 T	108.6	855.3	1069.6	0.0	46.0
	4	.0	8.6 T	144.1	4.2	156.9	13.5	21.6
		1.00	8.6 T	107.1	360.7	476.4	28.8	46.0
	5	.0	4.1 C	88.5	6071.4	6164.0	406.3	13.4
		1.00	8.9 C	188.2	12918.6	13115.7	406.3	13.4
	6	.0	8.2 C	87.2	735.5	830.9	70.5	13.2
		1.00	12.9 C	185.6	2051.8	2250.3	85.7	13.2
	7	.0	4.1 C	0.0	115.6	119.7	13.5	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0
	8	.0	101.6 T	142.6	739.7	983.9	13.5	21.6
		1.00	101.6 T	108.6	1096.2	1306.4	28.8	46.0
	9	.0	8.2 C	88.5	5955.8	6052.5	419.8	13.4
		1.00	12.9 C	188.2	13159.5	13360.6	435.1	13.4
19	1	.0	4.1 C	0.0	97.6	101.7	14.7	0.0
		1.00	4.1 C	0.0	216.5	220.6	0.6	0.0
	2	.0	0.0 C	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	3	.0	48.9 C	148.1	6133.5	6330.5	351.9	0.1
		1.00	52.7 C	110.1	651.6	814.4	351.9	11.2
	4	.0	6.4 C	147.7	957.4	1111.5	34.6	0.3
		1.00	10.2 C	110.8	307.8	428.8	48.7	11.0
	5	.0	93.8 T	64.5	2553.6	2711.9	203.1	27.1
		1.00	91.6 T	183.2	611.5	886.2	203.1	7.5
	6	.0	9.1 T	66.5	455.7	531.3	13.8	27.0
		1.00	7.0 T	184.5	130.8	322.3	27.9	7.4
	7	.0	4.1 C	0.0	97.6	101.7	14.7	0.0
		1.00	4.1 C	0.0	216.5	220.6	0.6	0.0
	8	.0	53.0 C	148.1	6231.1	6432.2	337.2	0.1
		1.00	56.7 C	110.1	868.1	1034.9	351.3	11.2
	9	.0	89.7 T	64.5	2651.2	2805.4	188.5	27.1

		1.00	87.5 T	183.2	395.0	665.6	202.6	7.5
20	1	.0	4.1 C	0.0	216.5	220.6	0.6	0.0
		1.00	4.1 C	0.0	115.6	119.7	13.5	0.0

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 22

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	52.6 C	110.1	651.6	814.3	351.9	11.2
		1.00	56.4 C	5.3	4830.3	4892.0	351.9	22.5
	4	.0	10.2 C	110.8	307.8	428.8	48.7	11.0
		1.00	14.0 C	3.5	561.5	579.0	62.8	22.3
	5	.0	91.6 T	183.2	611.5	886.2	203.1	7.5
		1.00	89.4 T	167.7	3776.5	4033.6	203.1	12.0
	6	.0	7.0 T	184.5	130.8	322.3	27.9	7.4
		1.00	4.8 T	168.4	413.7	586.9	42.0	12.1
	7	.0	4.1 C	0.0	216.5	220.6	0.6	0.0
		1.00	4.1 C	0.0	115.6	119.7	13.5	0.0
	8	.0	56.7 C	110.1	868.1	1034.9	351.3	11.2
		1.00	60.5 C	5.3	4714.7	4780.5	365.4	22.5
	9	.0	87.5 T	183.2	395.0	665.6	202.6	7.5
		1.00	85.3 T	167.7	3660.9	3913.9	216.7	12.0
21	1	.0	4.1 C	0.0	115.6	119.7	13.5	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0
	2	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0
	3	.0	56.5 C	5.3	4830.3	4892.1	351.9	22.5
		1.00	60.6 C	217.3	10760.0	11037.9	351.9	34.7
	4	.0	14.0 C	3.5	561.5	579.0	62.8	22.3
		1.00	18.1 C	214.3	1749.3	1981.6	78.1	34.5
	5	.0	89.4 T	167.7	3776.5	4033.6	203.1	12.0
		1.00	87.0 T	0.0	7200.1	7287.1	203.1	33.2
	6	.0	4.8 T	168.4	413.7	586.9	42.0	12.1
		1.00	2.4 T	0.0	1250.1	1252.6	57.3	33.3
	7	.0	4.1 C	0.0	115.6	119.7	13.5	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0
	8	.0	60.6 C	5.3	4714.7	4780.5	365.4	22.5
		1.00	64.6 C	217.3	11000.9	11282.9	380.6	34.7
	9	.0	85.3 T	167.7	3660.9	3913.9	216.7	12.0
		1.00	83.0 T	0.0	7441.0	7523.9	231.9	33.2
22	1	.0	4.1 C	0.0	240.9	245.0	28.8	0.0
		1.00	4.1 C	0.0	102.3	106.3	14.4	0.0
	2	.0	0.0 C	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	3	.0	45.2 C	108.7	11615.3	11769.1	351.8	11.4
		1.00	49.0 C	148.1	6021.6	6218.7	351.8	0.1
	4	.0	2.7 C	107.1	1387.3	1497.1	20.5	11.6
		1.00	6.5 C	147.7	946.3	1100.6	34.9	0.0
	5	.0	95.9 C	188.2	5718.6	6002.7	203.1	46.6

	1.00	93.7 C	68.3	2489.0	2651.0	203.1	26.7
6	.0	19.4 C	185.6	1042.6	1247.6	57.3	46.5
	1.00	17.2 C	70.3	246.7	334.2	42.9	26.6
7	.0	4.1 C	0.0	240.9	245.0	28.8	0.0
	1.00	4.1 C	0.0	102.3	106.3	14.4	0.0

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 23

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	8	.0	49.2 C	108.7	11374.4	11532.3	323.1	11.4
		1.00	53.1 C	148.1	6123.8	6325.0	337.5	0.1
	9	.0	100.0 C	188.2	5959.5	6247.7	231.9	46.6
		1.00	97.8 C	68.3	2386.7	2552.7	217.5	26.7
23	1	.0	4.1 C	0.0	102.3	106.3	14.4	0.0
		1.00	4.1 C	0.0	216.7	220.7	0.0	0.0
	2	.0	0.0 C	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	3	.0	48.9 C	148.1	6021.6	6218.6	351.8	0.1
		1.00	52.8 C	106.9	427.7	587.3	351.8	11.6
	4	.0	6.5 C	147.7	946.3	1100.6	34.9	0.0
		1.00	10.4 C	107.7	276.6	394.6	49.3	11.5
	5	.0	93.7 C	68.3	2488.9	2651.0	203.1	26.7
		1.00	91.5 C	185.2	740.7	1017.4	203.1	6.7
	6	.0	17.2 C	70.3	246.7	334.2	42.9	26.6
		1.00	15.0 C	186.5	320.4	521.9	28.5	6.6
	7	.0	4.1 C	0.0	102.3	106.3	14.4	0.0
		1.00	4.1 C	0.0	216.7	220.7	0.0	0.0
	8	.0	53.0 C	148.1	6123.8	6324.9	337.5	0.1
		1.00	56.8 C	106.9	644.3	808.1	351.8	11.6
	9	.0	97.8 C	68.3	2386.7	2552.8	217.5	26.7
		1.00	95.6 C	185.2	957.4	1238.2	203.1	6.7
24	1	.0	4.1 C	0.0	216.7	220.7	0.0	0.0
		1.00	4.1 C	0.0	102.3	106.3	14.4	0.0
	2	.0	0.0 C	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	3	.0	52.8 C	106.9	427.7	587.4	351.9	11.6
		1.00	56.7 C	14.9	5166.2	5237.8	351.9	23.1
	4	.0	10.4 C	107.7	276.6	394.6	49.3	11.5
		1.00	14.2 C	13.0	621.9	649.2	63.7	23.0
	5	.0	91.5 C	185.2	740.7	1017.4	203.1	6.7
		1.00	89.3 C	162.4	3970.4	4222.1	203.1	13.2
	6	.0	15.0 C	186.5	320.4	521.9	28.5	6.6
		1.00	12.8 C	163.1	658.8	834.6	14.1	13.3
	7	.0	4.1 C	0.0	216.7	220.7	0.0	0.0
		1.00	4.1 C	0.0	102.3	106.3	14.4	0.0
	8	.0	56.9 C	106.9	644.3	808.1	351.9	11.6
		1.00	60.7 C	14.9	5063.9	5139.6	366.2	23.1
	9	.0	95.6 C	185.2	957.4	1238.1	203.1	6.7
		1.00	93.3 C	162.4	4072.7	4328.5	188.8	13.2
25	1	.0	4.1 C	0.0	102.3	106.3	14.4	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0

2	.0	0.0	C	0.0	0.0	0.0	0.0	0.0
	1.00	0.0	C	0.0	0.0	0.0	0.0	0.0
3	.0	56.6	C	14.9	5166.2	5237.7	351.8	23.2
	1.00	60.5	C	217.3	10760.0	11037.8	351.8	34.7

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 24

MEMBER STRESSES

ALL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	4	.0	14.2 C	13.0	621.9	649.1	63.7	23.0
		1.00	18.1 C	214.3	1749.2	1981.6	78.1	34.5
	5	.0	89.2 C	162.4	3970.4	4222.1	203.1	13.2
		1.00	87.0 C	0.0	7200.1	7287.1	203.1	33.2
	6	.0	12.8 C	163.1	658.8	834.6	14.1	13.3
		1.00	10.6 C	0.0	768.3	778.9	0.3	33.3
	7	.0	4.1 C	0.0	102.3	106.3	14.4	0.0
		1.00	4.1 C	0.0	240.9	245.0	28.8	0.0
	8	.0	60.7 C	14.9	5063.9	5139.5	366.2	23.2
		1.00	64.5 C	217.3	11000.9	11282.8	380.6	34.7
	9	.0	93.3 C	162.4	4072.7	4328.4	188.8	13.2
		1.00	91.1 C	0.0	6959.2	7050.3	174.4	33.2

************** END OF LATEST ANALYSIS RESULT **************

80. PRINT JOINT DISPLACMENTS LIST 1 TO 24

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
1	1	0.00000	0.00000	0.00000	-0.00002	0.00000	0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	3	0.00000	0.00000	0.00000	0.00031	0.00019	-0.00548
	4	0.00000	0.00000	0.00000	0.00002	0.00019	-0.00081
	5	0.00000	0.00000	0.00000	0.00584	-0.00011	-0.00031
	6	0.00000	0.00000	0.00000	0.00085	-0.00011	-0.00003
	7	0.00000	0.00000	0.00000	-0.00002	0.00000	0.00001
	8	0.00000	0.00000	0.00000	0.00029	0.00019	-0.00547
	9	0.00000	0.00000	0.00000	0.00581	-0.00011	-0.00030
2	1	-0.00039	-0.00005	-0.00067	-0.00002	0.00000	0.00001
	2	0.00000	-0.00033	0.00000	0.00000	0.00000	0.00000
	3	0.16598	0.00013	0.00888	0.00024	0.00019	-0.00533
	4	0.02451	-0.00003	0.00058	0.00002	0.00019	-0.00078
	5	0.00888	0.00023	0.17623	0.00560	-0.00011	-0.00024
	6	0.00086	-0.00002	0.02566	0.00081	-0.00011	-0.00002
	7	-0.00039	-0.00038	-0.00067	-0.00002	0.00000	0.00001
	8	0.16559	-0.00014	0.00821	0.00022	0.00019	-0.00532
	9	0.00849	-0.00004	0.17556	0.00559	-0.00011	-0.00023
3	1	-0.00059	-0.00009	-0.00102	0.00000	0.00000	0.00000
	2	0.00000	-0.00066	0.00000	0.00000	0.00000	0.00000
	3	0.32280	0.00026	0.01349	0.00003	0.00019	-0.00488
	4	0.04743	-0.00005	0.00088	0.00000	0.00019	-0.00071
	5	0.01350	0.00046	0.33838	0.00492	-0.00011	-0.00003
	6	0.00131	-0.00003	0.04918	0.00071	-0.00011	0.00000
	7	-0.00059	-0.00075	-0.00102	0.00000	0.00000	0.00000
	8	0.32221	-0.00027	0.01247	0.00003	0.00019	-0.00488
	9	0.01291	-0.00008	0.33736	0.00491	-0.00011	-0.00003
4	1	-0.00042	-0.00012	-0.00073	0.00002	0.00000	-0.00001
	2	0.00000	-0.00099	0.00000	0.00000	0.00000	0.00000
	3	0.46167	0.00040	0.00959	-0.00032	0.00019	-0.00416
	4	0.06755	-0.00007	0.00062	-0.00002	0.00019	-0.00060
	5	0.00960	0.00069	0.47275	0.00379	-0.00011	0.00032
	6	0.00093	-0.00002	0.06880	0.00056	-0.00011	0.00003
	7	-0.00042	-0.00111	-0.00073	0.00002	0.00000	-0.00001
	8	0.46125	-0.00039	0.00886	-0.00030	0.00019	-0.00417
	9	0.00918	-0.00010	0.47202	0.00381	-0.00011	0.00031
5	1	0.00001	-0.00013	0.00001	0.00004	0.00000	-0.00003
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54337	0.00047	-0.00029	-0.00058	0.00019	-0.00363
	4	0.07947	-0.00007	-0.00002	-0.00004	0.00019	-0.00053
	5	-0.00027	0.00082	0.54304	0.00296	-0.00011	0.00058
	6	-0.00003	-0.00002	0.07944	0.00046	-0.00011	0.00006
	7	0.00001	-0.00131	0.00001	0.00004	0.00000	-0.00003
	8	0.54337	-0.00045	-0.00027	-0.00053	0.00019	-0.00365
	9	-0.00027	-0.00011	0.54305	0.00300	-0.00011	0.00055
6	1	0.00000	0.00000	0.00000	0.00002	0.00000	0.00001

2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3	0.00000	0.00000	0.00000	-0.00031	-0.00019	-0.00548

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 26

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	4	0.00000	0.00000	0.00000	-0.00002	-0.00019	-0.00081
	5	0.00000	0.00000	0.00000	0.00584	-0.00011	0.00031
	6	0.00000	0.00000	0.00000	0.00090	-0.00011	0.00006
	7	0.00000	0.00000	0.00000	0.00002	0.00000	0.00001
	8	0.00000	0.00000	0.00000	-0.00029	-0.00019	-0.00547
	9	0.00000	0.00000	0.00000	0.00586	-0.00011	0.00032
7	1	-0.00039	-0.00005	0.00067	0.00002	0.00000	0.00001
	2	0.00000	-0.00033	0.00000	0.00000	0.00000	0.00000
	3	0.16598	0.00013	-0.00888	-0.00024	-0.00019	-0.00533
	4	0.02451	-0.00003	-0.00058	-0.00002	-0.00019	-0.00078
	5	-0.00888	-0.00023	0.17623	0.00560	-0.00011	0.00024
	6	-0.00163	-0.00008	0.02700	0.00085	-0.00011	0.00004
	7	-0.00039	-0.00038	0.00067	0.00002	0.00000	0.00001
	8	0.16559	-0.00014	-0.00821	-0.00022	-0.00019	-0.00532
	9	-0.00927	-0.00050	0.17690	0.00562	-0.00011	0.00025
8	1	-0.00059	-0.00009	0.00102	0.00000	0.00000	0.00000
	2	0.00000	-0.00066	0.00000	0.00000	0.00000	0.00000
	3	0.32280	0.00026	-0.01349	-0.00003	-0.00019	-0.00488
	4	0.04743	-0.00005	-0.00088	0.00000	-0.00019	-0.00071
	5	-0.01350	-0.00046	0.33838	0.00492	-0.00011	0.00003
	6	-0.00248	-0.00015	0.05122	0.00072	-0.00011	0.00001
	7	-0.00059	-0.00075	0.00102	0.00000	0.00000	0.00000
	8	0.32221	-0.00027	-0.01247	-0.00003	-0.00019	-0.00488
	9	-0.01409	-0.00099	0.33940	0.00492	-0.00011	0.00003
9	1	-0.00042	-0.00012	0.00073	-0.00002	0.00000	-0.00001
	2	0.00000	-0.00099	0.00000	0.00000	0.00000	0.00000
	3	0.46167	0.00040	-0.00959	0.00032	-0.00019	-0.00416
	4	0.06755	-0.00007	-0.00062	0.00002	-0.00019	-0.00060
	5	-0.00960	-0.00069	0.47275	0.00379	-0.00011	-0.00032
	6	-0.00177	-0.00022	0.07026	0.00051	-0.00011	-0.00006
	7	-0.00042	-0.00111	0.00073	-0.00002	0.00000	-0.00001
	8	0.46125	-0.00039	-0.00886	0.00030	-0.00019	-0.00417
	9	-0.01002	-0.00147	0.47348	0.00376	-0.00011	-0.00033
10	1	0.00001	-0.00013	-0.00001	-0.00004	0.00000	-0.00003
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54336	0.00047	0.00029	0.00058	-0.00019	-0.00363
	4	0.07947	-0.00007	0.00002	0.00004	-0.00019	-0.00053
	5	0.00027	-0.00082	0.54304	0.00296	-0.00011	-0.00058
	6	0.00004	-0.00025	0.07942	0.00037	-0.00011	-0.00011
	7	0.00001	-0.00131	-0.00001	-0.00004	0.00000	-0.00003
	8	0.54337	-0.00045	0.00027	0.00053	-0.00019	-0.00365
	9	0.00028	-0.00174	0.54303	0.00291	-0.00011	-0.00060
11	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00003
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00602
	4	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00093

5	0.00000	0.00000	0.00000	0.00530	0.00022	0.00000
6	0.00000	0.00000	0.00000	0.00080	0.00022	-0.00003

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 27

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	7	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00003
	8	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00604
	9	0.00000	0.00000	0.00000	0.00530	0.00022	-0.00003
12	1	0.00077	-0.00005	0.00000	0.00000	0.00000	-0.00002
	2	0.00000	-0.00033	0.00000	0.00000	0.00000	0.00000
	3	0.18136	-0.00026	0.00000	0.00000	0.00000	-0.00574
	4	0.02782	-0.00009	0.00000	0.00000	0.00000	-0.00087
	5	0.00000	0.00000	0.16086	0.00519	0.00022	0.00000
	6	0.00077	-0.00005	0.02417	0.00077	0.00022	-0.00002
	7	0.00077	-0.00038	0.00000	0.00000	0.00000	-0.00002
	8	0.18213	-0.00054	0.00000	0.00000	0.00000	-0.00576
	9	0.00077	-0.00027	0.16086	0.00519	0.00022	-0.00002
13	1	0.00118	-0.00009	0.00000	0.00000	0.00000	0.00000
	2	0.00000	-0.00066	0.00000	0.00000	0.00000	0.00000
	3	0.34617	-0.00053	0.00000	0.00000	0.00000	-0.00493
	4	0.05247	-0.00016	0.00000	0.00000	0.00000	-0.00072
	5	0.00000	0.00000	0.31502	0.00487	0.00022	0.00000
	6	0.00118	-0.00009	0.04692	0.00071	0.00022	0.00000
	7	0.00118	-0.00075	0.00000	0.00000	0.00000	0.00000
	8	0.34735	-0.00106	0.00000	0.00000	0.00000	-0.00494
	9	0.00118	-0.00053	0.31502	0.00487	0.00022	0.00000
14	1	0.00084	-0.00012	0.00000	0.00000	0.00000	0.00003
	2	0.00000	-0.00099	0.00000	0.00000	0.00000	0.00000
	3	0.47828	-0.00079	0.00000	0.00000	0.00000	-0.00360
	4	0.07115	-0.00023	0.00000	0.00000	0.00000	-0.00048
	5	0.00000	0.00000	0.45616	0.00434	0.00022	0.00000
	6	0.00084	-0.00012	0.06720	0.00062	0.00022	0.00003
	7	0.00084	-0.00111	0.00000	0.00000	0.00000	0.00003
	8	0.47912	-0.00158	0.00000	0.00000	0.00000	-0.00357
	9	0.00084	-0.00079	0.45616	0.00434	0.00022	0.00003
15	1	-0.00001	-0.00013	0.00000	0.00000	0.00000	0.00005
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54287	-0.00094	0.00000	0.00000	0.00000	-0.00262
	4	0.07940	-0.00027	0.00000	0.00000	0.00000	-0.00032
	5	0.00000	0.00000	0.54355	0.00396	0.00022	0.00000
	6	-0.00001	-0.00013	0.07949	0.00056	0.00022	0.00005
	7	-0.00001	-0.00131	0.00000	0.00000	0.00000	0.00005
	8	0.54286	-0.00187	0.00000	0.00000	0.00000	-0.00257
	9	-0.00001	-0.00092	0.54355	0.00396	0.00022	0.00005
16	1	0.00001	-0.00257	0.00001	0.00006	0.00000	-0.00003
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.55113	0.01725	-0.00015	-0.00029	0.00017	-0.00363
	4	0.08732	-0.00016	-0.00001	0.00002	0.00017	-0.00053
	5	-0.00181	-0.04267	0.54305	-0.00027	0.00001	0.00029
	6	-0.00166	-0.00856	0.07944	0.00002	0.00001	0.00002
	7	0.00001	-0.00375	0.00001	0.00006	0.00000	-0.00003

8	0.55113	0.01389	-0.00014	-0.00023	0.00017	-0.00365
9	-0.00181	-0.04603	0.54305	-0.00021	0.00001	0.00027

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
17	1	0.00001	-0.00396	0.00000	0.00000	0.00000	-0.00003
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.55484	0.02314	-0.00001	-0.00001	0.00001	-0.00363
	4	0.09105	-0.00071	0.00000	0.00000	0.00001	-0.00053
	5	-0.00009	-0.00227	0.54305	-0.00141	0.00006	0.00001
	6	-0.00008	-0.00427	0.07944	-0.00019	0.00005	-0.00002
	7	0.00001	-0.00513	0.00000	0.00000	0.00000	-0.00003
	8	0.55484	0.01839	-0.00001	-0.00001	0.00001	-0.00365
	9	-0.00009	-0.00701	0.54305	-0.00140	0.00006	-0.00001
18	1	0.00001	-0.00277	-0.00001	-0.00006	0.00000	-0.00003
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.55165	0.01814	0.00013	0.00027	-0.00016	-0.00363
	4	0.08785	-0.00022	0.00001	-0.00002	-0.00016	-0.00053
	5	0.00175	0.04142	0.54305	-0.00044	0.00002	-0.00027
	6	0.00162	0.00304	0.07943	-0.00012	0.00002	-0.00006
	7	0.00001	-0.00394	-0.00001	-0.00006	0.00000	-0.00003
	8	0.55166	0.01458	0.00013	0.00021	-0.00016	-0.00365
	9	0.00176	0.03787	0.54304	-0.00050	0.00002	-0.00030
19	1	0.00000	-0.00257	0.00001	0.00005	0.00000	-0.00004
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54592	-0.04558	-0.00483	-0.00184	0.00007	-0.00096
	4	0.08214	-0.00896	-0.00465	-0.00021	0.00008	-0.00017
	5	-0.00315	-0.00639	0.54826	0.00240	-0.00016	0.00184
	6	-0.00300	-0.00347	0.08462	0.00039	-0.00016	0.00022
	7	0.00000	-0.00375	0.00001	0.00005	0.00000	-0.00004
	8	0.54592	-0.04894	-0.00482	-0.00178	0.00007	-0.00100
	9	-0.00314	-0.00976	0.54827	0.00245	-0.00016	0.00180
20	1	0.00000	-0.00396	0.00001	0.00002	0.00000	0.00001
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54604	-0.01354	-0.00518	-0.00219	-0.00005	0.00014
	4	0.08238	-0.00585	-0.00509	-0.00028	-0.00004	0.00003
	5	-0.00508	0.01891	0.55186	0.00236	-0.00004	0.00219
	6	-0.00501	-0.00131	0.08812	0.00035	-0.00003	0.00032
	7	0.00000	-0.00514	0.00001	0.00002	0.00000	0.00001
	8	0.54604	-0.01828	-0.00517	-0.00216	-0.00005	0.00015
	9	-0.00508	0.01416	0.55186	0.00238	-0.00004	0.00220
21	1	-0.00001	-0.00277	0.00000	-0.00001	0.00000	0.00006
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54438	0.02680	-0.00244	-0.00163	-0.00010	-0.00034
	4	0.08082	0.00099	-0.00243	-0.00024	-0.00010	0.00002
	5	-0.00406	0.03642	0.55034	0.00284	0.00013	0.00163
	6	-0.00404	0.00234	0.08645	0.00039	0.00013	0.00029
	7	-0.00001	-0.00394	0.00000	-0.00001	0.00000	0.00006
	8	0.54437	0.02325	-0.00244	-0.00163	-0.00010	-0.00027
	9	-0.00407	0.03287	0.55034	0.00284	0.00013	0.00169
22	1	0.00000	-0.00262	-0.00001	-0.00005	0.00000	-0.00004

2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
3	0.54594	-0.04547	0.00488	0.00185	-0.00007	-0.00092

SOFIA HEAD SUPPORT FRAME -- PAGE NO. 29

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	4	0.08217	-0.00900	0.00470	0.00021	-0.00007	-0.00017
	5	0.00321	0.00607	0.54837	0.00239	-0.00015	-0.00185
	6	0.00307	-0.00177	0.08471	0.00028	-0.00015	-0.00030
	7	0.00000	-0.00380	-0.00001	-0.00005	0.00000	-0.00004
	8	0.54594	-0.04888	0.00487	0.00180	-0.00007	-0.00096
	9	0.00321	0.00265	0.54836	0.00234	-0.00015	-0.00189
23	1	0.00000	-0.00396	-0.00001	-0.00002	0.00000	0.00001
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54600	-0.01158	0.00511	0.00218	0.00005	0.00015
	4	0.08234	-0.00558	0.00502	0.00028	0.00005	0.00003
	5	0.00510	-0.02005	0.55191	0.00237	-0.00003	-0.00218
	6	0.00503	-0.00677	0.08815	0.00031	-0.00003	-0.00029
	7	0.00000	-0.00514	-0.00001	-0.00002	0.00000	0.00001
	8	0.54599	-0.01632	0.00510	0.00216	0.00005	0.00016
	9	0.00510	-0.02480	0.55190	0.00235	-0.00003	-0.00217
24	1	-0.00001	-0.00262	0.00000	0.00001	0.00000	0.00006
	2	0.00000	-0.00118	0.00000	0.00000	0.00000	0.00000
	3	0.54425	0.02799	0.00224	0.00156	0.00010	-0.00042
	4	0.08071	0.00130	0.00223	0.00023	0.00010	0.00001
	5	0.00390	-0.03634	0.55007	0.00289	0.00014	-0.00156
	6	0.00386	-0.00772	0.08617	0.00041	0.00014	-0.00015
	7	-0.00001	-0.00380	0.00000	0.00001	0.00000	0.00006
	8	0.54425	0.02457	0.00224	0.00157	0.00010	-0.00035
	9	0.00389	-0.03976	0.55007	0.00290	0.00014	-0.00150

************** END OF LATEST ANALYSIS RESULT **************

81. PRINT SUPPORT REACTION LIST 1 TO 24

```
    SOFIA HEAD SUPPORT FRAME                                  -- PAGE NO.   30


   SUPPORT REACTIONS -UNIT POUN INCH    STRUCTURE TYPE = SPACE
   -----------------

 JOINT  LOAD   FORCE-X   FORCE-Y   FORCE-Z     MOM-X     MOM-Y     MOM Z


     1    1     13.70    431.06     23.73      0.00      0.00      0.00
          2      0.00   2642.00      0.00      0.00      0.00      0.00
          3   -694.54  -1055.55   -315.73      0.00      0.00      0.00
          4   -133.17    283.10    -20.53      0.00      0.00      0.00
          5   -315.75  -1828.32  -1059.12      0.00      0.00      0.00
          6    -30.56    174.77   -174.25      0.00      0.00      0.00
          7     13.70   3073.06     23.73      0.00      0.00      0.00
          8   -680.84   1145.65   -292.00      0.00      0.00      0.00
          9   -302.05    372.88  -1035.39      0.00      0.00      0.00
     6    1     13.70    431.06    -23.73      0.00      0.00      0.00
          2      0.00   2642.00      0.00      0.00      0.00      0.00
          3   -694.53  -1055.55    315.73      0.00      0.00      0.00
          4   -133.17    283.10     20.53      0.00      0.00      0.00
          5    315.75   1828.32  -1059.11      0.00      0.00      0.00
          6     57.97    687.35   -221.71      0.00      0.00      0.00
          7     13.70   3073.06    -23.73      0.00      0.00      0.00
          8   -680.83   1145.65    292.00      0.00      0.00      0.00
          9    329.45   4029.53  -1082.84      0.00      0.00      0.00
    11    1    -27.40    431.06      0.00      0.00      0.00      0.00
          2      0.00   2642.00      0.00      0.00      0.00      0.00
          3  -1241.41   2111.10      0.00      0.00      0.00      0.00
          4   -250.94    726.99      0.00      0.00      0.00      0.00
          5      0.00      0.00   -512.25      0.00      0.00      0.00
          6    -27.40    431.06   -121.31      0.00      0.00      0.00
          7    -27.40   3073.06      0.00      0.00      0.00      0.00
          8  -1268.81   4312.31      0.00      0.00      0.00      0.00
          9    -27.40   2201.20   -512.25      0.00      0.00      0.00


   ************** END OF LATEST ANALYSIS RESULT **************


    82. FINISH


            *************** END OF STAAD-III ***************

              **** DATE= SEP 12,2000   TIME= 10:17:37 ****

         **********************************************************
         *  FOR  QUESTIONS REGARDING THIS VERSION OF PROGRAM      *
         *              RESEARCH ENGINEERS, Inc at                *
         *       Ph: (714) 974-2500   Fax:  (714) 921-2543        *
         **********************************************************
```

Chart Industries, Inc. PROCESS SYSTEMS DIVISION

WESTBOROUGH, MA 01581					ENGINEERING	NO: V095-1-033
THERMAL / VACUUM TECHNOLOGY GROUP					CALCULATIONS	Page 1 of 7
REV	DEO#	DATE	BY:	CHECK	TITLE:	
0		5/8/00			**Head Support Brackets**	
					BY: R. D. Ciatto	DEPT: 744
PROJECT: SOFIA MIRROR COATER NASA AMES					PROJECT NO: V59095	

PURPOSE: Design head support brackets in accordance with structural design criteria (SDC).
Ensure that brackets meet requirements for supporting weight of head with an impact factor of 1.5.

METHOD: Hand calculations.

ASSUMPTIONS: The minimum angle between the lifting cable and the horizontal plane is 30°.

INPUTS: Design temperature = 100°F for allowable stress.
Bracket reaction force from calculation V095-1-008.

REFERENCE: V095-1-005, Structural Design Criteria.
Roark & Young, Formulas for Stress & Strain, 6th Edition.
Project drawings and sketches.

CALCULATIONS:

see Attachments.

CONCLUSIONS: The head support brackets conform to project requirements. As assumed above, the minimum angle between the lifting cable and the horizontal plane is 30°. A smaller angle will result in a higher cable load that could endanger the structural integrity of the support brackets.

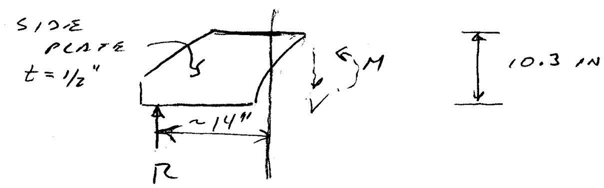
NOTES:

Revision History

Rev.	Comments	Date
0	Initial Issue	May, 2000

2

BRACKET PRIMARY STRESS AT SHELL



$R = 2360\#$ w/ IMPACT FACTOR = 1.5
(V095-1-008)
= MAX REACTION AT PIN

$\Rightarrow V = R = 2360\#$

$M = 14(2360) = 33040$ IN-LB

THERE ARE 2 BRACKET SIDE PLATES, EA. IS 1/2" THK

BENDING STRESS IN SIDE PLATE

$$f_b = \frac{6M}{2t(b)^2} =$$

$$= \frac{6(33040)}{2(1/2)(10.3)^2} =$$

$$= 1870 \text{ psi} \quad \text{ok}$$

USE DOUBLE FILLET WELD FOR CONNECTION OF SIDE PLATE TO HEAD. USE 3/8"

WELD AREA : $A_w = 4(.707)(3/8)(10.3)$
$= 10.9 \text{ in}^2$

6

WELD MOMENT OF INERTIA

$$I_w = 4(.707)(3/8)\frac{(10.3)^3}{12}$$

$$= 96.6 \ in^4$$

WELD DIRECT STRESS

$$f_{v_D} = \frac{V}{A_w} = \frac{2360}{10.5} = 217 \ psi$$

WELD SHEAR STRESS DUE TO BENDING

$$f_{vM} = \frac{MC}{I_w} = \frac{33040\left(\frac{10.3}{2}\right)}{96.6}$$

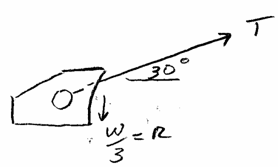
$$= 1762 \ psi$$

TOTAL WELD SHEAR STRESS

$$f_v = f_{vD} + f_{vM}$$

$$= 217 + 1762 = 1979 \ psi \ ok$$

CHECK PIPE FOR CABLE FORCE
MIN ANGLE ASSUMED TO BE 30°



$$T = \frac{W}{3} \times \frac{1}{\sin 30°}$$

$$= \frac{2360}{.5}$$

$$= 4720 \ \#$$

TRY 2 1/2 SCH 40 PIPE

PIPE LENGTH BETWEEN 2 SIDE PLATES
SEE DWG V 093-5-200, SHEET 2

$$L \simeq \frac{10}{19.38} \times (12-6) + 6$$

$$= 9.1 \quad \text{SAY } 10''$$

PIPE BENDING MOMENT

$$M = \frac{PL}{4} = \frac{4720(10)}{4} = 11800 \text{ IN-\#}$$

BENDING STRESS

$$f_b = \frac{M}{S} = \frac{11800}{1.064} = 11090 \text{ psi ok}$$

MAX SHEAR STRESS

$$f_v = \frac{V}{A} = \frac{4720}{1.708} = 2763 \text{ psi ok}$$

RING BENDING OF HEAD FLANGE DUE TO BRACKET LOAD

$$MAX\ +M = \frac{WR\left(\frac{1}{S} - \frac{k_2}{\theta}\right)}{2}$$

REF: ROARK - TABLE 17 CASE 7.

$k_2 = 1 - \alpha$

$\alpha = \frac{I}{AR^2}$

A = CROSS-SECTION AREA
$= 1.5 \times 4 = 6\ IN^2$

R = RADIUS = 80 IN TO CENTROID

$I = \frac{1.5(4)^3}{12} = 8\ IN^4$

$\alpha = \frac{8}{6(80)^2} = 2.0833(10)^{-4}$

$k_2 = .99979$

$s = \sin\theta$

$2\theta = 120°$
$\theta = 60° \approx 1.047$ RAD
$\sin\theta = .866 = S$ ← .2

$$+M = \frac{W(80)\left(\frac{1}{.866} - \frac{.99979}{1.047}\right)}{2}$$

$= W(80)\left(\frac{.2}{2}\right) = 8.0\ W$ IN-LB

$MAX\ -M = -\frac{WR}{2}\left(\frac{k_2}{\theta} - \frac{c}{s}\right)$

$c = \cos\theta = .50$ ← .3775

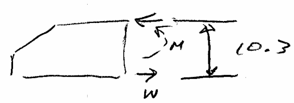
$-M = \frac{W(80)}{2}\left(\frac{.99979}{1.047} - \frac{.50}{.866}\right)$

$= 15.10\ W$ IN-LB ⇐ MAX

e

W = FORCE IN PLANE OF RING FROM COUPLE DUE TO BENDING OF BRACKET

$$W = \frac{M}{10.3}$$



$$= \frac{33040}{10.3} = 3200 \text{ LB}$$

MAX $-M = 15.1\,W = 15.1(3200) = 48325$

BENDING STRESS

$$f_b = \frac{Mc}{I} \quad (c = 2)$$

$$= 48325\,\frac{(2)}{8} = 12080 \text{ psi}$$

ok

MAX RADIAL DEFLECTION

$$\Delta = K_{\Delta R}\,\frac{WR^3}{EI} \qquad \text{REF: ROARK}$$

$K_{\Delta R} = .01594$ FOR $\theta = 60^\circ$

$$\Delta = \frac{.01594(3200)(80)^3}{29(10)^6(8)} = .113 \text{ IN}$$

ok

Chart Industries, Inc. PROCESS SYSTEMS DIVISION

WESTBOROUGH, MA 01581					ENGINEERING	NO: V095-1-031
THERMAL / VACUUM TECHNOLOGY GROUP					CALCULATIONS	Page 1 of 7
REV	DEO#	DATE	BY:	CHECK	TITLE:	
0		5/8/00			**Platform Design**	
					BY: R. D. Ciatto	DEPT: 744
PROJECT: SOFIA MIRROR COATER NASA AMES					PROJECT NO: V59095	

PURPOSE: Design platform in accordance with structural design criteria (SDC).
Ensure that frame meets requirements for supporting weight of platform DL & LL.

METHOD: Hand calculations for single angle members.

ASSUMPTIONS: N/A

INPUTS: Design temperature = 100°F for allowable stress.
Platform Live Load = 100 psf.

REFERENCE: V095-1-005, Structural Design Criteria.
AISC Manual of Steel Construction, 9th Ed. Spec. for Single Angle Members.
Ciatto Et. Al. Design Criteria for Single Angle Members, 1991 ASME Pressure Vessel & Piping Conference.
Walker, W. W., Tables for Single Angles in Compression, AISC Engineering Journal, 2nd Quarter, 1991.
Roark & Young, Formulas for Stress & Strain, 6th Edition.

CALCULATIONS:

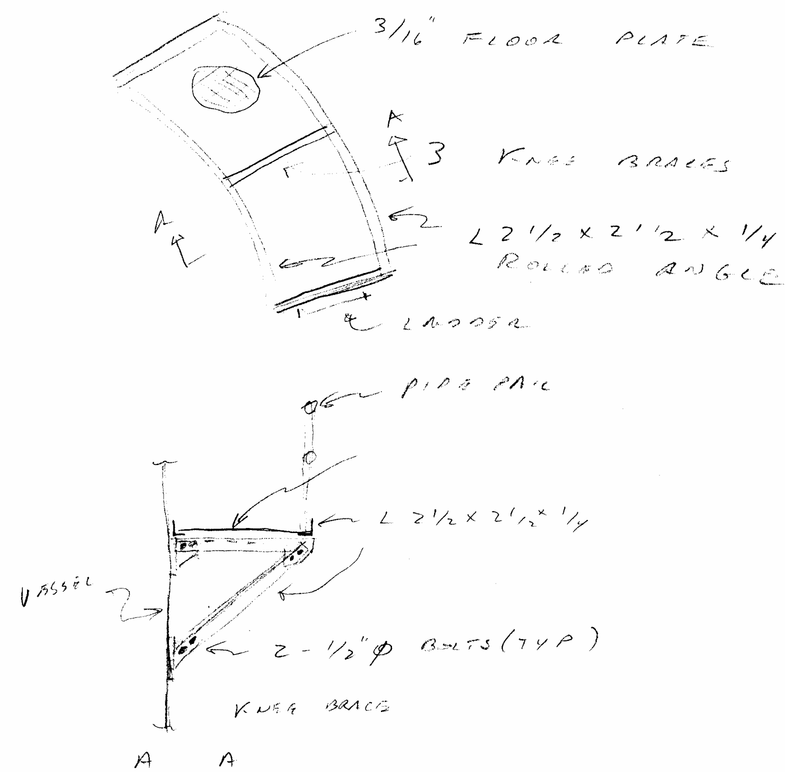
see Attachments.

CONCLUSIONS: The platform conforms to AISC and project requirements.

NOTES:

Revision History

Rev.	Comments	Date
0	Initial Issue	May, 2000


3/16" FLOOR PLATE
A
3 KNEE BRACES
A
∠ 2 1/2 x 2 1/2 x 1/4
ROLLED ANGLE
℄ LADDER
PIPE RAIL
∠ 2 1/2 x 2 1/2 x 1/4
VESSEL
2 - 1/2" φ BOLTS (TYP)
KNEE BRACE
A A

PLATFORM FLOOR PLATE

FROM AISC, P. 2-145 SELECT

$t = 3/16$ IN

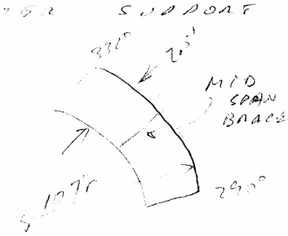
FOR FLOOR PLATE ALLOW LOAD IS

120 psf

DEAD WT = 8.70 psf

∴ LOAD CAPACITY > DL + LL = 9 + 100 = 109 psf

OUTER SUPPORT BEAM



ARC LENGTH: $S = \frac{42^\circ}{360^\circ} \times \pi(2 \times 107)$

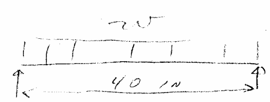
$= 78.4$ IN

USE A MIDSPAN BRACE, THEN SPAN LENGTH IS:

$L = \frac{S}{2} = 39.2$ SAY 40 IN

DESIGN AS SIMPLY SUPPORTED STRAIGHT BEAM

BEAM LOAD



@ $\frac{2.5'}{2}$

$w = U \times 1.25'$

$U = LL + DL = 100$ psf $+ 8.7 = 109$ psf

$U = 120$ w/ HANDRAILS, ETC

$w = 120(1.25) = 150$ LB/FT

$= 12.5$ LB/IN

$$M = \frac{wL^2}{8}$$

$$= \frac{12.5(40)^2}{8} = 2500 \text{ IN-LB}$$

TRY $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$ ANGLE.

$$S_x = .394$$

$$f_b = \frac{M}{S} = \frac{2500}{.394}$$

$$= 6345 \text{ psi}$$

$$b/t = \frac{2.5}{.25} = 10$$

FOR LOCAL BUCKLING

$$F_B = 24\text{ KSI WHEN } b/t \le \frac{65}{\sqrt{F_y}} = \frac{65}{6} = 10.8$$

FOR LAT/TOR BUCKLING

$$L/b = \frac{40}{3} = 13.3$$

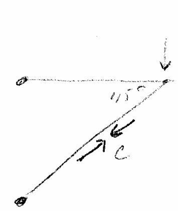
FROM FIG 3 OF C1A220 - DESIGN CRITERIA FOR SINGLE ANGLE MEMBERS

$$F_B = 24\text{ KSI FOR } L/b = 13.3\ \&\ b/t = 10$$

$\therefore$ ∠ $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$ OK

FOR DIAGONAL OR KNEE BRACE

TRY ∠ $2\frac{1}{2} \times 2\frac{1}{2} \times 1/4$



$$P = 1.25 \times \frac{40}{12} \times U$$

$$= 1.25 \times \frac{40}{12} \times 120$$

$$= 500 \text{ LB}$$

$$C = \frac{P}{.707} = \frac{500}{.707} = 707 \text{ LB}$$

$$L = \frac{2.5'}{.707} = 3.54'$$

$$KL = 3.54'$$

ALLOW AXIAL LOAD =

$$P_{ALL} = 5.2^K \text{ FOR } KL = 4$$

REF: TABLES FOR EQUAL ANGLES IN COMPRESSION

$$P < P_{ALL} \quad OK$$

CHECK PLATE FOR CONCENTRATED LOAD.

LOAD $W = 300$ LB OVER 4" Ø CIRCLE

PLATE RECTANGULAR DIMENSIONS

$a = 40$

$b = 28$

REF: ROARK & YOUNG, 6TH EDITION, TABLE 26
CASE 1b, P. 454

$r_o' = \sqrt{1.6 r_o^2 + t^2}$

$r_o = 2"$

$t = 3/16"$

$r_o' = (1.6(2)^2 + .1875^2)^{1/2}$
$= 2.54$ IN

$\frac{a}{b} = \frac{40}{28} = 1.43$

$\beta = .802$ (INTERPOLATED)

$\sigma_{MAX} = \frac{3W}{2\pi t^2}\left[(1+\nu)\ln\frac{2b}{\pi r_o'} - \beta\right]$

$= \frac{3(300)}{2\pi(.1875)^2}\left[1.3(7.651) + .802\right]$

$= 17,700$ psi OK

Attachment J.7.6

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

SPECIFICATION FOR

PIPING DESIGN AND MATERIAL

FOR

PRIMARY MIRROR COATING SYSTEM

SOFIA PROJECT

NASA AMES RESEARCH CENTER

Moffett Field, CA

PREPARED BY: JOHN FLINN

CIVIL/STRUC. ENGINEER: RAY CIATTO

REVIEWED BY: DAVID McWILLIAMS

PROJECT MANAGER: MICHAEL FREEMAN

1	**JBF – 7/13/00**	**DMcW-8/1/00**	Revise per CDR comments
0	**JBF – 4/21/00**	**DMcW-4/22/00**	Initial Release Per DEO # 0002
REV LTR	BY-DATE	APPD. DATE	DESCRIPTION OF CHANGE

CHART IND. - PROCESS SYSTEMS DIVISION					**SPECIFICATION**	
INITIAL APPROVALS	PREPARED JBF	DATE 04/21/00	Approved MAF	DATE 4/22/00	Number: **V095-2-013**	Rev. **1**

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

TABLE OF CONTENTS

SPECIFICATION	
Number: **V095-2-013**	Rev. **1**

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

1.0 INTRODUCTION

1.1 The following piping and material specifications define the piping and fittings to be used for the Mirror Coating System for the Primary Mirror on the SOFIA project.

1.2 All attachments are made part of this specification.

1.3 See V095-0-001 P&ID for line routing.

1.4 Questions regarding specified system shall be directed to: Mike Freeman
ph: (508) 898-0327, fax: (508) 898-0308.

2.0 CODES AND STANDARDS

2.1 PRIORITY OF DOCUMENTS

Priority of documents shall be as follows:

1) Codes and Standards (highest priority)
2) This Specification

2.2 APPLICABLE CODES AND STANDARDS

ANSI American National Standards Institute

- B31.3 Chemical Plant and Petroleum Refinery Piping (for process piping only)
- B31.5 Refrigeration Piping
- B36.19 Stainless Steel Pipe
- B16.5 Pipe Flanges and Flange Fittings

ASTM American Society of Testing and Materials

- A380-88 Standard Practice for Cleaning and De-scaling Stainless Steel
- E427-71(81) Standard Practice for Testing for Leaks Using the Halogen Leak Detector
- E493-73(80) Standard Practice for Testing for Leaks Using the Mass Spectrometer Leak Detector in the Inside-out Testing Mode
- E498-73(80) Standard Test Method for Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode
- E499-73(80) Standard Methods of Testing for Leaks Using the Mass Spectrometer Leak Detector Probe Mode

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

2.3 SPECIFICATION COMPLIANCE

The equipment shall comply with any drawings, data sheets, specifications, codes and standards (latest editions) referred to or attached as part of this specification. Vendor will comply with State or local codes or regulations. The vendor is responsible for compliance with such standards, specifications, codes and regulations, if attached.

2.4 The following standards will also be used:

a) Standard Temperature: 60°F (15.6°C)

b) Standard Pressure: 14.7 psia (101.325 kPa)

3.0 MATERIAL/MANUFACTURING REQUIREMENTS

3.1 All materials used to manufacture the piping, tubing, flanges or fittings, as designated per this specification, are to be of U.S.A. or foreign origin and manufacture as allowed by U.S. laws or regulations.

4.0 EXAMINATION AND TESTING

Examination and pressure testing as required by ANSI B31.3-1990 CHAPTER VI, if applicable.

5.0 LINE NUMBER SYSTEM

5.1 Lines shall be numbered according to the following chart:

2 PL 0008 XYZ 3 FP3

- **FP3** — Insulation Mat'l Service (See Section 5.5)
- **3** — Insulation Thickness (inches)
- **XYZ** — Piping Specification Designation (See Section 5.4)
- **0008** — Sequential Number (See Section 5.3)
- **PL** — Fluid Service Code (See Section 5.2)
- **2** — Line Size (Nominal Pipe, inches).

5.2 Fluid Codes

Code	Fluid
AIR	Air
AR	Gaseous Argon
GN2	Gaseous Nitrogen
HE	Helium
IA	Instrument Air
LN2	Liquid Nitrogen
N	Nitrogen (Either Gas or Liquid)
O2	Gaseous Oxygen
PV	Process Vacuum
VA	Vent and Relief to Atm.

5.3 Sequential Number Identification

5.3.1	Roughing System:	100 – 199
5.3.2	Meissner System:	200 – 299
5.3.3	Cryopump System:	300 – 399
5.3.4	Glow Discharge System:	400 – 499
5.3.5	Filament System:	500 – 599
5.3.6	Backfill System:	600 – 699
5.3.7	Chamber:	700 – 799

5.4 Piping Specification Designation

5.4.1 "X" First Digit Identifiers (none for tubing)

1 = 150 # ANSI

5.4.2 "Y" Second Digit Identifiers

A = 6061 T6 Aluminum
B = 304 Stainless Steel
C = Type L Copper Tubing
T = Stainless Steel Tubing

5.4.3 "Z" Third Digit Identifiers

1 = Cryogenic
2 = Non-Cryogenic
3 = Vacuum
4 = Instrument Air

5.5 Insulation Material Codes

If no insulation material code appears in the line number then, it shall be understood that no insulation is required. The suffix VJ refers to piping which is insulated by vacuum-jacketing.

Insulation thickness is shown in inches followed by the insulation symbol

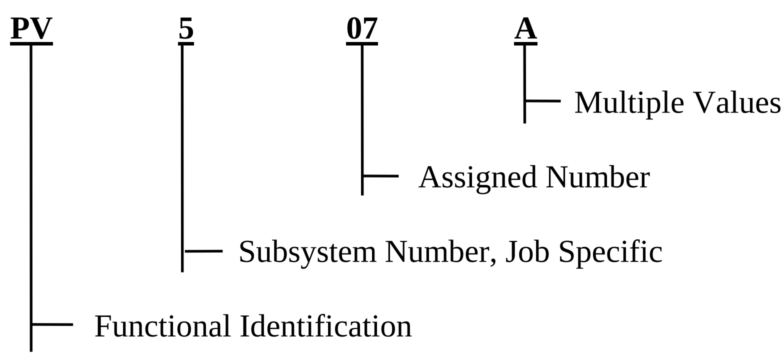
Insulation Symbol	Insulation Service
CC	Cold Conservation
FP	Freeze Protection
PP	Personnel Protection

Use a closed cell foam insulation for freeze protection. No jacket is required.

See Tables I and II in Appendix for required thickness.

6.0 VALVE AND INSTRUMENT NUMBER SYSTEM

6.1 Control valves and associated instruments shall be designated according to P&ID Drawing Symbols. Unless required otherwise the symbology on the P&ID drawing will follow ISA-S5.1, Table 1.



7.0 ATTACHMENTS

ATTACHMENT 7.1

TABLE I

COLD INSULATION THICKNESS

THERMAL / PROCESS

POLYISOCYANURATE - *INCHES*

PIPE SIZE	*** +32°F to -25°F**	**-26°F to -50°F**	**-51°F to -100°F**	**-101°F to -150°F**	**-151°F to -200°F**	**-201°F to -265°F**	**-266°F to -320°F**
1½" or less	1-1/2	2	2	2-1/2	3	3-1/2	4
2"	2	2	2-1/2	3	3-1/2	4	4-1/2
3"	2	2-1/2	3	3-1/2	4	4-1/2	5
4"	2-1/2	2-1/2	3	4	4-1/2	4-1/2	5
6"	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2
8"	2-1/2	3	3-1/2	4	5	5-1/2	6
10"	3	3	3-1/2	4-1/2	5	5-1/2	6
12"	3	3	3-1/2	4-1/2	5	5-1/2	6
14"	3	3-1/2	4	4-1/2	5-1/2	5-1/2	6
16"	3	3-1/2	4	4-1/2	5-1/2	5-1/2	6
18"	3	3-1/2	4-1/2	4-1/2	6	6	6-1/2
20" thru 24"	3	3-1/2	4-1/2	5	6	6-1/2	7
Over 24" and Flat	3	3-1/2	4-1/2	5	6-1/2	7	7-1/2

* Freeze protection

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

ATTACHMENT 7.2

TABLE II

COLD INSULATION THICKNESS

PERSONNEL PROTECTION

POLYISOCYANURATE - *INCHES*

PIPE OPERATING TEMPERATURE, F	**PIPE SIZES** 1/2" TO 3"	4" TO 10"	Over 12"
+32°F to -50°F	1	1	1
-51°F to -200°F	1	1	1-1/2
-201°F to -265°F	1-1/2	2	2-1/2
-266°F to -320°F	2	2-1/2	3

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

ATTACHMENT 7.3

1B1

PIPING DESIGN AND MATERIAL SPECIFICATION

Service:	Cryogenic
Primary Rating:	150# ANSI 304 SSTL
Design Conditions:	
Pressure	0 To 150 psig [0 To 1.034 MPa (gauge)]
Temperature	-320F To +247F [-195 C To +120 C]
Corrosion Allowance	Zero
Pipe:	
12" And Smaller	ASTM A312 TP304
Pipe Schedule:	
1 1/2" and Smaller	Schedule 10s Smls (Schedule 80 Smls or EFW For Threaded Components, If Any.)
8" and Smaller	Schedule 10s Smls or EFW
10" thru 12"	Schedule 10s EFW

Note: Vacuum jacketed piping will be designed and fabricated in accordance with the manufacturer's standard.

Fittings:	
2" And Smaller	Socket Welded 3000#
Larger than 2"	Butt Weld
	ASTM A403 Wp304 WPS, WPW
	O'let's ASTM A182-F304

Flanges:

Flanges shall be stainless steel raised-face design. Flanged joints shall have spiral wound, stainless steel gaskets, flexitallic or equal.

Valves:

Valves shall be furnished under their own unique specification.

Continued On Next Page

Title: SPECIFICATION FOR PIPING DESIGN AND MATERIAL

1B1

Branch Connections:

Run Size "

Run Size											
½	04										
¾	06	04									
1	12	06	04								
1½	05	05	06	04							
2	05	05	06	06	04						
3	05	05	05	05	06	04					
4	05	05	05	05	12	06	04				
6	05	05	05	05	12	12	06	04			
8	05	05	05	05	12	12	12	06	04		
10	05	05	05	05	12	12	12	12	06	04	
12	05	05	05	05	12	12	12	12	12	06	04
Branch Size	½	¾	1	1½	2	3	4	6	8	10	12

04 - Tee
05 - Sockolet
06 - Tee Then Reducer Or Reducing Tee
12 - BW O'let

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

ATTACHMENT 7.4

1B2

PIPING DESIGN AND MATERIAL SPECIFICATION

Service:	Non-Cryogenic
Primary Rating:	150# ANSI 304 SSTL
Design Conditions:	
Pressure	0 To 150 psig [0 To 1.034 MPa (gauge)]
Temperature	-40F To +211F [-40 C To +100 C]
Corrosion Allowance	Zero
Pipe:	
12" and smaller	ASTM A312 TP304
Pipe Schedule:	
1 1/2” and smaller	Schedule 10s (Schedule 80 or EFW for threaded components, if any)
8" and smaller	Schedule 10s
10" Thru 12"	Schedule 10s
Fittings:	
2” And Smaller	Socket Welded 3000#
Larger than 2”	Butt Weld ASTM A403 Wp304 WPS, WPW Elbow O'let ASTM A182-F304

Flanges:
Flanges shall be stainless steel raised-face design.

Gaskets:
Spiral wound, stainless steel graphite gaskets, flexitallic type flexicarb or equal.

Valves:
Valves shall be furnished under their own unique specification.

Continued On Next Page.

Title: SPECIFICATION FOR PIPING DESIGN AND MATERIAL

1B2

Branch Connections:

Run Size "

Run Size											
½	04										
¾	06	04									
1	12	06	04								
1½	05	05	06	04							
2	05	05	06	06	04						
3	05	05	05	05	06	04					
4	05	05	05	05	12	06	04				
6	05	05	05	05	12	12	06	04			
8	05	05	05	05	12	12	12	06	04		
10	05	05	05	05	12	12	12	12	06	04	
12	05	05	05	05	12	12	12	12	12	06	04
Branch Size	½	¾	1	1½	2	3	4	6	8	10	12

04 - Tee
05 - Sockolet
06 - Tee Then Reducer Or Reducing Tee
12 - BW O'let

SPECIFICATION

Number: **V095-2-013** Rev. **1**

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

ATTACHMENT 7.5

1B3

PIPING DESIGN AND MATERIAL SPECIFICATION

Service:	Process Vacuum
Primary Rating:	150# ANSI 304 SSTL
Design Conditions:	
Pressure	Vacuum 10^{-5} Torr To 2 psig [0.014 MPa (gauge)]
Temperature	84F To 148F [-29 C To +65 C]
Corrosion Allowance	Zero
Pipe:	
12" and smaller	ASTM A312 TP304
Pipe Schedule:	
1 1/2” and smaller	Schedule 10s (Schedule 80 or EFW for threaded components, if any.)
8" and smaller	Schedule 10s
10" Thru 12"	Schedule 10s
Fittings:	
1 1/2” And Smaller	Socket Welded 3000#
2" And Larger	Butt Weld ASTM A403 Wp304 WPS, WPW Elbow O'let ASTM A182-F304

Flanges: “JIS” Vacuum flanges.

Gaskets: O-ring.

Valves: Valves shall be furnished under their own unique specification.

Continued On Next Page.

Title: **SPECIFICATION FOR PIPING DESIGN AND MATERIAL**

1B3

Branch Connections:

Run Size "

Run Size											
½	04										
¾	06	04									
1	12	06	04								
1½	05	05	06	04							
2	05	05	06	06	04						
3	05	05	05	05	06	04					
4	05	05	05	05	12	06	04				
6	05	05	05	05	12	12	06	04			
8	05	05	05	05	12	12	12	06	04		
10	05	05	05	05	12	12	12	12	06	04	
12	05	05	05	05	12	12	12	12	12	06	04
Branch Size	½	¾	1	1½	2	3	4	6	8	10	12

04 - Tee
05 - Sockolet
06 - Tee Then Reducer Or Reducing Tee
12 - BW O'let

SPECIFICATION

Number: **V095-2-013** Rev. **1**

Title: SPECIFICATION FOR PIPING DESIGN AND MATERIAL

ATTACHMENT 7.6

T1

PIPING DESIGN AND MATERIAL SPECIFICATION

Service:	Cryogenic
Design Conditions:	
Pressure	0 To 150 psig [0 To 1.034 MPa (gauge)]
Temperature	-320F To +247F [-195 C To +120 C]
Corrosion Allowance	Zero
Tube:	
All Sizes	ASTM A269 Gr 304l Smls Tube sizes designated by OD dimensions.

Tube Size (OD):	Minimum Wall Thickness (Inches)
1/4"	0.035"
3/8”	0.035"
1/2"	0.049"
3/4"	0.049"
1"	0.065"

Fittings:

All fittings to be Swagelok® tube fittings, no substitutions.

Valves:

Valves shall be furnished under their own unique specification.

Title: SPECIFICATION FOR PIPING DESIGN AND MATERIAL

ATTACHMENT 7.7

T2

PIPING DESIGN AND MATERIAL SPECIFICATION

Service: Non-Cryogenic

Design Conditions:

Pressure	0 To 150 psig [0 To 1.034 MPa (gauge)]
Temperature	-40F To +211F [-40 C To +100 C]
Corrosion Allowance	Zero

Tube:

All Sizes — ASTM A269 GR TP304 Smls
Tube sizes designated by OD dimensions.

Tube Size (OD):	Minimum Wall Thickness (Inches)
1/4"	0.035"
3/8"	0.035"
1/2"	0.049"
3/4"	0.049"
1"	0.065"

Fittings:

All fittings to be Swagelok® tube fittings, no substitutions.

Valves:

Valves shall be furnished under their own unique specification.

Title: SPECIFICATION FOR PIPING DESIGN AND MATERIAL

ATTACHMENT 7.8

T3

PIPING DESIGN AND MATERIAL SPECIFICATION

Service: Process Vacuum

Design Conditions:

Pressure	Vacuum 10^{-5} Torr To 2 psig [0.014 MPa (gauge)]
Temperature	84F To 148F [-29 C To +65 C]
Corrosion Allowance	Zero

Tube: (Tube sizes designated By OD dimensions)

All Sizes Up To 1"	ASTM A269 GR TP304L Smls
1 1/2" And Larger	ASTM A26 GR TP304L Smls Or Welded.

Tube Size (OD):	Minimum Wall Thickness (Inches)	Conflat Flange Size	No. Bolts	B.C. Dia.	Thru Hole Dia.
¼"	0.035"	1 1/3" Nom. OD	6	1.062"	.172"
3/8"	0.035"	1 1/3" Nom. OD	6	1.062"	.172"
1/2"	0.035"	1 1/3" Nom. OD	6	1.062"	.172"
3/4"	0.035"	2 1/8" Nom. OD	4	1.625"	.265"
1"	0.065"	2 3/4" Nom. OD	6	2.312"	.265"
1 1/2"	0.065"	2 3/4" Nom. OD	6	2.312"	.265"
2"	0.065"	3 3/8" Nom. OD	8	2.85"	.332"
2 1/2"	0.065"	4 1/2" Nom. OD	8	3.628"	.332"
4"	0.083"	6" Nom. OD	16	5.128"	.332"
6"	0.083	8" Nom. OD	20	7.128"	.332"
8"	0.120	10" Nom. OD	24	9.128"	.332"
10"	0.120	12" Nom. OD	32	11.181"	.332"
12"	0.120	14" Nom. OD	30	12.810"	.390"
14"	0.120	16 1/2" Nom. OD	36	15.310"	.390"

Continued on next page.

T3

Flanges:
All flanges to be Conflat, ISO Large Flange or KF tube fittings 304 S. S.

Connectors:
All fittings to be 304 butt weld or flanged OD tube, wall thickness to match tube wall thickness listed above.

Valves:
Valves shall be furnished under their own unique specification.

SAFETY DATA SHEET
North American Version

FOMBLIN(R) Y LVAC

1. PRODUCT AND COMPANY IDENTIFICATION

1.1. Identification of the substance or preparation

Product name	:	FOMBLIN(R) Y LVAC
Product grade(s)	:	06/6; 14/6; 16/6; 25/6; 300
Structural formula		CF3-O- (C3F6O)n -(CF2-O)m-CF3
Molecular Weight	:	
Average value :		1,800 - 3,300

1.2. Use of the Substance/Preparation

Recommended use :
- Electronic industry
- Electrical industry
- Chemical industry
- For industrial use only.

1.3. Company/Undertaking Identification

Address : SOLVAY SOLEXIS, INC.
10 LEONARD LANE
WEST DEPTFORD NJ 08086
United States

1.4. Emergency and contact telephone numbers

Emergency telephone : **1 (800) 424-9300 CHEMTREC ® (USA & Canada)**

Contact telephone number (product information): : **(856) 853-8119 (Product information)**

2. HAZARDS IDENTIFICATION

2.1. Emergency Overview:

NFPA : H= 1 F= 0 I= 0

General Information

Appearance	:	liquid
Colour	:	colourless
Odour	:	odourless

Main effects
- The product is biologically inert.
- Not hazardous in normal conditions of handling and use
- Ecological injuries are not known or expected under normal use.
- Thermal decomposition can lead to release of toxic and corrosive gases.

2.2. Potential Health Effects:

Inhalation

- No known effect.

Eye contact
- Contact with eyes may cause irritation.
- Redness

Skin contact
- Redness

Ingestion
- Ingestion may provoke the following symptoms:
- Symptoms: Nausea, Vomiting, Diarrhoea.

Other toxicity effects
- See section 11: Toxicological Information

2.3. Environmental Effects:
- See section 12: Ecological Information

3. COMPOSITION/INFORMATION ON INGREDIENTS

1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.

CAS-No.	:	69991-67-9
Concentration	:	**> 99.0 %**

4. FIRST AID MEASURES

4.1. Inhalation
- Move to fresh air in case of accidental inhalation of fumes from overheating or combustion.
- Oxygen or artificial respiration if needed.

4.2. Eye contact
- Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes.
- If eye irritation persists, consult a specialist.

4.3. Skin contact
- Wash off with soap and water.
- If symptoms persist, call a physician.

4.4. Ingestion
- Drink 1 or 2 glasses of water.
- Do NOT induce vomiting.
- If symptoms persist, call a physician.

5. FIRE-FIGHTING MEASURES

5.1. Suitable extinguishing media
- Water
- powder
- Foam
- Dry chemical
- Carbon dioxide (CO_2)

5.2. Extinguishing media which shall not be used for safety reasons
- None.

5.3. Special exposure hazards in a fire
- The product is not flammable.

- Not explosive
- In case of fire hazardous decomposition products may be produced such as: Gaseous hydrogen fluoride (HF), Fluorophosgene

5.4. Hazardous decomposition products
- Gaseous hydrogen fluoride (HF).
- Fluorophosgene

5.5. Special protective equipment for fire-fighters
- Wear self-contained breathing apparatus and protective suit.
- When intervention in close proximity wear acid resistant over suit.

5.6. Other information
- Evacuate personnel to safe areas.
- Approach from upwind.
- Protect intervention team with a water spray as they approach the fire.
- Keep containers and surroundings cool with water spray.
- Keep product and empty container away from heat and sources of ignition.

6. ACCIDENTAL RELEASE MEASURES

6.1. Personal precautions
- Ensure adequate ventilation.
- Material can create slippery conditions.
- Prevent further leakage or spillage if safe to do so.
- Keep away from open flames, hot surfaces and sources of ignition.
- Refer to protective measures listed in sections 7 and 8.

6.2. Environmental precautions
- Should not be released into the environment.
- The product should not be allowed to enter drains, water courses or the soil.
- In case of accidental release or spill, immediately notify the appropriate authorities if required by Federal, State/Provincial and local laws and regulations.

6.3. Methods for cleaning up
- Soak up with inert absorbent material.
- Suitable material for picking up
- Earth
- Sawdust
- Shovel into suitable container for disposal.

7. HANDLING AND STORAGE

7.1. Handling
- Do not use in areas without adequate ventilation.
- To avoid thermal decomposition, do not overheat.
- Keep away from heat and sources of ignition.

7.2. Storage
- No special storage conditions required.
- Keep in properly labelled containers.
- Keep away from heat and sources of ignition.
- Keep away from combustible material.
- Keep away from Incompatible products.

7.3. Packaging material
- Polyethylene

7.4. Other information
- Provide tight electrical equipment well protected against corrosion.
- Refer to protective measures listed in sections 7 and 8.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1. Exposure Limit Values
Remarks:
- Threshold limit values of by-products from thermal decomposition

Hydrogen fluoride anhydrous
- US. ACGIH Threshold Limit Values 2007
  time weighted average = 0.5 ppm
  Remarks: as F
- US. ACGIH Threshold Limit Values 2007
  Ceiling Limit Value = 2 ppm
  Remarks: as F
- US. OSHA Table Z-1-A (29 CFR 1910.1000) 1989
  time weighted average = 3 ppm
  Remarks: as F
- US. OSHA Table Z-1-A (29 CFR 1910.1000) 1989
  Short term exposure limit = 6 ppm
  Remarks: as F
- US. ACGIH Threshold Limit Values 2008
  Remarks: as F, Can be absorbed through skin.
- US. OSHA Table Z-2 (29 CFR 1910.1000) 02 2006
  time weighted average = 3 ppm
- US. OSHA Table Z-1 Limits for Air Contaminants (29 CFR 1910.1000) 02 2006
  Permissible exposure limit = 2.5 mg/m3
  Remarks: as F

Carbonyl difluoride
- US. ACGIH Threshold Limit Values 01 2006
  time weighted average = 2 ppm
- US. ACGIH Threshold Limit Values 01 2006
  Short term exposure limit = 5 ppm
- US. OSHA Table Z-1-A (29 CFR 1910.1000) 1989
  time weighted average = 2 ppm
  time weighted average = 5 mg/m3
- US. OSHA Table Z-1-A (29 CFR 1910.1000) 1989
  Short term exposure limit = 5 ppm
  Short term exposure limit = 15 mg/m3
- US. OSHA Table Z-2 (29 CFR 1910.1000) 02 2006
  time weighted average = 2.5 mg/m3
  Remarks: Dust
- US. OSHA Table Z-1 Limits for Air Contaminants (29 CFR 1910.1000) 02 2006
  Permissible exposure limit = 2.5 mg/m3
  Remarks: as F

ACGIH® and TLV® are registered trademarks of the American Conference of Governmental Industrial Hygienists.

SAEL = Solvay Acceptable Exposure Limit, Time Weighted Average for 8 hour workdays. No Specific TLV STEL (Short Term Exposure Level) has been set. Excursions in exposure level may exceed 3 times the TLV TWA for no more than a total of 30 minutes during a workday and under no circumstances should they exceed 5 times the TLV TWA.

8.2. Engineering controls

- Provide local ventilation appropriate to the product decomposition risk (see section 10).
- Refer to protective measures listed in sections 7 and 8.
- Apply technical measures to comply with the occupational exposure limits.
- For additional information, consult the current edition of The Guide to the Safe Handling of Fluoropolymers published by the Society of Plastics Industry, Inc. (SPI) Fluoropolymer Division.

8.3. Personal protective equipment

8.3.1. Respiratory protection

- No personal respiratory protective equipment normally required.
- Wear self-contained breathing apparatus in confined spaces, in cases where the oxygen level is depleted, or in case of significant emissions.
- Use only respiratory protection that conforms to international/ national standards.

8.3.2. Hand protection

- Rubber or plastic gloves
- Latex gloves
- Take note of the information given by the producer concerning permeability and break through times, and of special workplace conditions (mechanical strain, duration of contact).

8.3.3. Eye protection

- Safety glasses with side-shields
- If splashes are likely to occur, wear: Tightly fitting safety goggles

8.3.4. Skin and body protection

- Rubber apron
- long sleeved clothing

8.3.5. Hygiene measures

- Ensure that eyewash stations and safety showers are close to the workstation location.
- When using do not eat, drink or smoke.
- Wash hands before breaks and at the end of workday.
- Handle in accordance with good industrial hygiene and safety practice.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1. General Information

Appearance	:	liquid
Colour	:	colourless
Odour	:	odourless

9.2. Important health safety and environmental information

Boiling point/boiling range	:	> 270 °C (518 °F)
Flash point	:	*Remarks*: The product is not flammable.
Flammability	:	*Remarks*: The product is not flammable.
Explosive properties	:	*Explosion danger*: *Remarks*: Not explosive
Oxidizing properties	:	*Remarks*: Non oxidizer

Vapour pressure	:	0.0000001 - 0.000013 hPa *Temperature*: 20 °C (68 °F)
Relative density / Density	:	1.88 - 1.90 g/cm3
Solubility	:	Water *Remarks*: insoluble
	:	fluorinated solvents *Remarks*: soluble
Viscosity	:	ca. 95 - 560 mPa.s *Temperature*: 20 °C (68 °F)

9.3. Other data

Melting point/range	:	*Remarks*: not applicable
Decomposition temperature	:	> 290 °C (554 °F)

10. STABILITY AND REACTIVITY

10.1. Stability
- Stable under recommended storage conditions.

10.2. Conditions to avoid
- To avoid thermal decomposition, do not overheat.
- Keep away from flames and sparks.
- Keep at temperature not exceeding: 290 °C (554 °F)

10.3. Materials to avoid
- Combustible material, Flammable materials, metals promote and lower decomposition temperature, Lewis acids (Friedel-Crafts) above 100°C, Aluminum and magnesium in powder form above 200°C

10.4. Hazardous decomposition products
- Gaseous hydrogen fluoride (HF)., Fluorophosgene

11. TOXICOLOGICAL INFORMATION

Toxicological data

Acute oral toxicity
- LD50, rat, > 15,000 mg/kg

Acute dermal irritation/corrosion
- LD50, rat, > 5,000 mg/kg

Skin irritation
- rabbit, No skin irritation
- rabbit, No skin irritation

Eye irritation
- rabbit, No eye irritation

Sensitisation
- guinea pig, Did not cause sensitization on laboratory animals.

Genetic toxicity in vitro
- Not mutagenic in Ames Test.
- negative , Remarks: Chromosome aberration test in vitro

Remarks
- Description of possible hazardous to health effects is based on experience and/or toxicological characteristics of several components.
- The product is biologically inert.

12. ECOLOGICAL INFORMATION

12.1. Ecotoxicity effects

Acute toxicity
- Fishes, Brachydanio rerio, LC50, 96 h, > 360 mg/l
  Remarks: saturated aqueous solution
- Daphnia magna (Water flea), EC50, 48 h, > 360 mg/l
  Remarks: saturated aqueous solution

12.2. Mobility
- Remarks: no data available

12.3. Persistence and degradability

Abiotic degradation
- Result: no data available

Biodegradation
- Remarks: no data available

12.4. Bioaccumulative potential
- Result: no data available

12.5. Other adverse effects
- no data available

12.6. Remarks
- Ecological injuries are not known or expected under normal use.

13. DISPOSAL CONSIDERATIONS

13.1. Waste from residues / unused products
- Can be incinerated, when in compliance with local regulations.
- The incinerator must be equipped with a system for the neutralisation or recovery of HF.
- In accordance with local and national regulations.

13.2. Packaging treatment
- Empty containers can be landfilled, when in accordance with the local regulations.

13.3. RCRA Hazardous Waste
- Listed RCRA Hazardous Waste (40 CFR 302) - No

14. TRANSPORT INFORMATION

- Sea (IMO/IMDG)
- not regulated
- Air (ICAO/IATA)
- not regulated
- U.S. Dept of Transportation

- not regulated
- It is recommended that ERG Guide number 111 be used for all non-regulated material.
- Canadian Transportation of Dangerous Goods
- not regulated

15. REGULATORY INFORMATION

15.1. Inventory Information

Toxic Substance Control Act list (TSCA)	: -	In compliance with inventory.
Australian Inventory of Chemical Substances (AICS)	: -	In compliance with inventory.
Canadian Domestic Substances List (DSL)	: -	In compliance with inventory.
Inventory of Existing Chemical Substances (China) (IECS)	: -	In compliance with inventory.
Korea Existing Chemicals Inv. (KECI) (KECI (KR))	: -	In compliance with inventory.
Japanese Existing and New Chemical Substances (MITI List) (ENCS)	: -	In compliance with inventory.
New Zealand Inventory (in preparation) (NZ)	: -	In compliance with inventory.
Philippine Inventory of Chemicals and Chemical Substances (PICCS)	: -	In compliance with inventory.
EU list of existing chemical substances (EINECS)	: -	not applicable, Product falls under the EU-polymer definition..

15.2. Other regulations

US. EPA Emergency Planning and Community Right-To-Know Act (EPCRA) SARA Title III Section 302 Extremely Hazardous Substance (40 CFR 355, Appendix A)

- not regulated.

SARA Hazard Designation (SARA 311/312)

- Acute Health Hazard: No.
- Chronic Health Hazard: No.
- Fire Hazard: No.
- Reactivity Hazard: No.
- Sudden Release of Pressure Hazard: No.

US. EPA Emergency Planning and Community Right-To-Know Act (EPCRA) SARA Title III Section 313 Toxic Chemicals (40 CFR 372.65) - Supplier Notification Required

- not regulated.

US. EPA CERCLA Hazardous Substances (40 CFR 302)

- not regulated.

US. New Jersey Worker and Community Right-to-Know Act (New Jersey Statute Annotated Section 34:5A-5)

- not regulated.

US. Pennsylvania Worker and Community Right-to-Know Law (34 Pa. Code Chap. 301-323)

- not regulated.

US. California Safe Drinking Water & Toxic Enforcement Act (Proposition 65)

- This product does not contain any chemicals known to State of California to cause cancer, birth, or any other reproductive defects..

OSHA Hazard communication standard

- This material is non-hazardous as defined by the American OSHA Hazard Communication Standard.

15.3. Classification and labelling

Canada. Canadian Environmental Protection Act (CEPA). WHMIS Ingredient Disclosure List (Can. Gaz., Part II, Vol. 122, No. 2)

- Does not contain a controlled product

Remarks: This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

16. OTHER INFORMATION

Ratings :

NFPA (National Fire Protection Association)
Health = 1 Flammability = 0 Instability = 0

Further information

- New (MSDS)
- Distribute new edition to clients

Material Safety Data Sheets contain country specific regulatory information; therefore, the MSDS's provided are for use only by customers of the company mentioned in section 1 in North America. If you are located in a country other than Canada, Mexico or the United States, please contact the Solvay Group company in your country for MSDS information applicable to your location. The previous information is based upon our current knowledge and experience of our product and is not exhaustive. It applies to the product as defined by the specifications. In case of combinations or mixtures, one must confirm that no new hazards are likely to exist. In any case, the user is not exempt from observing all legal, administrative and regulatory procedures relating to the product, personal hygiene, and integrity of the work environment. (Unless noted to the contrary, the technical information applies only to pure product). To our actual knowledge, the information contained herein is accurate as of the date of this document. However, neither the company mentioned in section 1 nor any of its affiliates makes any warranty, express or implied, including merchantability or fitness for use, or accepts any liability in connection with this information or its use. This information is for use by technically skilled persons at their own discretion and risk and does not relate to the use of this product in combination with any other substance or any other process. This is not a license under any patent or other proprietary right. The user alone must finally determine suitability of any information or material for any contemplated use in compliance with applicable law, the manner of use and whether any patents are infringed. This information gives typical properties only and is not to be used for specification purposes. The company mentioned in section 1 reserves the right to make additions, deletions or modifications to the information at any time without prior notification. Trademarks and/or other products of the company mentioned in section 1 referenced herein are either trademarks or registered trademarks of the company mentioned in section 1 or its affiliates, unless otherwise indicated.

J.9.1

ACTIVITY HAZARD ANALYSIS

ACTIVITY: ______________________________ ANALYZED BY / DATE: __________________

PRINCIPAL STEPS	POTENTIAL SAFETY/HEALTH HAZARDS	RECOMMENDED CONTROLS

EQUIPMENT TO BE USED	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS

EXAMPLE

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment ANALYZED BY / DATE: _______________

PRINCIPAL STEPS	POTENTIAL SAFETY/HEALTH HAZARDS	RECOMMENDED CONTROLS
Identify Substation and Circuit to be Accessed	• Notification not Given to NASA and PRIDE • Wrong Selection of Circuit to be Monitored • Substation Selected Changes Classification to Critical Due to Shuttle Launch	• Notify NASA and PRIDE of Each Substation and Circuit to be monitored at the Beginning of Each Work Day. • Verify Substation and Circuit Selected for Monitoring with NASA to Ensure Accuracy • Cease All Current Activity and Planned Activity at the Substation until All Clear is given for Work to Proceed Post Mission. Mission Critical Substations Include Substations 1, 5, 6, 9, 11, 16, 17 and any Electric Panels Located in Buildings fed from These Subs or in Area A
Open Substation Breaker Cabinet, Relay Cabinet, or Metering Cabinet	• Door Does Not Open • Screws or Loose Latches Holding Door in Place Present a Drop Hazard • Opening of Panel Door Could Trigger Breaker Trip on Circuit	• Loosen Screws or Latches to the Visibly Open Position on Panel Door – Gently Use Approved Insulated Gloved Hands PPE* to Work Door Open. Verify All Latches Clear Before Continuing to Open Door • Remove Screws from Panel Doors when Appropriate and Place Away from Immediate Electrical Hazard Area • Verify Opening Door will not Trip Breaker by Visually Inspecting behind Door as Door is Slowly Opened. If Door Stops While Opening, Discontinue Opening Until

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment ANALYZED BY / DATE: ________________

		Obstruction is Cleared
Access Current Transformers and Potential Transformers in Cabinet to Visually Verify Sizing and Ratios	• Exposes Individual to High Voltage Cables or Bus Bars	• Persons Accessing Areas in Cabinet Where Shock Risk is Possible Will be Trained in Arc Flash Protection, High Voltage, and will Wear Insulated Gloves and Other PPE* as Necessary
Install Temporary Current Transformers on Low Side of Metering Current Transformers (typically in rear of switchgear)	• Exposes Individual to Medium Voltage Cabling and Metering Equipment	• Persons Accessing Areas in Cabinet Where Shock Risk is Possible will be Trained in Arc Flash Protection, High Voltage, and will Wear Insulated Gloves and Other PPE* as Necessary
Access main terminals of substation only in instances where sub-metering is not already installed or sub-meter CTs or PT can not be used. Current transformers will be installed on main conductors and/or voltage reference leads will be connected to bus bars or PTs..	• Exposure to 480 volt terminal lugs and sub-station main conductors.	• Persons Accessing Areas in Cabinet Where Shock Risk is Possible Will be Trained in Arc Flash Protection, High Voltage, and will Wear Insulated Gloves and Other PPE* as Necessary • Ensure that all equipment being installed is rated for the local conditions. • The subs that require this type of access are Sub 10, and the transformer that feeds buildings 4859 and 4864 off of Sub 5.

EQUIPMENT TO BE USED	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS
• Screwdriver • Hand Held Voltage Meter and Clamp Ammeter • Temporary Split-core Current	• Screwdriver Should be Electrician's Grade • Inspect Unit and Voltage Leads for Wear or Damage • Inspect Leads for Wear or Damage	• Read Instructions for Meter Operation, PPE* use, High Voltage Training, and Arc Flash Training

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment ANALYZED BY / DATE: _______________

Transformers • Data Logger	• Check Case for Damage	

*PPE Equipment Includes: Hard Hat and Face Shield with Arc Rating 10 Cal/cm2, Coveralls with Arc Rating 8 Cal/cm2, and Class 0 Insulated Gloves with Leather Protectors

Electrical substations to be accessed for the proposed data logging project are: Sub 1, Sub 3, Sub 4, Sub 5, Sub 9, Sub 10, Sub 17, and Sub 25.

Scope of work

Contractor has been subcontracted to install data loggers in support of baseline calculations of energy savings. Loggers are installed on electrical equipment to monitor Time of Use and power draw. All loggers make use of split-core current transformers. These current transformers require no direct contact with electrical sources, but they open to be installed over the insulated portion of the conductors. Voltage leads make use of an alligator-type clip to provide reference voltage and calculate power.

All loggers installed on electrical equipment require a spot measurement of the equipment kW. During this measurement a current clamp is applied over the insulated portion of the corresponding conductor and test leads are applied to the corresponding voltage to derive equipment kW. It is during this time that the only direct contact is made with electrical source voltage/current.

This work will be completed by a certified high voltage electrician along with a Contractor employee. PRIDE will also be notified of any work being completed for this project and will be given the option of providing an electrician to accompany the data logging team. A member of the NASA safety team will accompany the contractors at each of the substations as well.

Electrical Safety

Electrical dangers shall be observed and improper electrical conditions shall be notified to all project personnel.

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment ANALYZED BY / DATE: ________________

Use of the following equipment is prohibited for all involved personnel:

- All personnel shall be protected from such electrical hazards:
- Exposed live electrical parts
- Ungrounded electrical equipment (double insulated tools is acceptable)
- Unprotected electrical test leads

Daily tests and inspections on the following equipment shall be made to ensure it is safe, free from defects, and functioning properly:

- Testing and metering equipment
- Power and Electrical Equipment
- Data logging equipment and associated current transformers
- Hand and power tools

Work with voltages less than 50 volts is not considered working on or near energized conductors. Energized parts that operate at less than 50 V to ground are not required to be de-energized if there is no increased exposure to electrical burns or to explosion due to electric arcs.

For work near circuits greater than 50V to ground a Control Zone shall be utilized to protect personnel who may accidentally encounter exposed energized components in a facility because of a lack of knowledge or awareness of the hazards.

Personnel who may come in contact with energized circuits greater than 50V while working within a Control Zone shall be protected by the following:

- Training in accordance with Departmental procedure
- A barricade (a physical obstruction to keep unauthorized persons from entering into the work area)
- Personal Protective Equipment appropriate for the task

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment ANALYZED BY / DATE: ________________

All work around energized circuits will be performed in accordance with safe work practices, personal protective equipment and NFPA 70-E guidelines and per Section 0144D General Safety Requirements.

Due to the nature of measuring and verifying electrical energy usage, work on de-energized circuits is not feasible. OSHA regulation 1910.333 (a) (1) Note 2 states that "Examples of work that may be performed on or near energized circuit parts because of infeasibility due to equipment design or operational limitations include testing of electric circuits that can only be performed with the circuit energized."

Arc Protection

All personnel involved with work on or near exposed and energized circuits shall have and use electrical safety products that comply with **ASTM 1506 requirements, OSHA 1910 regulations and NFPA 70E standards.**

The following guidelines shall be used to minimize potential hazards from arc flash:

- **Arc flash-protection boundary**, defined as "an approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electrical arc flash were to occur."

- **Proper personal protective equipment (PPE) and protective clothing necessary**, based on the incident energy present at the working distance for the task to be performed.

All Participants have Viewed Arc Flash Safety Slide Presentation Conducted by Code F COTR and have Reviewed Section 0144D General Safety Requirements.

Sign Name Here: ____

ACTIVITY HAZARD ANALYSIS

ACTIVITY: Datalogger Deployment

ANALYZED BY / DATE: ________________

Sign Name Here: ____

Sign Name Here: ____

Sign Name Here: ____

BASTION TECHNOLOGIES

SOFIA PROJECT

SOFIA SCIENCE INSTRUMENTS

SAFETY ASSESSMENT REPORT

MIRROR COATING FACILLITY
N-211

NASA AMES
Mountain View, Ca.

Prepared By: R. Julta **Systems Safety Engineer**	**Date:** 5/21/08
Reviewed/Approved By: Ed **SMA Chief Science Officer**	**Date:** 5/27/08
Approved By: K. Dutta **Code QS Division Chief**	**Date:** 5/27/08
Approved By: Edward Harmon **SOFIA Science Project Operations Manager**	**Date:** 5/27/08

BASTION TECHNOLOGIES

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BASTION TECHNOLOGIES

EXCUTIVE SUMMARY

Introduction

The SOFIA Mirror Operations Center (SMOC) Primary Mirror Assembly Safety Assessment Report is generated to provide an overall safety assessment of the Primary Mirror Assembly (PMA) operations within building N211 at NASA Ames. The intent is to review and assess all aspects of the facility design and accommodations as well as support equipment and personnel to support the operations. The report will address the PMA pre-operations activities (i.e. Industrial Safety, Mirror Coating Tank Design, and Programmable Logic Controller) and the PMA post delivery operations (i.e. Critical Lift and Operational Procedures). The goal is to ensure full functionality of systems and operational safety to personnel, facilities and equipment.

The Industrial Safety operations were conducted by Code QH to ensure that the facility meets all NASA, and CAL-OHSA safety requirements prior to the facility operations. Chemical manifest, environmental monitoring, personnel training, building and equipment safety were all reviewed. PMA cleaning and effluents disposition will be determined once a ph test has been conducted. Operational procedures have been reviewed to implement confined space entry, lock-out/tag-out, personnel protective equipment and fall protection requirements. Pressurized cylinders have been relocated and racked. Lifting Equipment certifications and personnel trainings/certifications are all completed. All hazards identified have been migrated to a risk level acceptable for operations.

The Mirror Coating Tank and operations have been assessed using current configuration and heritage information. Some designs, components and operations have changed and are indicated within. A review of the Mirror Coating Tank as a pressure vessel has been reviewed by ARC Pressure Systems Safety Manager for compliance to NPR 8719.5. A number of hazards reports have been generated for the design and operations and assessed and all verifications completed. Therefore there are no hazards or hazardous conditions that require additional mitigation.

BASTION TECHNOLOGIES

The Programmable Logic Controller operations were conducted during the mirror sample coating process. The logic to control critical equipment functions during the process has been reviewed and will be a part of the reactivation procedure to ensure mission assurance through logic. All credible hazards associated with the PLC have been reviewed and the controls verified via demonstration and documentation changes. The risk associated is designated as “Low”, as the worst potential hazard will only create a failure to complete the operation.

The critical lift operations using the PMA Lifting Device (PLD) and 5 Ton Overhead Bridge Crane. All lifting and support equipment has met the requirements of NASA-STD-8719.9; Standard for Lifting Devices and Equipment as well as personnel training associated with the lifting operations. There are many single point failures associated with the lifting operations, however there are significant controls in place to migrate the risk to an acceptable level. The 5 Ton Bridge Crane has been modified by Allied Crane Manufacturers to certify compliance to NASA-STD-8719.9 Critical Lift operations. The crane’s braking system employs a primary electrical disc braking system and a secondary paw gear braking system as a backup. The crane was load tested at the Allied facility to 125% and re-installed back into N211. Certification documentation is available.

Operational procedures for the Mirror Coating Operations are completed. The PMA Handling Cart Operations Procedure is completed and the German specialists (DLR) were involved in the handling process. A safety review and assessment for Dryden and Ames N211 hanger work was conducted by NCAS and provided to Ames for review and concurrence.

Safety Concerns

There has been ongoing concern on PMA bonding. The issue was forwarded and addressed by DLR. The bonding was reviewed, studied and tested and deemed “not an issue”. A secondary load path shall be installed prior to installation into the mirror coating chamber. Operations procedures will be updated to ensure no chemicals are used on the bonding area.
A structural engineer has reviewed the PMA bonding documentation showed

in Appendix -1. Hardware is provided that prevents mirror cleaning solutions from seeping behind the glass.
An Ames engineer re-reviewed the manufacturer (Chart Industries) analysis on mirror coating chamber pressure differentials in Appendix-2. Analysis is adequate for use.

Conclusions

The Operational procedures and safety features are implemented for PMA operations at N211 to eliminate or significantly reduce the probability of occurrence for potential hazardous conditions and to reduce the inherent risks.

BASTION TECHNOLOGIES

1.0 INTRODUCTION

This SOFIA Science Instruments Primary Mirror Assembly (PMA) Mirror Coating Facility Safety Assessment Report is generated to provide an overview of the facilities safety design, functions and operations. Additionally, it will provide an assessment into the safety critical systems including support equipment used during PMA operations at NASA Ames. The PMA operations will take place in bldg. N211.

BASTION TECHNOLOGIES

1.1 OBJECTIVE

The intent is to provide a safety assessment for all phases of operations at the Mirror Coating Facility at NASA Ames. The goal is to ensure safe delivery, handling, mirror coating and delivery back to Dryden. The review includes an industrial safety assessment, operational hazards review, critical lifts and operational procedural review to ensure overall safety to personnel, hardware and equipment.

BASTION TECHNOLOGIES

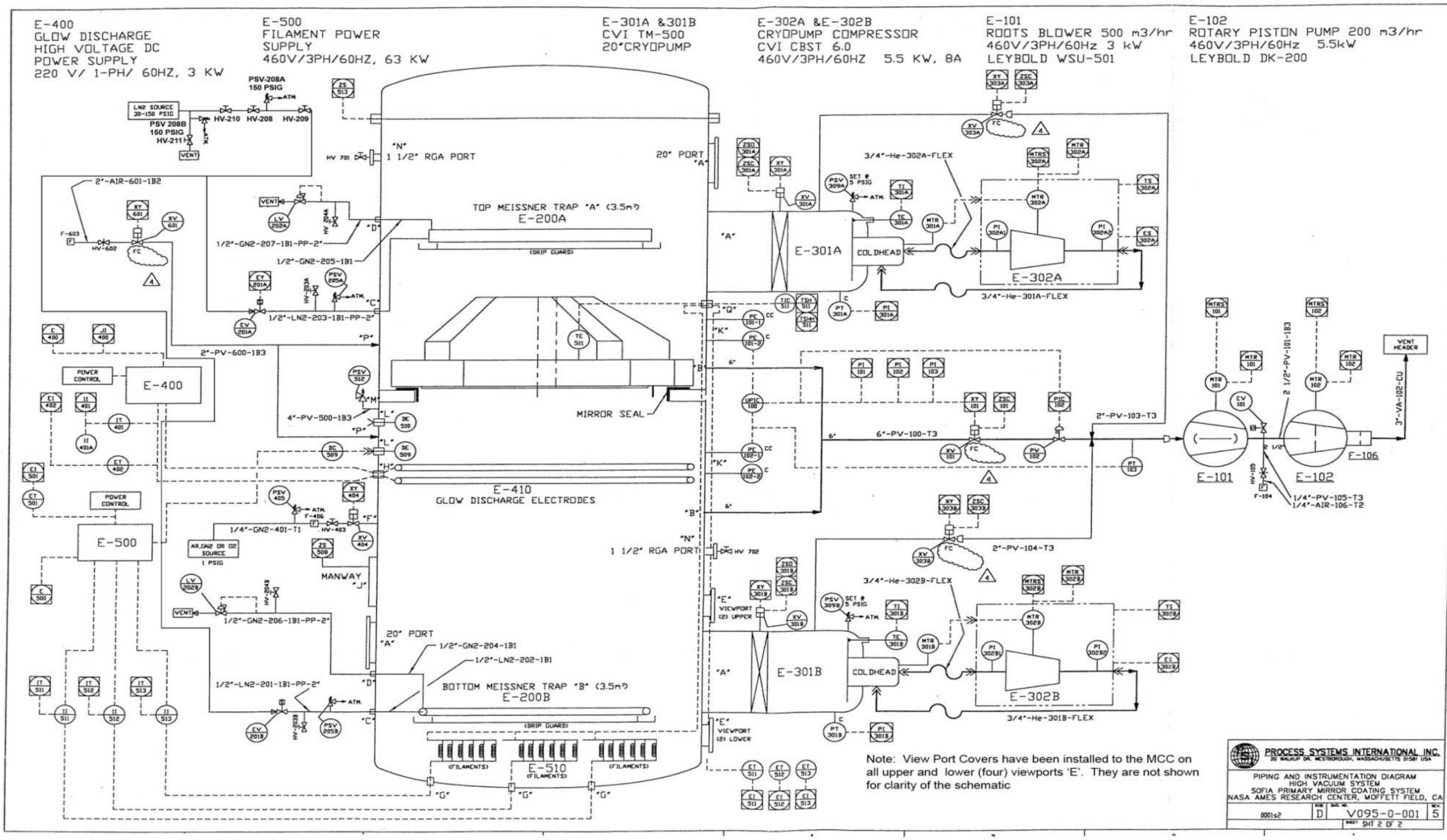
1.2 FACILITY DESCRIPTION

The SOFIA Science Project will operate from a facility leased by NASA to USRA at Ames Research Center (ARC) Moffett Field CA.
Building N211 is an existing hanger facility. It's basic structure will not change with the proposed alterations. Alterations and/or additions are limited to internal spaces and equipment required for SOFIA.
The Primary Mirror Assembly (PMA) of the SOFIA telescope has to be removed for periodic inspections, cleaning and recoating. This initial process will be done at a special facility at the NASA Ames Research center (ARC), SOFIA Mirror Coating Facility.

2.0 APPLICABLE DOCUMENTS

- NASA-STD-8719.7; Facility Safety
- NASA-STD-8719.9; Standard For Lifting Devices And Equipment
- APR-1700.1 Ames Health & Safety Procedural Requirements – Lifting Devices And Equipment
- NPR-1800.1; NASA Occupational Health program Procedures
- NPD-1820.1; NASA Environmental Health Program
- NPR-8719.5; Pressure Vessels and Pressurized Systems
- NPD-8730.5; NASA Quality Assurance Program Policy

BASTION
TECHNOLOGIES



MIRROR COATING TANK FLOW DIAGRAM

BASTION TECHNOLOGIES

3.0 INDUSTRIAL SAFETY AND HYGIENE

Industrial Safety assessments were conducted by NASA Ames Code QH. The facility site survey focused on personnel interfacing and operations as well as the functionality and safety compliance of the critical operating support systems and to ensure that proper personnel trainings were identified. The industrial safety assessment includes the hazardous materials and chemicals manifest, hazardous materials storage and disposal, personnel support equipment compliance to CA-OHSA requirements, permitted and non-permitted confined space entry requirements, waste water contamination, noise levels, chemical reactions, personnel injury associated with mirror coating tank operations, personnel injury associated with machinery operations, fire hazards, ignition hazards, personnel protective equipment, and excessive UV exposure. The initial hazard reports are documented PA10-003, The following table is a summary of all the safety critical hazards associated with industrial safety.

INDUSTRIAL SAFETY HAZARDS

Hazard Report Title	Number	Risk	Status
Potential Chemical Reaction	211 OP1	Medium	Closed
Noise Levels Exceed Limits	211 OP2	Low	Closed
Hazard Material Spill/Leak	211 OP4	Medium	Closed
Waste Water Contamination	211OP5	Low	Closed
Chemical Splash Danger	211 OP6	Low	Closed
Personnel Injury from chamber door	2111OP7	Medium	Closed
Personnel Injury from machinery	211 OP8	Medium	Closed
High Pressure System Hazard	211OP9	Low	Closed
Fire Hazard/Accidental Ignition	211OP19	Low	Closed

BASTION TECHNOLOGIES

3.1 HAZARD STATUS

HR-211 OP1; Eliminated. P. Ford. Covered by standard procedures and training. E Ingraham - Covered by HR #53. This item review by code QH in their facility review and mitigations to prevent this have been established. Chemical reactions are limited to the use of one chemical at a time with proper PPE selected for each chemical. The procedure for use is that a small amount 10 – 20 ML are squirted onto a clean room chemwipe and then wiped across the mirror. Per 4/4/08 email, R Razik agreed.

HR-211 OP2; Eliminated. E. Ingraham. - Only noise items in MCF are pumps and air handling. This item review by code QH in their facility review. Determine not to be severe enough to cause personnel injury. The noise levels have not been measured in the chamber area. They will be measured during the next sample coating. Time inside the MCF during operation should be limited based on specific operations that need to be performed. Per 4/4/08 email, R Razik agreed.

HR-211 OP4; Covered by HR #53. - This item was also reviewed by code QH in their facility review and being worked via the standard JHA process. Per 4/4/08 email, R Razik agreed.

HR-211 OP5; Covered by HR #53. - Closed for Phase 1 activities. Moved to HR #53 for Phase2. Closed via HR #53 & code QH review. This item review by code QH in their facility review and being worked via the standard JHA process. Waste water will not be generated during sample coating. Per 4/4/08 email, R Razik agreed.

HR-211 OP6; Covered by HR #53. - This item was also reviewed by code QH in their facility review and being worked via the standard JHA process. Per 4/4/08 email, R Razik agreed.

HR-211 OP7; Eliminated. E. Ingraham. The procedure to enter chamber is documented to provide warnings and technicians entering the chamber are properly trained. The confined space attendant assists all entrants as they enter and exit the chamber to ensure hazards are safeguarded prior to entering and exiting (i.e. step ladder in place, hard hats are worn, clearance areas stated while entering. Per 4/4/08 email, R Razik agreed.

HR-211 OP8; Eliminated. P Ford. Covered by standard procedures and training. Machinery in MCF limited to just what is needed all personal who operate machinery in the MCF have been trained in how to use the machinery. Per 4/4/08 email, R Razik agreed.

HR-211 OP9; Mitigation states that all purchased items meet OSHA, SAE, ASTME standards. Per Ray Schuler, the only item in the MCF to which this applies is a single Argon tank - a standard high pressure tank. Check that tank is up to date, properly secured, and that regulator has been inspected recently. SMA inspected the facility.

BASTION TECHNOLOGIES

ARC High Pressure Safety Engineer Lead has reviewed and certified the facility and systems.
HR-211 OP19; Eliminated. Covered by HR #57. O2 was eliminated from system. This item review by code QH in their facility review and mitigations to prevent this have been established. Fire hazard minimized by use of small quantities of flammable materials. All flammable materials are pre mixed or prepared in the chemical wet room of the MCF. Acetone would only be used to remove a small stain. This would be done by wetting clean room techwipe and wiping the surface. Per 4/4/08 email, R Razik agreed.

4.0 MIRROR COATING CHAMBER

This section will address all the hazards generated against the mirror coating chamber design and operations to include its ancillary systems and facility support systems. These systems include hazards to the primary mirror assembly, meissner coils, vacuum equipment, cryogenic equipment, electrical systems, roughing pumps, glow discharge electrodes, aluminum filaments, pressure valves, solenoid valves, manual valves, LN_2, $GN_{2,}$ electrical shock, burns, fire, overvoltage, excessive temperature and hazardous chemicals. The initial hazard reports are documented Chart Industries V095-2-001. This list was expanded to include all PMA cleaning and handling hazards in the MCF. The following table is a summary of the hazard reports generated for the mirror coating process.

MIRROR COATING HAZARDS

Hazard Report Title	Number	Risk	Status
Overpressure of LN2 Meissner coils	ARCX-MCF-001-H	Medium	Closed
A rupture of the Meissner coils	ARCX-MCF-002-H	Medium	Closed
Overfilling Meissner Trap with liquid nitrogen during normal operation	ARCX-MCF-003-H	Medium	Closed
Cryo pump mechanical failure during normal High Vacuum operation	ARCX-MCF-005-H	Low	Closed
Roughing pump mechanical failure during normal operation	ARCX-MCF-006-H	Low	Closed
Overpressurization of main vacuum chamber	ARCX-MCF-008-H	Low	Closed
Loss of vacuum due to venting of the chamber	ARCX-MCF-009-H	Low	Closed
Failure to close roughing pump valve (XV101) before performing repairs or maintenance on the roughing/backing pumps with vacuum in chamber	ARCX-MCF-011-H	Low	Closed
Energizing Glow Discharge electrodes (5 kVdc and 600ma) while at atmospheric pressure	ARCX-MCF-012-H	Low	Closed

BASTION TECHNOLOGIES

LN2 spills on a persons skin while setting up LN2 supply for normal coating chamber operation	ARCX-MCF-019-H	Low	Closed
Mirror temperature exceeds maximum allowable design temperature (+70° C (+158° F) for PMA)	ARCX-MCF-020-H	Low	Closed
High energy electrical power available, Risk of electrical fire, shock, or burns	ARCX-MCF-021-H	Low	Closed
Roughing Pump vents to vacuum chamber.	ARCX-MCF-024-H	Low	Closed
Over temperature due to Glow Discharge electrodes remaining energized (Fail On)	ARCX-MCF-030-H	Low	Closed
Incomplete aluminizing coating (filament failure)	ARCX-MCF-037-H	Low	Closed
Incomplete aluminizing coating (sycon crystal problem)	ARCX-MCF-038-H	Low	Closed
Pneumatic valve XV101 is opened unexpectedly or inadvertently during normal operation	ARCX-MCF-039-H	Low	Closed
Pneumatic valve XV301A & B is opened unexpectedly or inadvertently during normal operation	ARCX-MCF-040-H	Low	Closed
Solenoid Valves Fail Closed	ARCX-MCF-045-H	Low	Closed
Manual valve is opened inadvertently during normal operation	ARCX-MCF-048-H	Low	Closed
Asphyxiation from GN2 venting into mirror coating room, if ventilation system fails	ARCX-MCF-049-H	Low	Closed
Lifting the mirror with differential pressure	ARCX-MCF-050-H	Low	Closed
Lifting the PMA from cart (side and back-lift) with inadequate hardware	ARCX-MCF-051-H	Low	Closed
Bonding failure of mirror to supporting structure	ARCX-MCF-052-H	Med	Closed
Loss of control of hazardous chemicals	ARCX-MCF-053-H	Low	Closed
Mirror cleaning off the Aircraft in confined space with oxygen displacing agent	ARCX-MCF-054-H	Low	Closed
Mirror Handling using PMA cart. Uncontrolled rotation of PMA, or rolling cart, and inadvertent rotation of PMA.	ARCX-MCF-055-H	Low	Closed
Striking metallic, or hard, objects against mirror surface while working near or above mirror surface	ARCX-MCF-056-H	Low	Closed
Flammable cleaning fluids	ARCX-MCF-057-H	Low	Closed
Moving PMA into chamber strikes solid object	ARCX-MCF-060-H	Low	Closed
PMA Cart Pneumatic air motor system endangers the PMA	ARCX-MCF-061-H	Low	Closed

BASTION TECHNOLOGIES

4.1 HAZARD STATUS

- ARCX-MCF-001H; Closed. Signature A. Briceno 1-13-03. PSV205A on supply line to Meisner Coil sized to relieve pressure with trapped liquid in Coil with discharge facing away from personnel.

- ARCX-MCF-002H; Closed Signature A. Briceno 1-13-03. Demonstration shows control logic shuts down operations with pressure increase on PE101-1 or PE101-2. PPSV512 free to move dead load valve certified weight 1.5#.

- ARCX-MCF-003H; Closed Signature A. Briceno 1-13-03. LN2 storage verification during Ops HA. Valve orientation directed away from operating personnel.

- ARCX-MCF-005H; Closed Signature A. Briceno 1-13-03. Demonstrated automatic shutoff of Cryopumps with interlock on pump or power failure or vessel pressure increase.

- ARCX-MCF-006H; Closed Signature A. Briceno 1-13-03. Demonstrated automatic shutoff valve XV101 on Roughing Pump Line is interlocked to close after pump failure, or power failure protecting aluminization process.

- ARCX-MCF-008H; Closed Signature A. Briceno 1-13-03 Demonstrated weight of plate in PSV512 is correct per V095-1-020 Rev1 and moves freely.

- ARCX-MCF-009H; Closed Signature A. Briceno 1-13-03 Demonstrated that pressure gauges PE101-1 & PE102-1 register a breach and automatically shut-down operations.

- ARCX-MCF-011H; Closed Signature A. Briceno 1-13-03. Demonstrated Limit Switches ZSC101 on valve XV101 correctly indicate valve position.

- ARCX-MCF-012H; Closed Signature A. Briceno 1-13-03. Demonstrated Manway and/or lid interlocks ZS508 and ZS513 energize to prevent Pressure interlocks PE101 & PE102 from energizing at atmospheric Chamber pressure. LO/TO procedures padlock power to glow discharge power supply before entering the chamber.

- ARCX-MCF-018H; Closed Signature A. Briceno 1-13-03. Demonstrated Manway interlocks prevent filament from energizing. Pressure switches do not allow filaments to energize.. LO/TO procedures padlock power to Filaments before entering chamber.

BASTION TECHNOLOGIES

- ARCX-MCF-019H; ARCX-MCF-012H; Closed Signature A. Briceno 1-13-03.Operators receive NASA Safety Training.

- ARCX-MCF-020H; ARCX-MCF-012H; Closed Signature A. Briceno 1-13-03TC511 operates by shutting down glow discharge and filament power when temperature reaches 50 degrees C and sets off alarm at 60 degrees C.

- ARCX-MCF-021H; ARCX-MCF-012H; Closed Signature A. Briceno 1-13-03. NASA inspected for NEC compliance.

- ARCX-MCF-024H; Closed Signature A. Briceno 1-13-03.Verified acceptance with DR attached.

- ARCX-MCF-030H; Closed Signature A. Briceno 1-13-03. TI511 shuts-down on over temperature at 50 degrees C and alarms at 60 degrees C.

- ARCX-MCF-037H; Closed Signature A. Briceno 1-13-03.Verified that filament evaporation process was approved by NASA.

- ARCX-MCF-038H; Closed Signature A. Briceno 1-13-03 Verified Control Logic for deposition rate monitor and sensitivity performs safely.

- ARCX-MCF-039H; Closed Signature A. Briceno 1-13-03 Verified that controls and control interlocks ZSC101 are in place.

- ARCX-MCF-040H; Closed Signature A. Briceno 1-13-03. Training will be provided by NASA/USRA. Verified Operator access limited during Aluminization Mode.

- ARCX-MCF-041H; Closed Signature A. Briceno 1-13-03.Verified Limit switches operation on valves XV101, XV301 A&B, and XV303A&B.

- ARCX-MCF-042H; Closed Signature A. Briceno 1-13-03. Control Logic recognizes process parameters.

- ARCX-MCF-045H; Closed Signature A. Briceno 1-13-03. Control Logic recognizes incorrect process parameters.

- ARCX-MCF-048H; Closed Signature A. Briceno 1-13-03.Proper warning signs on High Vacuum valves HV202A&B, and HV204A&B.

- ARCX-MCF-049H; Closed Signature E. Ingraham & J. McClelland. 1/30/08 Added O2 monitor in room and warning placards.

BASTION TECHNOLOGIES

- ARCX-MCF-050H; Closed NASA SRM&QA Mgr /DQ signature A.Briceno 1-13-03. Witnessed testing and Adjusted HV601 fill rate to 'slow refill greater than 45 minutes.

- ARCX-MCF-051H; Closed. NASA SRM&QA Mgr /DQ signature A.Briceno 1-13-03 & Ramsey Melugin (PM) 7-2-03. Witnessed testing and Adjusted HV601 fill rate to 'slow refill' greater than 45 minutes.

- ARCX-MCF-052H; Closed. Signature E. Ingraham & H. Hall. 5/27/08. The recommended bond testing was not performed by NASA as it was deemed out of scope of the SSP and unnecessary. These bonds are part of the PMA which is German Government Furnished Equipment (GGFE). Discussions with German (DLR) reps. (H Hammes) indicated that this issue was reviewed, studied, and tested by their organization prior to delivery and deemed not to be an issue. Secondary Load Path installed prior to installation into the chamber. Written procedures to protect bonding area from chemicals. Mike Gima reviewed historical data obtained from P Waddell.

- ARCX-MCF-053H; Closed. Signature E. Ingraham & H. Hall. 4/23/08. Code QH (R Razik) performed hazardous chemical assessment and implemented safeguards/training. Procedures reviewed and signed off by code Q representative.

- ARCX-MCF-054H; Closed. Signature E. Ingraham & H. Hall. 4/23/08. Code QH (R Razik) performed hazardous chemical assessment for cleaning operation/facility and implemented safeguards/training. Procedures reviewed and signed off by code Q representative.

- ARCX-MCF-055H; Closed. NASA SRM&QA Mgr /DQ signature A. Briceno for O. Gruelich 7-29-03 & Ramsey Melugin (PM) 7-2-03.. USRA Reviewed analysis of rotation locking provisions for capacity and strength and margin of safety.

- ARCX-MCF-056H; Closed. NASA SRM&QA Mgr /DQ signature A. Briceno for O. Gruelich 7-29-03 & Chris B Wiltsee (PM) 8-5-04. Mirror Handling hazards. Lists include Tool tethering as standard practice by L3Com. Adequate observers positioned during all PMA motion with crane of cart. Reviewed installation and removal procedures for PMA. Process Witnessed. Note: All ARC/USRA procedures include tool tethering over PMA (E. Ingraham).

- ARCX-MCF-057H; Closed. Signature E. Ingraham & H. Hall. 4/23/08. Code QH (R Razik) performed hazardous chemical assessment and implemented safeguards/training. Procedures reviewed and signed off by code Q representative.

BASTION TECHNOLOGIES

- ARCX-MCF-060H; Closed. Signature E. Ingraham & H. Hall. 5/27/08. Detailed approved procedures. Crane operator and operation team perform practice with Dummy Mass.

The above HRs were re-reviewed by the CSO (E. Ingraham) in 2008 to determine any critical omissions. An analysis of the chamber pressures differential seen in the tank during mirror coating during both during pump down and pump up (see ARCX-MCF-050H) was requested and performed by Paul Lam. Paul Lam's report can be found in Appendix-2.

HAZARD REPORT ELIMINATED OR DELETE:

Cryopump Mechanical Failure. Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Reverification - Agree with elimination of this HR. (E Ingraham) Cryopump only effect system performance during high vacuum operations. Non-high vacuum problem would just prevent HVAC not a real risk. Transferred to HR#5.

Excessive Stress on Vacuum Equipment; "Eliminated. Per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Proper installation made per acceptance testing of system..System recertified by ARC Pressure Systems Group prior to use." Reverification - Verify Pumps (E101, E102, E301A&B) and major hardware (XV301A&B) are bolted down and installed correctly. - E. Ingraham visually inspected and verified bolt down. Agree this issue can be closed or eliminated.

Chamber backfill; Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. See HR #039, #24. Reverification - Concur with elimination. This is better dealt with in HR #039 and HR #24. (E. Ingraham)

O2 vents into room; Eliminated. Original number from Chart Industries (year 2000) document V095-2-001. No O2 will be used. Reverification - Concur with elimination. Use of O2 in system has been eliminated. Verified O2 eliminated from system. (E. Ingraham)

Backfilling chamber with pure O2 to atmosphere; Eliminated. Original number from Chart Industries (year 2000) document V095-2-001. No O2 will be used. Reverification - Concur with elimination. Use of O2 in system has been eliminated. Verified O2 eliminated from system. (E. Ingraham)

Pure O2 saturates the cryopump charcoal; Eliminated. Original number from Chart Industries (year 2000) document V095-2-001. No O2 will be used. Reverification - Concur with elimination. Use of O2 in system has been eliminated. Verified O2 eliminated from system. (E. Ingraham)

O2 combined with high voltage during glow discharge operation; Eliminated. Original number from Chart Industries (year 2000) document V095-2-001. No O2 will be used. Reverification - Concur with elimination. Use of O2 in system has been eliminated. Verified O2 eliminated from system. (E. Ingraham)

Pure O2 saturates carbon fiber, epoxy mirror support structure; Eliminated. Original number from Chart Industries (year 2000) document V095-2-001. No O2 will be used. Reverification - Concur with elimination. Use of O2 in system has been eliminated. Verified O2 eliminated from system. (E. Ingraham)

Emergency stop button pressed; Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Reverification - Agree with elimination. E. Ingraham. Console emergency stop is in place to shut power in emergency situation. None success of mirror coating, secures chamber in present state. Could cause problems if wrong valve was open, but emergency stop is needed for personnel safety that takes precedence over mirror damage.

Vacuum pump down time takes too long; Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. This is not a hazard and we think it will occur. Added 10 days in schedule for pump down because of this concern.

Roughing pump shutdown; Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. No apparent hazard if this occurs.

Hazardous light occurring during glow discharge process; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Added use of UV eye protection in procedure and Ramsey Razik will measure UV dissipation. Not Safety and not significant Mission Assurance issue. Reverification - Agree this is closed or eliminated. 4/4/08 E Ingraham Added use of UV eye protection in procedure. Verified USRA has UV 4 pairs of UV goggles in MCF. R Razik will conduct light survey during the next glow discharge to evaluate UV transmittance through the view ports. Per 4/4/08 email, R Razik agreed. On 5/14/08 R Razik performed UV test during glow discharge which showed acceptable signs of UV for operator to look into chamber without any UV protection.

Cryopump vents to vacuum chamber; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. This is not a real risk. To really have a risk requires a double failure, cryopump would need to leak up to high pressures and XV301 would need to fail.

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Cryopump regeneration failure; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. No real risk to hardware or personnel. Worst that could happen is that you can't run HVAC. This is run before any critical operations begin.

Power supply shutdown on glow discharge; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. No real risk to hardware or personnel. Worst that could happen is an incomplete glow discharge cycle. Harmless event.

Glow discharge electrodes never energized (Fail Off); Eliminated prior to CDR.. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. No real risk to hardware or personnel. Worst that could happen is a failure to start glow discharge cycle. Harmless event.

Incomplete glow discharge cycle; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. No real risk to hardware or personnel. Worst that could happen is an incomplete glow discharge cycle. Harmless event.

Power supply shutdown on Filament array; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. Worst that could happen would be a thin coating that may require a recoat.

Filament array stay energized (Fail on); Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Related to HR37 & HR38. Real risk is too hot which is addressed in HR30. Reverification - Agree that this has the same safety mechanisms as HR#30, but it is a different source failure (and more significant heating). Demonstrate temperature recording continues after Filament shutdown to indicate the highest temperature seen at the interface stratum. - E Ingraham verified temperature recording runs continuously regardless of operation. A data files during process shows that TC511 is taking data every second independently of operations (while laptop is hooked up running data logger, rstrend).

Filament array never energized (Fail off); Eliminated prior to CDR. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Related to HR37 & HR38. Reverification - Agree with elimination. E. Ingraham. No real risk to hardware or personnel. Worst that could happen is no coating. Harmless event.

Incomplete aluminizing coating; Moved issue to item 37 & 38. Original number from Chart Industries (year 2000) document V095-2-001. Reverification - Agree that this not a hazard. Worst case is thin coating. May be correctible with new run without stripping. Sycon crystal will tell us coating thickness.

Pneumatic Valves Fail Closed; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. E. Ingraham. Little harm in failing closed, except delay process.
Verified positive indication of valve closure (or open) is provided by limit switches (ZSC/ZSO301A&B, ZSC101, ZSC303A&B).

Pneumatic Valves Fail Open; Eliminated prior to CDR.. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - OK to close with low risk or eliminate. While there is risk if these valves failed open, these valves are spring-to-close valves (XV101, XV404, XV201A&B, XV303A&B, XV601) that have been tested. If XV301A&B (not spring-to-close) fails open, there is no harm, basically we can't terminate HVAC.

Solenoid Valves Fail Open; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. Double check of software for XV404 & XV601 during USRA software audit on PLC software.

Solenoid valve is opened unexpectedly or inadvertently during normal operation; Eliminated as non-safety issue per Phil Ford's spreadsheet. Original number from Chart Industries (year 2000) document V095-2-001. Not Safety and not significant Mission Assurance. Reverification - Agree with elimination. Written way too broadly. Critical valve failures are address individually in other HRs.

ARCX-MCF-059; Contaminants introduced to the MCF, Eliminated as non-safety issue per Phil Ford's spreadsheet. Reverification - Per Phil Ford, Gap in sequence of numbering. No further action required per E. Ingraham.

BASTION TECHNOLOGIES

5.0 PROGRAMMABLE LOGIC CONTROLLER (PLC)

This section is provided to identify those hazards to the mirror coating process using the programmable logic controller that is designed to operate the mirror coating tank programmed software and hardware systems. This includes the Sycon Crystal Display, electrical solenoid valves, gate valves, rough pump isolation valves, glow discharge system pressure check valves, filament system, Cryopumps, vent valves, argon supply, and thermocouple. This included a "PLC Software" review and "PLC Wiring" review for each PLC/W number.

PLC HAZARDS

Hazard Report Title	Number	Risk	Status
Liquid Nitrogen supply Solenoid EV201A or EV201B stops and stays stopped for 1.5 hours at wrong time	PLC/W#1	Low	Closed
E101 or E102 Motor fail while Roughing Pump Isolation XV101 is open	PLC/W#2	Med	Closed
E400 glow discharge system (pressure check PE101 and PE102)	PLC/W#3	Med	Closed
E500 filament system	PLC/W#4	Low	Closed
Cryopumps E302A or E302B turn off during cryopump while XV301A and XV301B open	PLC/W#5	Med	Closed
Vent Valve XV601 open at wrong time	PLC/W#6	Med	Closed
Roughing Pump Isolation XV101 open at wrong time	PLC/W#7	Med	Closed
argon supply valve XV404 open at wrong time	PLC/W#8	Med	Closed
Gate Valves XV301A & Regen valves XV303A open at wrong time	PLC/W#9	Med	Closed
Gate Valves XV301B & Regen valves XV303B open at wrong time	PLC/W#10	Med	Closed
Sycon Crystal System reads out incorrectly	PLC/W#11	Med	Closed
TE511 Thermometer	PLC/W#12	Med	Closed

5.1 HAZARD STATUS

PLC SOFTWARE REVIEW

PLC/W#1 - "Search/audit EV201A&B uses (not suggested since risk is low). Agreed to by MRB.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

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PLC/W#2 - "Search/audit for E101 and E102 uses in sw and search for XV101 permissive. (Olyvia and Ken will look at sw) - Complete - Audit showed consistent references to E101/MTR101/Roots Blower (2nd stage pump) and E102/MTR102/Roughing (1st stage pump). Audit indicates 1 change to shut down both pumps when either pump fails >5 secondes and XV101, XV303A/B verified closed. Change made and tested.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#3 - "Search/audit for E400 (or E410) permissive in sw (PI101 and/or PI102 should show up in permissive to activate glow discharge) - SW Search has already been done by USRA. Audit indicates 1 change to switch permissive to look at pressure of front of mirror (PI102) not back of mirror (PI101). Change made and tested.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#4 - "Search/audit for E500 permissive in sw. - SW Search has already been done by USRA. Audit indicates 1 change to switch permissive to look at pressure of front of mirror (PI102) not back of mirror (PI101). Change made and tested.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#5 - "Search/audit for XV301A&B permissives and commands. Verify XV301A closes if E302A failure. Verify XV301B closes if E302B failure. - (Olyvia and Ken will look at sw) - Audit indicated no need for any critical upgrades. One future upgrade option that will not be implement during this software update because it is not critical is to verfiy XV301A/B closed before opening XV404 during glow discharge. Hardware testing verified XV301A closes on E302A failure and XV301B closes on E302B failures.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#6 - "Search/audit for XV601 open in software. (Olyvia and Ken will look at sw) - Complete - Audit produced no recommended or required upgrades.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#7 - "Search/audit XV101 permissive and commands in sw - SW Search has already been done by USRA. Audit indicates 2 changes to valve XV101 permissive, 1) sanity check of chamber pressure is coded incorrrect 2) comparison of roughing volume

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and chamber volume was coded incorrectly. Change made and tested.
This update was slightly more complex than first anticipated and required logic to manage turbulence affecting gauge readings.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#8 - "Search/audit XV404 permissives and commands in sw (Olyvia and Ken will look at sw) - Audit indicated no need for any critical upgrades. One future upgrade option that will not be implement during this software update because it is not critical is to verfiy XV301A/B closed before opening XV404 during glow discharge.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#9 - "Search/audit XV301A and XV303A permissives and commands in sw (Olyvia and Ken will look at sw) - Complete - Audit indicated 2 changes to: 1) reference to motor function omitted in lower cryopump RGEN sequence; 2) reference motor function verification, rather than motor function command, in XV303A/B operation. Change made and tested.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#10 - "Search/audit XV301B and XV303B permissives and commands in sw (Olyvia and Ken will look at sw) - Complete - Audit indicated 2 changes to: 1) reference to motor function omitted in lower cryopump RGEN sequence; 2) reference motor function verification, rather than motor function command, in XV303A/B operation. Change made and tested.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#11 - "Search/audit DE509 actually cuts power when the desire thickness has been met. Review/audit the control system for sycon crystal system. (Not to be done. SW already shown to be reading out currently. Risk is small, worst case is a recoat). Agreed to by MRB.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#12 - "Search/audit for TI511 permissives in sw (Olyvia and Ken will look at sw) - Complete - Audit produced no recommended or required upgrades.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

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PLC WIRING REVIEW

PLC/W#1 - "Verify when we command valve (EV201A&B), it functions correctly (already part of reactivation procedure) - Complete - This wiring was verified during 1st reactivation procedure by USRA.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#2 - "Verify if we kill power on motors (E101), XV101 closes. (redline into IST) Verify if we kill power on motors (E102), XV101 closes. (redline into IST) - Completed on 4/27/08, commanded each pump to halt while XV-101 was open: each resulted in an immediate closing of XV-101 and a MRT failure as planned. Wiring trace of control and power lines from PLC to pumps indicated a design deviation. The manufacturer of the Power Panel Center identified MTR101 as the roughing pump and MTR102 as the roots blower. The panel wiring had been modified to work correctly with the PLC. Notified Ray Schuler (Engineering Lead at time of chamber installation) of need to update facility panel schematic drawing.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#3 - "Verify PE101-1 and PE101-2 output to PI101. Verify PE102-1 and PE102-2 output to PI102. (already part of new IST procedure) Completed - On 4/27/08 we disconnected cables to each of four gauges and verified error signals to MKS controller channels and PLC readout channels correct.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#4 - "Verify PE101-1 and PE101-2 output to PI101. Verify PE102-1 and PE102-2 output to PI102. (already part of new IST procedure) - Completed - On 4/27/08 we disconnected cables to each of four gauges and verified error signals to MKS controller channels and PLC readout channels correct.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#5 - "Verify shutoff power to compressor (E302A) makes XV301A close (may happen in after a few minutes when cryopump starts warming up). Verify shutoff power to compressor (E302B) makes XV301B close (may happen in after a few minutes when cryopump starts warming up).

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(redline into IST) - Completed - On 4/27/08, verified XV301A closes immediately when E302A powered off. On 4/27/08, verified XV301B closes immediately when E302B powered off.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#6 - "Verify XV601 open/closes upon command. (already part of reactivation procedure). - Complete - This wiring was verified during 1st reactivation procedure by USRA.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#7 - "Verify XV101 open/closes upon command. (already in activation procedure) Verify chamber and pumping line holds vacuum when limit switch ZSC101 indicates XV101 is closed. (redline to IST) - Complete - On 4/27/08, verified chamber has held <10millitorr for >20 hours while XV-101 closed and PI-103 at ambient. Verified XV101 open/closes upon command.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#8 - "Verify XV404 open/closes upon command. (already in reactivaton procedure). - Complete - This wiring was verified during 1st reactivation procedure by USRA.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#9 - "Verify XV301A open/closes upon command. (already in reactivation procedure) Verify XV303A open/closes upon command. (already in reactivation procedure) Verify that the chamber doesn't leak into cyropump when limit switch ZSC301A indicates XV301A is closed (and XV301B cable is disconnected). Verify that cryopump remains at vacuum when pumping lines are at ambient when limit switch ZSC303A indicates XV303A is closed (and XV303B cable is disconnected). - Ken and Olyvia will determine testable way to verify this. - Complete - On 5/1/08 with all volumes under static pressures and ambient temperatures, verified XV301A leaktight when ZSC301A indicates closed, XV303A leaktight when ZSC303A indicates closed. XV301A & XV303A verified under independent control. XV301B cable not disconnectable -- verified non-function by tracing wiring in PLC console, monitoring

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VCP display, and feeling individual valve cycles (sounds and shocks).
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#10 - "Verify XV301B open/closes upon command. (already in reactivation procedure) Verify XV303B open/closes upon command. (already in reactivation procedure) Verify that the chamber doesn't leak into cyropump when limit switch ZSC301B indicates XV301B is closed (and XV301A cable is disconnected). Verify that cryopump remains at vacuum when pumping lines are at ambient when limit switch ZSC303B indicates XV303B is closed (and XV301A cable is disconnected). - Complete - On 5/1/08 with all volumes under static pressures and ambient temperatures, verified XV301B leaktight when ZSC301B indicates closed, XV303B leaktight when ZSC303B indicates closed. XV301B & XV303B verified under independent control. XV301A\ cable not disconnectable -- verified non-function by tracing wiring in PLC console, monitoring VCP display, and feeling individual valve cycles (sounds and shocks).
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#11 - "Disconnecting sycon crystal wire DE509 from PLC and verify DC509 signal changes. (redline to IST) - Completed - On 4/29/08, cabling from Sycon crystal to Sycon controller verified by disconnection at both ends. Additional testing indicates that second crystal and second controller channel also appear to function when using existing cables from primary channels.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

PLC/W#12 - "Calibrate thermometer and verify that when we disconnect TE511 from PLC that TI511 changes to non-valid reading. (redline to IST) - Complete - On 4/27/08 disconnected TE-511 from back of readout device. Readout device read ""OPN"", TI-511=210.5C, mirr.temp.trip and mirr.temp.warning flags indicated on PLC as planned. TE-511 during PMA coating utilizes a temperature sensor which is permanently bonded to the PMA glass. New instrumentaion ordered to allow independent comparison of flight thermometer to calibrated source prior to PMA coating.
CLOSED by E. Ingraham (CSO) and Ken Bower (MCC Engineer) on 5/14/08."

BASTION TECHNOLOGIES

6.0 PMA LIFTING DEVICE (PLD)

The PMA Lifting Device (PLD) is necessary for attaching the PMA to the crane considering the limited clearance between top of RVC and crane-hook. The available clearance (max. 740 mm), dimensions of PMA and crane-hook as well as the coordinates of the three PMA attachments points are illustrated in figure below.
It consists of 5 standard hoist ring (HEBEZONE, RSN24) attached to the top mounting point, turnbuckles for adjusting the position of the hoist ring and a frame for compensating horizontal forces in the attachment points. The connection of the turnbuckles to the top mounting point and to the frame is realized by standard swivel heads (ASK KI 20-D-L, ASK KIL 20-D-L) and steel bolts. Screw joints are used for connecting the three square tubes for the frame with the attachment-point-turnbuckle interface.

PMA Lifting Device (PLD)

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PMA LIFT HARDWARE HAZARDS

Hazard Report Title	Number	Risk	Status
Primary Lifting Device	1.1 Rigging Hazard	Low	Closed
Pear Shape Link	1.2 Rigging Hazard	Low	Closed
Hoist Ring	1.3 Rigging Hazard	Low	Closed
Swivel Head	1.4 Rigging Hazard	Low	Closed
Top Mounting Plate	1.5 Rigging Hazard	Low	Closed

6.1 HAZARD STATUS

1.1 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

1.2 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.Author's Comment: Refer to PMA Lifting Device Construction Analysis Report".

1.3 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed. Author's Comment: Refer to PMA Lifting Device Construction Analysis Report".

1.5 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed. Author's Comment: Refer to PMA Lifting Device Construction Analysis Report".

BASTION TECHNOLOGIES

7.0 N211 OVERHEAD BRIDGE CRANE

The 5 Ton Overhead Bridge Crane will be used for all PMA critical lifts in the building. The approach here is to review all single point failures relating to the facilities 5 ton overhead bridge crane. The table below identifies the safety critical components.

5 TON BRIDGE CRANE CRITICAL COMPONENTS

Bridge Trucks (Welds, Bolts)	Bumper / Stops	Gearing Couplings
Wheels (Treads, Flanges, Axies)	Drive Shaft, Couplings, Bearings	Load Brake
Wheel Bearings	Gear Reducer Couplings	Hoist Motor (Brushes, etc)
Wheel Gears, Pinions	Trolley Motor (Brushes, etc)	Hoist Motor Brake
Sweep Plates, Drop Lugs. Bumpers	Trolley Motor Brakes	Hoist Control Panel
Lineshaft, Couplings, Bearings	Trolley Control Panel	Hoist Resistors
Gear Reducer Couplings	Trolley Resistors / Soft Start	Hoist Limit Switches
Bridge Motor (Brushes, etc)	Upper Tackle (Sheaves, Pins, Bearings)	Control Station Switch
Bridge Motor Brakes	Rope Drum Anchors	Control Conductor Collectors
Bridge Control Panel	Wire Rope / Load Chain Fittings	Power Conductor Collectors
Bridge Resistors / Soft Start	Hook Block Sheaves Bearings	Mainline Conductors Collectors
Bridge Trucks (Welds, Bolts)	Hoist Frame Suspension	Mainline Disconnect (On-Bridge)
Wheels (Treads, Flanges, Axies)	Upper Tackle (Sheaves, Pins, Bearings)	Mainline Contactor
Wheel Bearings	Rope Drum Anchors	Runway Beams, Rails
Trolley Frame (Welds, Bolts)	Wire Rope / Load Chain Fittings	Operational Test All Functions
Wheels (Treads, Flanges, Axies)	Hook Block Sheaves Bearings	Hoist Frame Suspension
Wheel Bearings	Wheel Gears, Pinions	Load Hook Safety Latch

BASTION TECHNOLOGIES

5 TON OVERHEAD BRIDEGE HAZARDS

Hazard Report Title	Number	Risk	Status
Hook	2.1	Med	Closed
Hook Nut	2.2	Med	Closed
Block Frame	2.3	Med	Closed
Sheave Pin	2.4	Med	Closed
Sheave Bearings	2.5	Med	Closed
Sheaves	2.6	Med	Closed
Sheave Pine Keeper/Bolts	2.7	Med	Closed
Wire Rope	2.8	Med	Closed
Wire Rope Collar	2.9	Med	Closed
Upper Block Sheaves	2.10	Med	Closed
Upper Block Sheaves Bearings	2.11	Med	Closed
Upper Block Sheave Pin	2.12	Med	Closed
Upper Block Sheaves Pin Keeper/Bolts	2.13	Med	Closed
Drum	2.14	Med	Closed
Main Gear Cage	2.15 & 2.17	Med	Closed
Geartrain Key	2.16	Med	Closed
Main Gear End Frame	2.18	Med	Closed
Electric Brake Keys	2.19	Med	Closed
Trolley	2.20	Med	Closed
Bridge / Girder Structure	2.21	Med	Closed
Bridge Shaft	2.22	Med	Closed
Electrical Speed Control Contactors	2.23 & 2.25	Med	Closed
Electrical Upper Limit Switch	2.24	Med	Closed
Electrical Up-down push button switches	2.26	Med	Closed
Electrical Indicator Lamp	2.27	Med	Closed
Inadequate Workspace	3.1	Med	Closed
Tag Lines	3.2	Med	Closed
PMA Handling Cart	3.3	Med	Closed

BASTION TECHNOLOGIES

7.1 HAZARD STATUS

1.1 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

1.2 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed. Author's Comment: Refer to PMA Lifting Device Construction Analysis Report"

1.3 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed. Author's Comment: Refer to PMA Lifting Device Construction Analysis Report"

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1.5 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.1 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.1 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.2 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.3 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.4 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

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2.5 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.6 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.7 .CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.8 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.9 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.10 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.11 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.12 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.13 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.14 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.15 & 2.17 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.16 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed

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Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.18 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.19 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.20 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.21 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.22 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.23 & 2.25 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.24 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.26 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

2.27 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

3.1 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

3.2 "CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Procedures will be detailed for all critical lift operations and practice runs will take place. No additional mitigation needed.

Author's Comments: Consider providing load tagging locations in a staging / operations plan.
"

3.3 CLOSED 2/22/08- Per meeting on 2/22/08 between Chief Safety Officer (Ed Ingraham) and USRA PMA Lead (Nancy McKown). Issue reviewed, no additional mitigation needed.

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8.0 OPERATIONAL DOCUMENTS

This SOFIA Science Instruments Primary Mirror Assembly (PMA) Mirror Coating Facility Safety Assessment Report shall also consider the safety critical documentation as a part of the assessment process. The documentation review includes both operational and design criteria to ensure that all safety considerations have been incorporated to eliminate or mitigate the risk associated. Some documentation will be modified and redlined during actual operations. The documents listed below are considered safety critical for PMA operations at NASA Ames.

- SOF-PRO-DR-1151.0.01; Handling of PMA Cart (with PMA) (SSMOC-MCF-PRO-7550; Special Procedure for PMA and PMA Cart Handling within Hangar N-211)
- SSMOC-MCF-PRO-1000; Mirror Strip and Clean Procedure
- SSMOC-MCF-PRO-2000; Primary Mirror Coating Master Procedure
- SSMOC-MFC-PRO-2400; Mirror Aluminizing Procedure
- SSMOC-MCF-PRO-2009; Primary Mirror Assembly to Mirror Coating Chamber Installation and Removal Procedures

PMA Bonding reference documentation:
- INGE0358; Gluing Qualification Plan
- INGE0625; Technical Report for Gluing Qualification
- INGE0356; Definition Justification Documentation of SOFIA Primary Mirror Assembly

Code Q representative also reviewed and approved all other operational procedures associated with mirror coating operation at Ames as part of the embedded SMA process.

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8.1 SOF-PRO-DR-1151.0.01

The following document review was provided by subcontract service to NASA HQ by jointly in coordination by DFRC & ARC. The analyst methodology is to assess each operational step in the procedure and provide safety recommendations as necessary.

1) If Necessary, Assemble Spreader Bar acc, to Fig.1 in Procedure. Attach Each of the Cross Beams Onto the Main Beam at the I/F's With 8 Screws and Appropriate Nuts.Note: Slings May be Used if the Crane Hook does not Fit Into the Eyelet. Loose Screw(s) Could Result in Shifting of Crossbeam in Subsequent Steps. Provide a Torque Wrench and QA Verify Torque.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Part will be shipped fully assembled. No torque needed at ARC. QA involved throughout step by step in updated procedure.

2) Attach the Spreader Bar to the Crane Hook at the Crane Eyelet. Position Eyelet Straight Above the C.G. of the Turning Frame Including the PMA. Note: The Spreader Will Not be Leveled in this Position. Uncertified Operator is Utilized Leading to Critical Error. Human Error of Commission QA Verification of Completion of Preparatory Tasks is Appropriate. Recommend Determining CG of the Turning Frame/PMA Could Be Determined With Load Cells, Which Would Facilitate Step Below.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Mobile crane comes with professional rigger. Analysis has been checked by hardware developers. CG will be load leveled and lifting eye position measured at Site 9 (Palmdale) prior to shipment.

3) Attach 2 Tag Lines to Spreader Bar to Support Positioning . Potential Spreader Bar Contact With Turning Frame. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. In procedure -7550.

4) Attach the Spreader Bar to the Four Eyelets of the Turning Frame acc.to Fig. 2 .in This Procedure. Note: Slings May Be Used in Case the Crane Hook Does not Fit Into the Eyelet. Faulty Connection Could Adversely Impact Step 6.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

5) Remove the 4 x 2 M16 Bolts Between the Turning Frame and the Standoffs (Corners of PMA Cart). Store Them in a Proper Box for Further Use.Potential Harm to Fingers or Inadvertent Non-removal of one or More Bolts.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

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6) Lift the Turning Frame Including the Turning Frame About 2 m (6'-2").- Caution Lift Slowly In Case That the Spreader Bar is Not Leveled in Within 5", Lower Turning Frame and Place it on the Stand Offs . Adjust the Eyelet of the Spreader Bar to a Better Position. Start Lifting Again. Repeat If necessary. Leveling Process is Manual, and as Such is Subject to Human Error. Level Tolerance Could be Exceeded. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. This items are premeasured at Site 9 during operations to prepare for shipment to ARC.

7) Turn and Position Spreader Bar with PMA Above Dedicated Holding Area for PMA. Dropped Load Could Result in Personnel Harm and/or Damage to PMA. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

8a) Start Lifting Slowly in Case that the Spreader Bar is not Leveled in Within 5 Degrees, Lower Turning frame With PMA and Place it on the Three Stands of the PMA. Adjust the Eyelet of the Spreader Bar to a Better Position. Start Lifting Again. Repeat if Necessary. Unleveled Spreader Bar Results in Shift of CG and Possible Contact. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. This items are premeasured at Site 9 during operations to prepare for shipment to ARC.

8b) Slowly Lower Whole Assembly Into Holding Area-Lower Crane Hook to Relieve Strain from Spreader Bar/Turning Frame Assembly.. Detach Turning Frame from PMA by Loosening and Removing 3xM30 Bolts and Washers from I/F A (2x) and I/F C (1x). Dropped Load Could Result in Personnel Harm and/or Damage to PMA. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

9) Unscrew Shackles at Eyebolts of Turning Frame an Move Spreader Bar Away from PMA Cart. Dropped Load Could Result in Personnel Harm and/or Damage to PMA. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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10) Slowly Lift Spreader Bar with Turning Frame and Place on Stands with a Minimum Height of 100cm/40 inches near PMA-Cart.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

11) Detach Spreader Bar From Crane Hook. Failure to Detach Could Affect the Following Step.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.
12a) Unscrew All Bolts Between First Standoff and Base Frame and Remove the 2 Shear Pins. Potential Harm to Fingers or Inadvertent Non-removal of one or More Bolts. Utilize Verification Practices
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

12b) Unscrew All Bolts at the Base Frame and the 4 x 2 Shear Pins at the Frame Supports (4 Vertical Bars in the Edges) except Screw of Lifting Jacks. Potential Harm to Fingers or Inadvertent Non-removal of one or More Bolts. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

13) Attach One Sling in a Choker Configuration to Stand-Off and Attach Other End of Sling g to Crane Hook. Potential Base Frame Contact With Crane Hook. Provide Instructions Even If the Configuration Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

14) Remove Stand-Off from Base Frame and Place in Proper Storage Area. Failure to Remove Could Affect Effectiveness of Subsequent Steps.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

15) Repeat Steps 13 and 14 to Remove Remaining 3 Stand-Offs From the Base Frame.Failure to Remove Could Affect Effectiveness of Subsequent Steps.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

16) Attach Slings to the Drive Frame and to Frame Hook. (Use M12 Bolts , Torque 56Nm 41 lbf*ft)). Potential Drive Frame Contact With Frame Hook. Provide Instructions Even If the Attachment Action Appears Obvious.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

17) Lift Drive Frame From the Base Frame and Attach to the Base Frame. (use M12 Bolts-Torque 56Nm (41 lbf*ft). Dropped Load by Crane. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

18) Repeat Steps 16 and 17 to Attach Bearing Frame to the Base Frame (Use , Torque 56 Nm (41lbf*ft))Potential Drive Frame Contact With Frame Hook. Provide Instructions Even If the Attachment Action Appears Obvious.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

20) Screw the Special Centering Pin (SOF-DWG-KT-1151.1.104 in Anyone Thread in the Drive Frame I/F of the Turning Frame (Pin Included in GSE Box With the M12 Bolts, for I/F to the Drive Frame). Failure to Install Centering Pin Properly. Provide Instructions Even If the Centering Pin Installation Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

21) Move the Axle of the Bearing Frame to the Most Outer Position. Axle Out of Position.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

22) Attach 2 Tag Lines to the Spreader Bar to Support Positioning-Attach Spreader Bar to Crane Hook at the Crane Eyelet Straight Above the CG of the Turning Frame. Axle Out of Position.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

23) Lift Spreader Bar With Turning Frame Attached Onto the Cart Assembly-Position Centering Pin Into Anyone Bolt Hole of the Gear Box Flange of the Drive Frame I/F. Centering Pin Partially Installed. Confirmation Verification Action of Proper Installation.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

24) Adjust Position of Turning Frame t Achieve Contact Between Turning Frame and Drive Frame. - This Can Also Be Achieved by Adjusting Position of the Base Frame On Wheels-TD to Decide Which Method Will Be Used.Final Position Could Shift During Subsequent Step 25. Consider Installation of a Position Locking Mechanism.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

25) Fix Position of PMA Cart by Lowering the Jacks. Potential PMA Cart Contact With Turning Frame. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

26) Apply All bolts to the I/F. Unscrew The Centering Pin and Replace it by a Bolt (M12 (M12 Bolts, Torque 56 Nm (41lbf*ft)) Potential Harm to Fingers or Inadvertent Failure to Remove Centering Pin and Install one or More Bolts. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

27. Screw the Special Centering Pin (SOF-DWG- KIT- 1151.1.04) in Anyone Thread at the Bearing Frame I/F of the Turning Frame (Pin Included in the GSE-Box). Failure to Install Centering Pin Properly. Utilize Verification Practices
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

28) Lower the Turning Frame (if Necessary) Move the Movable Axle of the Bearing Frame to Achieve to Achieve Contact With the Bearing Frame at the Interface. Position the Movable Axis Such That the Centering Pin Fits into the Anyone Bolt Hole of the Axles Flange. Manual Positioning operation With Crane Assist Offers the Potential for Damage to the Turning Frame and/or the Centering Pin. A mating Guide to the Anyone Bolt Hole Might Facilitate the Operation.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

29) Apply All Bolts to the I/F. Unscrew the Centering Pin and Replace by a Bolt (M12 Bolts, Torque, Torque56 Nm (41lbf*ft)) Potential Harm to Fingers or Inadvertent Failure to Remove Centering Pin and Install one or More Bolts. Utilize Verification Practices.

30) Screw Fixation Bolt Bracket to Bearing Frame (location acc. To Fig.3 of This Procedure). Note; The Fixation Bolt Bracket has to be Removed Before Turning or Removing the Turning Frame from the Bearing Frame. Failure to Install Fixation Bolt Properly. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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31) Lower Spreader Bar to Relieve Load. Unscrew Shackles at Eyebolts. Potential Harm to Personnel Fingers During Unscrewing Shackles at Eyebolts Especially if Load is Not Relieved.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

32) Remove Spreader Bar and Place in Dedicated Storage Area Placement in Non-dedicated Storage Area Could Result in Contamination and Subsequent Contamination of PMA in Subsequent Operations.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

Notes: The Turning Axis is Fixed by a Brake in the Air Motor as Soon as the Motor is Stopped. As an Additional Inhibit to Prevent Unintentional Turning The Fixation Bracket has to be Screwed to the Bearing Frame. The PMA-Cart can Now be Moved on Its Wheels. Lift the Jacks for Moving and Lower the Jacks for Braking. The Cart may be Coupled to a Forklift for Moving.

C- Turning of Turning Frame With PMA
Perquisites: The PMA-Cart is in the Slewing Configuration, Not in Transport Configuration. The Bearing Frame and the Drive Frame are attached to the Base Frame. The Turning Frame is Attached Between the Bearing and Drive Frame.-The Turning Frame is Attached to the Turning Frame of the PMA Cart The PMA Cart is Connected to a Compressed Air Supply.-The Turning Frame is Turned Into The Horizontal Position.

1) Fix the PMA Cart by Lowering the Jacks. Possible QA Verification Function
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

2) Remove Fixation Bolts of PMA Cart Failure to Remove Fixation Bolt Properly. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure..

3) Fix Eyelets to Turning Frame to Prevent Them from Touching the Base Frame During Turning (with Cable Ties for Example). Eyelets Rub Against Base Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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4a) Verify That Pressure System of PMA Cart is Connected to Shop Air Improper Connection Results in Air Pressure Degradation/Leakage. Verify Functionality of PMA-Cart Air Pressure System.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure..

4b) Verify That No Unsecured Objects Are On The Turning Frame or on the PMA. Unsecured Object Results in Damage to Turning Frame and/or PMA. Possible QA Verification Function.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

5) Connect Pressure System of PMA Cart to Shop Air. Potential Contamination of Shop Air Could Jeopardize Cleanliness Standard Requirements. QA Check Quality of Shop Air.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

6) Check Oil Reservoir and Fill If Necessary With Depragol or Equivalent (ESSO ER EP-68, Shell Torcula 68).
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

7) Turn and Unlock Remote Stop Button and Stop Button at Remote Control Failure to Unlock Could Inhibit the Effectiveness f Subsequent Operations.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

8) Press Start Button on Remote Control.

9) Choose the Turning Direction With the Switch. The Direction May Be Changed During Turning. Selection of Wrong Direction Begins Turn in Opposite Direction. Correction of Turning Direction Can Be Made.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Turning either direction doesn't matter to safety of PMA.

10) Turn Turning Frame Into Vertical Position. Determine Position by Visual Observation Degradation of Air Pressure During the Turn Degrades Position Control. Consider Back-up Air by Installing a Dedicated Accumulator.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Being at any orientation doesn't matter to safety of PMA.

11) Stop Turning by Pressing One of the Stop Buttons. This Will Lock the Button.Failure to Execute the Stop Button Procedure Properly Could Result in Equipment Damage.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

12) If Necessary Adjust Position So That Fixation Bolt of Fixation Bolt Bracket Fits Into Hole at Bracket of the Turning Frame. Unlock Stop Button by Turning and Press the Start Button.Failure to Execute Properly. Provide Instructions Even If the Positioning Action Appears Obvious.

CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

13) If Correct Position is Reached, Press Both Stop Buttons. Failure to Execute Properly. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

14) Fix Position of the Turning Frame by Installing Turning Fixation Bolt Between Bearing Frame and Turning Frame Flange Failure to Execute Properly. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

15) Repeat Steps 7-14 as Necessary to Verify Proper Functioning of the Cart-Motor and-Controls.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

16) Bring Turning Frame Back to Horizontal Position. Failure to Execute Properly. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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17) Attach the Spreader Bar to the Crane at the Crane Eyelet Faulty Attachment Could Impact Subsequent Steps. Provide Instructions Even If the Attachment Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

18) Attach Tag Lines as Necessary to Spreader Bar (Minimum 2). Faulty Attachment Could Impact Subsequent Steps. Provide Instructions Even If the Attachment Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

19) Lift and Position Spreader Bar Above Turning Frame. Crane Drops Load- Potential Personnel arm and /or Physical Damage. Consider Attaching Safety Line(s) That Limit the Extent of a Potential Drop.

CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

20) Remove Fixation Bolt Bracket and I/F Screws from the Bearing Frame. Failure to Remove Entirely Could Cause an Unsafe/Dame During Execution of Following Step 21. Provide Instructions Even If the Removal Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

21) Move the Axle of the Bearing Frame Away from the Turning Frame. Damage to Turning Frame During Movement Away. Provide Instructions Even If the Removal Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

22) Loosen and Remove I/F Screws from the Drive Frame.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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23) Slowly Lift and Move Turning Frame from Drive Frame. Stop Movement When Turning Frame is Hanging Free between the Drive Frame and the Bearing Frame. Potential Contact of the Turning Frame/PMA With Drive Frame and /or Bearing Frame. Provide Instructions Even If the Removal Action Appears Obvious-Consider Practice Training.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

24) Lift Turning Frame Out of Cart and Place Above PMA. Lower Turning Frame on 3 Cones. (I/Fs C1 and 2xA). Should Crane Drop the Load Prior to Turning Fame in Cones, Damage to the PMA is Possible at the Mirror I/Fs. Protect the PMA During Placement of Turning Frame on Cones or Affix Safety Tag Lines.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. There is tag lines and a hard cover over primary mirror surface.

25) Bolt PMA to Turning Frame Using 3xM30 Bolts/Washers at the Cones. Torque to 150 Nm. Secure Bolts with M10 Bolts Through the I/F Plate of the Cart. Failure to Execute Properly Could Inhibit Success of the Following Step 26. QA Verification.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been

walked thru. QA involved throughout step by step in updated procedure.

26) Lift The Turning Frame Including the PMA. Drop Of Turning Frame Onto the Cart.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

27) Lower Spreader Bar With Turning Frame Attached onto the Cart Assembly. Position Centering Pin Into Anyone Bolt Hole of the Gear Box Flange of the Drive Frame I/F. Failure to Execute Properly Could Inhibit Success of the Following Step 26. QA Verification
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

28) Adjust Position of Turning Frame to Achieve Contact Between Turning Frame and Drive Frame. This Can also be Achieved by Adjusting the Position of the Base Frame on Wheels. TD to Decide Which Method Will Be Used. Faulty Position Could Impact Subsequent Steps. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru.

29) Apply all Bolts to the I/F. Unscrew the Centering Pin and Replace it by a Bolt (M12bolts,torque 5656 Nm (41 lbf*ft). Improper Execution of This Step Could Inhibit the Next Step. Consider Practice Training Sessions.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC.

30) Screw The Special Centering Pin (SOF-DWG-KT-1151.1.04) in Anyone Thread at the Bearing Frame I/F of the Turning Frame (pin included in GSE Box).
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

31) Lower the Turning Frame. Move the Movable Axle of the Bering Frame to Achieve Contact with the Turning Frame at its Interface. Position the Movable Axle so that the Centering Pin Fits Into the Anyone Bolt Hole of the Axles Flange. Improper Execution of This Step Could Inhibit the Next Step. Consider Practice Training Sessions.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC.

32) Apply All Bolts to the I/F. Unscrew the Centering Pin and Replace it by a Bolt (M12 Bolts, Torque 56 Mn).Screw Fixation Bolt Bracket Bearing Frame Note: The Fixation Bolt Has to Be Removed Before Turning or Removing the Turning Frame from the

Bearing Frame. Improper Execution of This Step Could Inhibit the Next Step. Consider Practice Training Sessions.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC.

33) Screw Fixation Bolt Bracket to Bearing Frame. QA Verification.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

33a) Verify that Glued I/Fs at Back Side of Mirror do Not Show Damage. Visual Inspection Was Determined by NASA Safety to be a Sufficient Means of Verification I/Fs Should Not be Touched. Verification Technique Leads to Damage.. Care Should be Taken to Avoid Damage to the Edges of the Primary Mirror or Contamination of the I/Fs. QA Verification Actions Appropriate.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been

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walked thru. QA involved throughout step by step in updated procedure. Inspection is performed by expert who also performed inspection prior to shipment.

34) Lower Spreader Bar to Relieve Load. Unscrew Shackles at Eyebolts. Failure to Relieve Load Could Lead to Potential Harm to Operators Who Unscrew Shackles. Consider Practice Training Sessions.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC.

35) Remove Spreader Bar and Place in Dedicated Storage Area. Placement of Spreader Bar in Non-designated Area Could Lead to Contamination and Potential Contamination of Turning Frame/PMA. QA Verification Action.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

36) Remove Stands from PMC. Failure to perform Properly Could Inhibit Success of Subsequent Steps. QA Verification Action.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

37) Repeat Steps 3-9.

38) Bring Frame With PMA Into a 45 Degree Position (+/-10). Lack of Tolerance on the 45 Degree Position Could Inhibit the Success of Step 39 and Require More Repositioning. Consider a Vertical Position Measurement.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru.

39) Attach Handling Brackets to PMA acc.to SOF-DWG-KT-100.01-PMAInterfaces. Faulty Attachment Could Impact Subsequent Steps.. Provide Instructions Even If the Attachment Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru.

40) Torque All Handling Bracket Screws to 16 Nm+/- 2. Failure to Torque Screws to Requirement Could Inhibit Success of Steps 43 and 44.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

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41) Turn and Unlock Remote Stop Button at Remote Control.

42) Press Start Button on Remote Control Failure to Start Step.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

43) Choose The Turning Direction With the Switch Selection of Wrong Direction Begins Turn in Opposite Direction. Correction of Turning Direction Can Be Made.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Direction doesn't matter to safety.

44) Continue Turning the Turning Frame With PMA and Bring Into Vertical Position. Determine Position by Visual Observation. Lack of Tolerance on the Vertical Position Could Inhibit the Success of Step 46 and Require More Repositioning. Consider a Vertical Position Measurement.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Direction doesn't matter to safety.

45) Stop Turning by Pressing One of the Stop Buttons. This Will Lock he Button. Failure to Stop the Turning in Time Could Lead to an Overshoot of the Vertical Position Leading to Potential Damage to the Turning Frame/PMA. Practice Training of This Operation Should Be Considered.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC.

46) If Necessary, Adjust the Position so that the Fixation Bolt of the Fixation Bolt Bracket Fits Into Hole at Bracket of the Turning Frame. Unlock the Stop Button by Turning and Press the Start Button.

47) If Correct Position is Reached, Press Booth Stop Buttons.

48) Fix Position of Turning Frame by Turning Fixation Bolt of Fixation Bolt Bracket into Hole in Turning Frame Flange. Failure to Install Fixation Bolt Properly. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

Preparatory Tasks Carried Out: PMC Stands are Attached, PMA-Cart Four lifting Jacks Lowered; Cart is in Slewing Configuration,i.e. the Bearing Frame and the

Drive Frame are Attached to the Base Frame. The Turning Frame is Attached to the Turning Frame of the PMA Cart and is In Horizontal Position. Crane Rated for a Minimum of 4 Metric Tons is checked, Inspected, and in position to perform lifting tasks. Compressed Air Connected (6 bar or 87 psi). Uncertified Operator is Utilized Leading to Critical Error.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

1) Assemble Spreader Bar (if necessary) acc. To Figure 1. Attach Each Crossbeam Onto the Main Beam at the I/F's With 8 Screws and Appropriate Nuts.. Loose Screw(s) Could Result in Shifting of Crossbeam in Subsequent Steps. Provide a Torque Wrench Torque Specification.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

2) Attach the Spreader Bar to Crane Hook at the Crane Eyelet. Position Eyelet Straight Above the CG of the Turning Frame Including The PMA-Note Spreader Will Not Be Leveled This Cognition (Without PMA Attached). Note Slings May be Used in Case The Crane Hook Does Not Fit Into the Eyelet. Uncertified Operator is Utilized Leading to Critical Error. QA Verification of Completion of Preparatory Tasks is Appropriate. Recommend Determining CG of the Turning Frame/PMA Could Be Determined With Load Cells, Which Would Facilitate Step 2 Below.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

3) Attach 2 Tag Lines to the Spreader Bar to Support Positioning. Provide Some Training
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC and post shipment to ARC operations.

4) Lift and Position Spreader Bar Above Turning Frame -Lower the Spreader Bar to the Designated Foam Blocks at Top of the Turning Frame. Crane Drops Spreader Bar. Provide Some Training
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. Also participating in reverse work at Site 9 (Palmdale) prior to shipment to ARC and post shipment to ARC operations.

5(Attach the Spreader Bar to the 4 Eyelets the Turning Frame acc. To Fig.2 Faulty Attachment Could Impact Subsequent Steps. Provide Instructions Even If the Attachment Action Appears Obvious.

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CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

6) Remove Fixation Bolt Bracket from the Bearing Frame (See Fig.3) Failure to Remove Completely Could Jeopardize Subsequent Steps. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

7) Lift Spreader Bar Carefully and Slowly Until the 4 Eyelets of the Turning Frame are Under Tension. Improper Tension May Inhibit the Effectiveness of the Next Step. Can Crane Load Measurements b used as a Surrogate for their Purpose?
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure. We will have load sensor in series.

8) Remove I/F Screws between the Bearing Frame Axle and the Turning Frame. Manual Screw Removal Process May Result in Injury -Physical Damage. Inspection of Screw Threads Following Removal-It Would Facilitate the Process if the Tool for Screw Removal Such as a Powered Torque Wrench or a Hand Held Screwdriver or Hex Wrench Was Specified. A Removal Torque Limitation Could be Specified.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure. We will have load sensor in series.

9) Move the Axle of the Bearing Frame Away from the Turning Frame. Potential Collision of Bearing Frame With Turning Frame and Shock to PMA Assembly. Provide Protective Barriers.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

10) Loosen and Remove All I/F Screws From Bearing Frame and Drive Frame. An Overlooked Screw Will Impact the Following Step. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

11) Slowly Lift Turning Frame With PMA Away From Drive Frame. Stop Movement When Turning Frame is Hanging Free Between Drive Frame and Bearing Frame. Crane Drops Turning Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional

mitigation needed. Agree with QA &RM Services Inc. Recommendation.

12) Slowly Lift Turning Frame With PMA Out of Cart. Transfer to Staging Area Crane Drops Turning Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

13) Slowly Lower Turning Frame Onto Stands. Crane Drops Turning Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

14) Unscrew Shackles at Eyebolts of Turning Frame and Move Spreader Bar Away From PMA Cart. Crane Drops Spreader Bar.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

15) Loosen and Remove M2 Bolts From I/F of Drive Frame and Base Frame An Overlooked Bolt Will Impact the Following Step. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

16) Attach Slings to Drive Frame and Remove With Crane From Base Frame Crane Drops Drive Frame/Base Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

17) Repeat Steps 15 & 16 for Removal of Bearing Frame. Crane Drops Bearing Frame/Base Frame.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

18) Attach Sling to Stand-offs and Move by Crane to a Corner of the PMA Cart. Crane Drops Stand-Offs.
CLOSED 2/21/08- Per CSO (E. Ingraham) review. Issue reviewed, no additional mitigation needed. Agree with QA &RM Services Inc. Recommendation.

19) Attach the Spreader Bar to Crane Hook at the Crane Eyelet.Position Eyelet Straight Above the CG of the Turning Frame including the PMA. Note: Spreader Bar Will Not be Levelled in this Condition Wwithout PMA Attached). Note: Slings May Be Used in Case the Crane Hook Does Not Fit Into the Eyelet. Crane Drops Spreader Bar or Personnel Harmfi Operators Below Spreader Bar.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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20a) Attach 2 Tag lines to Spreader Bar to Support Positioning. Potential Spreader Bar Contact With Turning Frame. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

20b) Lift and Position the Spreader Bar Above the Turning Frame. Crane Drops Spreader Bar or Personnel Harmfi Operators Below Spreader Bar. Utilize Verification Practices
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

20c) Lower Spreader Bar to Designated Foam Blocks Crane Drops Spreader Bar. Utilize Verification Practices
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

20d) Attach the Spreader Bar to the 4 yelets of the Turning Frame. Acc. To Fig.2 of this Procedure Potential Harm to Fingers if Relative Motion Motion of the Spreader Bar and the Turning Frame Takes Place. Provide Instructions Even If the Positioning Action Appears Obvious.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

21) Lift Spreader Bar Carefully and Slowly Until The 4 Eyelits of the Turning Frame are Under Tension. Inproper Tension May Inhibit the Effectiveness of the Next Step. Can Crane Load Measurements b used as a Srrogate for thei Purpose?
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure. We will have load sensor in series.

22) Slowly Lift Turning Frame With PMA Using Spreader Bar About 2 m (6'- 2"). Caution: Start Lifting Slowly in Cas the Spreader BarIn Within 5". Lower Turning Frame and Place on the Stand-offs.Adjust the Eyelet of the Spreader Bar to a to a Better Position. Start Lifting Again. Repeat If Necessary. Dropped Load by Crane. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

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23) Move Turning Frame Over PMA-Cart and Lower On Stand-Offs. Use Tag Lines to Get Into Correct Position. Insufficient Clearance Results in Contact With PMA. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

24) Install 4 x 2 M16 Bolts Between the Turning Frame and the Stand-offs (corners of PMA Cart).-Torque 135Nm (100 lbf*ft) Inproper Torque May Inhibit the Effectiveness of the Next Step. Utilize Verification Practices
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

25) Loosen Shackles From Eyeblts of Turning Frame Incomplete Removal of Shackles May Cause Spreader Bar to Tilt in the Next Step and Make Contact With thr Turning Frame. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

26) Remove Spreader Bar Dropped Load by Crane. Follow NASA -STD-8719.9 Section4-Testing and Inspection, and DCPS-009 Chapter 6.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

27)Remove Three Stands From PMA and Store in Box for GSE and Accessories of PMA Cart Inproper Removal Technique Results in Damage to PMA. Utilize Verification Practices.
CLOSED 4/24/08- Per CSO (E. Ingraham) review with Test Director (P Waddell). Issue reviewed, no additional mitigation needed. Updated procedures in place and have been walked thru. QA involved throughout step by step in updated procedure.

28) Prepare PMA for Transportation DETAILS OF THE PREPARATION PENDING SELECTION OF TRANSPORT MODE

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APPENDIX – 1

PMA BONDING REFERENCE DOCUMENTATION

INGE0358; Gluing Qualification Plan

INGE0625; Technical Report for Gluing Qualification

BASTION TECHNOLOGIES

REOSC SAGEM	Projet / Project : SOFIA M1	Ref REOSC : INGE 0358 Edition : 05 Ref Client : SOF-TAN-RC-1110-0-09 Date : 22/04/99 Page : 1 / 6

Nature :

Document n° INGE0358

ORIGINAL EN ROUGE

Titre / Title :

GLUING QUALIFICATION PLAN

Résumé / Summary :	Classification Non classifié
	Archivage / Record Disquette : SOFIA Répertoire : DOC./INGE Fichier : INGE0358_05 Original : Archive technique

	Nom & Fonction Name & Function	Date	Signature
Préparé par : Prepared by :	Michel TARREAU Project manager	22/04/99	
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EVOLUTION		
Edition	Date	Observation
01	11/09/97	Original issue
02	24/03/98	See page 2
03	06/08/98	
04	09/12/98	
05	22/04/99	

DIFFUSION	Document complet Full document	X
Pages modifiées n°		

BASTION TECHNOLOGIES

REOSC SAGEM	Projet / Project : SOFIA M1	Ref REOSC : INGE 0358 Edition : 05 Ref Client : SOF-TAN-RC-1110-0-09 Date : 22/04/99 Page : 2 / 6

Edition	Date	Observations
01	11/09/97	First Issue
02	24/03/98	§ 2 - nb of AD03 ; AD04 ; DWG01 ; DWG02 & DWG03 / § 4.1 - new temperature for test on samples / Schedule updating
03		§ 2; suppression of DWG 04 & 05; Chgt issue DWG 01 & 02; § 4.1 modif according fax n°SOF-LE-KT-0453; § 4.2 complete rewriting - § 4.3 ::new tests.
04	22/04/99	§ 4.2.2.; 4.3 & 5.1.2.: Add a long thermal cycling for 6 samples
05	22/04/99	Suppression of AD04 (procedure not written) - schedule Update

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1. SCOPE

On the design of the SOFIA primary mirror equipped, there is several glued Invar pads which are used for the mirror fixation.
The purpose of this document is to check the glue behaviour and to give information for the finite element analysis of the mirror equipped. The aim points checked are:

- validation of surfaces preparation and gluing procedure,
- measurement of the mechanical characteristics of the gluing for loading cases equivalent to real cases (tensile forces),
- checking, on representative samples, of the gluing mechanical resistance (fatigue) for combined effort and thermal load cases.

2. APPLICABLE DOCUMENTS

AD01	doc. KT n°: *SOF-SP-1110-KT issue 2 revision B* SOFIA primary mirror procurement specification.
AD02	doc. REOSC n°: *SOF-TAN-RC-1110-0-04 issue 02 - 18/01/99* Definition justification document of SOFIA primary mirror assembly.
AD03	Procedure. REOSC n°: *770101 issue 02 - 24/03/98* Gluing of Invar pad on ZERODUR with DP490
AD05	Procedure. REOSC n°: *770104 issue 01 - 14/05/98* Gluing of axial & lateral pads on ZERODUR lightweighting samples
DWG01	Drawing. REOSC n°: *703-10032-000-20 issue 02 (SOF-DWG-RC-1110-3-32)* Lateral pad
DWG02	Drawing. REOSC n°: *703-10036-000-20 issue 02 (SOF-DWG-RC-1110-3-36)* Axial pad
DWG03	Drawing. REOSC n°: *703-01003-000-20 issue 00* Tensile gluing sample

3. SELECTED GLUE

Scotch Weld™ **DP 490**
Manufacturer: ***3M***
That glue is a bi-component structural glue
We have already qualified that glue for the gluing of a Zerodur mirror and Invar pads. They are parts of a military airborne optical devices which are operational for 2 years. At this time, about 20 devices have been manufactured and used without gluing problem. The temperature range for them is -60°C to +70°C with a nominal use temperature of +50°C.

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4.2.1.3 Endurance characterization sample

12 samples defined by DWG03

Those samples will be glued in conformance with procedure AD03.

- tensile test tool defined by file reference NI MT98_122.

6 samples are assembled on this tool and tested in the same time.

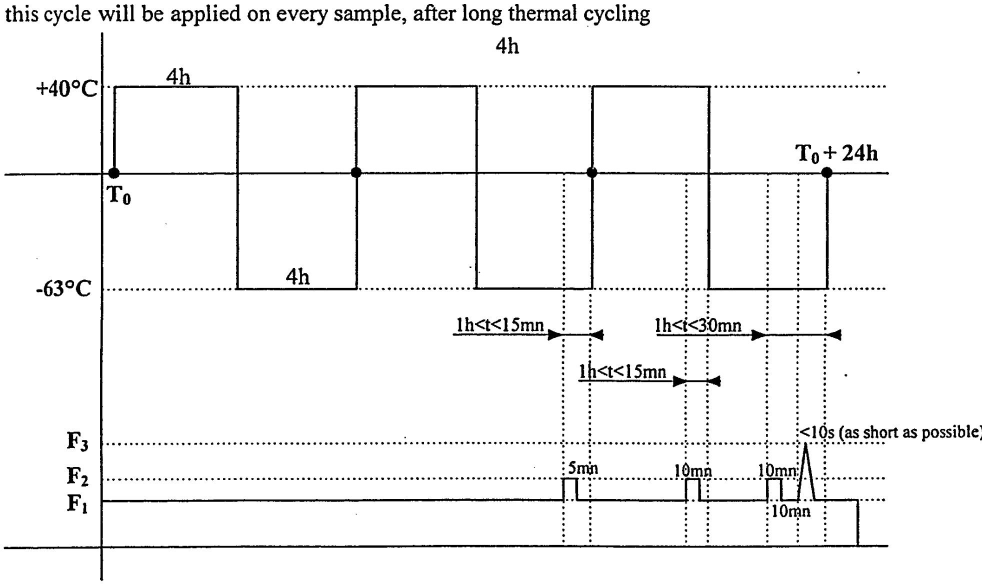
4.2.2 Thermal and force cycling

4.2.2.1 Long thermal cycling

50 cycles +40°C; -63°C - 4H for each step - will be applied on 6 Endurance characterization samples. No force applied on the samples during this test.

4.2.2.2 Thermal and force cycling

this cycle will be applied on every sample, after long thermal cycling



F_1 = 1.5 x non operational load

F_2 = crash load (worst case)

F_3 = 1.5 x crash load (worst case)

	F_1	F_2	F_3
Lateral I/F sample	4.05 kN	25.4 kN	38 kN
Axial I/F sample	1.34 kN	2.63 kN	3.95 kN
Endurance characterization samples (x 6)	434 N	2.7 kN	4.1 kN

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4.3 Gluing characterization after permanent tensile loading

The goal of those tests is to check that the tensile strength of the glue is not reduce by a long term static load.

After thermal and force cycling, 6 - including 3 long thermal cycled samples - of the 12 endurance characterization samples will be pull tested, until breakage, at room temperature (≈ 20°C).

The 6 other samples will be static loaded (force = F1) during one more year, at room temperature. After, they will be pull tested, until breakage, at room temperature.

5. ISSUED DOCUMENT

5.1.1 gluing qualification report

this report will give, for the tensile gluing samples:

- a detailed description of the samples manufacturing and tests
- all the results (breakage value, ...)
- curve $\sigma_R = f(\theta)$ and the glue characteristics for FE analysis

It will give, for the axial & lateral gluing samples:

- a detailed description of the samples manufacturing,
- a summary of the test results,
- a analysis of those tests

5.1.2 test report for thermal cycling

For each thermal end force cycling applied on the samples, a report will give,:

- a detailed description of the tests,
- all the results (temperature and stress curves; breakage value, ...)

6. MANUFACTURING AND TEST SCHEDULE

see appendix 1 (3 pages)

BASTION TECHNOLOGIES

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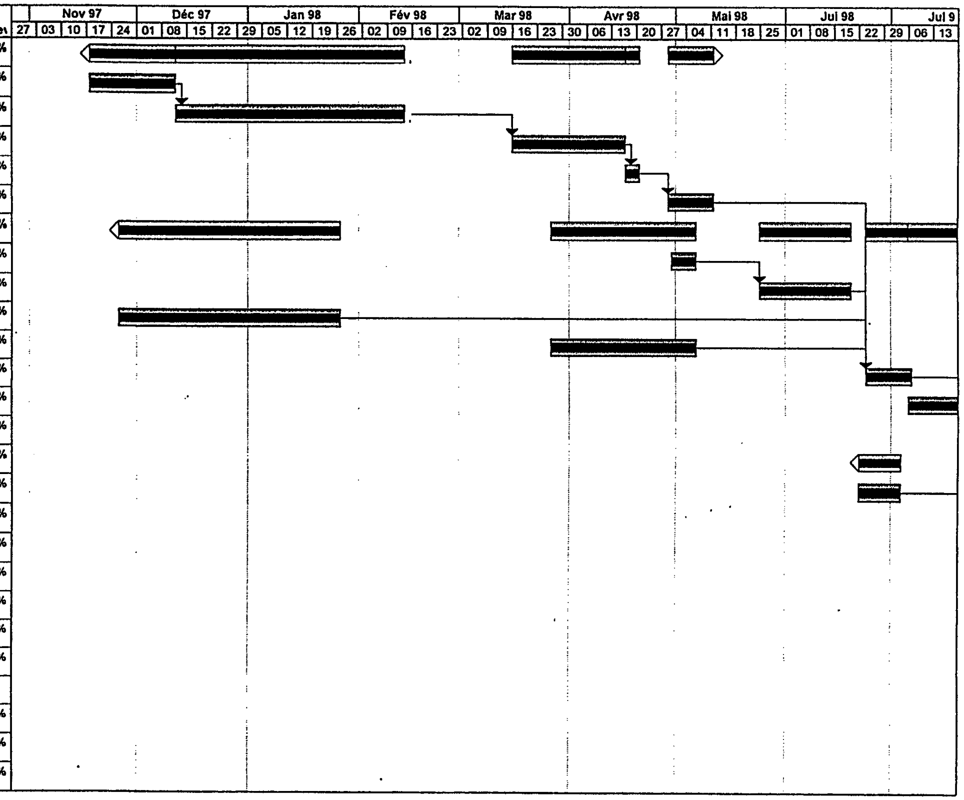
Planning validation collage

N°	Nom de la tâche	Durée	Début	Fin	% achev
1	**tensile gluing samples**	115 j	18/11/97	11/05/98	100%
2	design	18 j	18/11/97	11/12/97	100%
3	manufacturing	39 j	12/12/97	15/02/98	100%
4	gluing	23 j	16/03/98	16/04/98	100%
5	thermal cycling	2 j	17/04/98	20/04/98	100%
6	test	7 j	29/04/98	11/05/98	100%
7	**axial & lateral pad gluing samples**	221 j	26/11/97	21/10/98	100%
8	Design of gluing tools	4 j	30/04/98	06/05/98	100%
9	manufacturing of gluing tools	19 j	25/05/98	19/06/98	100%
10	ZERODUR samples manufacturing	37 j	26/11/97	26/01/98	100%
11	test pads manufacturing	27 j	27/03/98	06/05/98	100%
12	gluing	9 j	24/06/98	06/07/98	100%
13	manufacturing of test tools	13 j	06/07/98	24/07/98	100%
14	thermal cycling & test	19 j	25/09/98	21/10/98	100%
15	**Endurance characterization samples**	206 j	22/06/98	19/04/99	100%
16	manufacturing of test tools	10 j	22/06/98	03/07/98	100%
17	gluing	7 j	23/07/98	31/07/98	100%
18	Endurance thermal cycling	61 j	16/12/98	10/03/99	100%
19	thermal cycling & test	27 j	11/03/99	19/04/99	100%
20	**Report**	5 j	20/04/99	26/04/99	50%
21	**Due date (before KIP 3)**	0 j	15/07/99	15/07/99	0%
22	**Beginning of mirror pads manufacturing**	0 j	09/12/98	09/12/98	100%
23					
24	long term loading of 6 samples	251 j	22/04/99	25/04/00	1%
25	Test of those 6 samples	1 j	26/04/00	26/04/00	0%
26	**Update of Report**	5 j	27/04/00	04/05/00	0%



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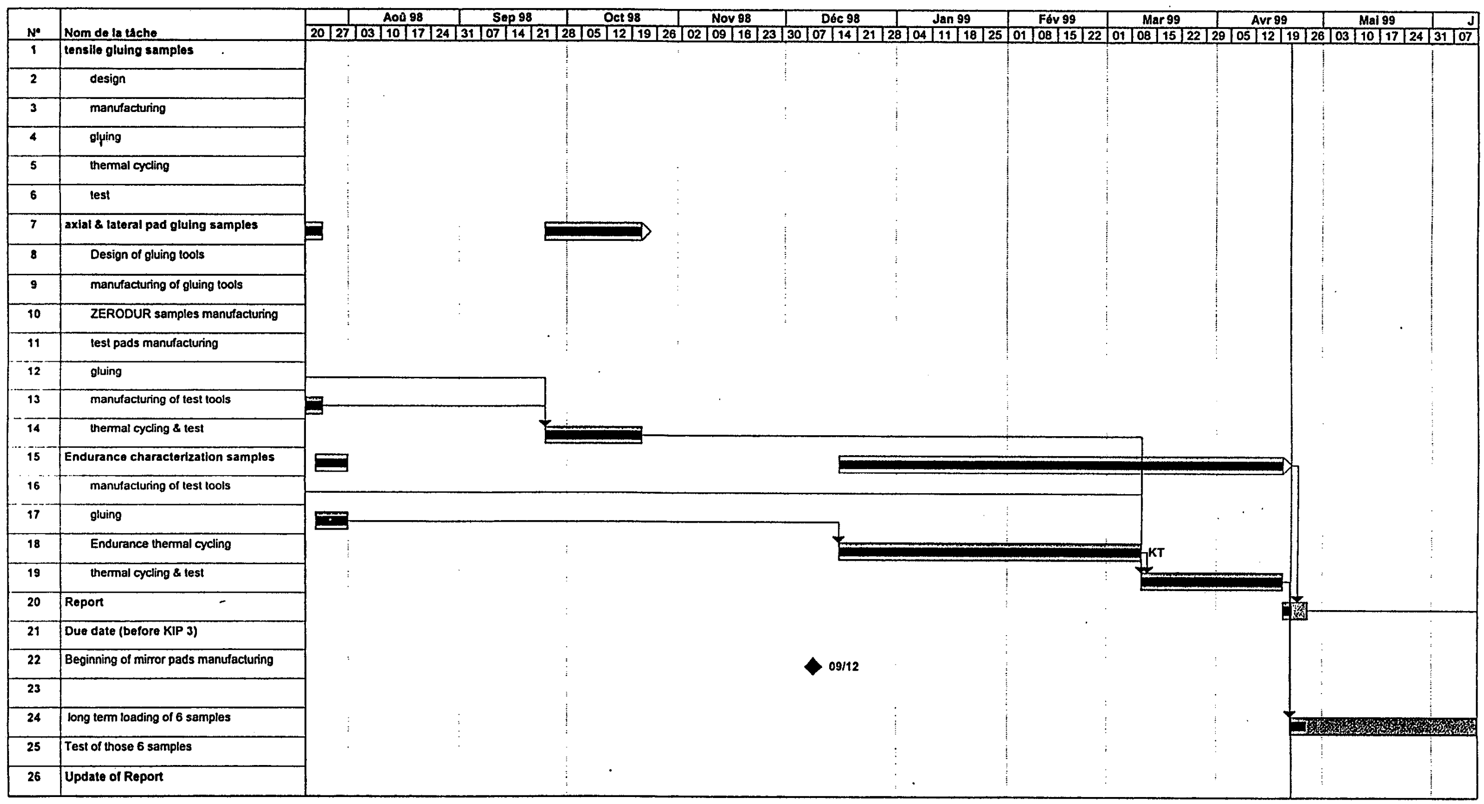
Planning validation collage



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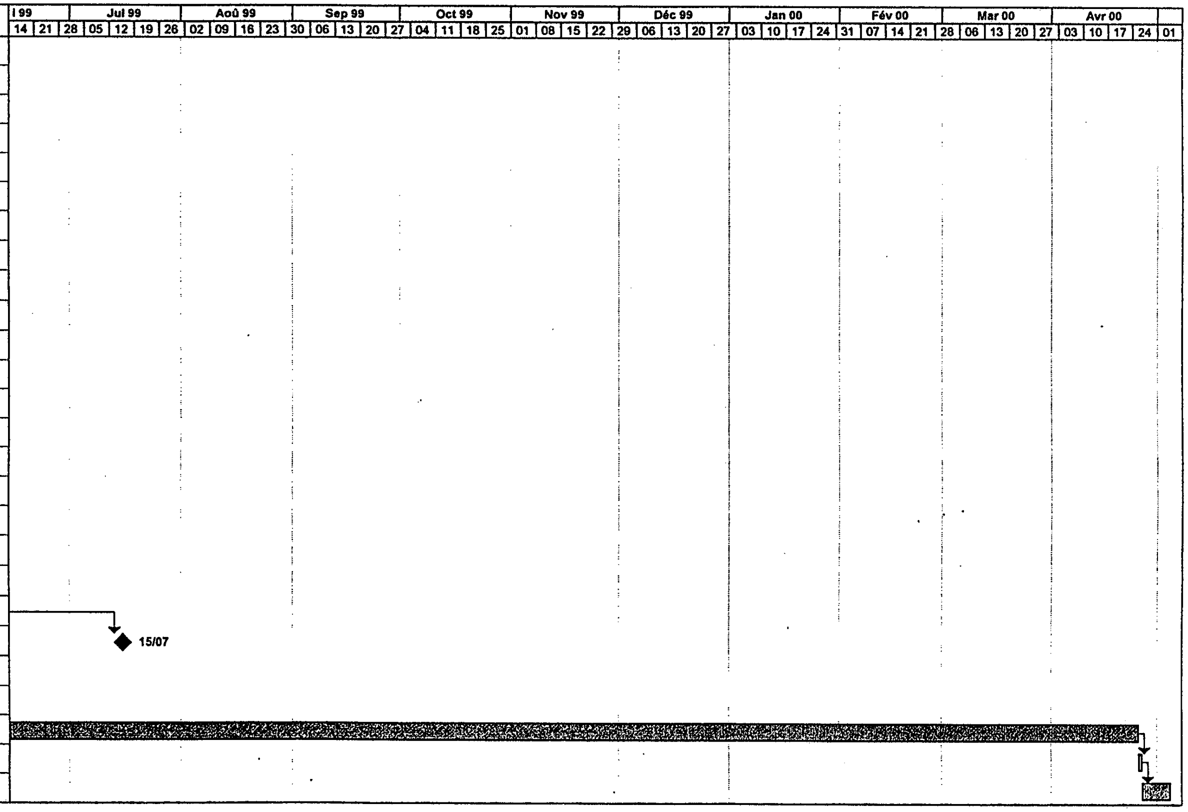
Planning validation collage

N°	Nom de la tâche
1	tensile gluing samples
2	design
3	manufacturing
4	gluing
5	thermal cycling
6	test
7	axial & lateral pad gluing samples
8	Design of gluing tools
9	manufacturing of gluing tools
10	ZERODUR samples manufacturing
11	test pads manufacturing
12	gluing
13	manufacturing of test tools
14	thermal cycling & test
15	Endurance characterization samples
16	manufacturing of test tools
17	gluing
18	Endurance thermal cycling
19	thermal cycling & test
20	Report
21	Due date (before KIP 3)
22	Beginning of mirror pads manufacturing
23	
24	long term loading of 6 samples
25	Test of those 6 samples
26	Update of Report



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SAGEM Etablissement de Saint-Pierre-du-Perray	Projet / Project : **SOFIA M1**	Ref SAGEM : INGE0625 Edition : 02 Ref Client : SOF-REP-RC-1110-0-11 Date : 20 septembre 2000 Page : 1 / 8

Nature :

NOTE TECHNIQUE INGE0625

SOF-REP-RC-1110-0-11

Titre / Title :

TECHNICAL REPORT ON GLUING QUALIFICATION

Résumé / Summary :

Characterization of 3M glue DP490 in SOFIA primary mirror working conditions.

Classification

DIFFUSION RESTREINTE
RESTRICTED DIFFUSION

Archivage / Record
Disquette : HD 20384 + serveur
Répertoire : ##REPLAN\Inge\SOFIA-M1
Fichier : INGE0625-02
Original : dans classeur INGE

	Nom & Fonction Name & Function	Date	Signature
Préparé par : Prepared by	**Michel TARREAU** IPDF	20/09/00	
Vérifié par : Checked by	**Patrick PLAINCHAMP** IPDE	6/10/00	
Autorisation de Diffusion : Release Approval	**Joël BERNIER** C-URD 26	07/10/00	

EVOLUTION

Edition	Date	Observation
01	17/06/99	Original issue
02	20/09/00	Review after ageing test completion and complementary tests with other glue seal thickness

DIFFUSION		Document complet Full document	X
Pages modifiées n° : N/A			
Destinataire	**Qté**	**Diffusé par**	**Date**
Kayser-Threde (sans annexes)			
Dr. H. Bittner	2		
SAGEM (sans annexes)			
M. Tarreau	1		
P. Plainchamp	1		

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1 Scope

The Sofia primary mirror is fixed in its cell by mechanical axial and lateral interfaces. The mirror attachment points are Invar pads glued on it by 3M glue DP 490.
The purpose of this study is to define the mechanical characteristics of the DP 490 in the using conditions of SOFIA :

- Tensile force applied on glue seal,
- Thermal cycling between -63°C and +40°C,
- Invar pad glued on glass (Zerodur),
- Permanent forces applied on glue seal during thermal cycling…

2 Document

2.1 Applicable document

	Reference	Issue	Designation	Title	Appendix
AD01	SOF-TAN-RC-1110-0-09	05	Plan	Gluing qualification plan	A1
AD02	SOF-TAN-RC-1110-0-04	03	Technical analysis	Definition justification document of SOFIA primary mirror assembly	
AD03	770101	02	Procedure	Gluing of Invar pad on ZERODUR with DP490	
AD04	770104	01	Procedure	Gluing of axial & lateral pads on ZERODUR lightweighting samples	

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2.2 Reference document

	Reference	Issue	Designation	Title	Appendix
RD01	RM # 055319	00	Log sheet	Gluing of 60 validation samples for characterisation test	A2
RD02	PV 055604	00	Control report	Tensile test of remaining pad on the 60 samples	A4
RD03	RM # 055565	00	Log sheet	Gluing of 3 validation Samples & 1 lateral I/F sample	A5
RD04	RM # 055566	00	Log sheet	Gluing of 2 validation samples & 1 axial I/F sample	A7
RD05	RM # 056182	00	Log sheet	Gluing of 7 validation samples	A9
RD06	PV # 056253	00	Control report	Tensile test of 6 validation sample after thermal test	A12
RD07	PV # 057793	00	Control report	Tensile test of 6 validation sample after thermal test and long-term loading	A13
RD08	DME/DTM/BP36/MB/DR/14454 (issued by Matra BAe Dynamics)	00	Test report	Characterisation of Invar pad gluing on ZERODUR with DP490	A3
RD09	SOF-REP-RC-1110-0-18	01	Test report	Qualification report for lateral I/F sample thermal test	A6
RD10	SOF-REP-RC-1110-0-17	02	Test report	Qualification report for axial I/F sample thermal test	A8
RD11	SOF-REP-KT-1110-0-01	01	Test report	Long time thermal cycling of PM gluing samples (6 validation samples)	A10
RD12	SOF-REP-RC-1110-0-23	01	Test report	Qualification report for 2 x 6 validation samples thermal test	A11
RD13	URD26 – NI0040	00	Test plan	Test program of complementary test with a glue thickness of 0.4mm	A14
RD14	PV # 057407	00	Control report	Gluing and test report of 20 samples with a glue thickness of 0.4 mm	A14
RD15	NI0119 – J. Billet	00	Computation report	Checking of induced thermal stresses with a glue layer of 0.46 mm, instead of 0.25 mm	A15

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3 SUMMARY OF RESULTS

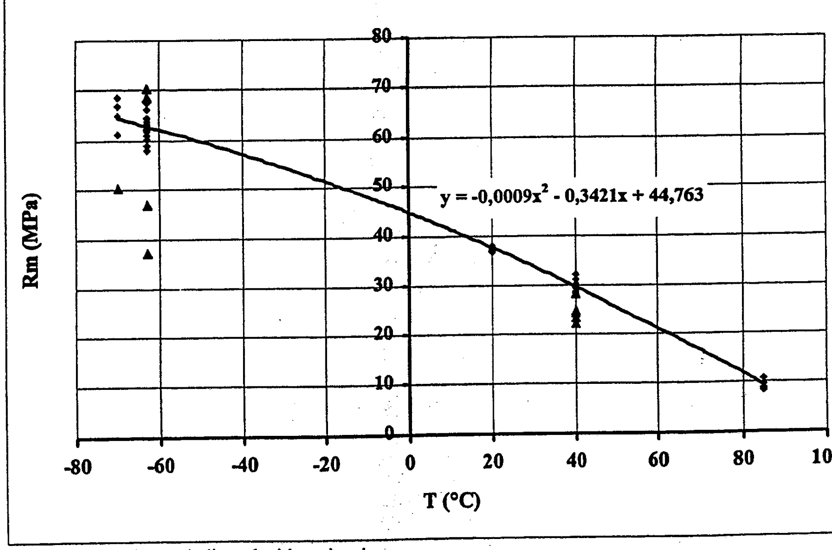
3.1 Characterisation of DP 490

See RD01 for the samples gluing; RD02 and RD08 for the test results
Before tensile strength testing, 55 validation samples have been thermal cycled (3 times; +40°C/3h - -63°c/3h).
5 validation samples have been thermal cycled (3 times; +85°C/3h - -63°c/3h).

Temperature of test	Number of samples	Thermal cycle	Tensile strength (average)	Standard deviation	Min value	Max value
°C			MPa	MPa	MPa	MPa
-70	4[1]	+40°C/-63°C	65.4	3.09	61.3	68.5
-63	16[2]	+40°C/-63°C	62.6	2.41	58.0	67.5
+20	5	+40°C/-63°C	37.3	0.56	36.7	38.0
+40	19[3]	+40°C/-63°C	29.8	1.02	27.8	32.1
+40	*5*	*+85°C/-63°C*	*25.8*	*2.36*	*23.2*	*28.3*
+85	5	+40°C/-63°C	9.1	0.91	7.0	8.3

Tab 1 - results

Fig 2 - Curve Rm = f(T)



N.B. :Excluded results are indicated with a triangle

[1] Result of sample # 316 (50.2MPa) is excluded because there is too much difference in regard to the other results.
[2] Are excluded: samples #320; 321; 328; 336
[3] Is excluded: sample #362

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SAGEM Etablissement de Saint-Pierre-du-Perray	Projet / Project : **SOFIA M1**	**Ref SAGEM : INGE0625** **Edition : 02** **Ref Client : SOF-REP-RC-1110-0-11** **Date : 20 septembre 2000** **Page : 5 / 8**

During the first tensile test, only one pad was unglued. Also we test the second pad, with a special tool, at ambient temperature (20°C).
54 samples was tested (see RD02)

Temperature of test	Number of samples	Tensile strength (average)	Standard deviation	Min value	Max value
°C		MPa	MPa	MPa	MPa
20	54	31.4	2.34	25.7	36.7

Tab 3 - results

After a loading, near the breakage value, the glue performances **decrease of about 15 to 20%**

3.2 Endurance test
We used 12 validation samples.
See RD03 ; RD04 & RD05 for the samples gluing

6 have been long-term thermal cycled (50 cycles -60°C/+40°C) - See RD11.
After that, we applied on the 12 samples, 3 thermal cycles -63°C/+40°C and, in the same time, a permanent load which was 1.5 time the non operational load. Temporary we applied a overload (about 15mn with crash load and about 10s with 1.5 time the crash load) - See RD12.

3.2.1 Test of first set of 6 validation samples
They were, including 3 samples which were long-term cycled, immediately tensile tested - see RD06 and table of results hereafter

Temperature of test	Number of samples	Long-term thermal cycle	Tensile strength (average)	Standard deviation	Min value	Max value
°C			MPa	MPa	MPa	MPa
22	3	yes	28.6	3.99	24.0	31.4
22	3	no	32.2	3.12	28.8	34.9

Tab 4 - results

In regard to the characterisation test, the expecting value is 36.8 MPa.
After ageing, the tensile strength decreases of 22.5%.

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SAGEM Etablissement de Saint-Pierre-du-Perray	Projet / Project : SOFIA M1	Ref SAGEM : INGE0625 Edition : 02 Ref Client : SOF-REP-RC-1110-0-11 Date : 20 septembre 2000 Page : 6 / 8

3.2.2 Test of second set of 6 validation samples

The 6 remaining samples, including 3 samples which were long-term cycled, were loaded during one year, with 1.5 time the non operational load.
After that they was tensile tested - see RD07 and table of results hereafter

Temperature of test	Number of samples	Long-term thermal cycle	Tensile strength (average)	Standard deviation	Min value	Max value
°C			MPa	MPa	MPa	MPa
22.8	3[4]	yes	26.1	1.51	24.0	27.3
22.8	3 + 2[5]	no	30.0	1.53	27.8	32.3

Tab 5 - results

In regard to the characterisation test, the expecting value is 36.5 MPa.
After one year ageing with permanent stress, the tensile strength decreases of about 8% in regard to the value obtained one year ago (see § 3.2.1).
In regard to the characterisation test, it decreases of 28.5%.

3.2.3 Complementary tests with glue seal thickness of 0.4mm

3.2.3.1 Test on samples

We realised 20 samples following the gluing procedure AD03, with a glue seal thickness of $0.4^{\pm 0.5}$ mm. We applied on them different thermal cycling with or without permanent stress, which are indicated in RD13 and RD 14.
After that, we tested them until breakage (tensile test). The results are in RD14 and a summary in table hereafter

Temperature of test	Number of samples	Long-term thermal cycle	Tensile strength (average)	Standard deviation	Min value	Max value
°C			MPa	MPa	MPa	MPa
Not indicated	20		**34.8**	**3.50**	27.52	39.35
Not indicated	18[6]		34.9	3.08	30.21	38.98
Not indicated	14	Yes	35.3	3.45	30.21	39.35
Not indicated	7	No	33.6	3.31	27.52	37.29

Tab 6 - results

These results are comparable with those given in § 3.2.1.. They are a little higher.
We can deduce of these tests that there is no big difference of tensile strength between a glue seal thickness of 0.25 and 0.40 mm. More, a thicker glue layer give best results.

[4] Value of breakage taken into account : sample number 314 => value of 2nd pad only ; 353 & 372 => value of 1st pad only
[5] Value of breakage taken into account : sample number 313 & 336 => value of the two pads ; 318 => value of 1st pad only
[6] We remove the 2 extreme values (sample 357 – max value – and 343 – min value)

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SAGEM Etablissement de Saint-Pierre-du-Perray	Projet / Project : SOFIA M1	Ref SAGEM : INGE0625 Edition : 02 Ref Client : SOF-REP-RC-1110-0-11 Date : 20 septembre 2000 Page : 7 / 8

3.2.3.2 FEM computation

During thermal cycling, the glue layer induces stress inside it and in the substrate, due to the differential of CTE.
To check the thickness influence of glue seal, we have made FEM computation with two thicknesses of glue seal (First computation with 0.25 mm and second computation with 0.46 mm). For the complete report, see RD15.
For the 2 thicknesses, the induced stresses are very close. We can deduce that there is no difference of behaviour due to the thickness, (between 0.25 and 0.46 mm).

3.3 Test on interfaces representative samples

The samples are exactly representative of the axial and lateral interfaces (blocs of Zerodur machined as per mirror and pads with the final design).
We applied on them 3 thermal cycles -63°C/+40°C and, in the same time, a permanent load which was 1.5 time the non operational load. Temporary we applied a overload (about 15mn with crash load and about 10s with 1.5 time the crash load)

See RD03 & RD04 for the samples gluing; RD09 and RD10 for the test results

No damage or degradation of the Zerodur, glue seal and pads was induced by the loading during thermal cycling.

4 CONCLUSION

The mechanical characteristics of DP 490 are depending of the temperature and are reduced after ageing (thermal and fatigue).
Taking into account the test results, we define in the table hereafter the ultimate strength we will use for glue seal computation.
Those values are calculated with the curve defines in §3.1 - Fig 2, reduced of 28.5% and decreased of 2 MPa (half of the worst standard deviation of the measurements).

Temperature	Rm
°C	MPa
-70	44,5
-63	43,4
-60	42,9
20	25,4
40	19,7
85	5,1

Tab 6- DP 490 / ultimate tensile strength for computation

As indicate in AD02, with those mechanical characteristics, the ***margin of safety*** for the worst load case applied on glue seal, is ***1.54 (C1).***
Even during crash, the risk of pads ungluing will remain quite zero.
But in case of crash, for mirror refurbishing, it would be preferable to unglue and glue again all the pads.

<u>Acceptance criteria for gluing following sample:</u>
For SOFIA-M1, we can accept a safety margin of 1.0 (C2).
C = (Rm / Rmesured)-1 => **C2** = C1 x (1 + 1) / 1.54 + 1) = ***C1 x 0.79***
So, After pads gluing, when we test the gluing following samples (glued in same time), the acceptance criteria will be:
At 20°C : Rm = 29.7 MPa
Equation: Rm (Mpa) = $-0.00071 \times T^2 - 0.2703 \times T + 35.363$ (T = temperature of test in °C)

NB: we take into account the value of characterisation tests because, before tensile testing, we don't applied on the gluing following samples, ageing test

<u>Glue seal thickness</u>
There is no difference of thermal behaviour and tensile strength between glue seal with a thickness of 0.25 mm and 0.40mm

BASTION
TECHNOLOGIES

APPENDIX – 2

DELTA PRESSURE REFERENCE DOCUMENTION

Communication from Karl-Heinz Zuknik
(PMA Responsible Engineer, Kayser-Threde)

Paul Lam's Report

From: karl-heinz.zuknik@kayser-threde.com [mailto:karl-heinz.zuknik@kayser-threde.com]
Sent: Friday, May 09, 2008 1:13 PM
To: kbower@sofia.usra.edu
Cc: markus.erhard@kayser-threde.com; peter.haberler@kayser-threde.com
Subject: Pressure difference in coating facility for SOFIA PM

Dear Ken,
The requirement §3.3.2 in TA_SSMO_06_FL was implemented due to an email from Kayser-Threde. I did not find out up to now, what the reason for it was. We suppose that it might be cleanliness aspects, which has to be discussed. As a first estimation due to structural reasons I would propose not to apply more than the analyzed load.

We analyzed a vertical load of 6g, which is about 880kg*6*9.81=51800N. The mirror surface is 6.6m². So the equivalent pressure would be 7800N/m². When you use a safety factor of 5, you end up with 1500 Pa or 11torr. That is what I would propose due to structural reasons. If this is a value that helps you, you may ask for a formal change in TA_SSMO_06.

Mit freundlichen Grüßen / Best regards
Karl-Heinz Zuknik

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Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 16 May 2008 Checked:

SOFIA Mirror Coating Facility
Delta Pressure Analysis Review

Summary

The SOFIA Mirror Coating Facility (MCF) is about to enter service and preparations are being made to address outstanding concerns. One previous concern, documented in Hazard Report # MCF-050-H, was that the differential pressure across the Primary Mirror Assembly (PMA) during the mirror coating process could exceed the specified 0.50 Torr limit. The contractor, Chart Industries, had prepared some analysis documents (Refs.1 to 5) to substantiate the differential pressure, but it is not clear that these had been reviewed. This note attempts to review the Chart analysis for the pressure differential during backfill and also briefly review pumpdown. The strength of the mirror and vacuum pressure vessel should be addressed elsewhere.

Since this reviewer is not an expert on vacuum system design, several standard texts and handbooks on the subject were studied. The Chart equations were verified and calculations were made, using slightly different assumptions, to arrive at results similar to those in the analysis documents.

It was found that the analysis results were acceptable, with some items noted. For an allowable differential pressure of 0.50 Torr, considering additional flow losses gives a Backfill flowrate of 0.059 kg/s compared to 0.036 kg/s in Ref.2 p.12 case f. Therefore, the flowrate specified by Chart appears conservative. For pumpdown, assuming a 500 m^3/hr flowrate appeared to produce the Chart result. This is believed conservative as the initial roughing pump capacity is 200 m^3/hr.

Review of preliminary test data apparently indicated a relatively large pressure differential (even though the upper and lower vacuum chambers were contiguous during the test) which is understood to be due to instrumentation errors. The measured pressure differential during pumpdown of up to 60 Torr greatly exceeds the specified limit of 0.50 Torr and would not be acceptable (may be sufficiently to lift mirror). The measured pressure differential during Backfill (venting) ranged from 2 to 6 Torrs and also exceeded the specified limit. It is understood the instrumentation will be corrected and another test run prior to the MCF entering service.

Comparisons of the test data were made to typical values.

The Roughing time to pumpdown from atmospheric pressure to approx.0.7 Torr is about 1.25 hours which is less than a typical value of 2.25 hours. Since the vacuum chamber was designed for laminar flow and some turbulence was apparently noted during initial pumpdown, perhaps the flowrate could be slightly reduced at start of pumpdown.

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The Backfill time to vent from 10^-3 Torr to atmospheric pressure is about 40 minutes which is about ten times longer than typical, due to the intended use of a hand valve to control the flow as mitigation for Hazard MCF-050-H.

It is recommended that the 0.5 Torr pressure differential limit be clarified. 0.5 Torr is approximately equal to the root-mean-square pressure on the primary mirror during SOFIA operations with an open door, but is much lower than the approx. 22 Torr (0.44 psi) nominal differential pressure needed to lift the mirror.

A wider seal gap could be considered which should help reduce any differential pressure across the mirror. However, this could lead to increased aluminum deposits on the mirror cell structure and may need baffles (noted by the Cryogenics group).

During the review, it was noted that the outgassing rates used for calculation were 70% of test values. Also, the outgassing area used was 65 m^2 instead of 95 m^2 used in a later system redesign study. The use of these assumptions should be confirmed.

The Ames Cryogenics group (Lou Salerno) is familiar with high vacuum systems and was briefly consulted during preparation of this report. It is recommended the Cryogenics group be consulted for further guidance.

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A. Introduction

The SOFIA Mirror Coating Facility (MCF) is about to enter service and preparations are being made to address outstanding concerns. One previous concern was with the differential pressure that could develop across the Primary Mirror Assembly (PMA) during the mirror coating process. The contractor, Chart Industries, had prepared analysis documents (Refs.1 to 5) to substantiate that the differential pressure met specified requirements. However, a search by others of the previous records (e.g. MCF CDR) had found no evidence that the contractor analysis had been reviewed. A review of the Chart analysis documents is desired prior to entering service.

A search by this reviewer found that USRA SOFIA Hazard Report # MCF-050-H (Ref.6; latest attached as Appendix A) describes the subject hazard as “lifting the mirror with differential pressure” caused by the automatic backfill operation when the flowrate control valve HV602[1] is too open. The concern was apparently that a pressure differential across the mirror could lead to damage of the mirror (unclear even after discussion with some of the persons originally involved). The mitigation was to ensure that the HV602 valve is adjusted so that fill time is greater than 45 mins. This appears to have been done and verified by USRA and NASA Safety representatives on 12/6/2002. Hazard MCF-050-H was closed by NASA Safety on 1/13/02. One of the Chart documents, V095-1-035, was referenced for the required slow refill rate, if necessary.

It is understood that the Primary Mirror itself was specified to withstand 0.75 torr differential pressure and its strength is not of concern. A cursory review of TA document SOF-SPE-MT-0000.0.02 Iss.05 dated 19.01.2001, “TA Airworthiness Certification Related Load Cases”, Sect.8.4 indicated that wind loads are not significant for strength. Similarly, it is understood the MCF pressure vessel was designed to ASME code and its strength is likely not of concern. No further action will be taken to

[1] MCF-050-H Sect.9) states to adjust HV601 to achieve a slow refill if necessary, but it is believed to be a typo and should be HV602 instead.

verify these values or to review structural strength.

The concern is if a differential pressure greater than 0.5 torr could develop across the Primary Mirror during backfill. This note attempts to review and comment on the Refs.1 to 5 documents for differential pressure during backfill and also briefly check pumpdown.

Note this reviewer is not an expert on vacuum system design and the comments may reflect a limited understanding[2]. This reviewer was not involved in the original design reviews and so may not have an accurate history of developments. The MCF CDR and System Requirements material in USRA-DAL-1123-00 and USRA-DAL-1120-00 were not reviewed in the interests of time.

Figure 1 shows a schematic of the MCF configuration used for this report. Texts on vacuum systems (Refs.7 to 9) were briefly studied as part of this review and flow of fluids books (Refs.11 and 12) were used for calculations.

[2] Note the Ames Cryogenics group (Lou Salerno) is familiar with vacuum pumps and was briefly consulted during this work. However, any errors in this report are due to this reviewer.

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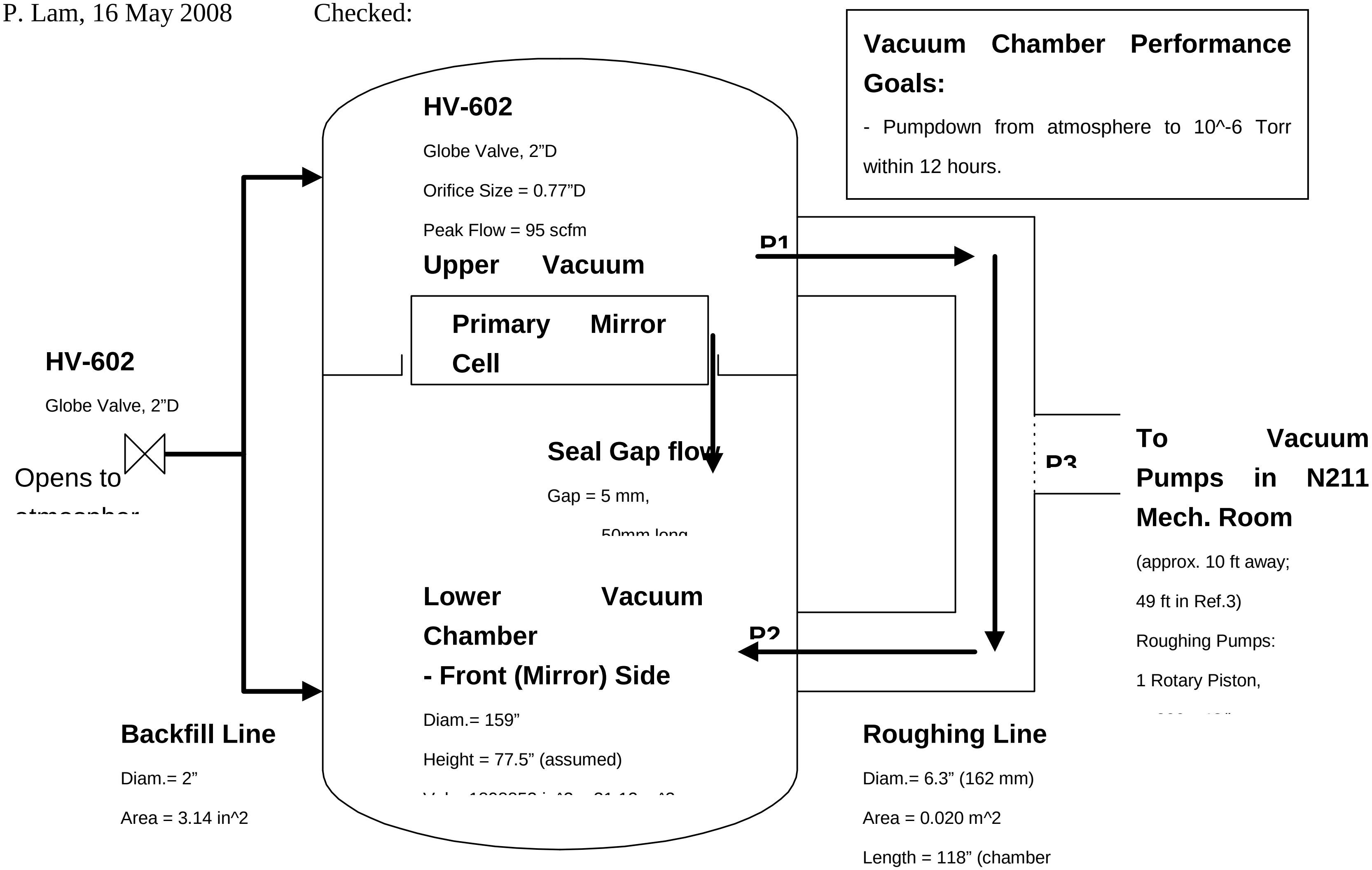

Figure 1. Schematic of Mirror Coating Facility
(adapted from Ref.2, dimensions revised per Ref.1 and Ref.3, arrows indicate direction of assumed airflow during backfill)

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B. Preliminary Estimates

B1. Pumping Times

For a vacuum pump system, typical estimates of performance (Ref.10 Sect.14.4) are,

Roughing Time, time to go from atmospheric pressure to 0.7 Torr,

$$tr = 10\ V / C$$

where

tr = roughing time, mins

V = volume, ft^3

C = rated speed, ft^3/min

Vent (Backfill) Time, time to go from 10^{-3} Torr to atmospheric pressure,

$$tv = V / (100\ D^2)$$

where

tv = vent time, mins

D = nominal diameter of globe valve, in.

For the dimensions shown in Fig.1,

$V = 14.04 + 31.12 = 45.16\ m^3 = 1595\ ft^3$

$C = 200\ m^3/hr$

$D = 2$ in

then

$tr = 10\ (45.16) / (200\ ) = 2.25$ hrs <------------------------- Roughing Time

tv = (1595) / [(100) (2)^2] = 4 mins <------------------------- Backfill Time

B2. Differential Pressure

These numbers will be kept in mind during this review. Note that the MCF is slightly unusual in that there is effectively two vacuum chambers connected by “leakage” paths and there is a restriction on the pressure differential between the two chambers.

The weight of the Primary Mirror is approx. 4000 lbs (SOF-DWG-KT-1100.0.00 Iss.3 dated 09.10.02, “SOFIA Primary Mirror Assembly”, indicates a weight of 1970 kg = 4334 lb). Assuming air acts uniformly over the mirror surface, estimate the pressure to lift the mirror:

P = W / A = 4000 lb / [pi (107”)^2 / 4] = 0.44 psi <-------------- approx. pressure needed to lift mirror

Note, DeltaP = 0.5 Torr = 0.0097 psi << 0.44

C. Backfill (Venting)

Since the original concern in Ref.6 was with differential pressure during backfill, this process will be addressed first.

Review of Refs.2 and 1 indicated apparent conflicting dimensions in the vacuum chamber. The later dimensions in Ref.1 were used, as shown in Fig.1, and resulted in slight changes in the upper and lower chamber volumes and volume ratios stated in Ref.2 Sect.1.0.

C1. Equations

Ref.2 p.6 gives the basic equations used in the Chart calculations which are to be verified.

The first equation, called "A" here,

$$\frac{fL_{\max}}{D} = \frac{1-M^2}{\gamma M^2} + \frac{\gamma+1}{2\gamma}\ln\frac{(\gamma+1)M^2}{2+(\gamma-1)M^2} \quad \text{-------------- (A)}$$

was found to be the same as that of Ref.11 eq.(9.66).

The second equation, called "B" here,

$$\dot{m} = \frac{P_0}{\sqrt{RT_0}} A\sqrt{\gamma}\cdot M\left(1+\frac{\gamma-1}{2}M^2\right)^{(\gamma+1)/(2-2\gamma)} \quad \text{-------------- (B)}$$

can be obtained as shown in Fig.2.

C2. Calculations

To solve these equations, an iteration procedure is indicated by Chart on Ref.2 p.6. An attempt to implement the calculation is shown in Fig.3 and the spreadsheet iteration in Fig.4.

Note that in the Fig.3 calculation several changes were made in the assumptions to check the effect on the results. The Seal Gap was considered as a concentric annulus instead of a plain orifice. Entry and exit losses were included for both the Seal Gap and Roughing Line. The result is that the maximum flowrate for a differential pressure of 0.5 Torr was about 1.5 times the values stated by Chart. Therefore, the Chart values appear to be acceptable.

In the Ref.4 p.3 Orifice Calculation, the 0.53 factor for P1 – P2 is not clear as it appears the ratio pf P2 to P1 approaches this value for choked flow. However, the results obtained using the revised value with Ref.12 eq.3-22 did not change significantly.

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In Ref.2 p.13 Valve Sizing, the value of Cv = 2.467 for a Flow of 0.012 kg/s could not be confirmed. Ref.12 eq.3-16 was used with a Flow = 0.012 kg/s = 157.2 gal/min to obtain Cv = 1.42. Another check is to use the Ref.5 data for 3 Turns Open and a backfill time of 2 hours. If the entire chamber volume and total backfill time is considered, the Flow would be 116.7 gal/min which would give Cv = 1.06. Future testing should verify operation of valve HV-602.

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V095-1-035 p.6

Check lower equation $\dot{m} = \frac{P_o}{\sqrt{RT_o}} A \sqrt{\gamma} M \left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{\gamma+1}{2-2\gamma}}$,

know, $\dot{m} = \rho A V$

but, $\rho = \frac{\rho_o}{\left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{1}{\gamma-1}}}$ White (9.28b)

$V = Ma = \frac{M a_o}{\left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{1}{2}}}$ White (9.27)

$\rho_o = \frac{P_o}{RT_o}$, $a_o = \sqrt{\gamma R T_o}$

$$\therefore \dot{m} = \left(\frac{P_o}{RT_o\left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{1}{\gamma-1}}}\right) A \left(\frac{M\sqrt{\gamma R T_o}}{\left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{1}{2}}}\right)$$

$$= \frac{P_o}{\sqrt{RT_o}} A M \sqrt{\gamma} \left[1 + \frac{\gamma-1}{2} M^2\right]^{-\frac{1}{2} - \frac{1}{\gamma-1}}$$

$$-\frac{1}{2} - \frac{1}{\gamma-1} = \frac{-(\gamma-1)-2}{2(\gamma-1)} = \frac{-\gamma-1}{2(\gamma-1)} = \frac{\gamma+1}{2(1-\gamma)}$$

$$\therefore \dot{m} = \frac{P_o}{\sqrt{RT_o}} A \sqrt{\gamma} M \left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{\gamma+1}{2-2\gamma}}$$

Figure 2. Check of Chart equation

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Backfill

Seal Gap (V095-1-035 p.6)

Consider gap as a concentric annulus,

$D_h = 2(5\times10^{-3}) = .01\,m$

White, Table 6.3

$a - b = 5\times10^{-3}\,m$

$\frac{b}{a} = 1 - \frac{5\times10^{-3}}{\frac{2.7}{2}} = .9963 \longrightarrow D_{eff} = .667\,D_h = .667(.01)$

$D_{eff} = .00667\,m$

$Re_{eff} = \frac{\rho V D_{eff}}{\mu} = \frac{(1.21\,\frac{kg}{m^3})(V\,\frac{m}{s})(.00667\,m)}{1.8\times10^{-5}\,\frac{Ns}{m^2}} = 448\,V$ — ①

(air at 1 atm, RT, White Table A.2)

(approx. by drawn tubing, White Table 6.1)

$\frac{\epsilon}{D_{eff}} \approx \frac{.002\times10^{-3}\,m}{.00667\,m} = .0003$

For choked flow,

$\frac{fL_{max}}{D} = \frac{fL}{D_h} + \Sigma K = \frac{f(50\times10^{-3}\,m)}{(.010\,m)} + .78 + 1.0 = 5f + 1.78$ — ②

(.78: entrance, re-entrant, White Fig. 6.20; 1.0: exit)

The iteration indicated by is implemented in a spreadsheet. Below are sample calculations.

Guess $V = 10\,m/s$

① => $Re = 448(10) = 4480 \xrightarrow[\text{White Fig. 6.13}]{\text{Moody}} f = .039$

② => $\frac{fL_{max}}{D} = 5(.039) + 1.78 = 1.975 \xrightarrow[\text{White (9.66)}]{\text{Ⓐ Fanno Line}} M_a = 0.42$

Ⓑ => $\dot{m} = \frac{p_o}{\sqrt{RT_o}}\,A\sqrt{\gamma}\,M_a\left[1 + \frac{\gamma-1}{2}M_a^2\right]^{\frac{\gamma+1}{2-2\gamma}}$

$p_o = p_1\left(1 + \frac{\gamma-1}{2}M_a^2\right)^{\frac{\gamma}{\gamma-1}} = p_1\left(1 + \frac{1.4-1}{2}(.42)^2\right)^{\frac{1.4}{1.4-1}} = 1.129\,p_1$

$T_o = T_1\left(1 + \frac{\gamma-1}{2}M_a^2\right) = (288\,K)\left(1 + .2(.42)^2\right) = 298\,K$

Figure 3. Calculation of Choked Flows during Backfill

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$$\therefore \quad \dot{m} = \frac{1.129 p_1}{\sqrt{(286.7)(298)}} (.0424\, m^2)(\sqrt{1.4})(.42)\left[1 + .2(.42)^2\right]^{\frac{1.4+1}{2-2(1.4)}}$$

$\dot{m} = .0000733\, p_1$ kg/s , p_1 in Pa

$\dot{m} = .00978\, p_1$ kg/s, p_1 in Torr ——— ③

↑ c.f. V095-1-035 Fig. 1.1 coeff ≈ .0094, in approx. agreement

Want $\Delta p = p_1 - p^* = 0.5$ Torr ——— ④

but, $\frac{p_1}{p^*} = \frac{1}{M_a}\left[\frac{\gamma+1}{2+(\gamma-1)M_a^2}\right]^{\frac{1}{2}}$ White (9.68)

$$= \frac{1}{.42}\left[\frac{1.4+1}{2+(1.4-1)(.42)^2}\right]^{\frac{1}{2}} = 2.53$$

$\therefore \ p_1 = 2.53 p^*$

④ => $0.5 = 2.53p^* - p^*$

$p^* = .327$ Torr

$p_1 = 2.53(.327) = .827$ Torr

③ => $\dot{m} = .00978(.827) = .0081$ kg/s (Gap)

Roughing Line (V095-1-035 p.8)

Similar choked flow,

$$\frac{fL_{max}}{D} = \frac{fL}{D_h} + \Sigma K = \frac{f(3m)}{.16m} + \underset{\text{entrance}}{.42} + \underset{\text{exit}}{1.0} + \underset{\text{2 elbows}}{2(\overset{\text{consv}}{.4})}$$

White Fig. 6.20

$$\frac{fL_{max}}{D} = 18.75f + 2.22 \quad \text{——— ⑤}$$

$$Re = \frac{\rho V D}{\mu} = \frac{(1.21)(V)(.16)}{1.8\times10^{-5}} = 10756V$$

Guess $V = 1$ m/s,

$Re = 10756 \xrightarrow{\text{Moody}} f = .030$

⑤ => $\frac{fL_{max}}{D} = 18.75(.030) + 2.22 = 2.78 \xrightarrow[\text{White Table B.3}]{Ⓐ} M_a = .38$

Figure 4 (cont'd). Calculation of Choked Flows during Backfill

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$$p_0 = p_1\left[1+.2(.38)^2\right]^{3.5} = 1.105\,p_1$$

$$T_0 = 288\left[1+.2(.38)^2\right] = 296\text{ K}$$

(B) => $$\dot{m} = \frac{1.105\,p_1}{\sqrt{(286.7)(296)}}(.020)(\sqrt{1.4})(.38)\left[1+.2(.38)^2\right]^{-3}$$

$\dot{m} = .0000313\,p_1$ kg/s, p_1 in Pa

$\dot{m} = \underline{.00418}\,p_1$ kg/s, p_1 in Torr

↑ c.f. V095-1-035 Fig.1.2 coeff ≈ .0040, approx. agrees

$$\frac{p_1}{p^*} = \frac{1}{(.38)}\left[\frac{1.4+1}{2+(1.4-1)(.38)^2}\right]^{\frac{1}{2}} = 2.84$$

$p_1 = 2.84\,p^*$

$\Delta p = p_1 - p^* = 0.5$ Torr

∴ $0.5 = 2.84p^* - p^*$

$p^* = .27$ Torr

$p_1 = 2.84(.27) = .77$ Torr

$\dot{m} = .00418(.77) = \underline{.0032}$ kg/s (Rough)

} c.f. V095-1-035 Fig.1.2 and p.12 case e
$C = \dot{m} = .002$ kg/s
$p = p_1 \cong .55$ Torr

Total

$\dot{m}_{tot} = \dot{m}_{gap} + \dot{m}_{rough}$

$= .0081 + .0032$

$\dot{m}_{tot} = \underline{.0113}$ kg/s

↑ c.f. V095-1-035 p.12 case f
$C = .006$ kg/s
Note this implies for gap only
$C_{gap} = .006 - .002 = .004$ kg/s
Fig.1.1 => $p \cong .45$ Torr

} These values are about half of those calculated above: $\dot{m} = .0081$ kg/s (Gap)
$p_1 = .827$ Torr

Figure 5 (cont'd). Calculation of Choked Flows during Backfill

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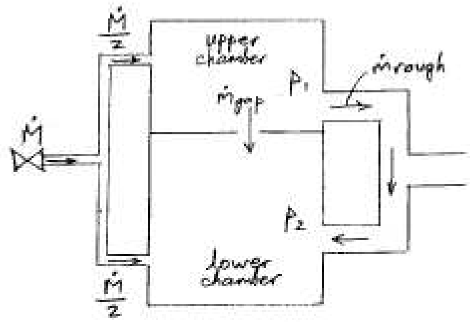

Assumed flow during Backfill

Want $p_1 \approx p_2$

but, $p = \rho R T$

$\dot{m} = \rho A V$

$\therefore p = \frac{\dot{m} R T}{A V}$

$p \propto \frac{\dot{m}}{V}$

$$\therefore \frac{\dot{m}_{upr}}{V_{upr}} = \frac{\dot{m}_{lwr}}{V_{lwr}} \quad \text{———} (6)$$

$$\dot{m}_{upr} = \frac{\dot{M}}{2} - \dot{m}_{gap} - \dot{m}_{rough}$$

$$\dot{m}_{lwr} = \frac{\dot{M}}{2} + \dot{m}_{gap} + \dot{m}_{rough}$$

sub in (6),

$$\left(\frac{V_{lwr}}{V_{upr}}\right)\left(\frac{\dot{M}}{2} - \dot{m}_{gap} - \dot{m}_{rough}\right) = \frac{\dot{M}}{2} + \dot{m}_{gap} + \dot{m}_{rough}$$

$$\left(\frac{V_{lwr}}{V_{upr}} - 1\right)\frac{\dot{M}}{2} = \left(\frac{V_{lwr}}{V_{upr}} + 1\right)\left(\dot{m}_{gap} + \dot{m}_{rough}\right)$$

$$\dot{M} = \frac{2\left(\frac{V_{lwr}}{V_{upr}} + 1\right)}{\left(\frac{V_{lwr}}{V_{upr}} - 1\right)}\left(\dot{m}_{gap} + \dot{m}_{rough}\right)$$

$\frac{V_{lwr}}{V_{upr}} = 2.22$,

$$\dot{M} = \frac{2(2.22+1)}{(2.22-1)}(.0113)$$

$$\dot{M} = \underline{\underline{.0596}} \text{ kg/s}$$

c.f. V095-1-035 p.12 case f

Flow = .036 kg/s

Figure 6 (cont'd). Calculation of Choked Flows during Backfill

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Adiabatic Flow in Ducts
White (9.66)
SOFIA Mirror Coating Facility

Vary Ma until RHS=LHS

Iter.	Iterate mdot kg/s	INPUT rho1 kg/m^3	INPUT A m^2	INPUT D m	INPUT mu N-s/m^2	V1 m/s	Re	INPUT f (from Moody)	LHS fLmax/D	INPUT gamma	Ma	RHS f(gamma and M)	po/p1	INPUT T1 K	To K	INPUT R m^2/(s^2K)	mdot/p1 kg/(s-Pa)	mdot/p1 kg/(s-Torr)	p1/p*	INPUT DeltaP Torr	p1 Torr	mdot kg/s
Chart doc.no. V095-1-035 Rev.0, p.6, Backfill																						
Iter.	Gap																					
0	0.008	1.21	0.0424	0.00667	1.80E-05	116853.7	5.239E+07	0.0148	1.8540	1.4	0.4282	1.8528	1.1343	288	298.561	286.7	0.00007476	0.009967	2.1706	0.50	0.927	0.009241
1	0.009241	1.21	0.0424	0.00667	1.80E-05	145.586	6.528E+04	0.0208	1.8840	1.4	0.426	1.8846	1.1329	288	298.453	286.7	0.00007438	0.009916	2.1814	0.50	0.923	0.009154
2	0.009154	1.21	0.0424	0.00667	1.80E-05	144.838	6.494E+04	0.0210	1.8850	1.4	0.42597	1.8850	1.1329	288	298.452	286.7	0.00007437	0.009915	2.1816	0.50	0.923	0.009153
Iter.	Roughing Line																					
0	0.004	1.21	0.02	0.16	1.80E-05	123864.9	1.332E+09	0.0190	2.5763	1.4	0.386	2.5790	1.1082	288	296.582	286.7	0.00003179	0.004238	2.3999	0.50	0.857	0.003633
1	0.003633	1.21	0.02	0.16	1.80E-05	131.239	1.412E+06	0.0153	2.5069	1.4	0.3895	2.5082	1.1103	288	296.739	286.7	0.00003208	0.004277	2.3790	0.50	0.863	0.003689
2	0.003689	1.21	0.02	0.16	1.80E-05	132.429	1.424E+06	0.0152	2.5050	1.4	0.3897	2.5042	1.1104	288	296.747	286.7	0.00003209	0.004279	2.3778	0.50	0.863	0.003692
																				TOTAL	mdot =	0.012845 kg/s

Figure 7. Spreadsheet Iteration for Backfill Calcuation

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D. Pumpdown

In Ref.1 Sect.1.5, Chart states that the Roughing Line was sized for a differential pressure of 0.50 Torr and gives the conservative assumptions used, but does not show any details.

For verification, Fig.5 shows a system energy calculation showing a differential pressure of 0.5 Torr for a 500 m^3/hr pump speed (if a 200m^3/hr pumping speed is used, the differential pressure drops to 0.3 Torr). Therefore, this calculation supports the Chart statement.

It was commented by the Ames Cryogenics group that the reason for the sharp corner in the pumpdown curves (e.g. Ref.1 Fig.1.3-1 at 5x10^-6 Torr) is not clear and should be clarified.

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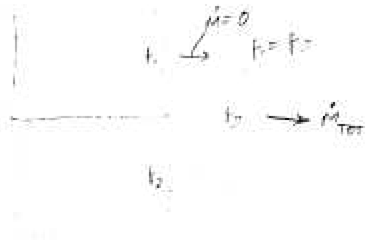
__Pumpdown__ (V095-1-004 Rev. 2 Sect. 1.5)



Want

$$\Delta p = p_2 - p_1 = p_2 - p_3$$

$$z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g} = z_3 + \frac{p_3}{\rho g} + \frac{V_3^2}{2g} \quad \text{——①}$$

In vacuum chamber,

$p_2 = 14.7\,\text{psia}$

$V_2 \approx 0$

In roughing line, assume pump capacity,

$p_3 = ?$

$$V_3 = \frac{Q}{A} = \frac{500\,m^3}{hr} \times \frac{1}{.020\,m^2} \times \frac{1\,hr}{3600\,s} = 6.94\,m/s$$

Assume,

$$z_3 - z_2 \cong 118'' = 3\ m$$

$$① \Rightarrow \quad p_2 - p_3 = \frac{1}{2}\rho\left(V_3^2 - V_2^2\right) + \left(z_3 - z_2\right)\rho g$$

$$\therefore \Delta p = \frac{1}{2}\left(1.21\,\frac{kg}{m^3}\right)\left(6.94^2 - 0\right)\frac{m^2}{s^2} + \left(3\,m\right)\left(1.21\,\frac{kg}{m^3}\right)\left(9.81\,\frac{m}{s^2}\right)$$

$$= 29.14 + 35.61 = 64.75\ Pa \times \frac{1\ Torr}{133.322\ Pa}$$

$$\Delta p = \underline{.49\ Torr} < 0.5\ Torr$$

Figure 8. Pumpdown Calculations

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

E. Other

E1. Outgassing

Although this review is not intended to address coating performance, several apparent inconsistencies were noted which should be pointed out for future reference. It may be that, as Chart indicates in Ref.1 Sect.3.2, the actual vacuum level at the present pressures would not significantly affect coating performance.

In a Vacuum System Redesign Study (Ref.3), Chart revisited the high vacuum capability because the Primary Mirror Cell (CFRP composite material) outgassing area had changed from 65 m^2 to 95 m^2. The result was that two additional cryopumps (4 total) were recommended to meet pumpdown performance requirements, but was not adopted.

In Ref.1 Sect.3.1, it was noted that the Vacuum System Process Design calculations used an outgassing area of 65 m^2 instead of 95 m^2 and 70% of the total measured outgassing rate. The reasons for these assumptions are not clear to this reviewer and should be confirmed.

A quick check of the Primary Mirror Cell (ref: drawing SOF-DWG-KT-1100.0.00 Iss.3) indicated an outgassing area of approx. 44.37 m^2. If this is doubled to account for inner and outer surfaces, the total would be approx. 90 m^2 which is close to the larger 95 m^2 area.

It is understood the option to add two cryopumps as Chart recommended could be implemented later depending on the results from future pumpdown tests.

E2. Test Data

A search for background material on the MCF found the test data in Refs.13 and 14 and several items were noted. However, it is understood from discussion with Rich Ross that the apparent discrepancies are due to instrumentation errors which will be corrected and the tests rerun in the future.

The Sample Coating tests in Jan.2008 (Ref.13, App.B.3, Pumpdown Test 1 dated 1-31-08) appeared to indicate a relatively large pressure differential measured between the upper and lower vacuum chambers even though it is understood the chambers were not blocked off from each other (i.e. no representation of Primary Mirror installed). The pressures are plotted in Fig.6, indicating differentials of up to 60 Torrs which would be too large to be acceptable (may even be sufficient to lift mirror). Again, it is understood the pressure readings may be due to instrumentation errors. Also, turbulence was apparently noted initially in the vacuum chamber despite it being designed (Ref.1 Sect.1.1) for laminar conditions. The Upper Chamber pressure PI-101 at Time 2:24 appears to be a typo (should read 0.020 Torr instead of 0.20 Torr).

During the same test, pressures were recorded during Backfill (Ref.13, App.B.9, Venting Log Test 1 dated 1-31-08). Again, the differential pressure between the upper and lower chambers appeared to exceed the 0.50 Torr limit (2 to 6 Torrs recorded), but to a lesser extent than during Pumpdown. Note that, due to the intended use of valve HV-602 for a slow flow, the Backfill time of approx.40 mins is about ten times longer than typical values (Sect.B1).

The system performance during Pumpdown was also compared to predictions made by Chart. In Fig.7, the predicted data (Ref.3 Fig.1.1-1, 2 Cryopumps) is plotted on the curve of test data (Ref.13 App.B.3, Pumpdown Test 1 dated 1-31-08). It can be seen that initial performance is predicted quite well (for first half hour), but it takes progressively longer than predicted to reach lower pressures (below 100 Torrs). The Roughing time to pumpdown from atmospheric pressure to approx.0.7 Torr is about 1.25 hours which is less than a typical value of 2.25 hours from Sect.B1.

An attempt to extract a “System Factor” (k) from the test data did not yield the expected result (0.15? instead of 2.30 from Ref.7 eq.8-5).

Title: Mirror Coating Facility Delta Pressure Review
Prepared: P. Lam, 22 April 2008 Checked:

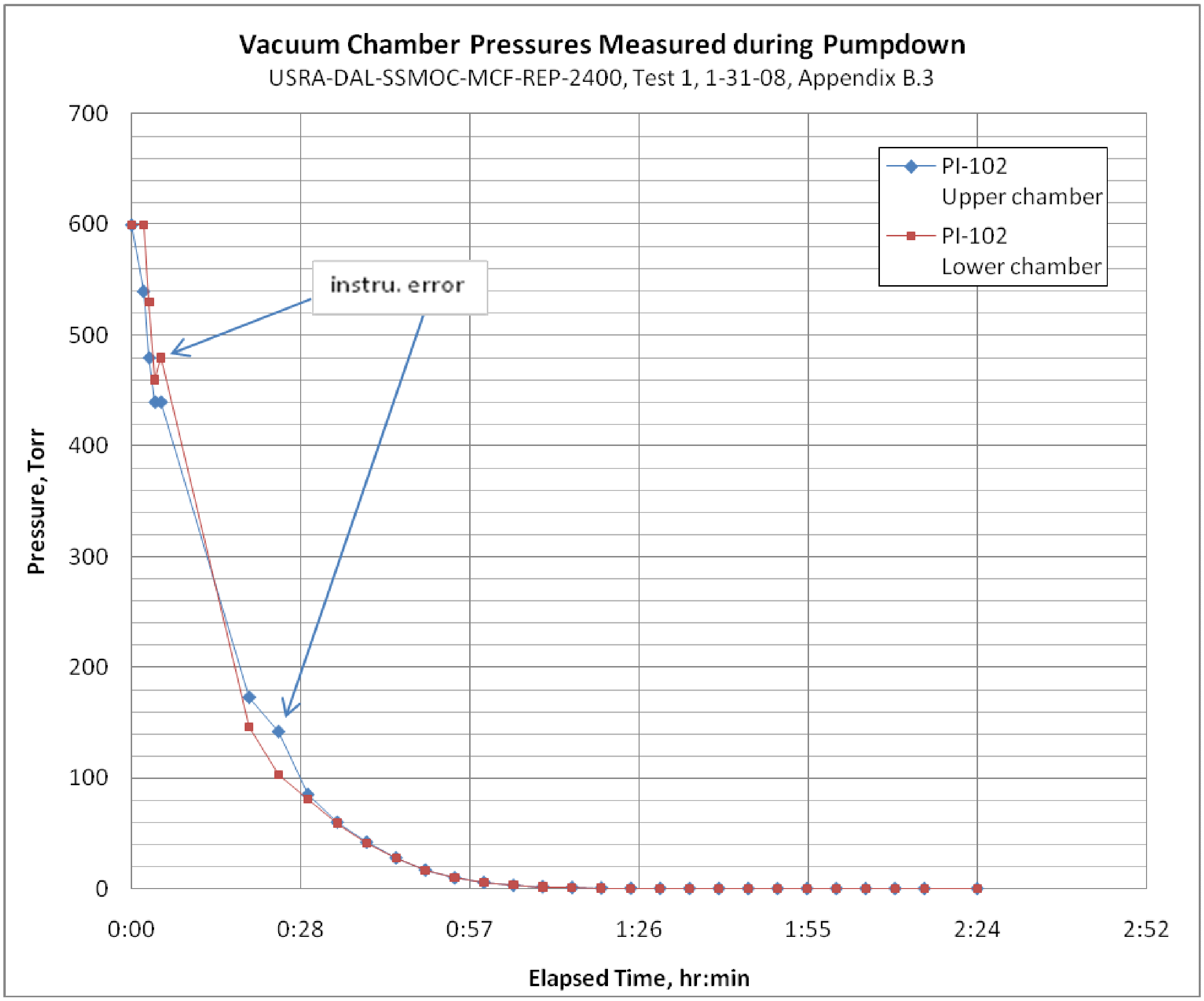


Figure 9. Sketch of Insulation Panel Deflected Shapes

Title: Mirror Coating Facility Delta Pressure Review
Prepared: P. Lam, 22 April 2008 Checked:

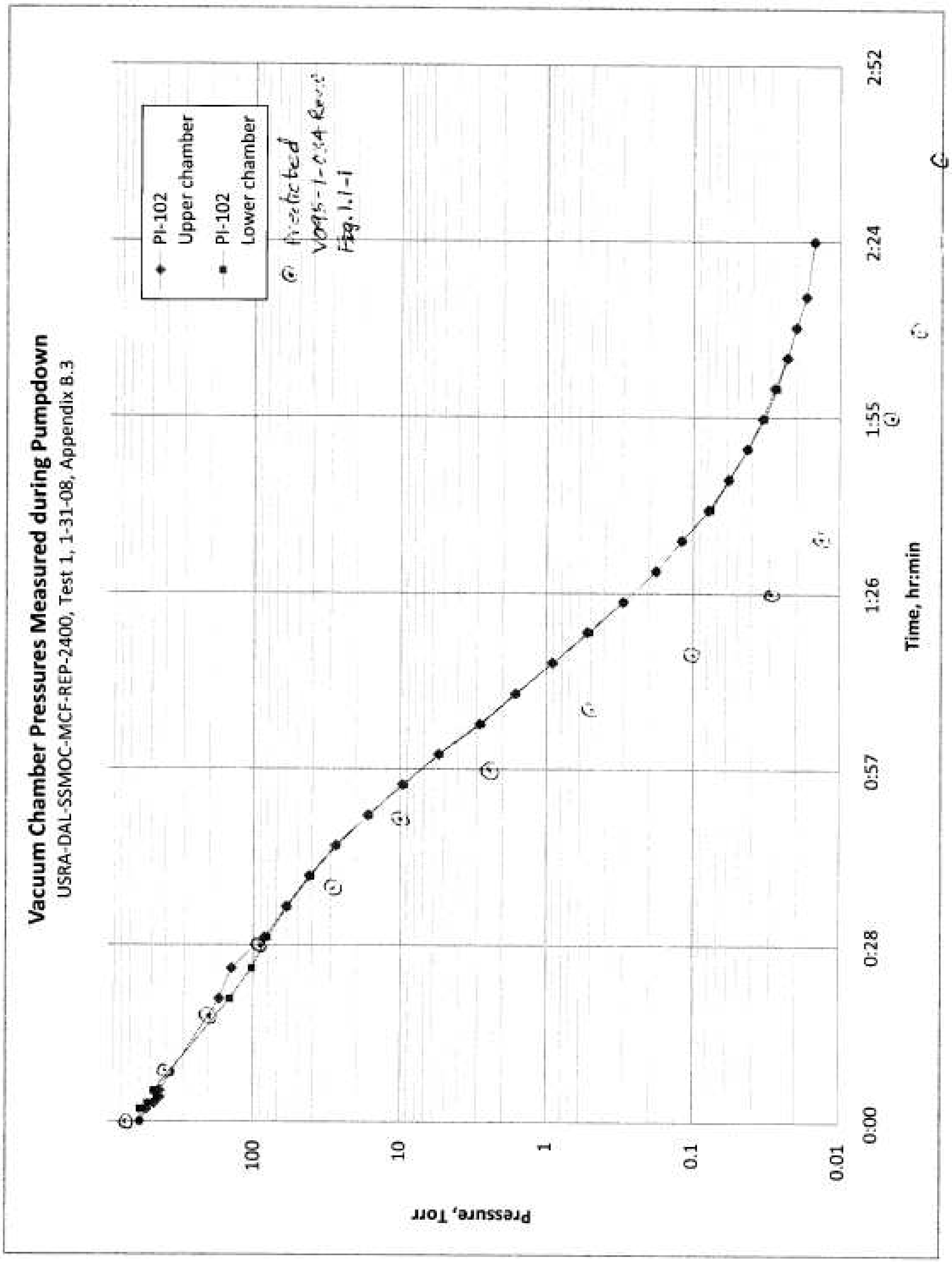


Figure 10. Predicted vs. Measured Pumpdown Performance

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

F. Conclusions and Recommendations

To support the SOFIA Mirror Coating Facility (MCF) Operational Readiness Review and address Hazard Report # MCF-050-H, a review has been made of the Refs.1 through 5 analysis documents by Chart for the pressure differential across the Primary Mirror during Backfill. A brief review was also made for Pumpdown. Structural strength was not reviewed.

An attempt was made to verify the equations used by Chart, flow calculations were made with slightly different assumptions to arrive at similar results, and comparisons were made with limited test data.

It was found that the analysis results were acceptable, with some items noted. For a specified allowable differential pressure of 0.50 Torr, a Backfill flowrate of 0.059 kg/s was calculated (compared to 0.036 kg/s by Chart conservative) and a pumpdown flowrate of 500 m^3/hr (actual rouging pump is 200 m^3/hr).

Review of preliminary test data apparently indicated pressure differentials (even though the upper and lower vacuum chambers were contiguous during the test) that exceeded the specified 0.50 Torr during both pumpdown and backfill, but this is understood to be due to instrumentation errors. The maximum differential of 60 Torr, measured during pumpdown would not be acceptable (may be sufficiently to lift mirror). It is understood the instrumentation will be corrected and another test run prior to the MCF entering service.

Comparisons of the test data were made to typical pumping times.

The Roughing time to pumpdown from atmospheric pressure to approx.0.7 Torr is about 1.25 hours which is less than a typical value of 2.25 hours. Since the vacuum chamber was designed for laminar flow and some turbulence was apparently noted during initial pumpdown, perhaps the flowrate could be slightly reduced at start of pumpdown.

The Backfill time to vent from 10^-3 Torr to atmospheric pressure is about 40 minutes which is about ten times longer than typical, due to the intended use of a hand valve to control the flow as mitigation for Hazard MCF-050-H.

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

It is recommended that the 0.5 Torr pressure differential limit be clarified. 0.5 Torr is approximately equal to the root-mean-square pressure on the primary mirror during SOFIA operations with an open door, but is much lower than the approx. 22 Torr (0.44 psi) nominal differential pressure needed to lift the mirror.

A wider seal gap could be considered which should help reduce any differential pressure across the mirror. However, this could lead to increased aluminum deposits on the mirror cell structure and may need baffles (noted by the Cryogenics group).

During the review, it was noted that the outgassing rates used for calculation were 70% of test values. Also, the outgassing area used was 65 m^2 instead of 95 m^2 used in a later system redesign study. The use of these assumptions should be confirmed.

The Ames Cryogenics group (Lou Salerno) is familiar with high vacuum systems and was briefly consulted during preparation of this report. It is recommended the Cryogenics group be consulted for further guidance.

G. References

1. V095-1-004 Rev.2 dated 8/16/00, “Vacuum System Process Design”, by R. Than, Chart Industries, Inc. - Process Systems Division.
2. V095-1-035 Rev.0 dated 8/08/00, “Back Fill Rate for Pressure Differential Limit”, by R. Than, Chart Industries, Inc. - Process Systems Division.
3. V095-1-034 Rev.0 dated 7/13/00, “Vacuum System Redesign Study”, by R. Than, Chart Industries, Inc. - Process Systems Division.
4. V095-1-032 Rev.0 dated 5/16/00, “Backfill Calculations”, by JBF, Chart Industries, Inc. - Process Systems Division.
5. Excerpt from V095-2-054, “System Handling and Operations”, Table 3 Rev.0, Chart Industries, Inc. - Process Systems Division.
6. SOFIA Project Hazard Report # MCF-050-H, “Pressure Differential”, closure date 01/13/03.
7. C.M. Van Atta, “Vacuum Science and Engineering”, McGraw-Hill Book Co., 1965.
8. A. Guthrie, “Vacuum Technology”, Krieger Publishing Co., 1990.
9. H.A. Steinherz, “Handbook of High Vacuum Engineering”, Reinhold Publishing Corp., New York, 1963.
10. E.A. Avallone and T.Baumeister III, “Marks’ Standard Handbook for Mechanical Engineers”, Ninth Edition, McGraw-Hill Book Co., 1987.
11. F.M. White, “Fluid Mechanics”, McGraw-Hill Book Co., 1979.
12. Technical Paper No. 410, “Flow of Fluids through Valves, Fittings, and Pipe”, Crane Co., Engineering Division, Chicago, IL, 1957.
13. USRA-DAL-SSMOC-MCF-REP-2400 Rev.-, dated Feb.27, 2008, “Mirror Coating Chamber Sample Coating Report”.
14. USRA-DAL-SSMOC-MCF-REP-2410 Rev.-, dated Mar.26, 2008, “Mirror Coating Chamber Sample Coating Report”.

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

Appendix A Hazard Report MCF-050-H

USRA SOFIA PROJECT

HAZARD REPORT

Page 1 of___

1) Facility/Project MCF	**Hazard Report #** MCF-050-H
2) System Mirror Coating	**Final HRA** 3 (Projected Value Only)
3) Subsystem Mirror	**Closed Date**
4) WBS Element	**Hazard Type** Pressure Differential

5) DESCRIPTION OF POTENTIAL HAZARD (Include Hazardous Conditions, Cause(s) & Effect(s))

Hazard: Lifting the mirror with differential pressure.

Caused By: Automatic Chamber Backfill operation when EV-601 opens while HV602 is Too open.

Worst Case Feasible Effect: In-rush of air could cause differential pressure across mirror.

6) EXISTING CONTROLS:

Backfill port has filter (F603)

Flowrate is controlled to be less than the building fresh air intake. The controlled flowrate is set using a micrometer valve (HV-602). This valve will be set at commissioning

7) INITIAL HAZARD RISK ASSESSMENT: II (SEVERITY) B (PROBABILITY) 1 (HRA)

8) RECOMMENDED CONTROLS:

ORIGINATOR: Richard E. Bacher **ORGANIZATION:** USRA **DATE:** 5/6/02

9) PLANNED ACTION(S):

Add to SOP that before mirror coating is conducted. Recheck the fill time is greater than 45 minutes. Adjust HV601 to achieve slow refill, if necessary, per V095-1-035.

IPT LEAD: Ray Schuler **ESTIMATED COMPLETION DATE:** **DATE:**

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

USRA SOFIA PROJECT

HAZARD REPORT — Hazard Report — MCF-050-H — Page 2 of ___

10) METHOD OF VERIFICATION:

Demonstrate fill time is greater than 45 minutes.

VERIFIED BY: ____________ DATE: 12/6/02 12/6/02

11) FINAL HAZARD RISK ASSESSMENT:

(Projected Value Only)	SEVERITY	PROBABILITY	HRA
	II	D	3

12) REVIEW BOARD CONCURRENCE: (NASA ONLY)

CHAIRMAN: ____________ DATE: ____________

13) RESIDUAL RISK ACCEPTANCE:

USRA SRM&QA MANAGER (FINAL HRA 1, 2, 3, & 4)	____________	DATE: 12/6/02 12/6/02
USRA PROJECT MANAGER (FINAL HRA 1, 2, 3, & 4)	____________	DATE: 12/16/02
NASA PROJECT MANAGER (FINAL HRA 1 & 2)	____________	DATE: ____________
CENTER DIRECTOR (FINAL HRA 1)	____________	DATE: ____________

14) HAZARD CLOSURE: (NASA ONLY)

NASA SRM&QA MANAGER: (FINAL HRA 1, 2, 3, & 4)	____________	DATE: 01/13/03
NASA SRM&QA OFFICE (DQ): (FINAL HRA & 2)	____________	DATE: ____________

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

NASA-AMES RESEARCH CENTER

HAZARD REPORT

Verification Page 1

HAZ. REP. #: MCF-050-H

10) METHODS OF VERIFICATION

Design Verification

	By:	Date

Procedural Verification

	By:	Date
3. SOP of adjustment of HV601 before coating mirrror and clean filter. V095-2-054 rev1 V095-2-054 rev1 para 3.11 and table 3.	Dave Black ___	10/24/02

Field Verification

	By:	Date
HV601 wide open uses 30 minutes to return to atmospheric pressure	R. E. Bacher	5/7/02
HV601 half open uses 35 minutes to return to atmospheric pressure	R. E. Bacher	5/8/02
HV601 2.5 turns open uses 120 minutes to return to atmospheric pressure	Dave Black	9/25/02
1. Filter in place.	R. E. Bacher	5/7/02
2. HV601 3.6 turns open provides 60 minutes to return to atmospheric pressure	Dave Black	9/25/02
2.	SPO/QS	

11) FINAL HAZARD RISK ASSESSMENT (Final Risk Assessment)

SEVERITY	PROBABILITY	HAZARD RISK ASSESSMENT
II	D	3

10) Compliance with NHB 1700.1

10) Hard Wired Safety System Incorporated

10) Quality Assurance functions

10) Safety Analyses performed

DOC NO: V095-1-035: TITLE: Back Fill Rate for Pressure Differential Limit

Very cautious approach, considering the 6"ø bypass line and vents around mirror.

Last Modification on Nov 20, 2002

Title: Mirror Coating Facility Delta Pressure Review

Prepared: P. Lam, 22 April 2008 Checked:

NASA-AMES RESEARCH CENTER

HAZARD REPORT

Verification Page 1

HAZ. REP. #: MCF-050-H

10) METHODS OF VERIFICATION

Design Verification **By:** **Date**

Procedural Verification **By:** **Date**

TBDone 3. SOP of adjustment of HV606 before coating mirror and clean filter.

Field Verification

	By:	Date
HV601 wide open uses 30 minutes to return to atmospheric pressure	R. E. Bacher ___	5/7/02
HV601 half open uses 35 minutes to return to atmospheric pressure	R. E. Bacher ___	5/8/02
HV601 2.5 turns open uses 120 minutes to return to atmospheric pressure	Dave Black	9/25/02
1. Filter in place.	R. E. Bacher ___	5/7/02
2. HV601 3.6 turns open provides 60 minutes to return to atmospheric pressure	Dave Black	9/25/02
2.	SPO/QS ___	

11) FINAL HAZARD RISK ASSESSMENT (Final Risk Assessment)

SEVERITY	PROBABILITY	HAZARD RISK ASSESSMENT
II	D	3

10) Compliance with NHB 1700.1

10) Hard Wired Safetv Svstem Incorporated

10) Quality Assurance functions

10) Safety Analyses performed

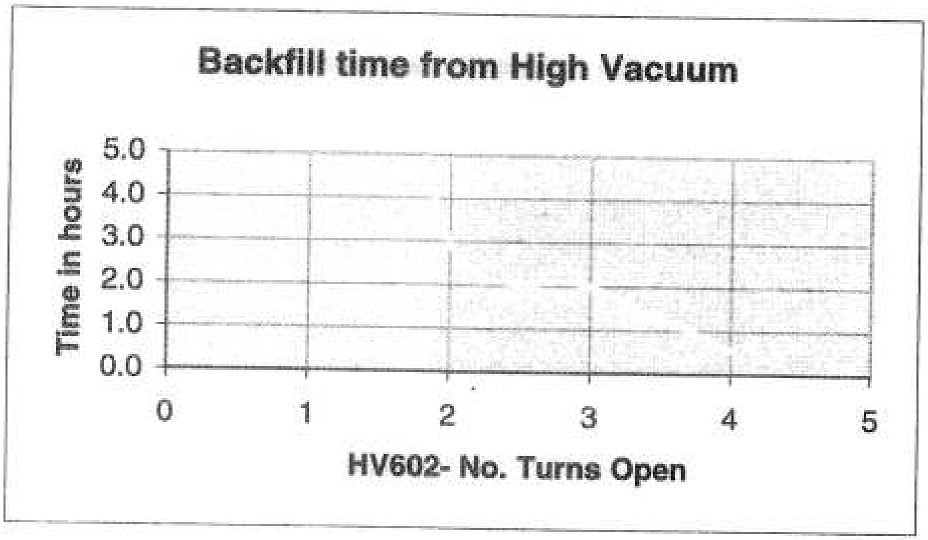
DOC NO: V095-1-035: TITLE: Back Fill Rate for Pressure Differential Limit

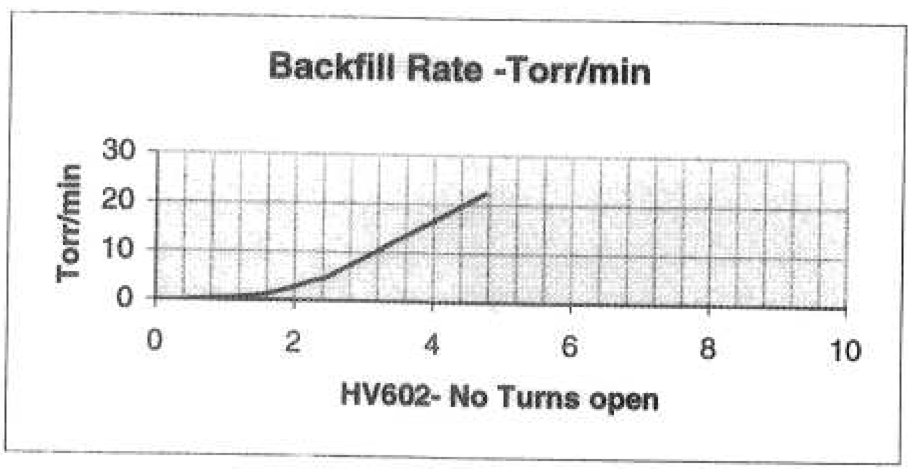
Very cautious approach, considering the 6"ø bypass line and vents around mirror.

Last Modification on Oct 11, 2002

Title: Mirror Coating Facility Delta Pressure Review
Prepared: P. Lam, 22 April 2008 Checked:

HV602 Turns open	dP/min Torr/min	Time to atm min	hours
0.5	0.067	11343	1.89E+02
1.5	1	760	1.27E+01
2.25	4	180	3.00E+00
2.5	5	120	2.00E+00
4.75	22.4	34	5.67E-01
9			





OPERATING & SUPPORT HAZARD ASSESSMENT SUMMARY

FOR

SOFIA SCIENCE INSTRUMENTS

CRITICAL LIFT OPERATIONS

Primary Mirror Assembly @ Bldg. N-211

NASA AMES
Mountain View, Ca.

SIGNATURES

Prepared by: Ron Tilton	
Reviewed by:	Date
[signature] Robert Munoz ARC Lift Device Equipment Manager	05-27-08
Edward Harmon Ed Harmon SOFIA Science Project Operations Manager	5/27/2008
[signature] Ed Ingraham SOFIA Science Project SMA Manager	27 May 08

TABLE OF CONTENTS

EXCUTIVE SUMMARY

Introduction

This report covers the preliminary assessment of potential operational hazards for the SOFIA Primary Mirror Assembly handling operations at NASA Ames for the Primary Mirror Assembly lifting and handling operations in building N211.

This summary Operations & Support Hazards Assessment addresses hazards which will be eliminated or mitigated by control of the potentially hazardous operations during equipment handling activities.

Safety Concerns

There are a total of 35 potentially critical hazards identified including those which can be controlled through the modification of activities in Building N211. These items have been identified and summarized in the Safety Assessment Summary Reports. The approach here is to review all single point failures relating to the facilities 5 ton bridge crane, the Primary Mirror Assembly (PMA) handling hardware, and lift operations within N211. Forklifts, portable cranes, or other industrial lifting vehicles or equipment used during Primary Mirror Assembly operations are not addressed. A general census of the risk associated with these potential hazards is assessed to be unlikely in occurrence.

It is this assessments recommendation that a staging and rigging plan be implemented to alleviate logistical issues during actual operations.

There are 17 individual attachment points in the Primary Lifting Device design with which one failure could create a hazardous condition for both equipment and personnel. Equipment certification, procedural controls and personnel trainings are mitigations in place to alleviate the potential for failures of the rigging configuration. It is also recommended that a mark lift exercise be conducted to mimic the operation prior to actual use on the Primary Mirror Assembly.

Crane certification issues are being evaluated and should be resolved prior to any critical lift operations in N211.

Due to the critical lift review of the overhead crane in N211, the crane hoist mechanism was returned to the manufacturer due to an incompatibility found with the varible frequency drive controller and the motor. The rebuild of the system by the manufacture included re-testing of the braking system. After installation, the crane was load tested and certified by the Ames Lift Device Equipment Manager (LDEM) for PMA critical lift operations. The crane operator and his alternate then practiced the PMA into chamber operation with the upgraded crane.

Conclusions

Operational procedures and safety features will be implemented for Building N211 to eliminate or significantly reduce the probability of occurrence of potential hazards and to reduce hazard risks.

1.0 INTRODUCTION

This Sofia Science Instruments Operational and Safety Hazard Assessment Summary is developed to address the Critical Lift operations at NASA AMES. The operations of the Primary Mirror Assembly (PMA) are the only items deemed critical lifts. The operations will take place in two separate facilities at AMES.

The PMA handling operations will take place in bldg. N211 and the AA handling operations will take place in bldg. N246. The scheduled dates for operations are late March and Feb 2008 respectively. In preparation for these activities, NASA AMES, USRA and Dryden are coordinating all efforts and interfaces to meet program assurance and safety compliance.

1.1 OBJECTIVE

The intent is to review and assess the Sofia Primary Mirror Assembly critical lift handling operations. The operations will be in accordance to NASA-STD-8719.9; Lifting Devices.
In addition to assessing the lifting operations and support equipment, a review of the operations procedures is conducted to ensure critical functions during the handling and transport process do not compromise the safety to personnel or equipment.

1.2 SCOPE

Provide a summary assessment of the SOFIA Primary Mirror Assembly critical lift operations at NASA AMES. BLDG N211. The assessment process will include drop and or impact hazards to the Primary Mirror Assembly while being lifted using the 5 ton bridge crane. Forklift handling operations of the Primary Mirror Assembly are not deemed critical lift operations and therefore not scoped in this assessment.
A summary report for each potential critical hazard of the Primary Mirror Assembly operations shall address drop hazards, load damage and personnel injury. Lesser hazards not deemed critical will not addressed here.

2.0 APPLICABLE DOCUMENTS

2.1 NASA DOCUMENTS

NASA-STD-8719.9; Standard for Lifting Devices And Equipment
DCP-S-009 - Chapter 6, Critical Lift (DFRC Document)
APR-1700.1 Ames Health & Safety Procedural Requirements – Lifting Devices And Equipment

2.2 OTHER DOCUMENTS

96131101 – Primary Mirror Assembly Assembly

A9747-9701-M804 – Primary Mirror Assembly Hoisting

A9747-9601-XR211 – Primary Mirror Assembly – LFD Ground Operations Procedures

A9747-9601-R206 – Primary Mirror Assembly – LFD Removal Procedure

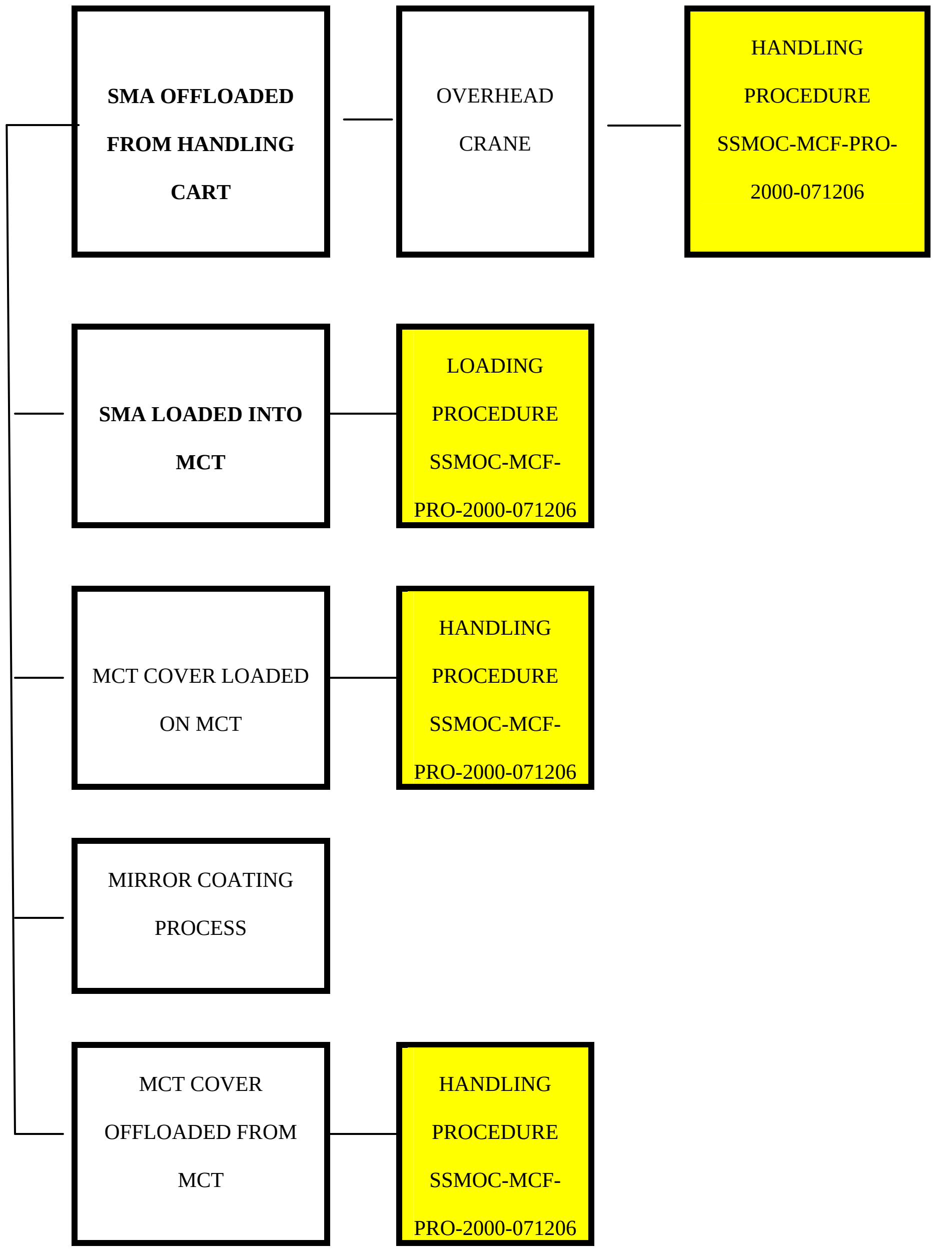
3.0 FACILITY DESCRIPTION

The SOFIA Project will operate from a facility leased by NASA to USRA at Ames Research Center (ARC) Moffett Field CA.
Building N211 is an existing hanger facility. It's basic structure will not change with the proposed alterations. Alterations and/or additions are limited to internal spaces and equipment required for SOFIA. The new spaces will be constructed to accommodate the SOFIA science mission requirements.

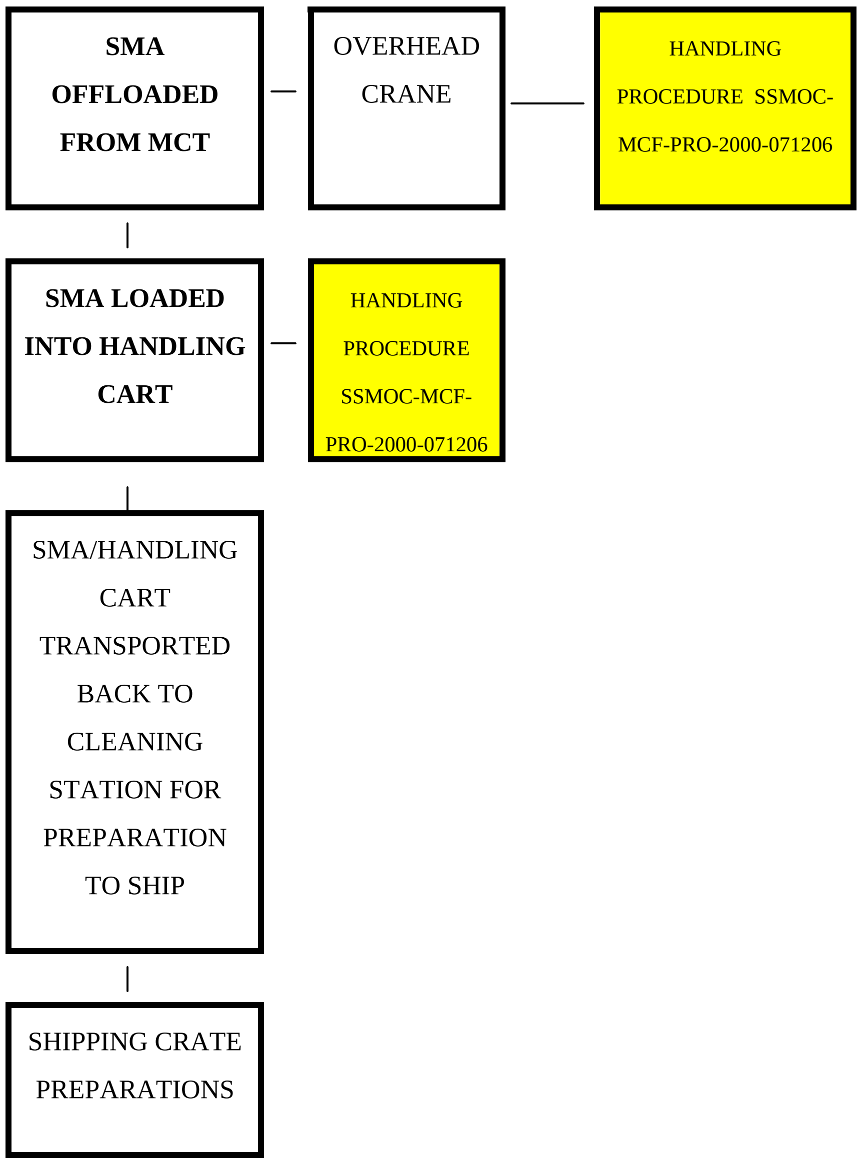
The Primary Mirror Assembly (PMA) of the SOFIA telescope has to be removed for periodic inspections, cleaning and recoating. This initial process will be done at a special facility at the NASA Ames Research center (ARC), SOFIA Mirror Coating Facility.

3.1 BLDG. N-211 CONFIGURATION

PRIMARY MIRROR AASSEMBLY TRANSPORT TO MCT



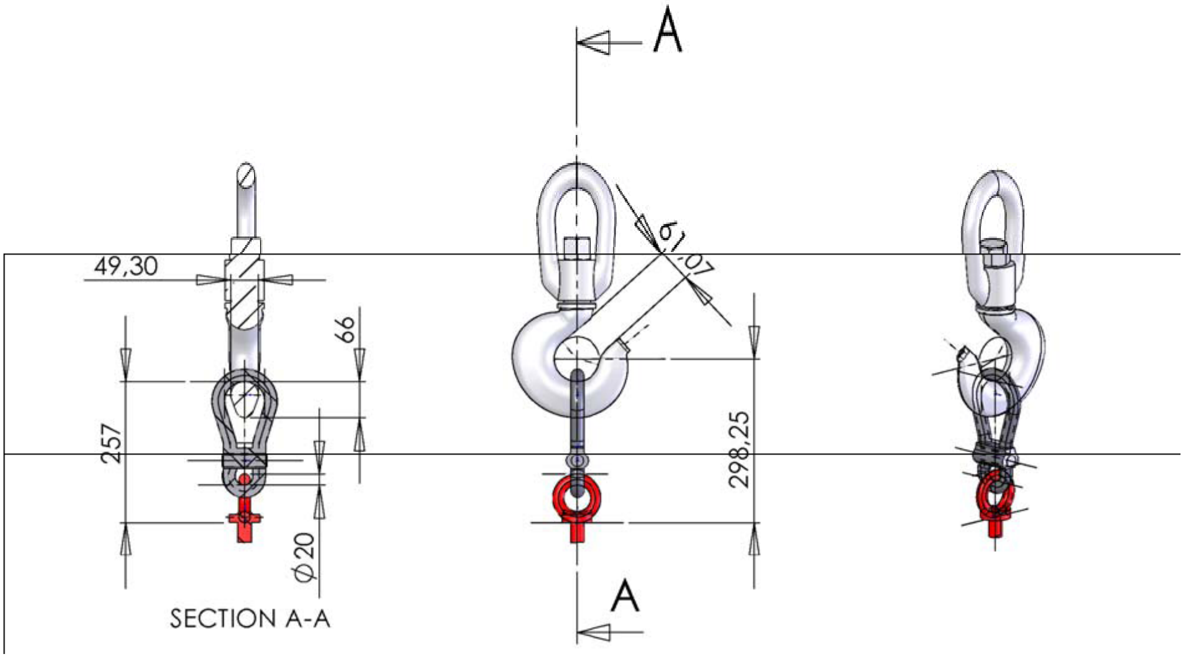
PMA TRANSPORT BACK TO HANDLING CART



3.2 PRIMARY LIFTING DEVICE (PLD)

The PMA Lifting Device (PLD) is necessary for attaching the PMA to the crane considering the limited clearance between top of RVC and crane-hook. The available clearance (max. 740 mm), dimensions of PMA and crane-hook as well as the coordinates of the three PMA attachments points are illustrated in figure below.

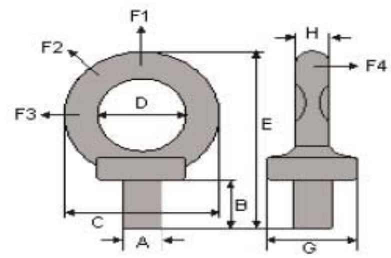
It consists of 5 standard hoist ring (HEBEZONE, RSN24) attached to the top mounting point, turnbuckles for adjusting the position of the hoist ring and a frame for compensating horizontal forces in the attachment points. The connection of the turnbuckles to the top mounting point and to the frame is realized by standard swivel heads (ASK KI 20-D-L, ASK KIL 20-D-L) and steal bolts. Screw joints are used for connecting the three square tubes for the frame with the attachment-point-turnbuckle interface.



Hochfeste Ringschraube RSN

- ☑ Allseitig belastbar
- ☑ Güteklasse 8
- ☑ BG geprüft
- ☑ Mit Flachstelle für Omega Glieder

Volle Tragfähigkeit bei Belastung in Richtung F1. F2 (bis 45 Grad) 35%, darüber bis F3 (90 Grad) und F4 max. 25% der Tragfähigkeit.



Hochfeste Ringschraube RSN

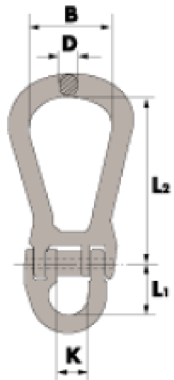
Bestell Nr.	Tragfähigkeit kg	Gewinde A	Abmessungen mm B	C	D	E	G	H	Gewicht kg	Preis EUR
RSN016	4000	M16	24	72	42	96	40	16	0,4	17,40
RSN020	6000	M20	30	72	42	104	40	16	0,5	25,80
RSN024	8000	M24	36	88	48	124	55	19	0,9	32,00
RSN030	12000	M30	45	106	60	151	64	22	1,4	48,70
RSN036	16000	M36	54	127	72	180	74	26	2,3	116,80

▸ Modelle bis 32000 kg
Lieferzeit: ab Lager, Zwischenverkauf vorbehalten
Preise ab Werk zzgl. Mwst.

Maximale Last für 1-4 Stück bei Verwendung in Anschlagart:

Bestell Nr.	1-Strang 0°	1-Strang 90°	2-Strang 90°	2-Strang 0°	2-Strang >0-45°	2-Strang >45-60°	3/4-Strang >0-45°	3/4-Strang >45-60°
RSN016	4000	1000	2000	8000	1400	1000	2100	1500
RSN020	6000	1500	3000	12000	2100	1500	3150	2300
RSN024	8000	2000	4000	16000	2800	2000	4200	3000
RSN030	12000	3000	6000	24000	4200	3000	6300	4500
RSN036	16000	4000	8000	32000	5600	4000	8400	6000

*Werden mehrstrangige Anschlagmittel mit unterschiedlichen Neigungs- und Spreizwinkeln der einzelnen Stränge eingesetzt und/oder ist der Schwerpunkt der Last ungleichmäßig verteilt, müssen die Anschlagpunkte so ausgewählt werden, daß ein einzelner Anschlagpunkt in der Variante 1-Strang 90° die gesamte Last tragen kann.



Aufhängeöse SKG

- ☑ Güteklasse 8
- ☑ geschmiedet und vergütet
- ☑ Sicherheitsfaktor 4

Die Aufhängeöse SKG kann auch mit folgenden Komponenten kombiniert werden:
– Drallfänger SKLI
– Sicherheitslasthaken SKN
– Schaftkupplung SKS

○ [Abbildung SKG/SKT]

○ [Abbildung SKN/SKLI/SKG]

◉ [Masszeichnung]

Aufhängeöse SKG

Modell	für Kette	Tragfähigkeit	Abmessungen mm					Gewicht	SKG*	SKT/SKA**
Bestell-Nr.	mm	kg	L1	L2	B	D	K	kg	CHF	CHF
83.8040.07	7/8	2000	28	99	50	14	18	0,4	37.50	14.50
83.8040.10	10	3150	34	127	66	18	25	0,8	50.50	19.50
83.8040.13	13	5300	44	145	72	22	29	1,5	63.00	24.50
83.8040.16	16	8000	52	175	82	25	36	2,4	96.50	35.50
83.8040.19	18/20	12500	63	204	105	30	43	3,9	168.50	51.50

* Preis für Aufhängeöse SKG ohne Kupplungsglied, Bolzen und Spannhülse SKT/SKA
** Preis für Kupplungsglied, Bolzen und Spannhülse SKT/SKA

SECTION 3.4

PRIMARY MIRROR ASSEMBLY LIFTING HARDWARE SAFETY ASSESSMENT SUMMARY REPORTS

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PRIMARY LIFTING DEVICE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
1.1 Primary Lifting Device	Yield or fracture	Material or manufacturing defect. Fatigue Corrosion Overstress	Loss of angular restraint resulting in load swing hazard, load drop and personnel injury	Lifting equipment and devices are designed to NASA-STD-8719.9 125% proof load tested for critical lift certification Annual rated load test. Daily, quarterly, and annual inspections All support lift equipment used and stored indoors	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PRIMARY LIFTING DEVICE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
1.2 Pear Shape Link	Yield or fracture	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	Lifting equipment and devices are designed to NASA-STD-8719.9 Annual rated load test. Daily, quarterly, and annual inspections Hardware overrated for actual working load All support lift equipment used and stored indoors	PMA Lifting Device Construction Analysis

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PRIMARY LIFTING DEVICE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
1.3 Hoist Ring	Yield or fracture	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	Lifting equipment and devices are designed to NASA-STD-8719.9 Annual rated load test. Daily, quarterly, and annual inspections Lifting hardware design is overrated for the actual work load All support lift equipment used and stored	Refer to PMA Lifting Device Construction Analysis Report

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PRIMARY LIFTING DEVICE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
1.4 Swivel Head	Yield or fracture	Material or manufacturing defect. Fatigue Corrosion Overstress	Loss of angular restraint resulting in load swing hazard and personnel injury	Lifting equipment and devices are designed to NASA-STD-8719.9 Annual rated load test. Daily, quarterly, and annual inspections Equipment load capacities are significantly over-rated for actual working loads All support lift equipment used and stored indoors	Refer to PMA Lifting Device Design Construction Analysis Report

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PRIMARY LIFTING DEVICE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
1.5 Top Mounting Plate	Yield or fracture Stress Under-rated design	Material or manufacturing defect. Fatigue Corrosion Overstress	Loss of angular restraint resulting in load swing hazard and personnel injury	Lifting equipment and devices are designed to NASA-STD-8719.9 Annual rated load test. Daily, quarterly, and annual inspections All support lift equipment used and stored indoors Personnel training / certification	

3.5 CRANE SAFETY CHECKLIST

Item	Item Description	OK	Serviced	Need Attn:	Comments
1	Bridge Trucks (Welds, Bolts)				
2	Wheels (Treads, Flanges, Axies)				
3	Wheel Bearings				
4	Wheel Gears, Pinions				
5	Sweep Plates, Drop Lugs. Bumpers				
6	Lineshaft, Couplings, Bearings				
7	Gear Reducer Couplings				
8	Bridge Motor (Brushes, etc)				
9	Bridge Motor Brakes				
10	Bridge Control Panel				
11	Bridge Resistors / Soft Start				
12	Bridge Other (Describe in Comments)				
13	Trolley Frame (Welds, Bolts)				
14	Wheels (Treads, Flanges, Axies)				
15	Wheel Bearings				
16	Wheel Gears, Pinions				
17	Bumper / Stops				
18	Drive Shaft, Couplings, Bearings				
19	Gear Reducer Couplings				
20	Trolley Motor (Brushes, etc)				
21	Trolley Motor Brakes				
22	Trolley Control Panel				
23	Trolley Resistors / Soft Start				
24	Trolley Other (Describe in Comments)				
5	Hoist Frame Suspension				
26	Upper Tackle (Sheaves, Pins, Bearings)				
27	Rope Drum Anchors				
28	Wire Rope / Load Chain Fittings				
29	Hook Block Sheaves Bearings				

CRANE SAFETY CHECKLIST
(CONTINUED)

Item	Item Description	OK	Serviced	Need Attn:	Comments
30	Load Hook Safety Latch				
31	Gearing Couplings				
32	Load Brake				
33	Hoist Motor (Brushes, etc)				
34	Hoist Motor Brake				
35	Hoist Control Panel				
36	Hoist Resistors				
37	Hoist Limit Switches				
38	Hoist Other (Describe in Comments)				
39	Control Station Switch				
40	Control Conductor Collectors				
41	Power Conductor Collectors				
42	Mainline Conductors Collectors				
43	Mainline Disconnect (On-Bridge)				
44	Mainline Contactor				
45	Runway Beams, Rails				
46	Misc: Other (Describe in Comments)				
47	Operational Test All Functions (Indicate Below)				

SECTION 3.6

BRIDGE CRANE SAFETY ASSESSMENT SUMMARY REPORTS

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.1 Hook	Yield, Fracture or threads shear	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 2**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.2 Hook Nut	Treads shear	Material or manufacturing defect. Fatigue Corrosion	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **2 of 2**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
Hook Nut (continued)	Yield, Fracture or threads shear	Overstress	Drops Load	Operator training/certification	
	Nut backs off	Normal vibration or torque from thrust bearing	Nut fails to hold hook, dropping load	A set screw locks the nut on the hook shank	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.3 Block Frame	Structural failure	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.4 Sheave Pin	Shears	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 211	**DATE:** 1/10/08
SYSTEM: 5 TON BRIDGE CRANE	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.5 Sheave Bearings	Seizes or excessive play and friction	Lack of lube Contaminated Lubrication Corrosion Overload Wear	Sheave and wire rope wear accelerated. Eventual failure of sheave or wire rope	Maintenance and inspection plan Annual rated load test. Daily, quarterly, and annual inspections/certifications Operator training/certification Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.6 Sheaves	Excessive groove wear	Dirt/grit in wire rope Lack of lube in wire rope Excessive fleet angle (design or improper reeving)	Excessive wore rope wear resulting in eventual failure of wire rope Wire rope jumps worn sheave groove and jams	Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) | **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 | **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE | **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.7 Sheave Pin Keeper/Bolts	Loss of Keeper	Vibration Improper Installation (over or under torquing)	Drops Load	Daily, quarterly, and annual inspections/certifications	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.8 Wire Rope	Tensile failure	Material or manufacturing defect. Fatigue Corrosion Overstress Kinking Excessive Wear Crushing Lack of lubrication Birdcaging	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections/certifications Design to ANSI B30.2.0-1967 Crane capacity clearly marked Operator training/certification Inspection/maintenance plan	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.9 Wire Rope Collar	Separates from rope	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections/certifications Design to ANSI B30.2.0-1967 Crane capacity clearly marked Operator training/certification Non-bearing surfaces painted/ (Cane lndoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.10 Upper Block Sheaves	Excessive groove wear	Dirt/grit in wire rope Lack of lube in wire rope Excessive fleet angle (design or improper reeving) Material or manufacturing defect. Fatigue Overstress Corrosion	Accelerated wire rope wear resulting in eventual failure of wire rope Wire rope jumps worn sheave groove and jam	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections/certifications Design to ANSI B30.2.0-1967 Crane capacity clearly marked Maintenance / test plan	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.11 Upper Block Sheaves Bearings	Seizes or excessive play and friction	Lack of lube Contaminated lube Corrosion Overload Wear	Sheave and wire rope wear accelerated. Eventual failure of sheave or wire rope	Daily, quarterly, and annual inspections/certifications Crane capacity clearly marked Maintenance / test plan Operator training/certification Exposed non-bearing surfaces painted. (Crane indoors)	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: 5 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.12 Upper Block Sheave Pin	Shears	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)

ENGINEER: R. TILTON

FACILITY: NASA AMES BLDG. 211

DATE: 1/10/08

SYSTEM: 5 TON BRIDGE CRANE

SHEET NO#: **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.13 Upper Block Sheave Pin Keeper/Bolts	Loss of Keeper	Vibration Improper Installation (over or under torquing)	Drops Load	Daily, quarterly, and annual inspections/certifications	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 211	**DATE:** 1/10/08
SYSTEM: 5 TON BRIDGE CRANE	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.14 Drum	Buckling, bending of main cylinder or shearing of shaft	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 211	**DATE:** 1/10/08
SYSTEM: 5 TON BRIDGE CRANE	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.15 Main Gear Cage	Shears	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.16 Geartrain Key	Shears	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.17 Main Gear Cage	Shears	Material or manufacturing defect. Fatigue Corrosion Overstress	Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.18 Main Gear End Frame	Structural failure	Material or manufacturing defect. Fatigue Corrosion Overstress	Drive train and both brakes lost. Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 246	**DATE:** 1/10/08
SYSTEM: 25 TON BRIDGE CRANE	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.19 Electric Brake Keys	Shear	Material or manufacturing defect. Fatigue Corrosion Overstress	Drive train and both brakes lost. Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.20 Trolley	Structural failure	Material or manufacturing defect. Fatigue Corrosion Overstress	Drive train and both brakes lost. Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) | **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 | **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE | **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.21 Bridge / Girder Structure	Structural failure	Material or manufacturing defect. Fatigue Corrosion Overstress	Drive train and both brakes lost. Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)

ENGINEER: R. TILTON

FACILITY: NASA AMES BLDG. 246

DATE: 1/10/08

SYSTEM: 25 TON BRIDGE CRANE

SHEET NO#: **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.22	Structural failure	Material or manufacturing defect. Fatigue Corrosion Overstress	Drive train and both brakes lost. Drops Load	125% proof load test. Annual rated load test. Daily, quarterly, and annual inspections Design to ANSI B30.2.0-1967 Crane capacity clearly marked Non-bearing surfaces painted/ (Cane lndoors) Operator training/certification	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 246 **DATE:** 1/10/08

SYSTEM: 25 TON BRIDGE CRANE **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.23 Electrical Speed Control Contactors	Fail to open on request	Shorted wiring, welded contacts	No speed control resulting in possible personnel hazard and damage to load	Maintenance and test plan	
2.24 Electrical Upper Limit Switch	Fail to open when activated by load	Shorted wiring, welded contacts	Damage to load and crane	Trained/Certified operators	
2.25 Electrical Speed Control Contactors	Closed when hoist motor is energized	Shorted wiring, welded contacts	No speed control resulting in possible personnel hazard and damage to load. Overload circuit tripped.	Maintenance and test plan	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 246	**DATE:** 1/10/08
SYSTEM: 25 TON BRIDGE CRANE	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
2.26 Electrical Up-down push button switches	Accidental actuation while system energized	Operator error	Random motion of load resulting in facility and load damage. Injury to personnel	Trained/Certified operators	
2.27 Electrical Indicator Lamp	Inoperative with system energized (permitting operator error or bumped controls)	Defective lamp, open wiring	Same as above	Trained/Certified operator in presence of key adjacent to indicator lamp will alert operator Maintenance and test plan	

3.7 OPERATIONAL SAFETYCHECK LIST

#	Description	Yes	No	Verification Required
1	N211 Overhead Crane Certification Annual Cert: Critical Lift Cert.	**X**		**YES**
2	Lift Equipment Proof Load Certification Annual Cert: Critical Lift Cert.	**X**		**YES**
3	Personnel Certifications	**X**		**YES**
4	Ground Support Equipment Certifications	**X**		**YES**
5	Safety Officer Required	**X**		**YES**
6	Safety Briefing Required	**X**		**YES**
7	Prerequisite conditions completed	**X**		**YES**
8	Highlight Cautions and Warnings noted in the procedure	**X**		**YES**
9	Establish limited access and stay-out areas	**X**		**YES**
10	Establish roles, responsibilities and positions of personnel *Lift Manager *Crane Operator *Ground Observer	**X**		**YES**
11	Tag Lines	**X**		**YES**
12	Establish clear area before lift operations	**X**		**YES**
13	Handling and Lift procedures required	**X**		**YES**
14	Pre-lift test	**X**		**YES**

SECTION 3.8

HANDLING OPERATIONS SAFETY ASSESSMENT SUMMARY REPORTS

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 211	**DATE:** 1/10/08
SYSTEM: PMA HANDLING OPERATIONS	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
3.1 Inadequate Workspace	Bumps Stags / Scrapes Dings / Dents Pinch Points Trips / Falls Entrapment	Insufficient space in crate unpacking area. Inadequate staging / rigging plan. Inadequate tag lining. Crane operator error. Objects / Debris in work path	Damage to the load Uncontrolled moved. Personnel injury Damage to collocated equipment and facility	Trained / Certified Operators PMA Ground Operations Procedure	

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT) **ENGINEER:** R. TILTON

FACILITY: NASA AMES BLDG. 211 **DATE:** 1/10/08

SYSTEM: PMA HANDLING OPERATIONS **SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
3.2 Tag Lines	Breaks Nicks / Snags Rips / Tears Knots Insufficient Length Inadequate Material Inadequate tag location on load Operator Error	Uncontrolled load swings Loss of load balance	Load damage Personnel injury Collocated equipment or facility damage	Certified / trained personnel Established 4 ft clearance work area	Consider providing load tagging locations in a staging / operations plan.

SAFETY ASSESSMENT SUMMARY

PROJECT: SOFIA (CRITICAL LIFT)	**ENGINEER:** R. TILTON
FACILITY: NASA AMES BLDG. 211	**DATE:** 1/10/08
SYSTEM: PMA HANDLING OPERATIONS	**SHEET NO#:** **1 of 1**

ITEM	FAILURE MODE	CAUSE(S)	EFFECT(S)	CONTROLS	COMMENTS
3.3 PMA Handling Cart	Collapse under load Moves out of position	Inadequate strength Inadequate material selection Sufficient floor support system	Drops load Damages load Unbalanced load Damage to collocated equipment and personnel injury	125% Proof load tested prior to operations Personnel training / certification	