TO: J. MISEK
MECHANICAL SAFETY COMMITTEE
REVIEW PANEL

FROM: A. SZYMUCHANSKI

SUBJECT: THE 48" VACUUM WINDOW (E731, 773, 799) COMPONENT INSPECTION AND ITS IMPACT ON 1.8m WINDOW ANALYSIS.

THE 48" VACUUM WINDOW, PART OF THE VACUUM SYSTEM IN MC-8 HAS BEEN DISASSEMBLED AND VISUALLY INSPECTED. PHOTOGRAPHS (1) TO (68) SHOW THE ASSEMBLY AS WELL AS DETAIL COMPONENTS. THE THICKNESS OF THE DOWNSTREAM FLANGE HAS BEEN MEASURED ACCORDING TO FIG. 2 AND FIG. 3 ARRANGEMENTS. THE RESULTS ARE TABULATED IN TABLE 1.

THE ALUMINUM WIRE PROTRUDES MINIMALLY OVER THE FACE OF THE FLANGE WITH ITS MAXIMUM OF 0.010" AND 0.005" MINIMUM. THE 1" BOLTS HAVE BEEN TORQUED TO THE LEVEL WHICH CAUSED BOLT ELONGATION OF 0.0065" (REF. [1]).

CORRESPONDING STRESS :

$$\sigma = E \cdot \varepsilon$$

$$\sigma = E \cdot \frac{\Delta L}{L}$$

$$\sigma = 30\,000\,000 \quad \frac{0.0065}{5}$$

REF. [1]

DWG. 9220.731-MD-202178

$$\sigma = 39\,000. \quad [psi]$$

$$\sigma = \frac{P}{A}$$

WHERE :

P - FORCE [lbs]

$$39000 = \frac{P}{A}$$

$$P = 39000\,(A)$$

A - AREA AT ROOT OF THREAD.

FOR 1-8 UNC BOLT :

$A = 0.551\ in^2$

$$P = 39000\,(A)$$

$$P = \underline{21489} \quad lbs$$

EQUIVALENT TORQUE !

23-4-2 Selecting the Correct Torque

Having said all this, we must still select an appropriate torque to produce, or attempt to produce, the target preload we have established for our design. Our best bet is to use the so-called short-form torque equation to make an estimate. This equation is

$$T = KdF_{PT} \tag{23-21}$$

The nut factor K is an experimental constant, a *bugger factor*, if you will, which defines the relationship which exists between applied torque and achieved preload in a given situation. The only way to determine what K should be in your application is to make some actual experiments in which you measure both torque *and* preload and compute the mean K and the scatter in K. If accuracy is not a big concern or you are merely trying to select the proper size of wrench or determine the approximate preloads you will achieve, then it is safe to use a nut factor listed in Table 23-5.

REF. [2]
pages: 23.29
23.30

TABLE 23-5 Nut Factors

Lubricant or coating on the fastener	Source	Nut factor	
		Reported mean	Reported range
1. Cadmium plate	1	0.194–0.246	0.153–0.328
2. Zinc plate	5	0.332	0.262–0.398
3. Black oxide	1	0.163–0.194	0.109–0.279
4. Baked on PTFE	1	0.092–0.112	0.064–0.142
5. Molydisulfide paste	2	0.155	0.14–0.17
6. Machine oil	2	0.21	0.20–0.225
7. Carnaba wax (5% emulsion)	2	0.148	0.12–0.165
8. 60 Spindle oil	2	0.22	0.21–0.23
9. As received steel fasteners	3	0.20	0.158–0.267
10. Molydisulfide grease	3	0.137	0.10–0.16
11. Phosphate and oil	3	0.19	0.15–0.22
12. Copper-based anti seize compound	3	0.139	0.08–0.23
13. As received steel fasteners	4	0.20	0.161–0.267
14. Plated fasteners	4	0.15	
15. Grease, oil, or wax	4	0.12	

SOURCES:

1. Values given are typical results from a very large and unpublished set of experiments on ASTM A193 B7 studs treated with various coatings. The tests were made in 1979–1980. Mean values for K varied with the diameter of the studs tested and the torques applied in various test series.
2. Kazuo Maruyama, Makoto Masuda, and Nobutoshi Ohashi, "Study of Tightening Control Methods for High Strength Bolts," *Bulletin of the Research Laboratory Precision Machine Selection*, Tokyo Institute of Technology, N46, September 1980, pp. 27–32.
3. John H. Bickford, *An Introduction to the Design and Behavior of Bolted Joints*, Marcel Dekker, Inc., New York, 1981, p. 429.
4. *Fastener Standards*, 5th ed., Industrial Fastener Institute, Cleveland, Ohio, 1970, p. N-16.
5. Edwin Rodkey, "Making Fastened Joints Reliable—Ways to Keep 'em Tight," *Assembly Engineering*, March 1977, p. 24.

THE TORQUE VALUE DEPENDS ON THE TYPE OF A LUBRICANT OR COATING ON THE FASTENER.

USING MACHINE OIL :

$K = 0.21$

$T = 0.21\,(1)\,21489$

$T = 4512.6$ in lbs

$T = \underline{376}$ [Ft lbs]

GRAPHICAL ARRANGEMENT OF THE CLAMPED MYLAR/KEVLAR/MYLAR SANDWICH.

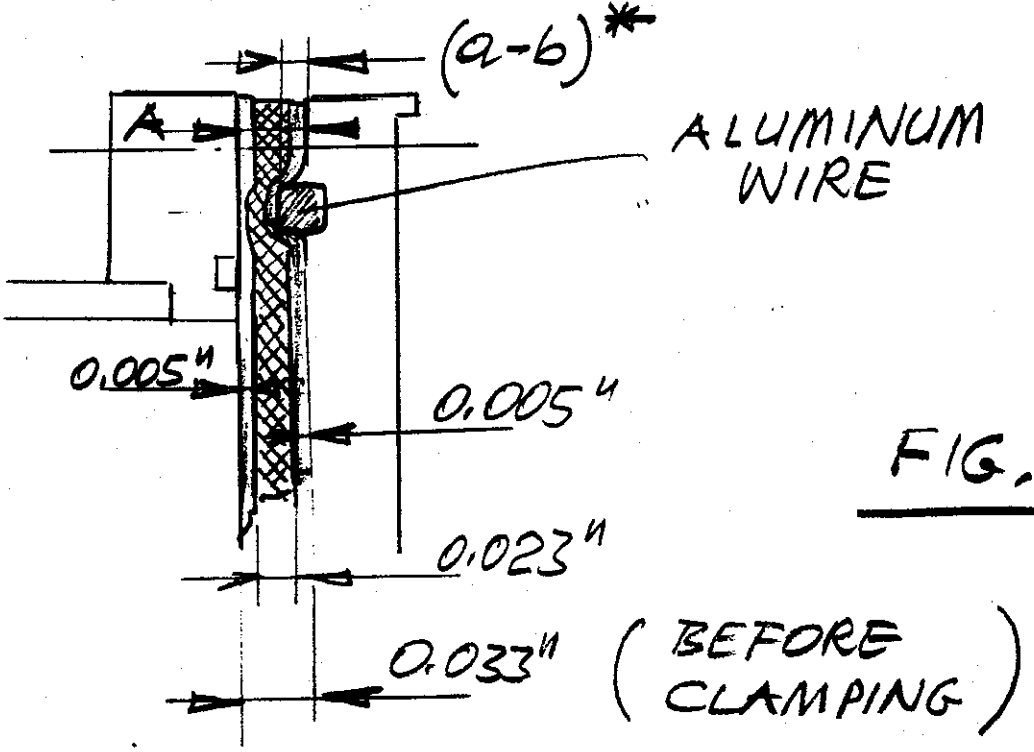
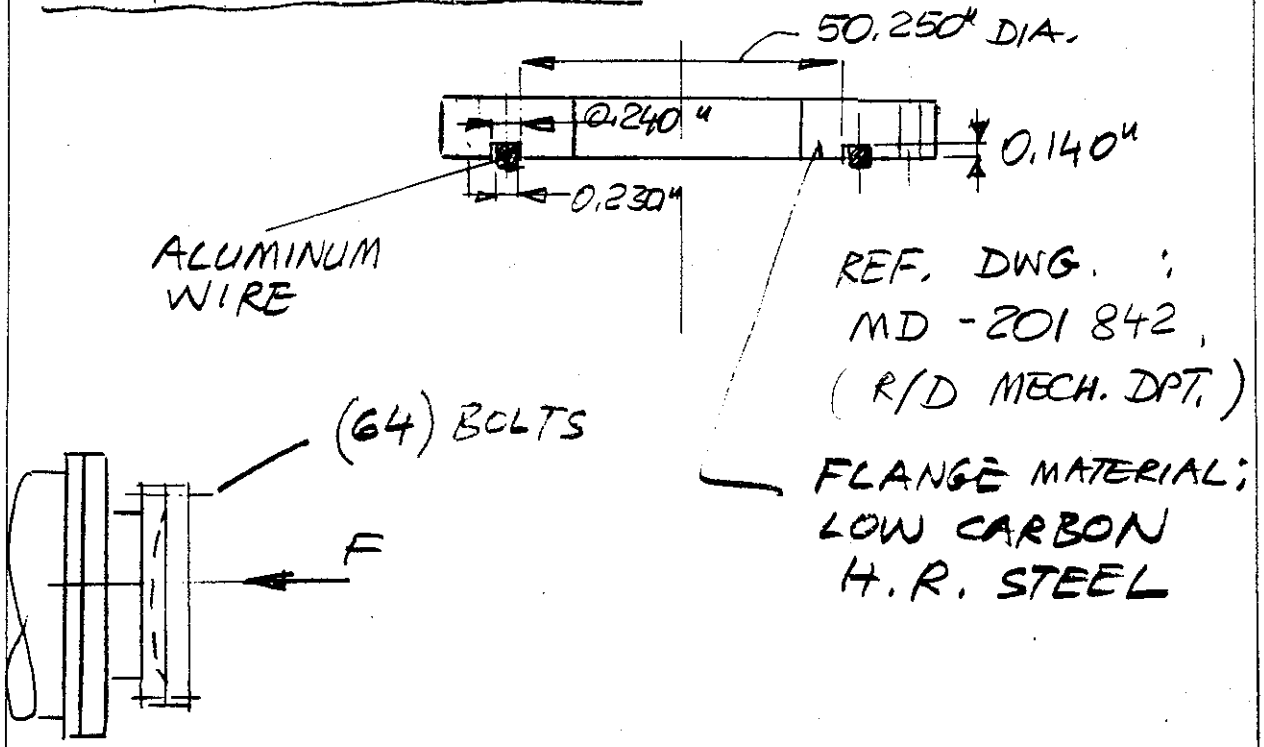


FIG. 1

* SEE TABLE 1

THE DIMENSION "A" (FIG. 1)
IS ALWAYS LOWER THAN 0.033"
AND DEPENDS ON THE PRELOAD OF
THE CLAMPING BOLTS.
PHOTOGRAPHS: (6A) AND (6B) SHOW
THE BOUNDRY OF COMPRESSED
AREA OF THE MYLAR/KEVLAR/MYLAR
SANDWICH.

CHECKING THE COMPRESSIVE STRESS IN THE "COMPOSITE" MATERIAL.



- FIND THE TOTAL COMPRESSIVE DUE TO BOLT PRELOAD

$$F = 21489\ (64)$$

$$F = 1\ 375\ 296 \quad [lbs]$$

WHERE :

21489 - PRELOAD OF THE 1" BOLT SEE page [2]

64 - NUMBER OF BOLTS

- FIND THE STRESS IN THE "COMPOSITE" MATERIAL, IN THE AREA IMPRINTED BY THE ALUMINUM WIRE :

$$\sigma_c = \frac{F}{A}$$

WHERE : A - AREA OF WIRE IMPRINT

$$A = \pi (50.250 + 0.240)(0.230)$$

$$A = \underline{36.48} \quad [in^2]$$

$$\bar{\sigma}_c = \frac{1\,375\,296}{36.48}$$

$$\bar{\sigma}_c = \underline{36\,697.5} \quad [psi]$$

THE VISUAL INSPECTION OF THE MYLAR / KEVLAR/MYLAR "COMPOSITE" ASSEMBLY SHOWED NO DAMAGE TO THE ASSEMBLY COMPONENTS.

THE ABOVE STRESS IS IN THE RANGE OF LOW CARBON H.R. STEEL.
THE FLANGES ARE MADE OF THE ABOVE MATERIAL.

THE COMPRESSED EPOXY IMPREGNATED COMPOSITE MATERIAL CAN BE VIEWED AS A CONTACT SPACER BETWEEN THE TWO STEEL FLANGES, THIS WOULD BE EQUIVALENT TO THE SPACER WASHERS USED IN THE TEST VESSEL DOCUMENT FLANGE ANALYSIS, THE ANALYSIS IS STILL VALID IN TREATING THE FLANGE AS A "FIXED EDGE" CASE.

DETERMINE THE STRESS VALUE IN THE PRELOAD $\frac{7}{8}$" BOLTS; FOR 1.8M WINDOW ASSEMBLY.

DURING THE KEVLAR SAMPLE TESTS, THE BOLTS OF THE CLAMPING ASSEMBLY WERE TORQUED TO THE HIGHEST LEVEL OF 250 [Ft lbs]

NO ADDITIONAL LUBRICANT WAS USED. THE BOLTS WERE COVERED WITH BLACK OXIDE.

THE EQUIVALENT PRELOAD FORCE:

$$F_{PT} = \frac{T}{K d}$$

$$K = \frac{0.163 + 0.194}{2}$$

$$K = 0.178$$

$$F_{PT} = \frac{250(12)}{(0.178)\left(\frac{7}{8}\right)}$$

$$F_{PT} = 19261.6 \quad [lbs]$$

STRESS IN THE BOLT;

$$\sigma_b = \frac{19261.6}{A_r}$$

A_r = CROSS SECTION AREA OF THE BOLT AT ROOT OF THREAD

$$A_r = 0.419$$

$$\bar{\sigma}_6 = \frac{19261.6}{0.419}$$

$$\bar{\sigma}_6 = 45970 \quad psi$$

THE MAX. TENSILE STRENGTH OF FERRY CAP SCREW MATERIAL (A 574 ALLOY STEEL) IS 170 000 psi

MIN. YIELD STRENGTH

$$\sigma_y = 153\,000 \left[psi\right]$$

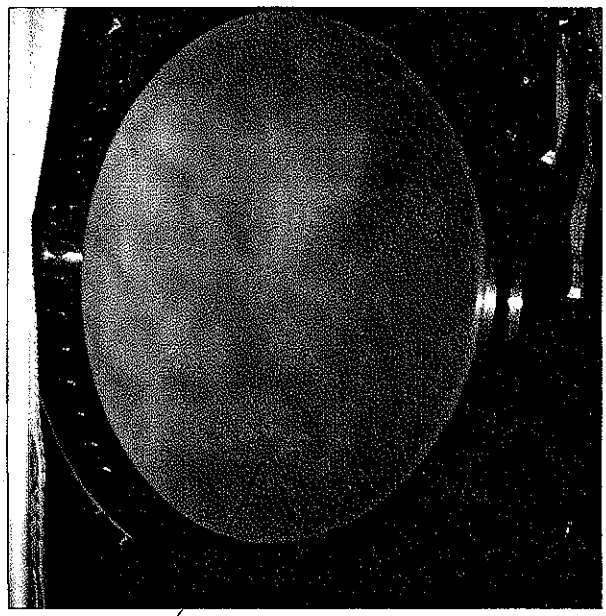
SAFETY FACTOR FOR BOLTS:

$$\frac{153,000}{45970} = 3.32$$

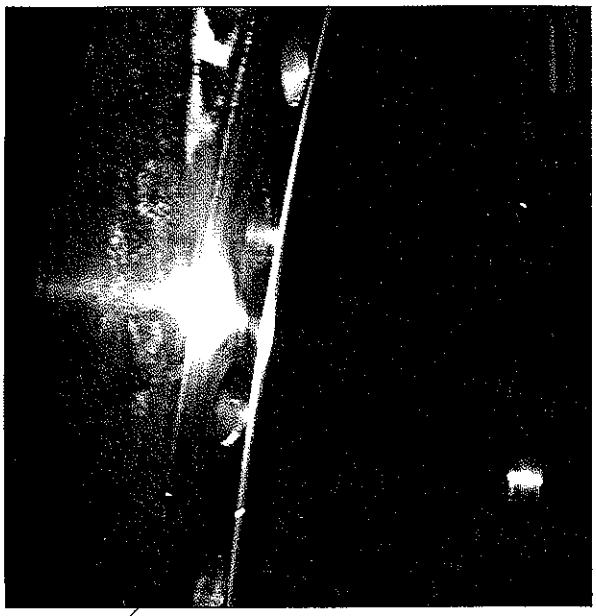
THE 1.8M WINDOW WILL USE BOLT TORQUES OF 250 [Ft-lbs.] THE SHORT SAMPLE TEST RESULTS SHOWED THAT AT THIS TORQUE LEVEL A PULLOUT FORCE, EQUAL TO THE PULLOUT FORCE REQUIRED AT THE 45 psi CAN BE OBTAINED. THIS GIVES A SAFETY FACTOR AT A VACUUM LOADED CONDITION FAR OVER 3. THE ADDITION OF EPOXY IN THE FINAL WINDOW ASSEMBLY WILL PROVIDE ADDITIONAL PULLOUT STRENGTH. THE 250 Ft-lb TORQUE DOESN'T EFFECT THE FLANGE ANALYSIS — THICKNESS REQUIREMENTS SUBMITTED FOR THE TEST VESSEL.

48" KEVLAR WINDOW

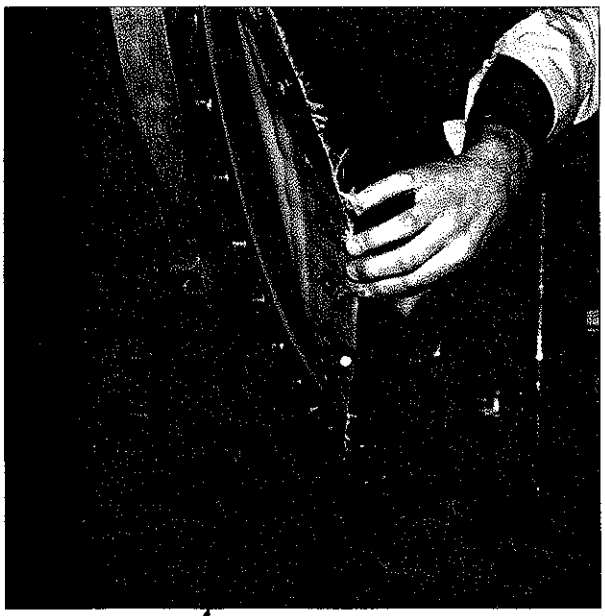
E773
E799



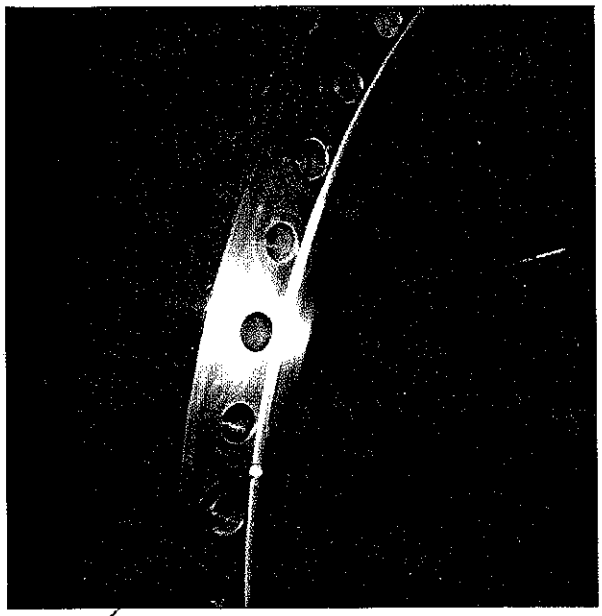
(1) DOWNSTREAM END OF THE WINDOW



ALUMINUM WIRE (2)



(3) MYLAR/KEVLAR/MYLAR SANDWICH



ALUMINUM WIRE (4)

DEC. 23. 92

48" KEVLAR WINDOW

E-773
E-799

ALUMINUM WIRE (5)

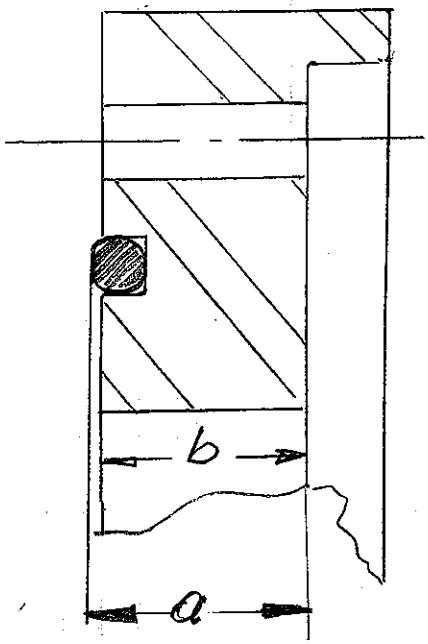


FIG. 2

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
			12.

SUBJECT: 48" KEVLAR WINDOW E-773 E-799

NAME:

DATE: DEC 8 93

REVISION DATE:

$\frac{a}{b}$ (SEE FIG. 2)

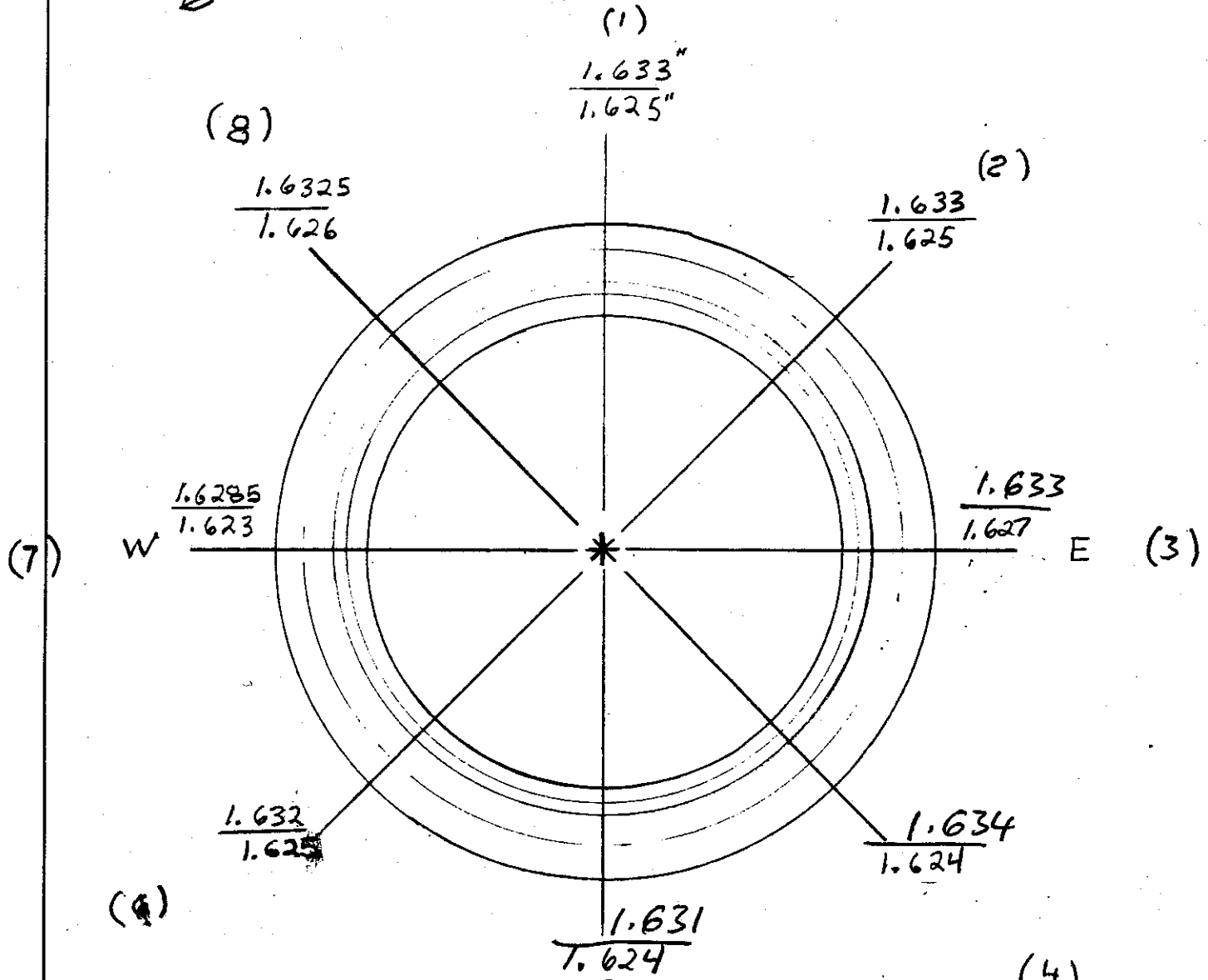
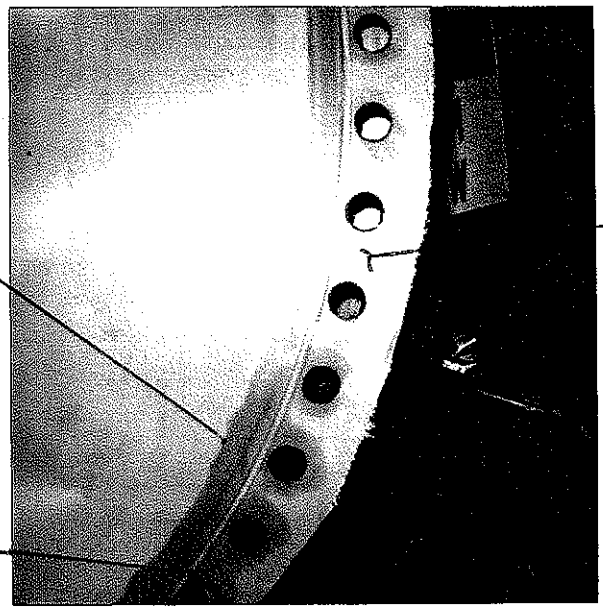


FIG. 3

TABLE 1.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(a-b)	0.008"	0.008"	0.006"	0.010"	0.007"	0.007"	0.005"	0.006"

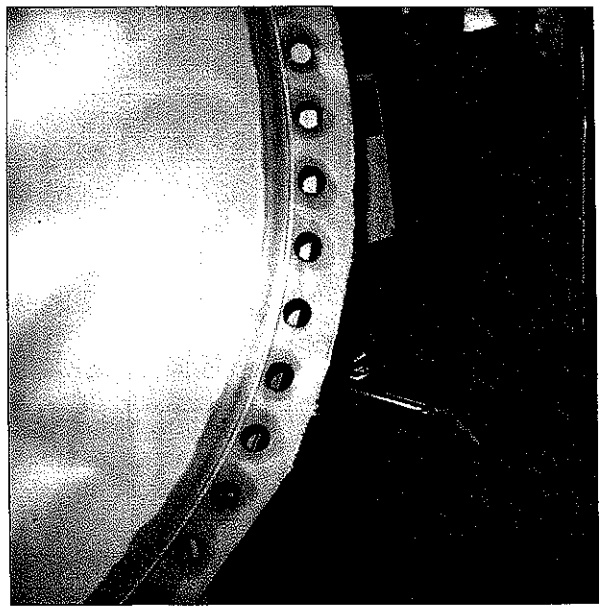


BOUNDRY OF SPREADED EPOXY

MYLAR / KEVLAR / MYLAR SANDWICH

ALUMINUM WIRE IMPRINT

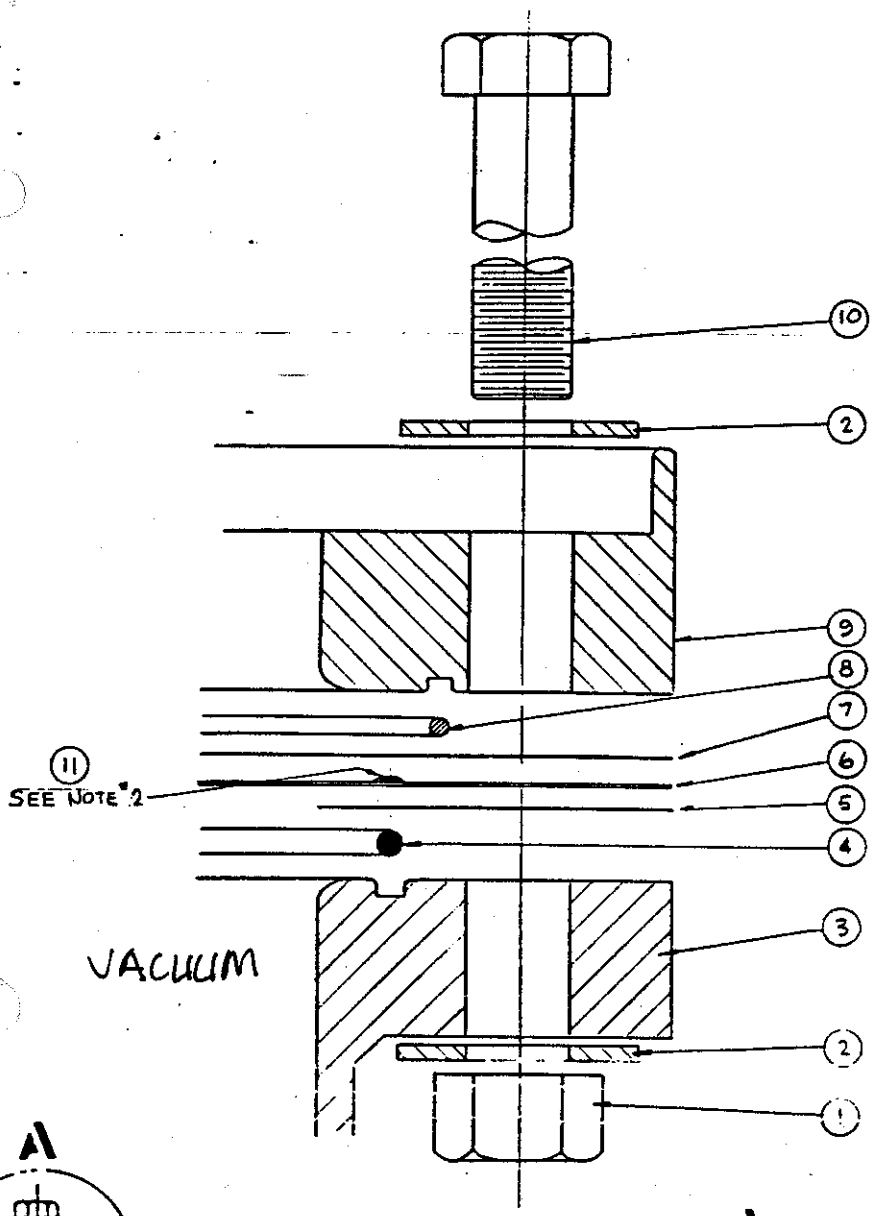
6A



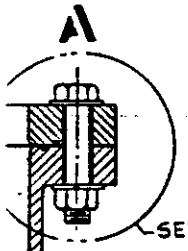
6B

REV.	DESCRIPTION	DRAWN / APPD.	DATE

14.



SECTION DETAIL A



CRIBING

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
11		EPOXY - MIX 100 PARTS OF 826 RESIN & 100 PARTS OF EM 306. USE WHEN CLEAR & FREE OF AIR BUBBLES	
10	(SEE NOTE "1)	SCR. HEX. HD. 1-8UNC 5 1/2 GRADE B. FINISH GRIND BOTH ENDS TO EQUAL LENGTHS	64
9	MD-201842	BEAM WINDOW CLAMP. RING	1
8		.187 DIA ALUM. WIRE ALLOY 1100	160"
7		MYLAR - .005 THICK 55 5/8 SQ.	1
6	CLARK-SCHWEBEL FIBERGLASS CORP.	KEVLAR - 29 FABRIC STYLE 735 MILITARY SPEC: MIL-C-44050, SECURED SPECIFICATION: 1500 DENIER KEVLAR-29, 2×2 BASKET WEAVE, 35×34 COUNT, 1800 - 1821 TEN. STR. 55 5/8 SQ.	1
5		MYLAR - .005 THK. 46" I.DIA × 55 5/8 SQ. OD	1
4		"O" RING "4 ORANGE CORD	156"
3	ME-201838	BEAM WINDOW WELDED ASSY.	1
2		WASHER 1" GRADE B	128
1		NUT-HEX 1"-8 UNC GRADE B	64

UNLESS OTHERWISE SPECIFIED	DRAWN	A. SKRABOLY	12/18/84
FRACTIONS DECIMALS ANGLES	CHECKED		
± ± ±	ENGR APPROVED		
1. BREAK ALL SHARP EDGES 1/64 MAX.	MFG APPROVED		
2. DO NOT SCALE DWG.	USED ON		
3. DIMENSIONS IN ACCORD WITH ANSI Y14.5 STD.	MATERIAL		

NOTES:

1. FINISH GRIND THE HEAD & THREAD ENDS OF THE 64 SCREWS SO THEY ARE EQUAL IN LENGTH WITHIN .0005. TORQUE THE 64 SCREWS EQUALLY AROUND THE FLANGE UNTIL THE MAXIMUM IS REACHED. THIS IS WHEN THE ELONGATION OF THE SCREWS HAVE REACHED .0065 BY MEASURING BETWEEN THE HEAD & THE THREAD END OF THE SCRS.
2. ASSEMBLE "O" RING ITEM 4, MYLAR RING ITEM 5, & KEVLAR FABRIC ITEM 6 TO LOWER FLANGE FACE. ON THE KEVLAR FABRIC [illegible] EPOXY [illegible] OF THE [illegible]

APPROX. WT. 247 #

REFERENCES :

1. DOCUMENTATION OF TECHNICAL PROCEDURES FOR THE ASSEMBLY OF THE 4 FOOT DIAMETER VACULIM WINDOW
BY : CHARLES D. PAUL
6/15/87

2. STANDARD HANDBOOK OF MACHINE DESIGN
J. E. SHIEGLEY
CH. R. MISCHKE

ENCLOSURE :

DOCUMENTATION OF TECHNICAL PROCEDURES FOR THE ASSEMBLY OF THE 4 FOOT DIAMETER VACUUM WINDOW
BY : CH. D. PAUL
6/15/87

6/15/87

To: Stan Sobsczynski

FROM: Charles D. Paul

Subject: Documentation of technical procedures for the assembly of the 4 foot diameter vacuum window.

The documentation of technical procedures for assembly of the 4 foot diameter vacuum window (located in M-Center beamline) has been completed. I have attached a copy of this procedure for you to review.

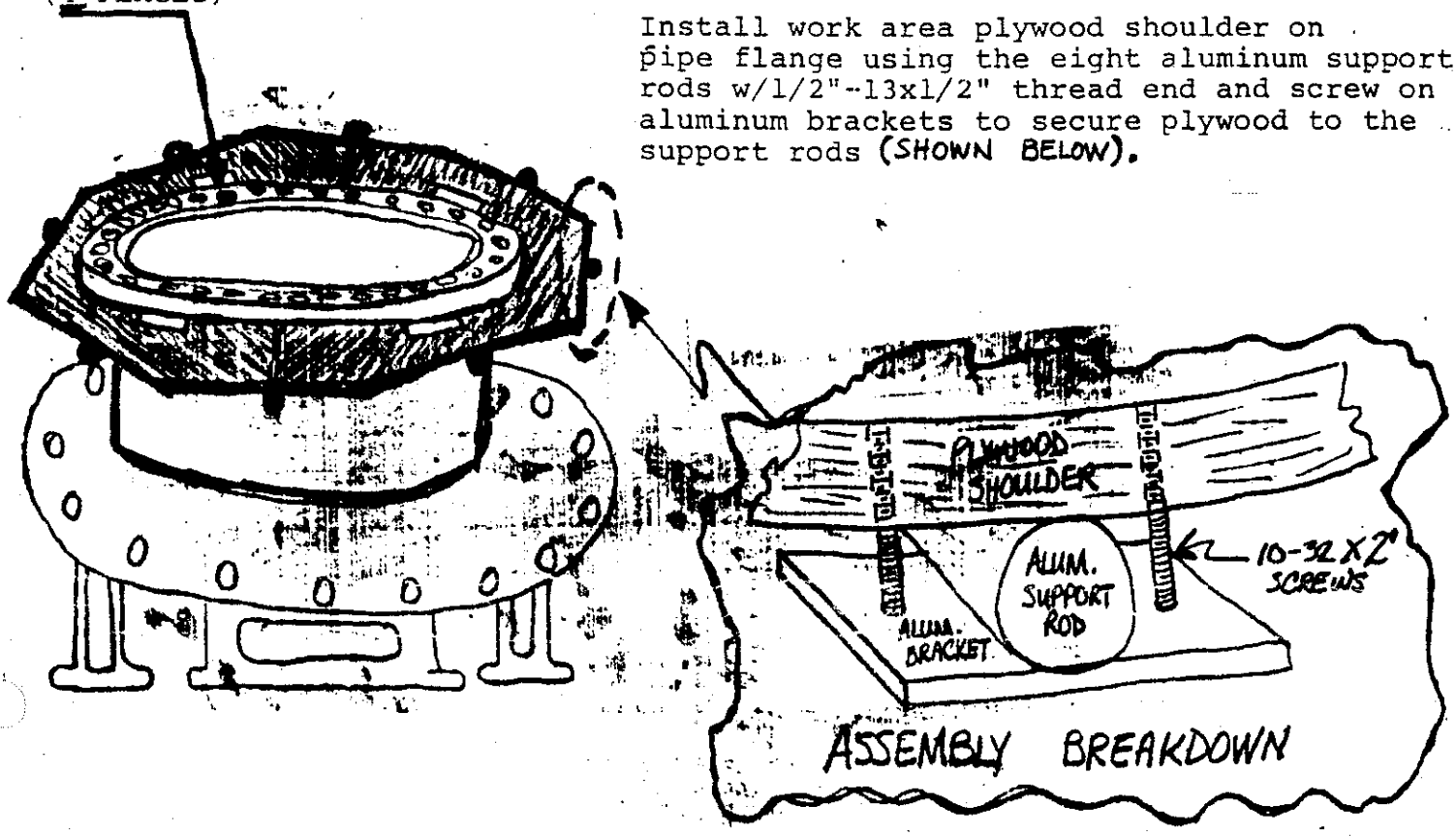
Respectfully,

Charles D. Paul

PREPARATION FOR ASSEMBLY:

CLEAN & POLISH BOTH FLANGE O-RING GROOVES
CLEAN & POLISH FLANGES & MATING SURFACES
MAKE ORANGE CORD O-RING FOR PIPE FLANGE GROOVE
MAKE ALUMINUM(1100ALLOY)O-RING FOR OUTER GROOVE
(weld with Al 1100 rod)

FLANGE CLAMP POSITION
(4 PLACES)



Install work area plywood shoulder on pipe flange using the eight aluminum support rods w/1/2"-13x1/2" thread end and screw on aluminum brackets to secure plywood to the support rods (SHOWN BELOW).

Keep Work area free of dust, debris, and chips! Prepare a workbench for materials by cleaning then applying a clean layer of new plastic protective cover.

The workbench should be used to store materials in use on the window to prevent pulling the weave of the Kevlar or snagging or scratching of mylar.

ASSEMBLY: (All materials should be inspected for [illegible] before using, during use, and after each step)

CAUTION: When any material has been stored, degradation occurs from sunlight and dust or dirt, so before using any material it is necessary to remove a couple windings from the roll to start with satisfactory material for the vacuum window.

Place a layer of Mylar film (.005 thk.) across the plywood shoulder, covering the 4 foot window evely. The film should be trimmed about 4" away from the pipe flange and secured with tape, allowing the film to sag, but not more than 1/4" at the center of the window.

The Mylar should be kept clean free of scratches, and with no crease marks from folding or bending.

The KEVLAR layer may now be rolled out across the Mylar inner skin. The Kevlar may be cut using sharp scissors. Be careful not to pull any thread or strand of the Kevlar fabric. Gently rub out any wrinkling using your hand from the window center out to the edge.

Trim the Kevlar slightly larger than the Mylar film and tape into position on the plywood shoulder. Be sure no tape is placed where it would interfere with the mating flanges or window membranes. The Kevlar should lay smoothly against the Mylar layer.

You must now mark the O-Ring groove location and bolt hole locations on the Kevlar fabric using a felt tip pen.

The bolt holes are readily identified by placing a light under the flange and marking the fabric at each location.

To locate the O-Ring groove, the Orange Cord O-Ring must be cleaned and seated in the groove from the bottom side of the window. Again be careful not to scratch or crease the Mylar film while tucking the Orange Cord O-Ring into the flange groove. Now the O-Ring groove diameter can be marked on the Kevlar fabric using the felt pen by marking the raised fabric at the top center of the O-Ring area. Now remove the Orange Cord O-Ring from the groove.

The final layer of Mylar should now be rolled out across the first two membrane layers, trimmed slightly larger, and taped down to the plywood maintaining the same sag contour of the first two membrane layers.

REMOVING MATERIALS FROM BOLT HOLE PATTERNS

This step requires the outer flange to be properly located and secured to the inner flange with the vacuum window in position. This may be accomplished by first cleaning the outer flange mating surface then positioning the flange above the window, being sure to align the matched marks on the outside diameter of each flange. Now, lower the outer flange until the flange begins to mate, then you can accommodate final alignment by viewing the hole pattern markings on the Kevlar through the bolt holes in the flange. Now lower the flange until most of the flange weight is on the membrane. Fine alignment is checked by using a light on the underside of the bolt hole pattern and viewing the hole from above for at least four positions around the circle. Tap the outer flange lightly with a rubber mallet to make the final alignment adjustments. Now the full weight of the outer flange should be applied to the membrane and lifting gear removed.

The next step will be to secure the position of the outer flange by clamping it to the inner flange using the fabricated "C" lamps at the four clamp positions cut in the plywood shoulder. To accomplish this it will be necessary to use surgical knives to cut the membrane materials at the clamp positions, fold the material and secure with tape to maintain membrane position.

The bolt holes edges will guide a surgical blade to accommodate membrane material removal with a relatively clean cut.

CAUTION: You must be extremely careful not to pull any Kevlar fabric thread or strand which will unevenly stress that fiber across the fabric.

Since this process invariably leaves strand ends or fibers of Kevlar in the bolt hole pattern as the surgical knives become dull, it will be necessary to more completely clean the hole positions without further cutting of materials, or as bolts pass thru the holes they will snag the Kevlar fabric or fibers and pull the fabric or fiber causing the uneven tensioning across the vacuum window. It was found that burning will accomplish fiber removal rapidly and cleanly; however, to prevent any possibility of damaging the window, the window must be covered during this process.

PREPARATION FOR EPOXY SEALANT HYSOL 308/826

After burning the bolt hole pattern clean of fibers, remove the "C" clamps from the flange to prepare for lifting the outer flange ring away from the vacuum window. Remove the outer ring and position it so the aluminum (1100 alloy) O-Ring may be installed. Clean the mating face and O-Ring groove of the outer ring to prepare for O-Ring installation. Inspect and polish the aluminum O-Ring completely. Be sure the weld interface has an even transition across the weld area. Now lay the aluminum O-Ring in the groove and tap the O-Ring lightly with a rubber mallet so

the O-Ring will lay flat within the groove. To hold the O-Ring in the groove during the final assembly of the vacuum window a small amount of RTV silicone was applied under the O-Ring at numerous positions about the groove circle. To keep the O-Ring flat in the groove it should be pressed down, excess RTV cleaned off, and a weight placed on the O-Ring at each RTV location until the RTV has time to set (about 2-4 hours).

While the RTV sets, the window membrane needs preparation for Epoxy Sealant application and final assembly. First the Orange Cord O-Ring is cleaned, then installed in the inner flange O-Ring groove from under the membrane assembly. Next, the outer Mylar membrane must be slowly separated from the window assembly. Burning bolt holes to remove Kevlar fibers causes the Mylar to melt and stick together at each bolt hole location. To separate the outer Mylar from the central Kevlar and inner Mylar a small section of the bolt pattern is untaped from the plywood material layers separated, then the section is retaped in position and another area untaped for separation. Separation of layers is done using tongue depressors. The tongue depressor is inserted flat against the Kevlar and pushed gently through the material interface at the bolt hole. Move the tongue depressor towards the hole center until separation of the Mylar occurs then extract the depressor and approach the hole from a different direction, always moving towards hole center when separating the Mylar. Once the Mylar is completely separated at one hole, go to the next hole until the untaped area is freed, then retape the Mylar in proper position and move on until the whole outer Mylar is separated from the assembly but properly taped. Because the O-Ring groove and bolt holes are marked on the Kevlar fabric and the Mylar is fully separated the window is now ready for the Epoxy application.

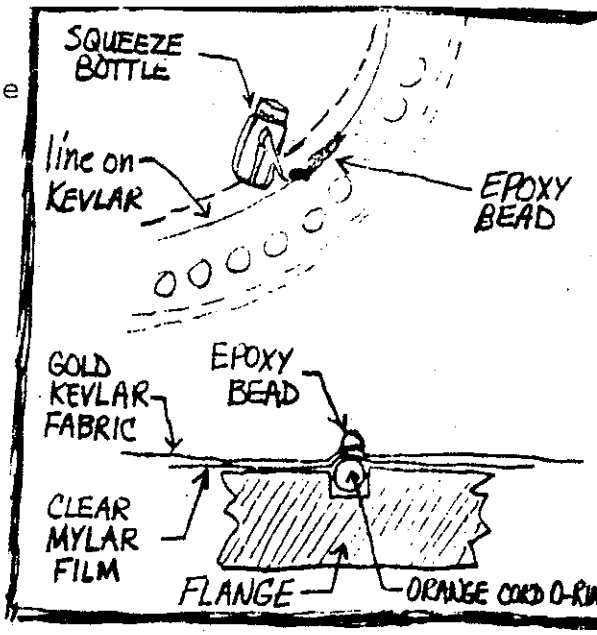
EPOXY PREPARATION (24 HR.CURE)

Epoxy is applied about the O-Ring circle, then around each bolt hole as indicated with felt pen markings on the Kevlar fabric.

To prepare the epoxy a 1:1 ratio of epoxy to resin is required. 75 ml of 826 resin and 75 ml of EM 308 hardener (catalyst) were mixed thoroughly in a large container (> 1000 ml capacity). The container is then placed under vacuum in a bell jar until the epoxy blend sits under full vacuum without bubbling from degassing. The bell jar is bled off to atmosphere and the resin blend poured into small spouted squeeze bottles for application to the Kevlar fabric.

Half of the bolt pattern and O-Ring circle should have the outer Mylar untaped from the plywood shoulder, and carefully folded back avoiding scratching or creasing of the Mylar, to expose the work area.

Using the spouted bottle, a bead of epoxy is applied approcimately 3/16" wide by 1/8" thick. Larger amounts could run or soak too far towards center. After applying epoxy at the O-Ring circle go around each bolt hole in the work area. Using tongue depressors, prod the epoxy bead to work the epoxy into the Kevlar where the epoxy has been applied.



The Mylar film must now be rolled back over the work area, carefully re-aligned and firmly secured to the plywood shoulder.

The whole procedure is repeated for the opposite half of the flange circle.

The outer flange should be cleaned, aluminum O-Ring intact and lifted for positioning on the vacuum window. Be sure the match marks on both flange sections are aligned and use the same procedure for alignment as used when marking the bolt hole pattern for cutting/removing membrane materials.

To secure the outer flange ring do not employ the fabricated "C" clamps, rather; place the 4 ground bolts through the flange with 90° spacing on the hole pattern. Tighten the bolts, using a torque wrench, to 100 ft./lbs. by sequencing. Tighten one pair of opposing bolts then tighten the remaining opposing pair of bolts to the 100 ft./lbs. torque value. Now the remaining 60 bolts should be installed and torqued to the 100 ft./lbs. step of tightening using the sequence in diagram "A"

There are two more steps necessary to increase torque to the value which corresponds with the designated elongation of the bolts (.0065 inch) as measured on the four ground to length bolts. The torque should be increased to 250 ft./lbs. and applied again using the diagram"A" sequence. Finally, the whole procedure is repeated at 375 ft./lbs.

The first time the window was assembled the unused bolts achieved full elongation with only 175 ft./lbs. tension, however, after ageing under stress (assembled for use in M-Center), the bolts may be in a pre-tensiled state, as indicated by the 375 ft/lbs. tension necessary to stretch the bolts for reassembly. We should consider replacing the bolts rather than risking ductile failure of

any bolt in the event the 4 foot vacuum window needs to be rebuilt in the future.

To finalize the vacuum window the inner Mylar layer is removed by cutting from center to the outside edge within 1" to 1 1/4" of the flange. Now cut the Maylar around the complete circle leaving approximately 1" to 1 1/4" lip of Mylar at the edge. This procedure is usually done at the installation site after the 4 foot vacuum window is in the vertical position.

Technical procedures developed and documented by:

Charles D. Paul

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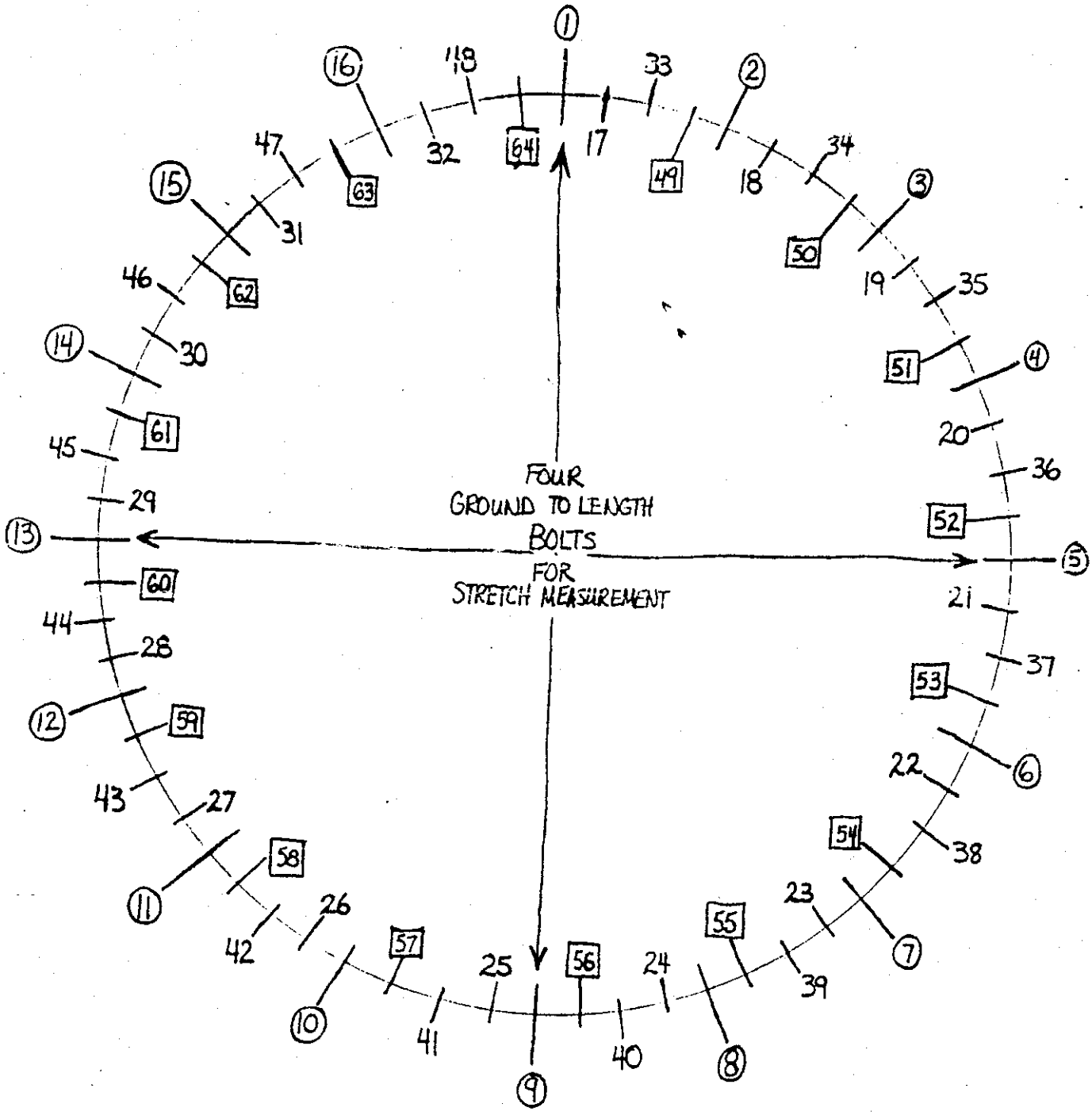
DIAGRAM A



4 FT. VACUUM WINDOW

BOLT TENSIONING SEQUENCE TO TORQUE FLANGE