ARDE, INC.
EG 10331, N/C
July 6, 2001

QUALIFICATION BY SIMILARITY REPORT

OF

SPHERE, CO2 STORAGE FILAMENT WOUND

PN D4816 TO PN D4683

FOR

TRD GAS SUPPLY SYSTEM

SUBMITTED TO:

Massachusetts Institute of Technology
Laboratory for Nuclear Science
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ARDE, INC.
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ARDE, INC.	TITLE: QUALIFICATION BY SIMILARITY REPORT OF SPHERE, CO2 STORAGE FILAMENT WOUND PN D4816 TO PN D4683 FOR TRD GAS SUPPLY SYSTEM	FORM NO.:	QS 05022
		DATE:	9 JULY 2001
	DOCUMENT NO.: EG 10331	REVISION:	A

ENGINEERING CHANGE RECORD

APPROVALS

Chg	Page	Index	Description	Date	Engr	QA	Mfg	Prog
NC	All	N/A	INITIAL RELEASE EO 2104					

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1.0 INTRODUCTION

This report presents the qualification by similarity of the Sphere, CO2 Storage Filament Wound PN D4816 for TRD CF4 or CO2 gas supply system to the qualified Accumulator, Helium PN D4683 (ref. 1) and the qualification of its mounting brackets, PN C4847 & C4848, by analysis. This report will show compliance of the CO2 storage vessel design and its mounting brackets with the Statement of Work for the TRD Gas Supply System of Alpha Magnetic Spectrometer (AMS 02) program per PM 10070 (ref.2) and MIL-STD-1522A (ref.3).

2.0 DISCUSSION

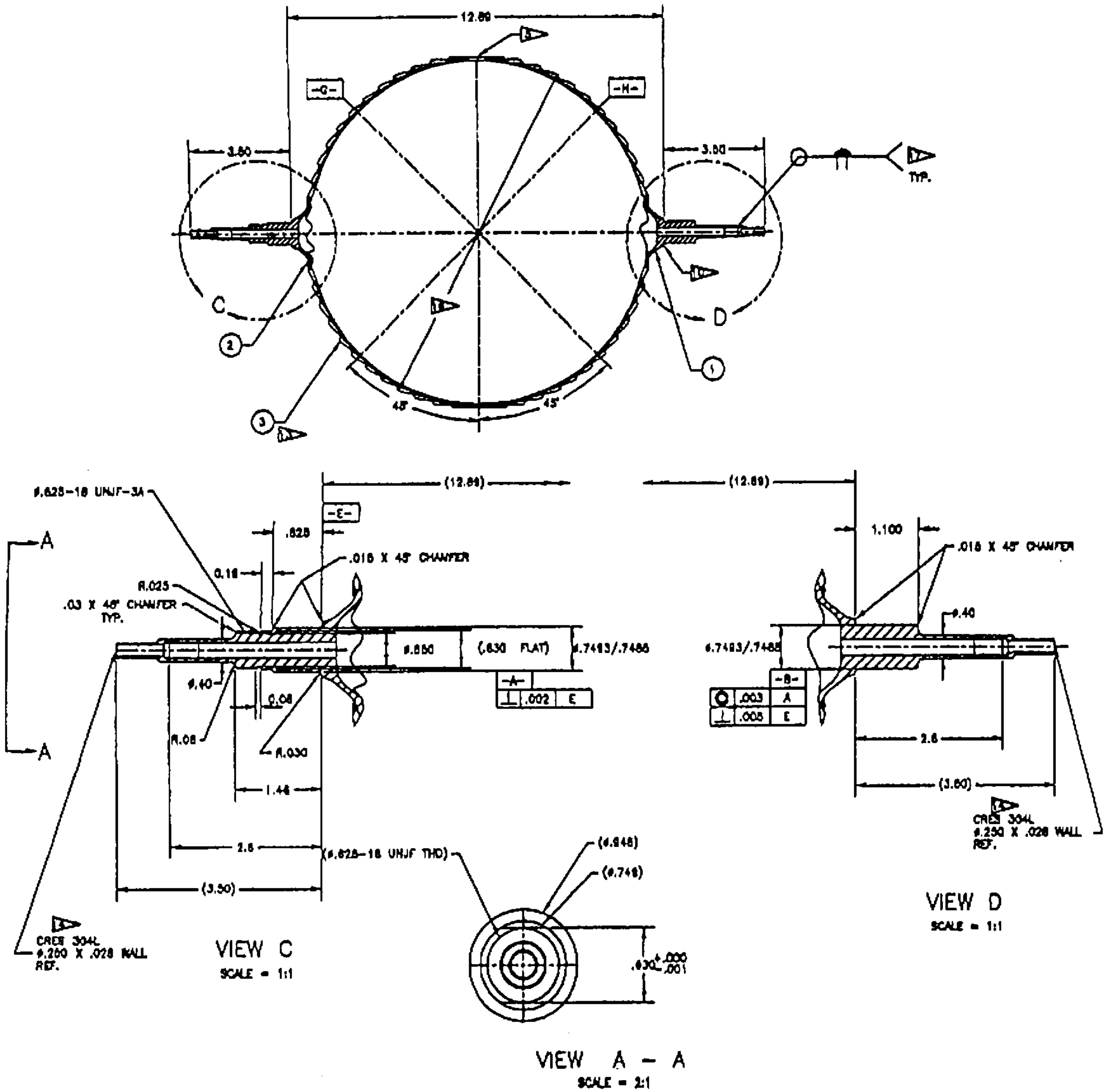
The purpose of this report is to show that the overwrapped pressurant tank design D4816 (figure 2-1) , rated at a maximum design pressure, MDP = 3200 psig, and mounted as shown in D4818 (figure 2-2) is a qualified design by similarity to PN D4683 (figure 2-3). The vessel PN D4816 is designed as CO_2 storage tank at an MDP of 3200 psig. This unit is identical (except for the mounting boss interface and tube interface) to a Helium Accumulator PN D4683 which was designed and qualified to Lockheed Martin's helium storage requirement per specification no. 10550300450 (ref. 4), as reported in ARDE's Fracture & Stress Analysis Report EG 10214 (ref. 5) and Qualification Test Report EG 10221 (ref. 6).

The vessels PN D4816 and PN D4683 have the same cryoformed CRES 301 liner design but with different mounting boss interface details, see figure 2-1 and 2-3. PN D4816 and D4683 have exactly the same reinforcing composite matrix, using carbon Toray 1000 fibers impregnated with resin formulation EPON 9405/Curing Agent W.

In the assembly of the tank and brackets figure 2-2, the mounting brackets are: Fixed End per PN C4847 (figure 2-4) and Sliding End per PN C4848 (figure ... ion 4.2.3 will show that these bracket assemblies are structurally adequate to su ... e 26.5 lb/g load (9.5 lb. tank + 18 lb CO_2) in the TRD CO_2 gas supply of AMS ... ram.

The qualification by similarity of D4816 to D4 ... gn is summarized in table 2-1. Additional evaluations are described in section 4.0.

Figure 2-1



17. ORBITAL WELD PER AES 510 AND INSPECT PER AES 450, 435, AND 551.
16. SPHERICAL DIAMETER 12.42 MAX. BETWEEN -G- AND -H-
15. CAP BOTH ENDS TO MAINTAIN CLEANLINESS DURING PROCESSING.
14. DO NOT BREAK EDGES.
13. COAT FIBERWRAP WITH ITEM NO. 3 PER AES 722. CURE PER AES 722 PARAGRAPH 4.6.1(e) ONLY.
12. ACCEPTANCE TEST PER QA 10157.
11. HELIUM LEAKAGE SHALL NOT EXCEED 10^{-6} SCC/SEC WHEN PRESSURIZED TO 3200 PSIG WITH HELIUM.
10. IDENTIFY PER AES 601 METHOD D WITH SERIAL NO. IN AREA INDICATED.
9. FLUID TEMPERATURE RANGE AT OPERATING PRESSURE -100°F TO 160°F.
8. OPERATING PRESSURE: 3200 PSIG MAX.
   PROOF PRESSURE: 4800 PSIG MINIMUM
   BURST PRESSURE: 8400 PSIG MINIMUM
7. VOLUME 813 CU. IN. MINIMUM. (UNPRESSURIZED)
6. WEIGHT 9.5 LBS. MAXIMUM.
5. SERIALIZE CONSECUTIVELY AND IDENTIFY WITH THE FOLLOWING INFORMATION IN THE AREA INDICATED PER AES 601, METHOD "D":

   SPHERE, CF4 OR CO2 STORAGE, FILAMENT WOUND
   OPERATING PRESSURE 3200 PSIG
   PROOF PRESS. 4800 PSIG TEST DATE ______
   IAT COMPLETION DATE ______
   ARDE P/N D4816- S/N ______
   M/R 05980
   ARDE INC., NORWOOD, N.J. 07648-1318
4. FINISH OF SURFACES MACHINED PER THIS DRAWING TO BE 63 EXCEPT WHERE OTHERWISE NOTED.
3. MACHINING FLUIDS SHALL BE CHLORIDE FREE. PARTS SHALL BE DEGREASED AFTER MACHINING. NO HALOGENATED FLUIDS SHALL BE USED. MACHINE PER AES 361.
2. CRYOGENICALLY STRETCH PER AES 352.
1. SERVICE – CF4 OR CO2

NOTES:

QTY RCQD PER DASH NO.				ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			2	4		B105584	REDUCER, TUBE		
				3			POLYURETHANE COATING	CONATHANE	AES 712
				2			POLYURETHANE SEALANT	PR1564	AES 711
				1		C4836	LINER/FIBERWRAP ASSY		

PARTS LIST

ARDE, INC.
NORWOOD, N.J.

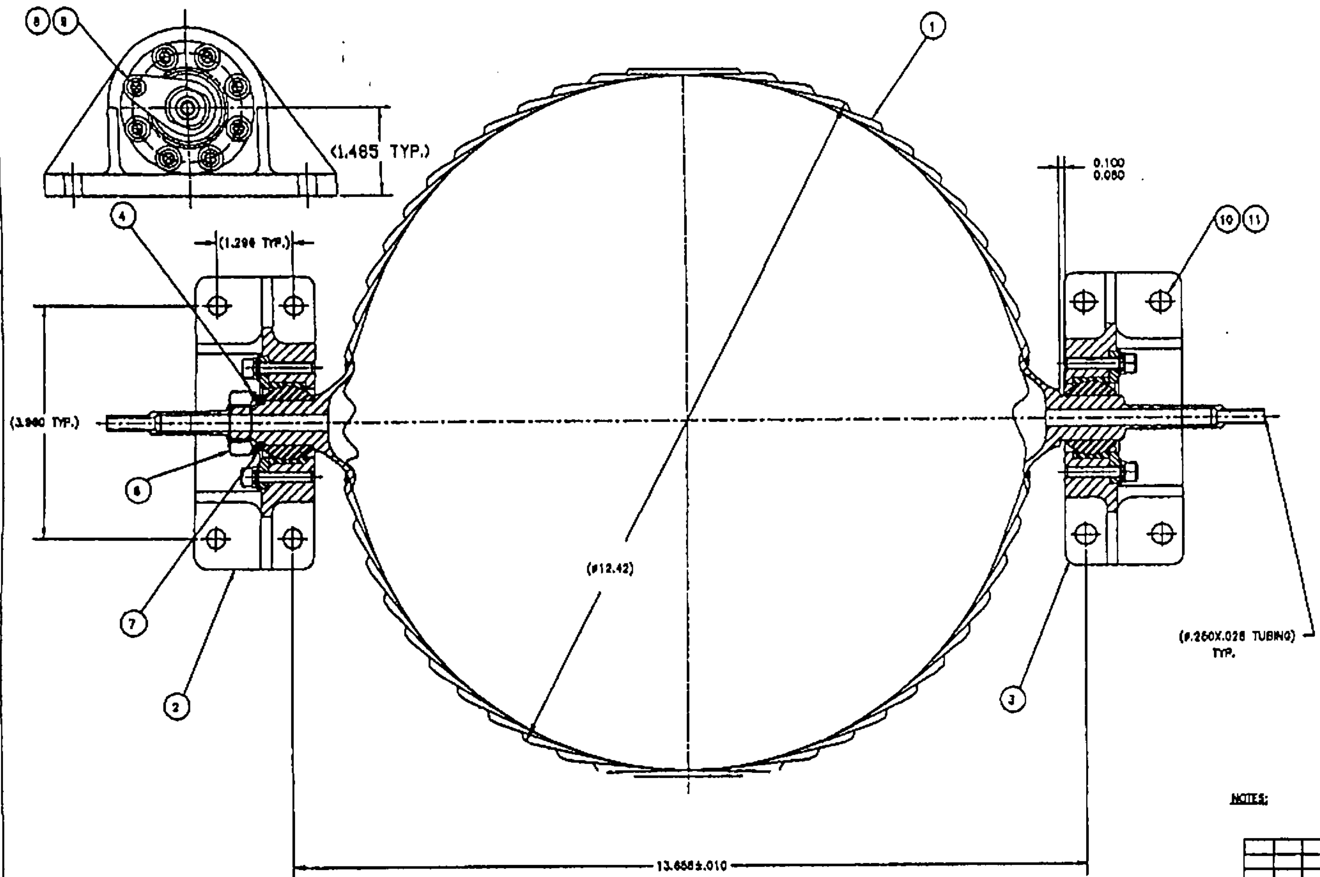
TITLE: SPHERE, CO2 STORAGE FILAMENT WOUND

SIZE D | CAGE CODE 05980 | D4816

SCALE 1/2 | SHEET 1 OF 1

NEXT ASSEMBLY D4818

DRAWN BY AVE



NOTES:

4. INSTALLATION PROCEDURE:

a) ASSEMBLE ITEMS 1(TANK), 2(BRACKET, FIXED END ASS'Y.), 4(THRUST WASHER), 6(JAM NUT), & 7(ANTI-ROTATIONAL WASHER) AS SHOWN. DO NOT TIGHTEN ITEM 6(JAM NUT).

b) ASSEMBLE ITEMS 1(TANK) AND 3(BRACKET, SLIDING END ASS'Y.) AS SHOWN IN THE OPPOSITE END.

c) INSTALL THE ABOVE ASSEMBLY TO THE SPACECRAFT STRUCTURE. THE TANK ASSEMBLY IS NOW SUPPORTED BY THE TWO BRACKETS RESTING ON THE SPACECRAFT STRUCTURE.

d) FASTEN THE FIXED END BRACKET TO THE SPACECRAFT STRUCTURE INTERFACE WITH ITEMS 10(LOCK WASHERS) & 11(⌀.312 SCREWS). DO NOT TIGHTEN SCREWS.

e) CHECK IF THE SLIDING END BRACKET ASSY. CAN SLIDE FREELY BEFORE FASTENING IT TO THE SPACECRAFT STRUCTURE INTERFACE WITH ITEMS 10(LOCK WASHERS) & 11(⌀.312 SCREWS). DO NOT TIGHTEN SCREWS.

f) APPLY 300 TO 325 IN-LB OF TORQUE TO THE ⌀.312 SCREWS AT THE FIXED END BRACKET.

g) APPLY 50 TO 60 FT-LB OF TORQUE TO ITEM 6(JAM NUT). DO NOT REACT THE TORQUE WITH THE FIXED END BRACKET. THE TANK SHOULD BE RESTRAINED MANUALLY, OR WITH A STRAP AT THE GIRTH DURING TORQUING OF THE JAM NUT. LOCKWIRE NUT TO BRACKET USING HOLES PROVIDED.

h) CHECK IF THE SLIDING END BRACKET ASS'Y. CAN SLIDE FREELY. WITH THE FIXED END BOSS SHOULDER BUTT AGAINST THE BEARING, MAINTAIN A .080/.100 GAP BETWEEN THE TANK SHOULDER AND THE INNER BEARING RACE AT THE SLIDING END. APPLY 300 TO 325 IN-LB TORQUE TO THE ⌀.312 SCREWS AT THE SLIDING END BRACKET. THE GAP IS DETERMINED BY:
   1) MEASURE THE DISTANCE OF THE INNER BEARING FACE TO THE FRONT FACE OF THE SLIDING END BRACKET ASSEMBLY, C4848.
   2) MEASURE THE GAP OF THE FRONT FACE OF THE BRACKET END ASSEMBLY TO THE SHOULDER FACE OF THE BLIND END BOSS.
   3) THE TOTAL GAP OF 1) AND 2) SHOULD BE 0.080 TO 0.100.

i) THE TANK SHOULD BE ABLE TO PARTIALLY SPIN WITH LEAST RESISTANCE. MAKE NECESSARY ADJUSTMENT TO THE BRACKET MOUNTING AS REQUIRED.

j) INSTALL ITEMS 8(#10 LOCK WASHER) & 9(#10 SCREW) AS SHOWN WITH 40 TO 45 IN-LB OF TORQUE.

2. DESIGN PARAMETERS:
   MEOP: 3200 PSIG
   PROOF: 4800 PSIG
   WEIGHT:
   TANK: 4.31 KG MAX. (9.50 LB. MAX.)
   2 BRACKETS: 0.77 KG MAX. (1.70 LB MAX.)
   2 BEARINGS: 0.22 KG MAX. (0.48 LB MAX.)
   NUTS, BOLTS, ETC.: 0.36 KG MAX. (0.80 LB MAX.)
   TOTAL: 5.66 KG MAX. (12.48 LB MAX.)
   VOLUME: 813 CU. IN. (UNPRESSURIZED)

1. SERVICE - CO2 FLUID.

QTY REQD PER DASH NO.				ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			8	11		NAS1351N5-16H	SCREW, SOCKET HEAD, [illegible]	A286	
			8	10		91812A230	WASHER, LOCK ⌀.312	CRES 316	
			1	9		NAS1351N3-16H	SCREW, SOCKET HEAD, #10X1.0	A286	
			1	8		91812A227	WASHER, LOCK, #10	CRES 316	
			1	7		B105576	WASHER, ANTI-ROTATIONAL		
			1	6		MS9362-16	NUT, HEX	A286	⌀.625-18 UNF
				5					
			1	4		B105577	WASHER, THRUST		
			1	3		C4848	BRACKET, SLIDING END, ASSY		
			1	2		C4847	BRACKET, FIXED END, ASSY		
			1	1		D4818	SPHERE, CO2 STORAGE		

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

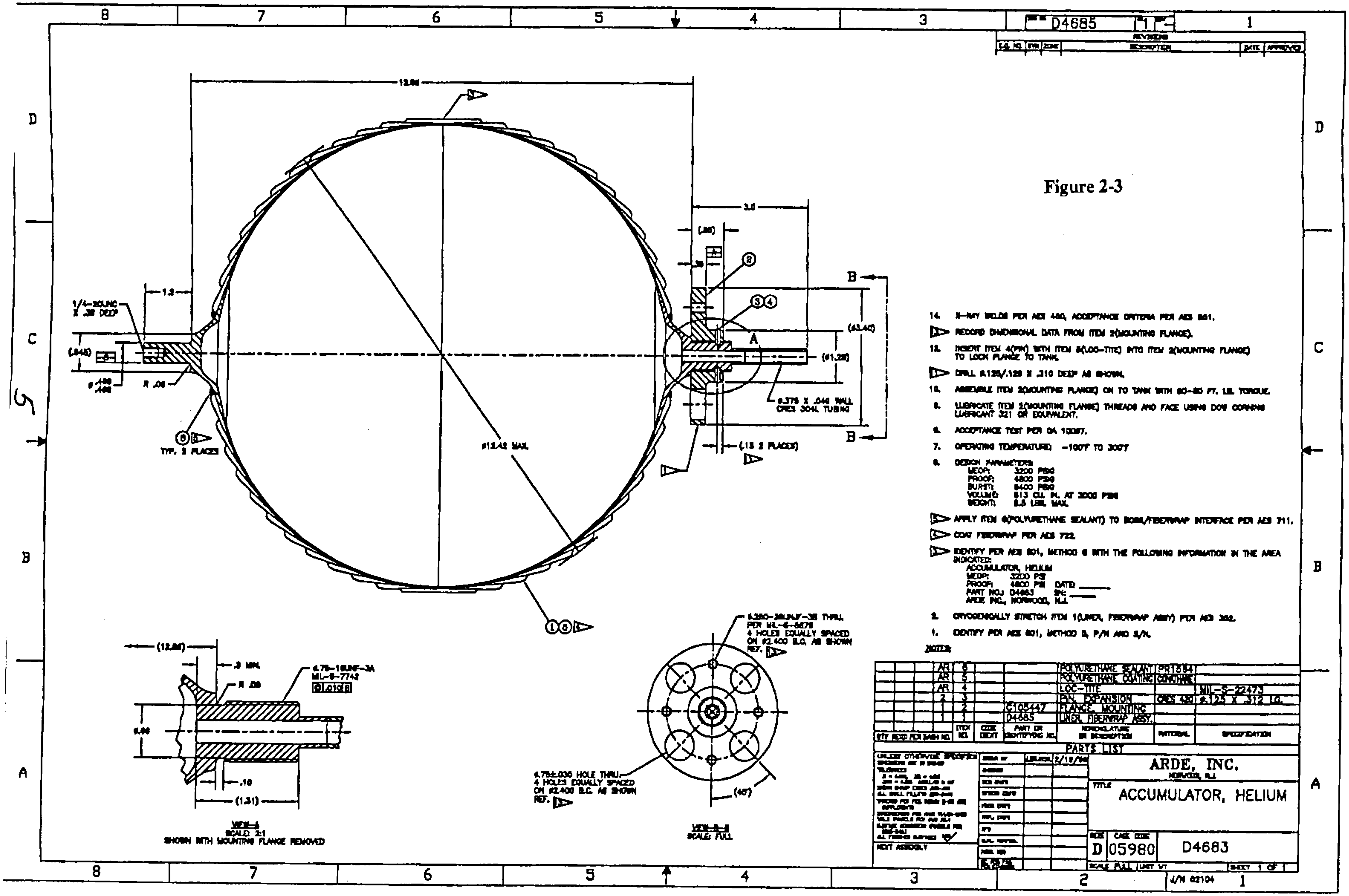
DRAWN BY N.A.A. 8/20/01

ARDE, INC.
NORWOOD, N.J.

TITLE
CO2 TANK MOUNTING ASSEMBLY

SIZE D | CAGE CODE 05980 | D4818
SCALE FULL | SHEET 1 OF 1
J/N 39001

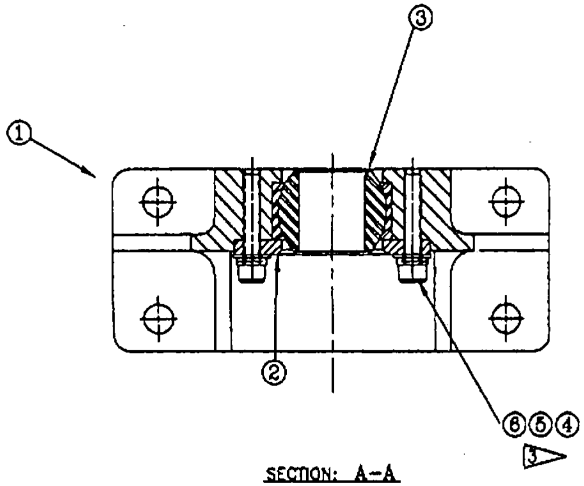
Figure 2-2



D4685
REVISIONS
12.86
3.0
(.86)
.38
B
(43.40)
(Ø1.28)
A
1.2
1/4-20UNC X .38 DEEP
(.845)
Ø .498 .496
R .06
TYP. 2 PLACES
Ø12.42 MAX.
Ø.375 X .049 WALL CRES 304L TUBING
(.13 2 PLACES)
(12.86)
.3 MIN.
R .06
0.75-16UNF-3A MIL-S-7742
.18
(1.31)
VIEW-A SCALE: 2:1 SHOWN WITH MOUNTING FLANGE REMOVED
0.250-28UNJF-3B THRU PER MIL-S-8879 4 HOLES EQUALLY SPACED ON Ø2.400 B.C. AS SHOWN REF.
Ø.75±.030 HOLE THRU 4 HOLES EQUALLY SPACED ON Ø2.400 B.C. AS SHOWN REF.
(45°)
VIEW-B-B SCALE: FULL
14. X-RAY WELDS PER AES 480, ACCEPTANCE CRITERIA PER AES 861.
RECORD DIMENSIONAL DATA FROM ITEM 2(MOUNTING FLANGE).
12. INSERT ITEM 4(PIN) WITH ITEM 5(LOC-TITE) INTO ITEM 2(MOUNTING FLANGE) TO LOCK FLANGE TO TANK.
DRILL Ø.125/.128 X .310 DEEP AS SHOWN.
10. ASSEMBLE ITEM 2(MOUNTING FLANGE) ON TO TANK WITH 80-90 FT. LB. TORQUE.
9. LUBRICATE ITEM 2(MOUNTING FLANGE) THREADS AND FACE USING DOW CORNING LUBRICANT 321 OR EQUIVALENT.
8. ACCEPTANCE TEST PER OA 10097.
7. OPERATING TEMPERATURE: -100°F TO 300°F
6. DESIGN PARAMETERS: MEOP: 3200 PSIG PROOF: 4800 PSIG BURST: 8400 PSIG VOLUME: 813 CU. IN. AT 3000 PSIG WEIGHT: 8.5 LBS. MAX.
APPLY ITEM 6(POLYURETHANE SEALANT) TO BOSS/FIBERWRAP INTERFACE PER AES 711.
COAT FIBERWRAP PER AES 722.
IDENTIFY PER AES 801, METHOD 6 WITH THE FOLLOWING INFORMATION IN THE AREA INDICATED: ACCUMULATOR, HELIUM MEOP: 3200 PSI PROOF: 4800 PSI DATE: PART NO.: D4683 SN: ARDE INC., NORWOOD, N.J.
2. CRYOGENICALLY STRETCH ITEM 1(LINER, FIBERWRAP ASSY) PER AES 382.
1. IDENTIFY PER AES 801, METHOD D, P/N AND S/N.
NOTES:
AR 6 POLYURETHANE SEALANT PR1564
AR 5 POLYURETHANE COATING CONATHANE
AR 4 LOC-TITE MIL-S-22473
2 3 PIN, EXPANSION CRES 420 Ø.125 X .312 LG.
1 2 C105447 FLANGE, MOUNTING
1 1 D4685 LINER, FIBERWRAP ASSY.
QTY REQD PER DASH NO. ITEM NO. CODE IDENT PART OR IDENTIFYING NO. NOMENCLATURE OR DESCRIPTION MATERIAL SPECIFICATION
PARTS LIST
ARDE, INC. NORWOOD, N.J.
TITLE ACCUMULATOR, HELIUM
SIZE D CAGE CODE 05980 D4683
SCALE FULL SHEET 1 OF 1
J/N 02104

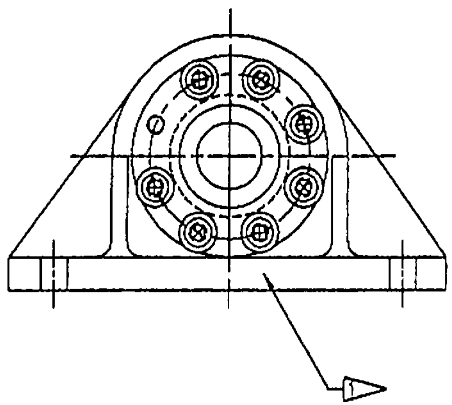
Figure 2-3

REVISIONS				
E.O. NO.	ZONE	DESCRIPTION	DATE	APPROVED



SECTION: A-A

Figure 2-4



NOTES:

6. NYLON BAG, PURGE WITH NITROGEN, SEAL ASSEMBLY.
5. CLEAN ASSEMBLY PER SN-C-0005, VISIBLY CLEAN LEVEL 2.
4. ITEMS #4 & #5 (WASHERS) SHALL BE PASSIVATED PER AES 254 PRIOR TO ASSEMBLY.
3. APPLY TORQUE AT 35-40 IN.-LB. TO THE SCREWS AT 180° CLOCKING SEQUENCE.
2. PRESS FIT BEARING INTO BRACKET BORE.
1. IDENTIFY PER AES 601, METHOD D.

QTY REQD PER DASH NO.	ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
7	6		NAS1351N3-16H	SCREW, SOC. HD. CAP	A286	#10-32 X 1.0 LG.
7	5		91812A227	LOCK WASHER, #10	CRES 316	
7	4		90107A011	WASHER, FLAT #10	CRES 300	
1	3		WE12	BEARING	CRES	HEIM
1	2		B105574	RETAINER, BEARING		
1	1		D105572	BRACKET, SLIDING END		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
.X = ±.030, .XX = ±.010
.XXX = ±.005 ANGULAR ± 30'
BREAK SHARP EDGES .003-.015
ALL SMALL FILLETS .020-.040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS
DIMENSIONING PER ANSI Y14.5M-1982
WELD SYMBOLS PER AWS A2.4
SURFACE ROUGHNESS SYMBOLS PER ANSI-B46.1
ALL FINISHED SURFACES 125

NEXT ASSEMBLY: D4818

DRAWN BY	AVE	8/08/01
CHECKER		
DES. ENG'R		
STRESS ENG'R		
PROG. ENG'R		
MATL. ENG'R		
MFG		
QUAL. CONTROL		
PROG. MGR		

ARDE, INC.
NORWOOD, N.J.

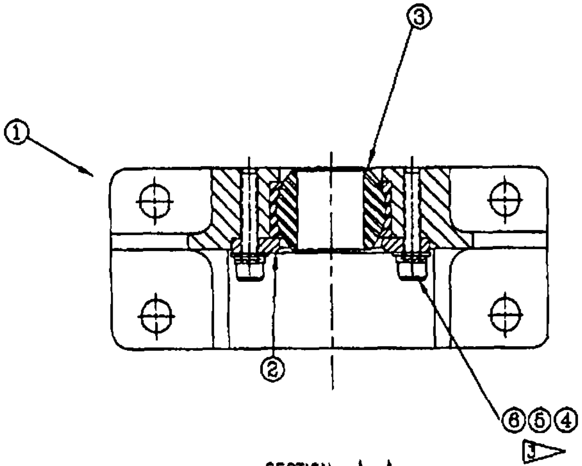
TITLE: BRACKET ASSEMBLY FIXED END

SIZE: C | CAGE CODE: 05980 | DWG NO: C4847 | REV: —

SCALE 1:1 | UNIT WT | SHEET 1 OF 1

J/N 39001

REVISIONS					
E.O. NO.	SYM	ZONE	DESCRIPTION	DATE	APPROVED



SECTION: A–A

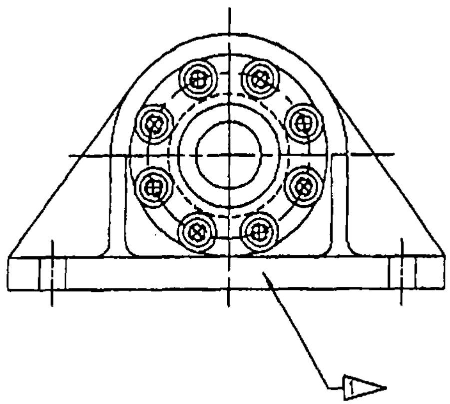


Figure 2-5

NOTES:

6. NYLON BAG, PURGE WITH NITROGEN, SEAL ASSEMBLY.
5. CLEAN ASSEMBLY PER SN-C-0005, VISIBLY CLEAN LEVEL 2.
4. ITEMS #4 & #5 (WASHERS) SHALL BE PASSIVATED PER AES 254 PRIOR TO ASSEMBLY.
3. APPLY TORQUE AT 35–40 IN.-LB. TO THE SCREWS AT 180° CLOCKING SEQUENCE.
2. PRESS FIT BEARING INTO BRACKET BORE.
1. IDENTIFY PER AES 601, METHOD D.

QTY REQD PER DASH NO.				ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			8	6		NAS1351N3-16H	SCREW, SOC. HD. CAP	A286	#10-32 X 1.0 LG.
			8	5		91812A227	LOCK WASHER, #10	CRES 316	
			8	4		90107A011	WASHER, FLAT #10	CRES 300	
			1	3		WE12	BEARING	CRES	HEIM
			1	2		B105574	RETAINER, BEARING		
			1	1		D105573	BRACKET, SLIDING END		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
.X = ±.030, .XX = ±.010
.XXX = ±.005 ANGULAR ± 30'
BREAK SHARP EDGES .003–.015
ALL SMALL FILLETS .020–.040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS
DIMENSIONING PER ANSI Y14.5M-1982
WELD SYMBOLS PER AWS A2.4
SURFACE ROUGHNESS SYMBOLS PER ANSI-B46.1)
ALL FINISHED SURFACES 125

NEXT ASSEMBLY
D4818

DRAWN BY	AVE	8/08/01
CHECKER		
DES. ENG'R		
STRESS ENG'R		
PROG. ENG'R		
MATL. ENG'R		
MFG		
QUAL. CONTROL		
PROG. MGR		

ARDE, INC.
NORWOOD, N.J.

TITLE
BRACKET ASSEMBLY
SLIDING END

SIZE	CAGE CODE	
C	05980	C4848

SCALE 1:1 | UNIT WT | SHEET 1 OF 1

DWG NO C4848 | SH 1 | REV —

J/N 39001

Table 2-1 Qualification by Similarity of PN D4816 to PN D4683

Item	PN D4816 TRD requirements	PN D4683 Qual EG 10221 (Ref. 6)	Remarks
MDP	3200 psig	3200 psig	Similar - Acceptable
Proof	4800 psig	4800 psig	Similar - Acceptable
External Leak	$1x10^{-5}$ sccs He max. @ 3200 psig	$1x10^{-7}$ sccs He max. @ 3200 psig	D4683 is stringent than D4816- Acceptable
Fluid	CO2	Helium	Acceptable - Cryoformed CRES 301 material is compatible with CO2 as demonstrated by past space station application vessel E4282 used on the CO2 portable fire extinguisher.
Internal Volume	813 cu. in. min.	813 cu. in. min.	Similar - Acceptable
Weight	9.5 lb maximum	9.5 lb. maximum	Similar - Acceptable
Cleanliness	Level 100	Level 100	Similar - Acceptable
Temperature	-100° to 150°F	-100° to 300°F	Acceptable - D4683's operating temperature condition envelopes D4816 and also note that autofrettage of both designs are performed at cryogenic temp.of -320°F and at 6500 psig.
Random Vib.	8.9 grms at .07 g^2/hz (Axial) 4.5 grms at .02 g^2/hz (Lateral)	8.9 grms at .07 g^2/hz (Axial) 4.5 grms at .02 g^2/hz (Lateral)	Similar - Acceptable
First Mode	>50 Hz	Lateral @ 250 Hz Axial @ 500 hz	Similar - Acceptable
Life Cycle	0-3200-0 psi -100 cycles	0-3200-0 psi - 250 cycles	D4683 life cycle requirement is greater than D4816 - Acceptable
Leak Test	$1x10^{-5}$ sccs He max. @ 3200 psig	$1x10^{-7}$ sccs He max. @ 3200 psig	D4683 is stringent than D4816- Acceptable
Burst	6400 psig min.	6400 psig . min. Ruptured @ 7600 psi	Acceptable

External Load/Dynamic Excitation Evaluation

The D4683 vessel was vibration tested in three axes, while pressurized with helium at 3200 psid. Evaluation of vibration response data from the formal D4683 qualification testing shows that load inputs measured at the tank response accelerometer are greater than the Liftoff and Load Factors for MS-02 Components, assuming that the TRD gas system uses the vessel with 18 lbm of CO_2. The D4683 was formally qualified with He gas. At MDP, 3200 psid, approximately 1 lbm is contained. Used for the TRD application the vessel contains 18 lbm of CO_2. The dry mass of the tank is 9.5 lbm. Thus the load factor scale between the two vessels under acceleration loading, assuming full mass participation of the contained gas is (18 lb CO2+9.5 lb Tank+.5 lb margin)/(1+9.5)= 2.67

Axial Axis

The test setup is illustrated in figure 2-6. The response accelerometer is mounted at the top of the tank. Inline input was 8.94 g_{rms} inline at the fixed end as shown by figure 2-7. Inline tank response was 24 g's at the 1 sigma level (72 g's peak in line response.) This translates to a peak response of 26.9 g's This is shown in figure 2-8. The use of a response accelerometer can be non-conservative in assessing the energy transmission into a vessel if there is evidence of significant contribution of higher order response modes within the response accelerometer response. In this case there is not evidence of these higher order modes. The response consists of rigid body and first mode resonance response at just over 850 hz. Thus in the axial axis there is evidence that TRD loads have been enveloped by the prior D4683 testing with helium gas. Additionally, the vibration testing was run for 15 minutes in this axis. The lo[illegible]iscussed were applied for a significant number of application cycles given the high natu[illegible]uency of the tank, and the extended duration of the test.

Lateral Axis

In the lateral axis the test setup was as shown in figure 2-9. The test was run under average control between C1 and C2. This is shown by figures 2-10, 2-11 and 2-12. Response under these modest input levels was 9.15 g_{rms} inline at R1, again being composed primarily of a rigid body mode and a narrow band first mode resonance at 600 hz, figure 2-13. The off axis response in the 90 opposed lateral axis was 4.3 grms, figure 2-14. Using a root sum square combination of these two lateral response provides for a

$$3 * (9.15^2 + 4.3^2)^{1/2} / 2.67 = 11.36 \text{ g}$$

peak static equivalent acceleration load for a case of 18 lbm CO_2 filled TRD vessel at R1. The rigid body and first mode response have full participation in boss loading developed at the mount points. Higher order modal response, such as shell modes attenuate and are not contributors to boss loading. The level measured at R1 is slightly above load specified for the application. However, confirmation of loading/load assumptions on this vessel by use of accelerometers is recommended during the acceptance/protoflight vibration of the TRD system. Analytically there are no issues, as the vessel is robust and reasonably insensitive to loading of the described magnitude. The limits of prior test demonstration however must not be violated in order to maintain the qualification by similarity status.

11

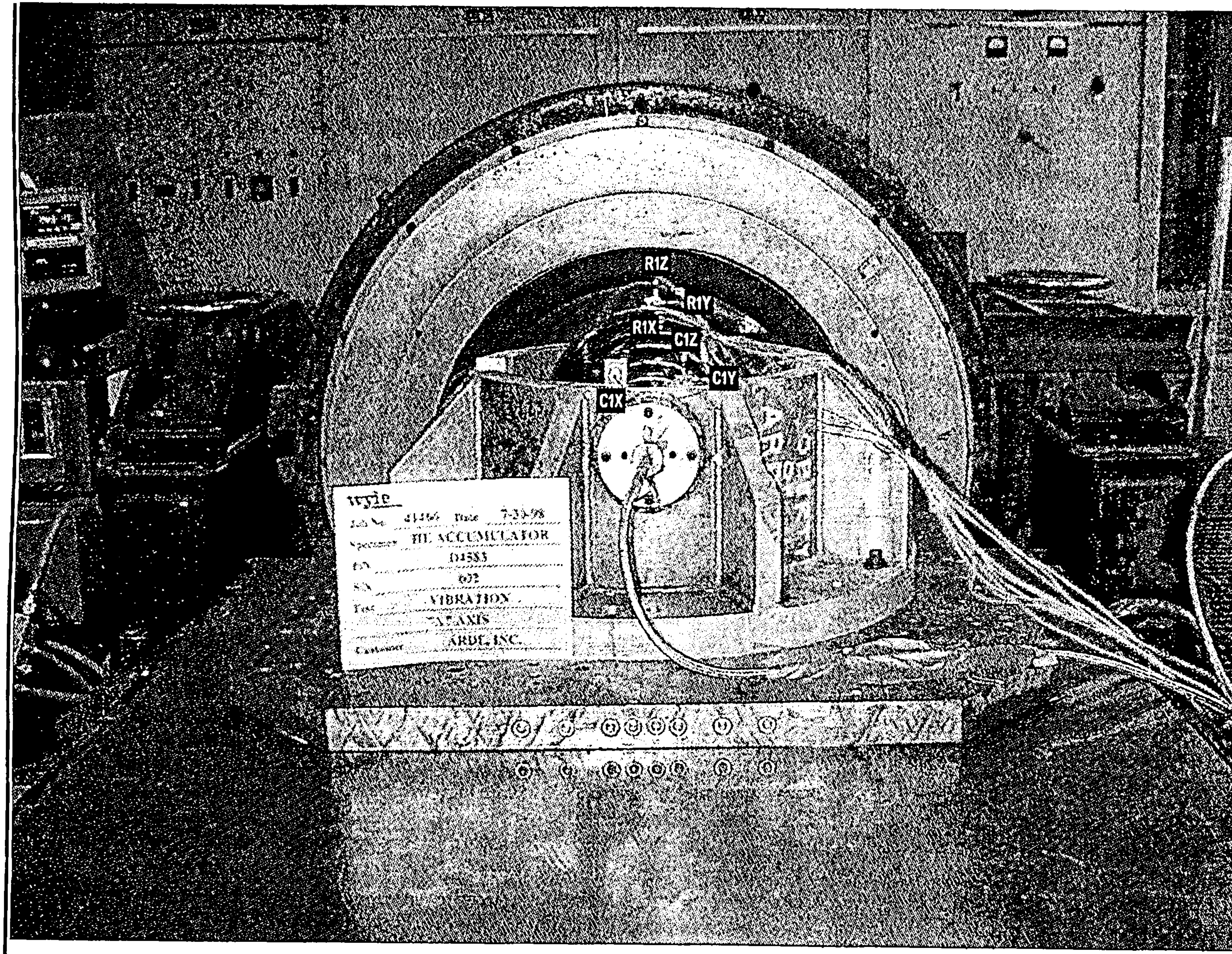


Figure 2-6

PHOTOGRAPH 1: TYPICAL X AXIS SETUP

PLOT NO. 37

JOB NO. 41466

PAGE NO. DYN.A111

wyle laboratories

Random Control Channel

Figure 2-7

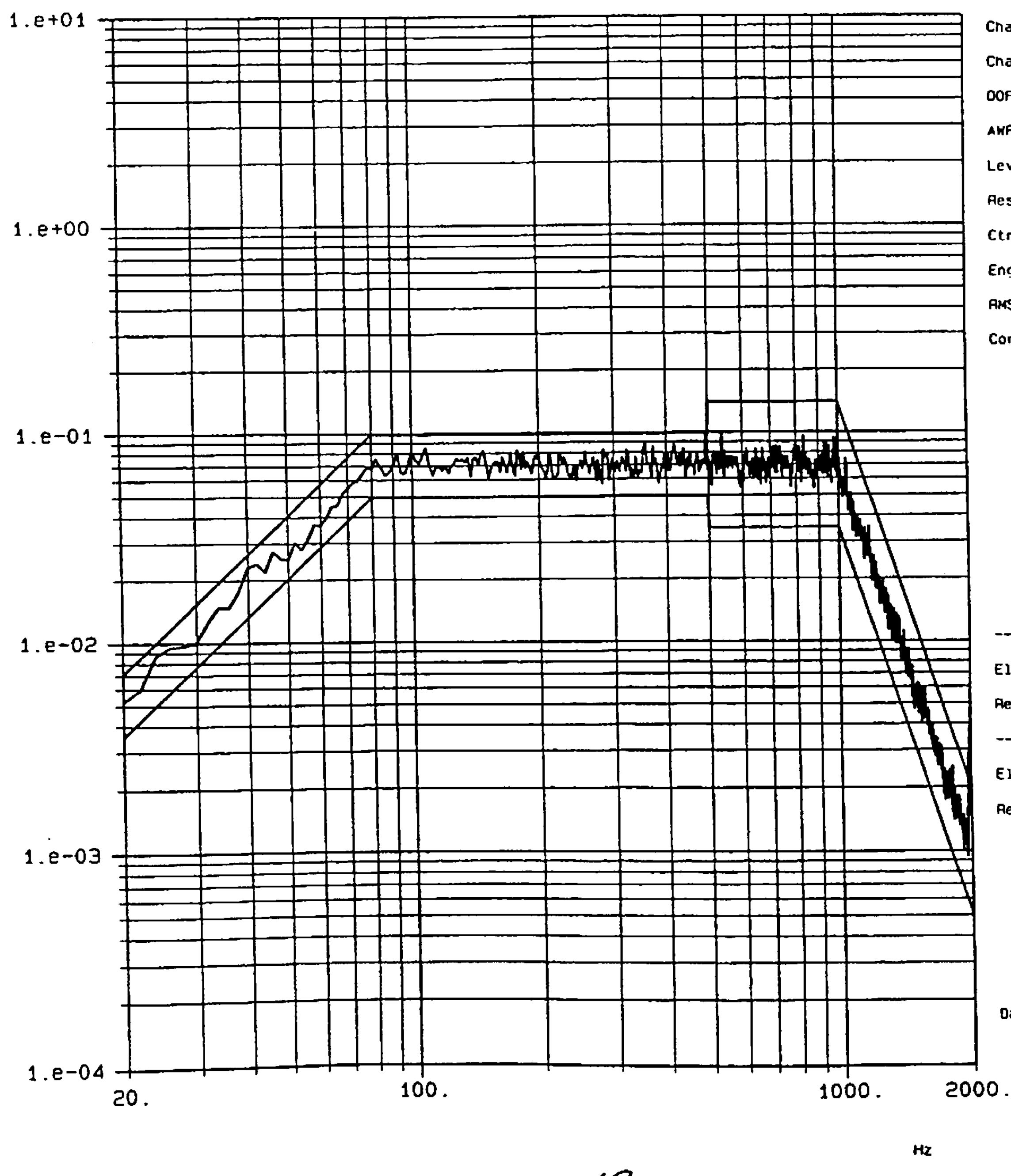
ARDE_41466_X

X AXIS QUALIFICATION RUN 3 ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA

g^2/Hz C1X HELIUM ACCUMULATOR P/N 04683 S/N 002



Chan. No. : 1
Chan. Type : C
DOF : 144
AWF : 5
Level : 0. dB
Resolution : 2. Hz
Ctrl Strat.: Average
Eng. Unit : g
RMS (act.) : 8.93997 g
Contr. Mode: Closed loop

-- Time on act. level --
Elapsed : 0:15:00
Remaining : 0:00:00
--- Time total ---
Elapsed : 0:20:31
Remaining : 0:00:00

Date : 7/30/1998
18:48:35

wyle laboratories

PLOT NO. 43

JOB NO. 41466

PAGE NO. DYN.A 117

Random Limit Channel

ARDE_41466_X

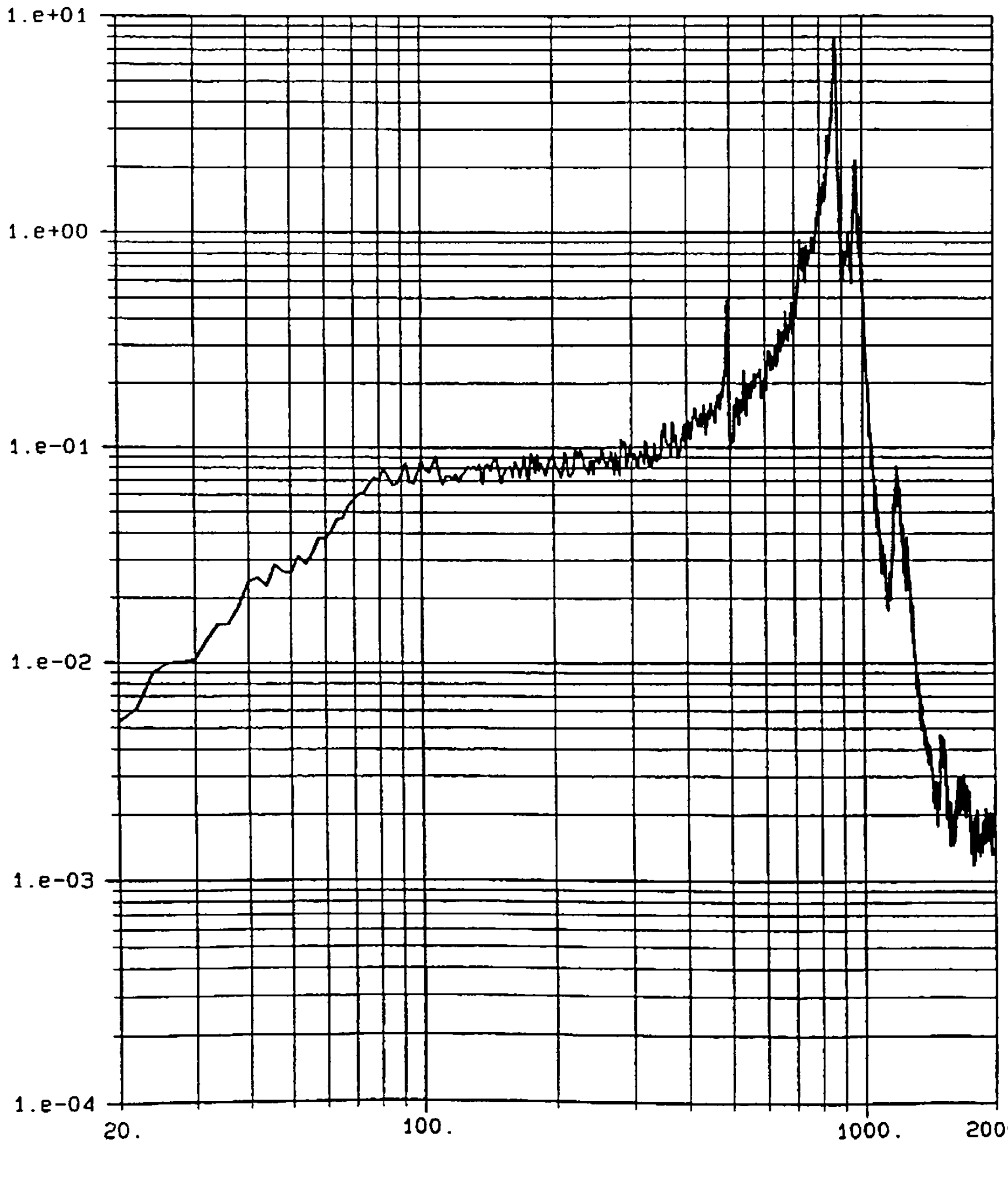
Figure 2-8

X AXIS QUALIFICATION RUN 3 ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA

g^2/Hz A1X HELIUM ACCUMULATOR P/N 04683 S/N 002



Chan. No. : 7
Chan. Type : W T
DOF : 144
AWF : 5
Level : 0. dB
Resolution : 2. Hz
Ctrl Strat.: Average
Eng. Unit : g
RMS (act.) : 24.0068 g
Contr. Mode: Closed loop

-- Time on act. level --
Elapsed : 0:15:00
Remaining : 0:00:00
--- Time total ---
Elapsed : 0:20:31
Remaining : 0:00:00

Date : 7/30/1998
18:48:35

ARDE Incorporated

P.O. NO. 0049158

14

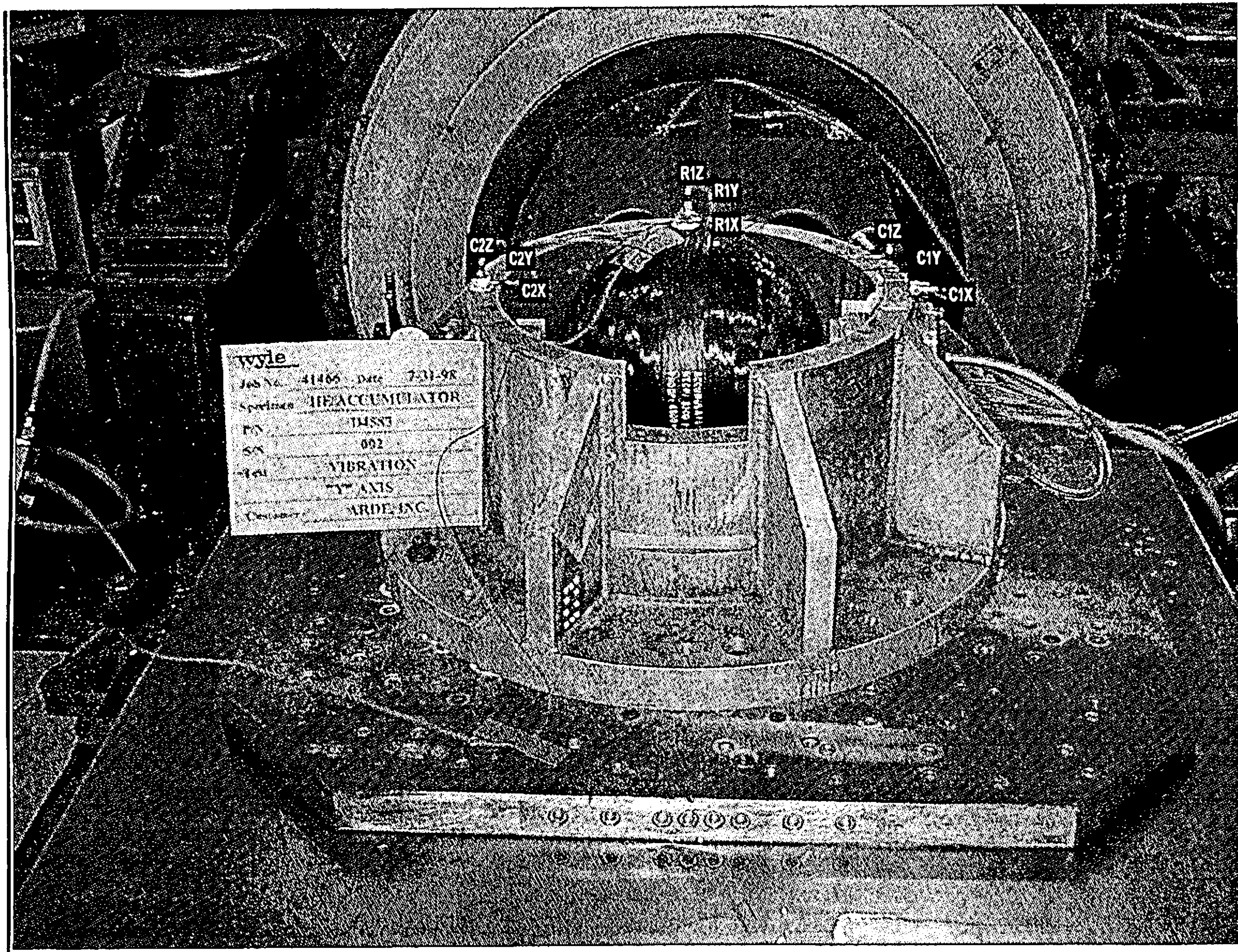


Figure 2-9

PHOTOGRAPH 3: TYPICAL Y AXIS SETUP

PLOT NO. 127

JOB NO. 41466

PAGE NO. DYN.A201

wyle laboratories

Random Control

Figure 2-10

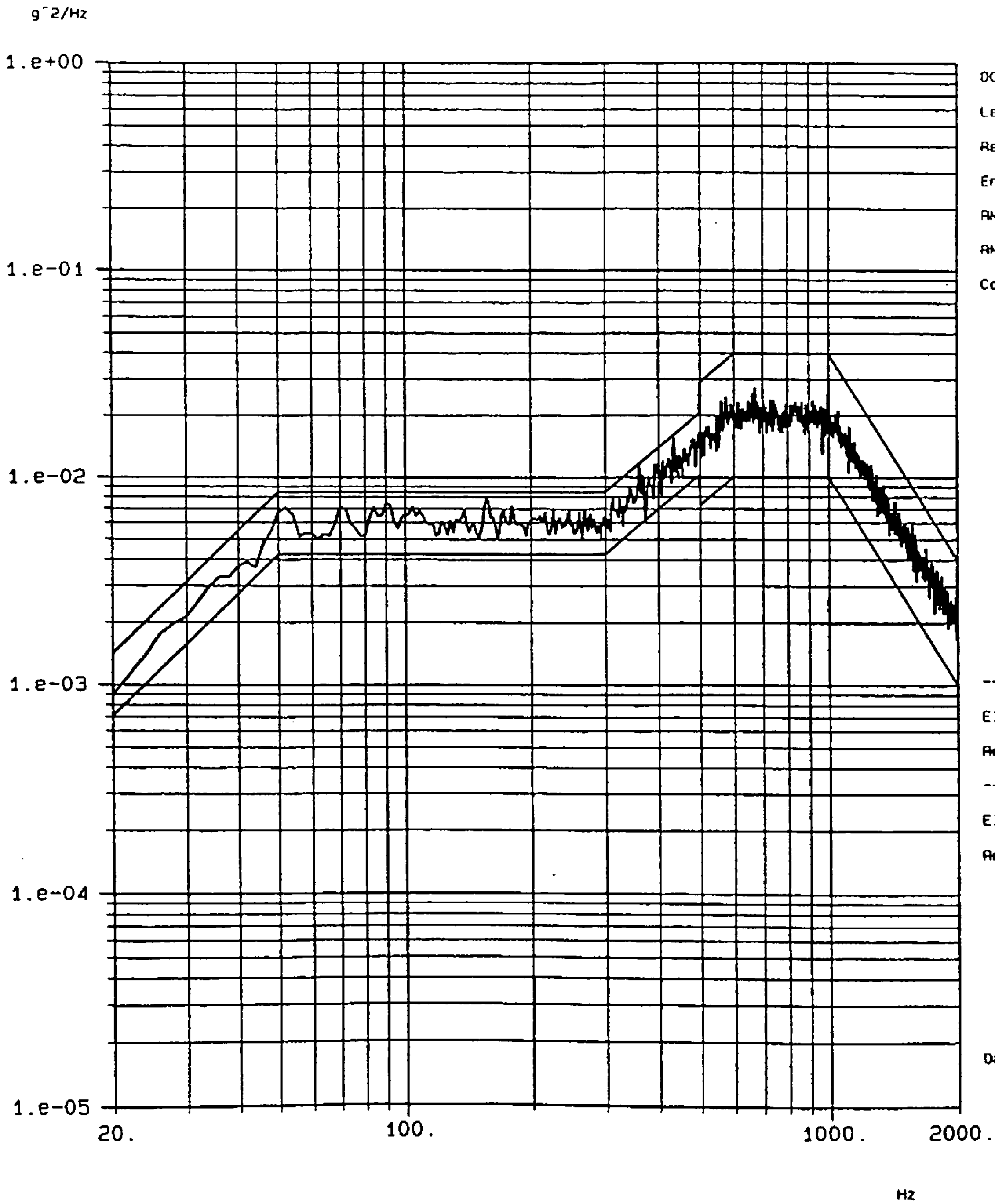
ARDE_41466_Z

Z AXIS QUALIFICATION RUN 1 ARDE, INC. J/N 41466

AVERAGE OF C1Z AND C2Z

Wyle Laboratories

El Segundo, CA



DOF : 288

Level : 0. dB

Resolution : 2. Hz

Eng. Unit : g

RMS (act.) : 4.49819 g

RMS (ref.) : 4.49615 g

Contr. Mode: Closed loop

-- Time on act. level --

Elapsed : 0:15:00

Remaining : 0:00:00

--- Time total ---

Elapsed : 0:20:30

Remaining : 0:00:00

Date : 7/31/1998

17:28:58

PLOT NO. 129

JOB NO. 41466

PAGE NO. DYN.A.203

wyle laboratories

Random   Control Channel

ARDE_41466_Z

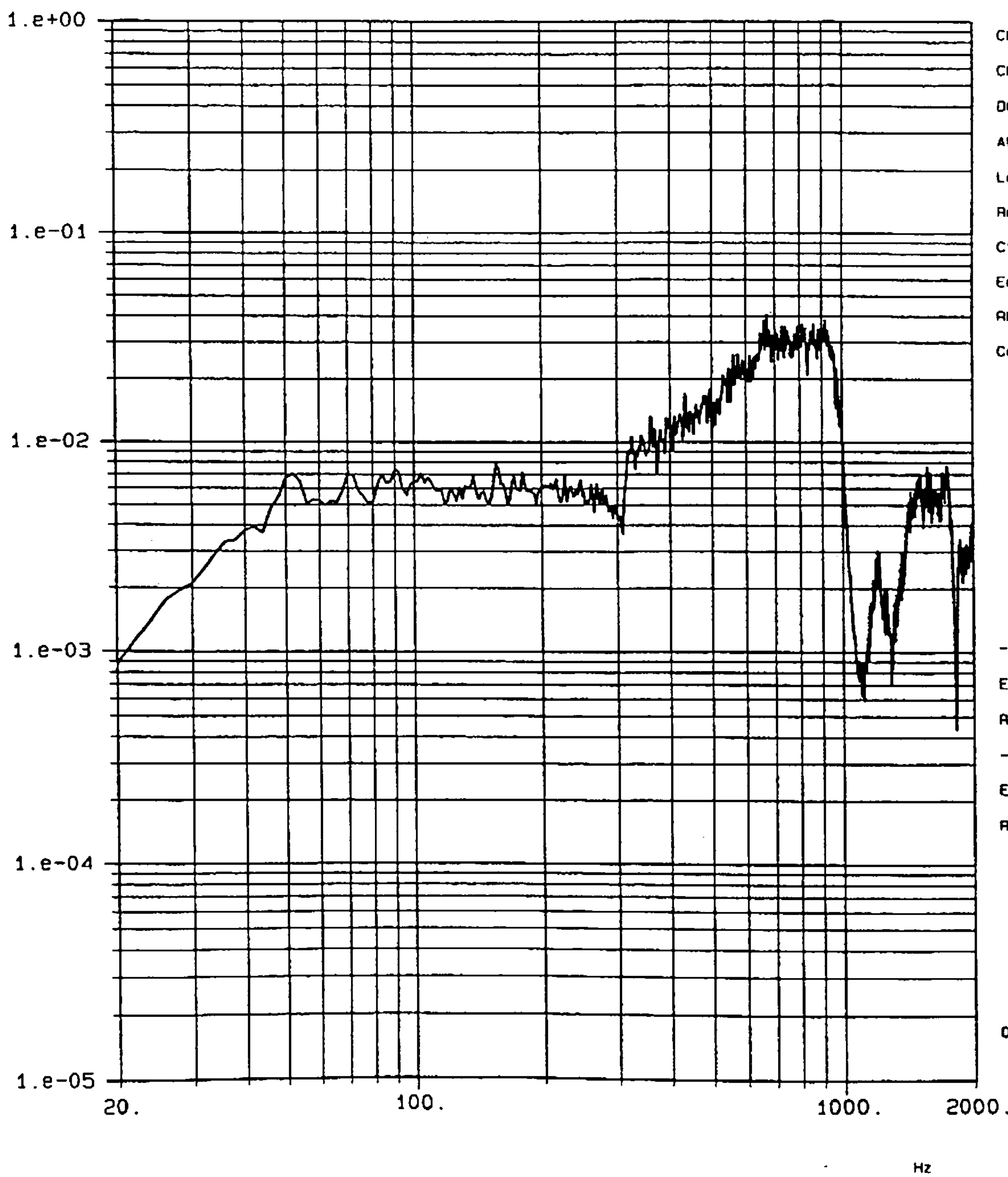
Figure 2-11

Z AXIS QUALIFICATION RUN 1   ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA

g^2/Hz C1Z HELIUM ACCUMULATOR P/N 04683 S/N 002



Chan. No. : 2
Chan. Type : C
DOF : 144
AWF : 5
Level : 0. dB
Resolution : 2. Hz
Ctrl Strat.: Average
Eng. Unit : g
RMS (act.) : 4.51004 g
Contr. Mode: Closed loop

-- Time on act. level --
Elapsed : 0:15:00
Remaining : 0:00:00
--- Time total ---
Elapsed : 0:20:30
Remaining : 0:00:00

Date : 7/31/1998
17:28:58

PLOT NO. 132

JOB NO. 41466

PAGE NO. DYN.A206

wyle laboratories

Random Control Channel

Figure 2-12

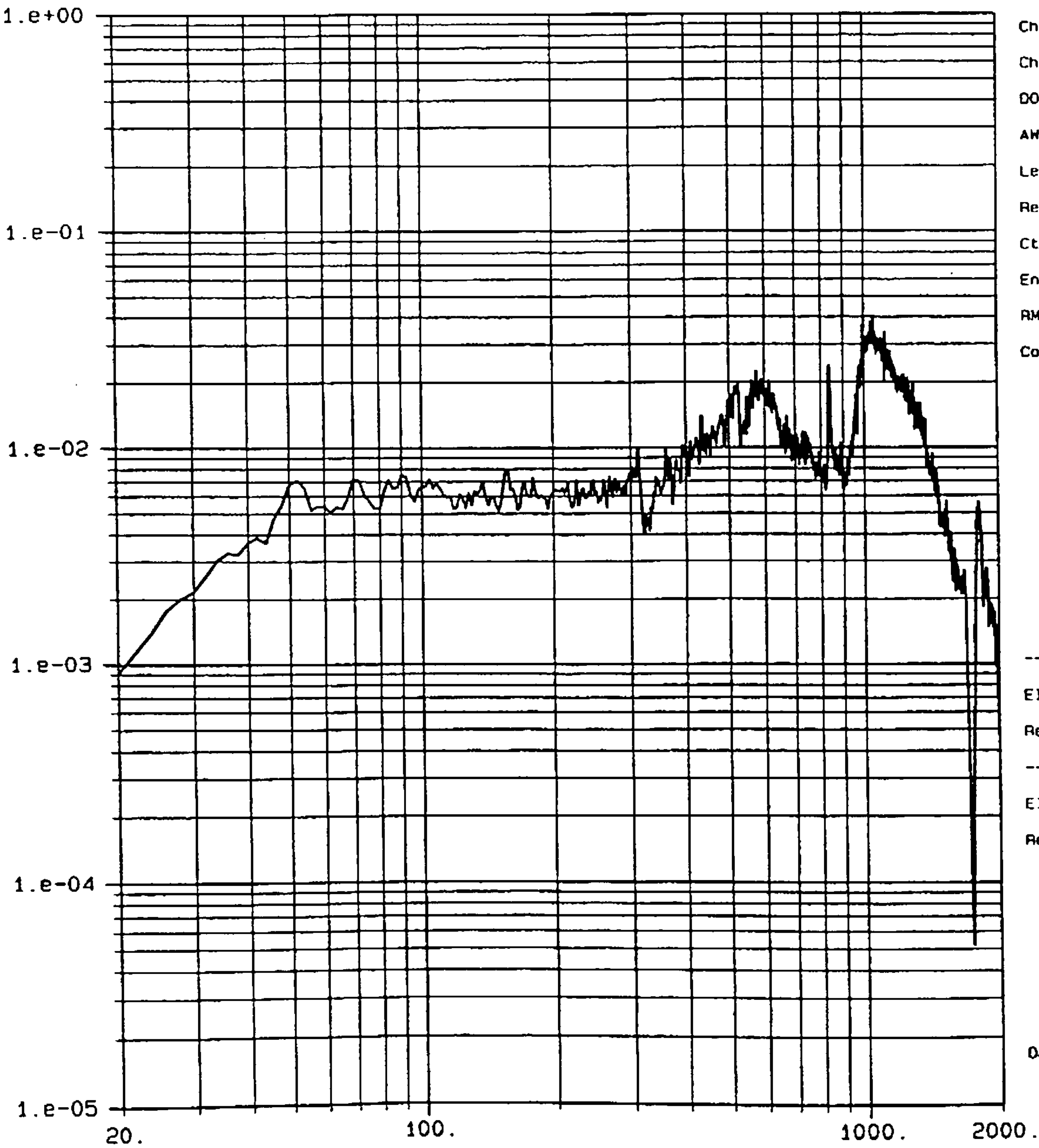
ARDE_41466_Z

Z AXIS QUALIFICATION RUN 1 ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA

g^2/Hz C2Z HELIUM ACCUMULATOR P/N 04683 S/N 002



Chan. No. : 14
Chan. Type : C
DOF : 144
AWF : 5
Level : 0. dB
Resolution : 2. Hz
Ctrl Strat.: Average
Eng. Unit : g
RMS (act.) : 4.48631 g
Contr. Mode: Closed loop

-- Time on act. level --
Elapsed : 0: 15: 00
Remaining : 0: 00: 00
--- Time total ---
Elapsed : 0: 20: 30
Remaining : 0: 00: 00

Date : 7/31/1998
17: 28: 58

Hz

wyle laboratories

PLOT NO. 136

JOB NO. 41466

PAGE NO. DYN.A210

Random Limit Channel

Figure 2-13

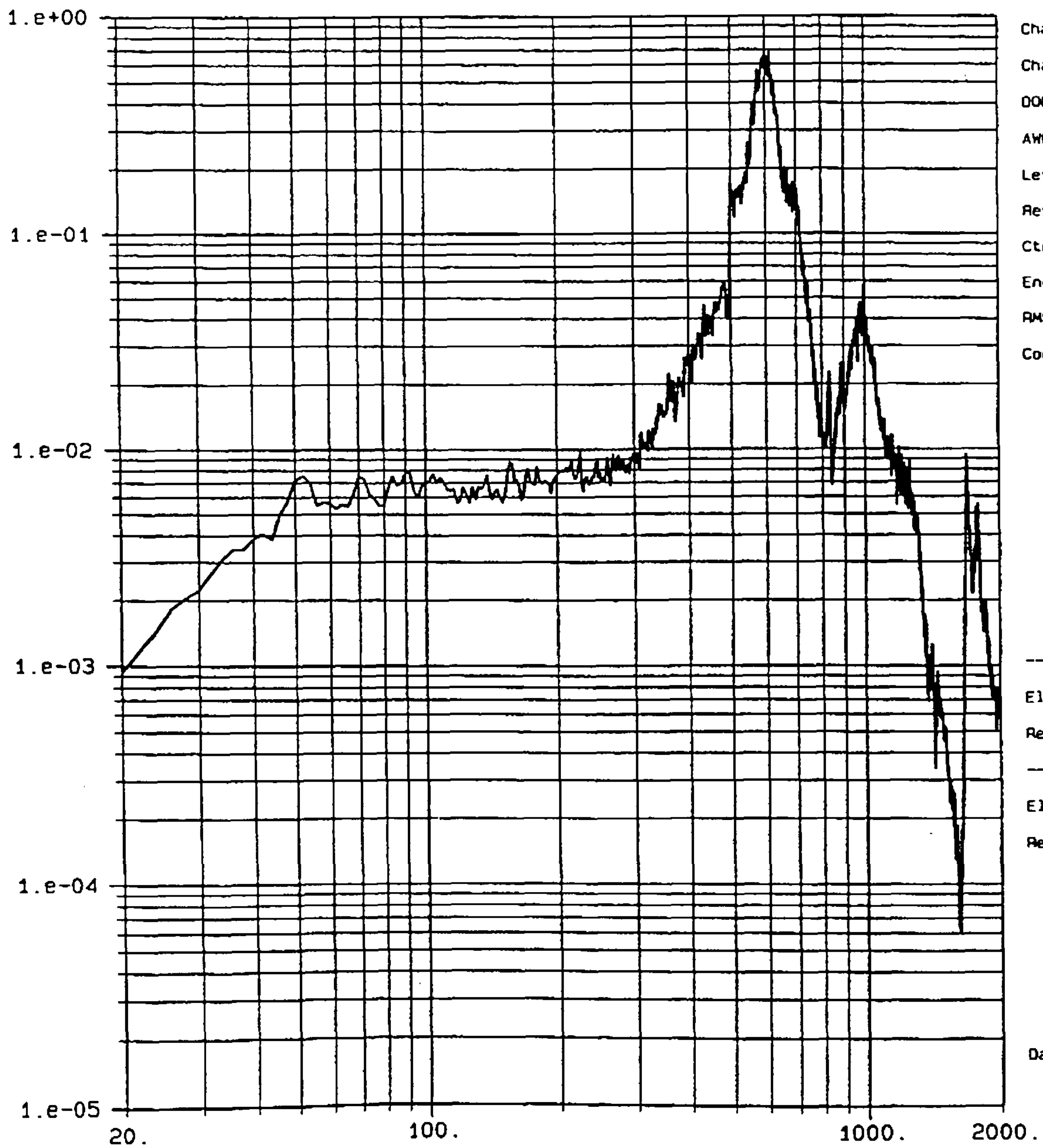
ARDE_41466_Z

Z AXIS QUALIFICATION RUN 1 ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA

g^2/Hz A1Z HELIUM ACCUMULATOR P/N D4683 S/N 002



Hz

Chan. No. : 9

Chan. Type : W T

DOF : 144

AWF : 5

Level : 0. dB

Resolution : 2. Hz

Ctrl Strat.: Average

Eng. Unit : g

RMS (act.) : 9.15455 g

Contr. Mode: Closed loop

-- Time on act. level --

Elapsed : 0: 15: 00

Remaining : 0: 00: 00

--- Time total ---

Elapsed : 0: 20: 30

Remaining : 0: 00: 00

Date : 7/31/1998

17: 28: 58

PLOT NO. 135

wyle laboratories

Figure 2-14

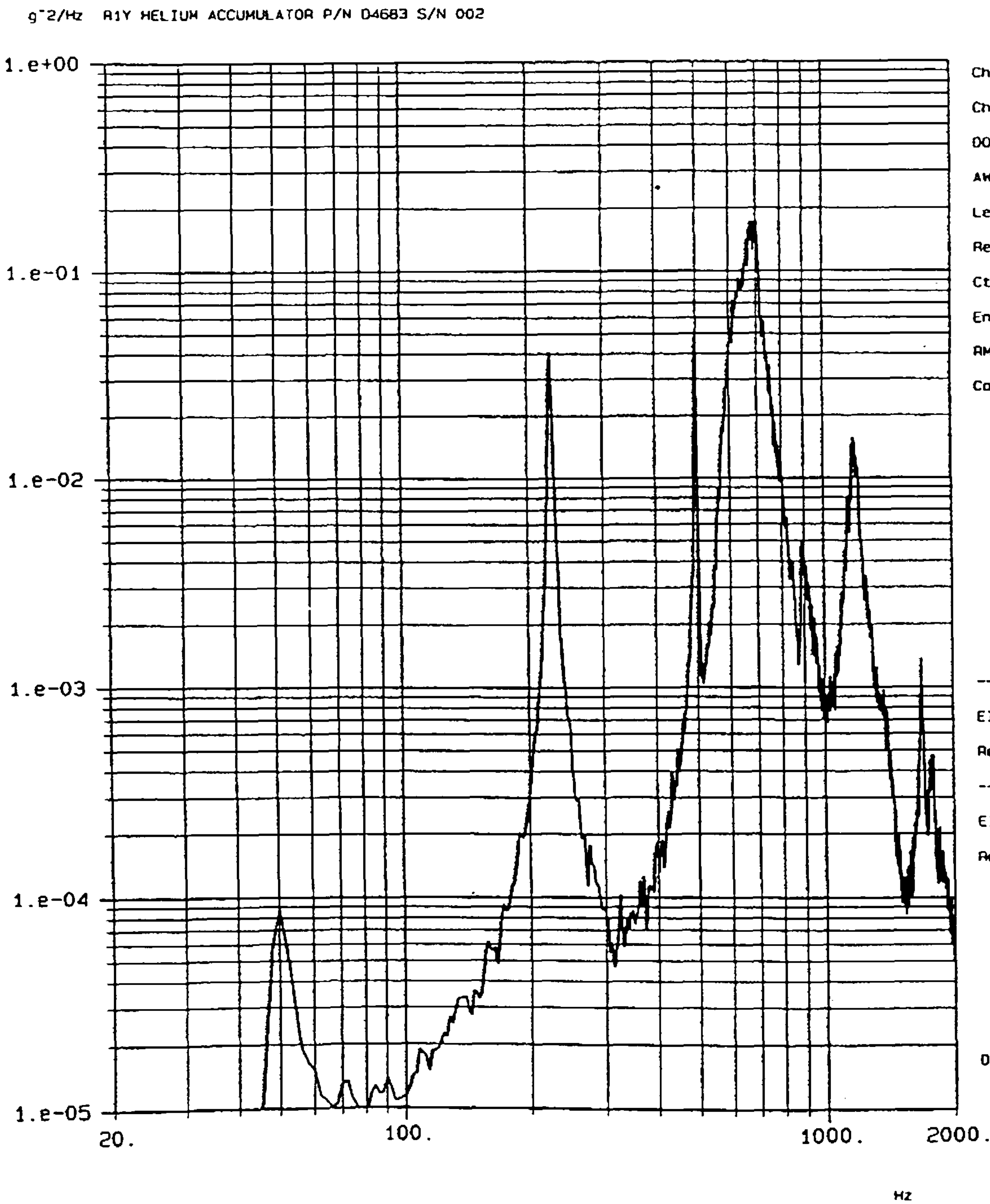
Random Limit Channel

ARDE_41466_Z

Z AXIS QUALIFICATION RUN 1 ARDE, INC. J/N 41466

Wyle Laboratories

El Segundo, CA



Chan. No. : 8
Chan. Type : M T
DOF : 144
AWF : 5
Level : 0. dB
Resolution : 2. Hz
Ctrl Strat.: Average
Eng. Unit : g
RMS (act.) : 4.29734 g
Contr. Mode: Closed loop

-- Time on act. level --
Elapsed : 0:15:00
Remaining : 0:00:00
--- Time total ---
Elapsed : 0:20:30
Remaining : 0:00:00

Date : 7/31/1998
17:28:58

3.0 RESULT

The result of evaluation indicates that PN D4816 environment are equal to or less severe than PN D4683. Vessel PN D4683 was designed as a helium storage and complied with Lockheed Martin's specification 10550300450 and MIL-STD-1522A as reported in ARDE's EG 10214. Vessel PN D4683 was tested and qualified as reported in ARDE's EG 10221. Design requirements of D4683 are equal to or greater than the D4816. By virtue of the similarity of the two designs, PN D4816 is therefore qualified by similarity to the structural and environmental conditions as specified in PM 10070.

The mounting bracket assemblies C4847 & C4848 are structurally adequate to support the D4816 C02 storage vessel for AMS 02 as shown in section 4.2.3.

4.0 EVALUATION

4.1 Fabrication and Design

The fabrication and design of PN D4816 and PN D4683 are identical with the exception of final machined boss interface details. The liner and wrap pattern are identical between the two designs. PN D4816 shares the same liner design with PN D4683 differing only in boss interface details. PN D4816 and D4683 have the same wrap pattern using Toray T-1000 carbon with EPON 9405/Curing Agent W resin system. The 7600 psid rupture value of the D4683 qual vessel provides a significant margin for the D4816.

4.1.1 Materials and Processes

The vessel liners are made of cryoformed CRES 301 of the same material specifications for all referenced applications. The hydroforming, welding, hydrostretching, solution annealing, and cryogenic stretching are performed using the same tooling. All identified operations are performed by ARDE except hydroforming which is subcontracted. Radiography and fluorescent penetrant inspections are also performed by ARDE to the preform (pre cryo liner) and postform (post cryo liner) assemblies to verify liner quality.

The composite overwrap for D4816 and D4683 are made of carbon fiber, Toray 1000, and EPON 9405/Curing Agent W resin system with the same curing cycle. F[illegible]ent winding is performed by the same vendor Composite Atlantic in Lunenburg, No[illegible]a, Canada. Cryogenic re-stretching, final machining, acceptance testing, and [illegible]leaning are performed by ARDE. The D4683 vessel was designed as a helium stora[illegible] the Lockheed Martin's X-33 program. Other qualified applications of cryoformed CRE[illegible]01 liner are as storage for CO2, Nitrogen, Air, MMH, MON3 and N204.

4.1.2 Design

4.1.2.1 Liner Design

The liner design of PN D4816 and D4683 are identical except for the boss interface. The 2 tank designs used the same hydroformed head PN C104954. The same hydrostretch die and cryostretch die are used to make the postform liner for the 2 tank designs. Therefore, all liner membrane dimensions are equivalent which result in the same liner material physical properties.

4.1.2.2 Boss Design

The final boss configurations at the final level of the two designs are shown in the blow-up figure 4-1 for D4816 and figure 4-2 for D4683. Note that the boss to boss shoulder lengths are the same for the two designs. The boss bearing diameter is equal or larger in the D4816 than the D4683. By review of the designs, the D4816 boss pressure stresses are less than the D4683 by virtue of greater cross-sectional area in the bearing diameter section. The alternating stresses due to environmental loads are the same at the boss flange sections and less for D4816 at the bearing diameter section (see section 4.2.1). The D4816 tube port is designed with a factor 4xMDP to satisfy tube interface and factor of safety requirement for lines and fittings (see section 4.2.2).

4.1.2.3 Fiberwrap Design

PN D4816 and D4683 have identical wrap pattern using Toray 1000 fiber with EPON 9405/Curing Agent W resin system. Fiber over-wrapping is performed by the same vendor Composite Atlantic in Lunenburg, Nova Scotia, Canada.

Figure 4-1 D4816 MOUNTING BOSSES

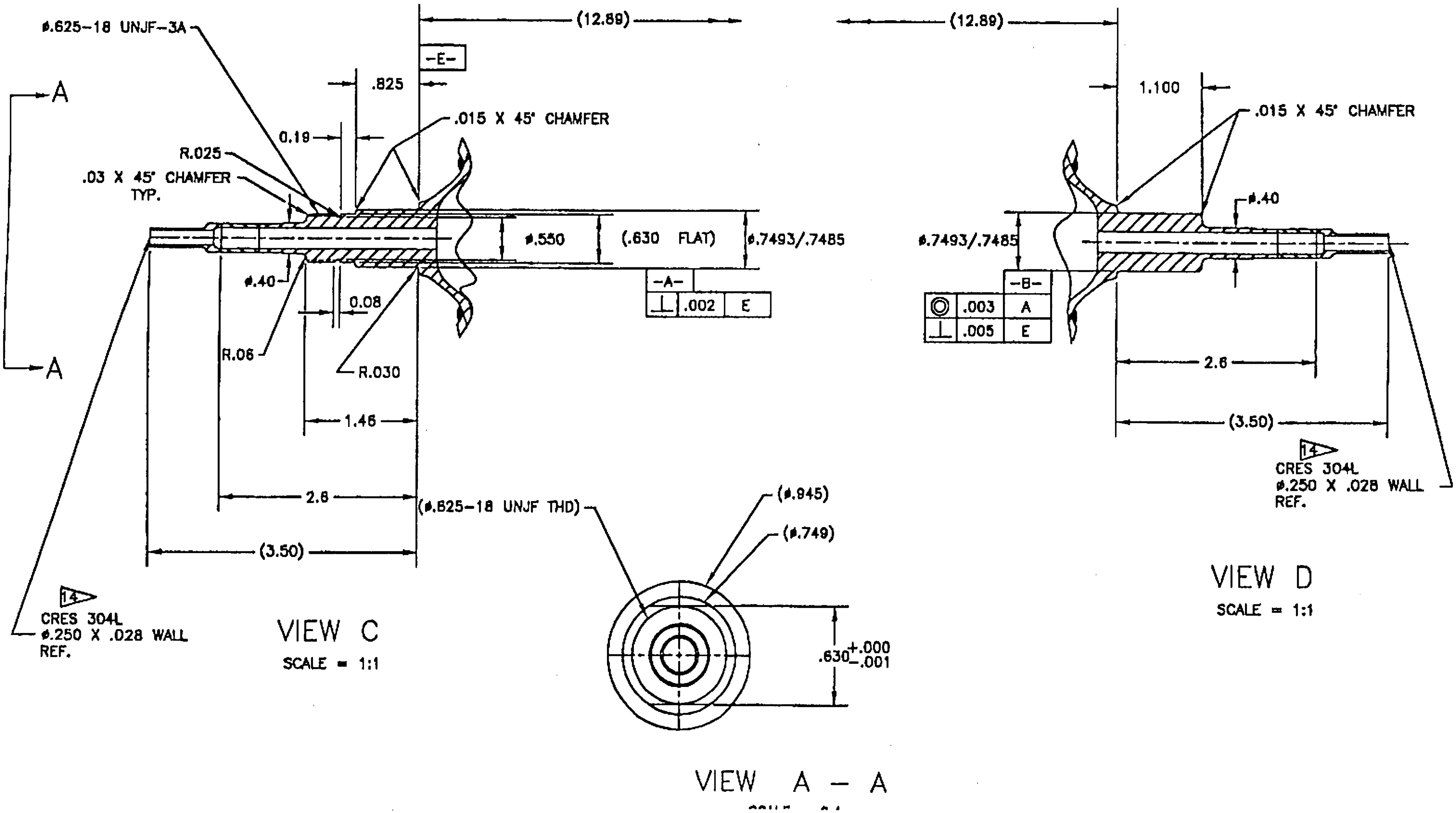
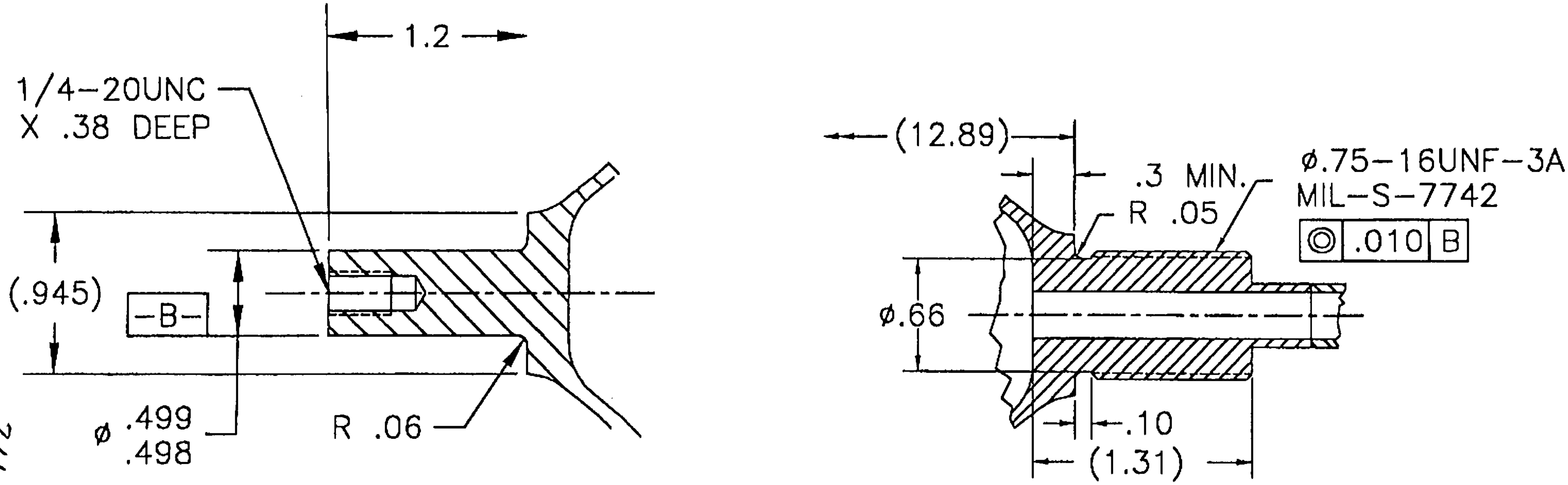


Figure 4-2 D4683 MOUNTING BOSSES



4.2 Additional Analyses

The fracture and stress analyses of D4683 is reported in EG 10214. Additional analyses to fully comply with TRD Gas Supply requirements are shown below with positive margins in all cases.

4.2.1 Boss Analysis

D4816 Bearing Cross section (figure 4-1) = $\pi/4$ (0.7485^2 - .277^2) = .3798 sq. in.

Pressure Stress, σ = p (b^2+a^2)/(b^2-a^2) where b = .37425, a = .1385

@ MDP, p = 3200 psi;

σ = 3200 (.37425^2+.1385^2)/(.37425^2-.1385^2) = 4215 psi

@ Proof, p = 1.5xMDP = 4800 psi

σ = 4800 (.37425^2+.1385^2)/(.37425^2-.1385^2) = 6323 psi

@ Burst, p = 6400 psi

σ = 6400 (.37425^2+.1385^2)/(.37425^2-.1385^2) = 8430 psi

For CRES 301, Annealed:

Allowable Yield Strength, Fty = 28 ksi

Allowable Ultimate Strength, Ftu =70 ksi

Therefore, margins of safety are:

M.S.y (at proof) = 28/6.3 - 1 = 3.44 M.S.u (at burst) = 70/8.4 - 1 = 7.4

Above margins are large, therefore boss interface is structurally adequate.

Note at the boss flange section, D4683 & D4816 are identical hence the pressure stresses plus combined with the alternating stresses due to the environmental loads are also identical.

4.2.2 Tube Analysis

Stress, $\sigma = p\,(b^2+a^2)/(b^2-a^2)$ where $b = .125$, $a = .085$

@ MDP, p = 3200 psi;

$$\sigma = 3200\,(.125^2+.085^2)/(.125^2-.085^2) = 8705 \text{ psi}$$

@ Proof, p = 1.5xMDP = 4800 psi

$$\sigma = 4800\,(.125^2+.085^2)/(.125^2-.085^2) = 13057 \text{ psi}$$

@ Burst, p = 4.0xMDP = 12800 psi

$$\sigma = 12800\,(.125^2+.085^2)/(.125^2-.085^2) = 34819 \text{ psi}$$

For CRES 304L, Annealed Tubing:

Allowable Yield Strength, Fty = 28 ksi

Allowable Ultimate Strength, Ftu = 70 ksi

Therefore, margins of safety are:

M.S.y (at proof) = 28/13.1 - 1 = 1.14

M.S.u (at burst) = 70/34.8 - 1 = 1.01

4.2.2 Mounting Bracket Analysis

Finite element analysis performed on the bracket using ABAQUS computer code showed that the bracket is structurally adequate to support the D4816 tank in the AMS 02 launch environment. Both brackets are identical in shape but only one (fixed end) supports the full axial load and the two share the lateral load. Hence, only the fixed end bracket was evaluated for the TRD CO2 gas supply system.

The bracket was analyzed with an equivalent 10g unit load of 28 lb/g (18 lb CO2 + 9.5 lb tank + .5 lb miscellaneous) in axial, lateral, and vertical directions. The unit load applied in lateral and vertical directions are half of the total load since each bracket supports half of the load. Von mises stress contour plots from each case at 10 g unit load are shown in figures 4-3, 4-4, & 4-5. At a 3 sigma peak of the random vibration spectrum, the stress responses on the bracket are:

Axial Load Stress, σ = 8.37 ksi/10 g x 8.9 grms x 3 = 25 ksi

Lateral Load Stress, σ = 1.86 ksi/10 g x 8.9 grms x

Vertical Load Stress, σ = 2.81 ksi/10 g x 8.9 gr ... ksi

With the Al 7075-T73 bracket material properties at 15(F from MIL-HDBK-5, ref. 7, at:

Fty = 54 x .96 = 52 ksi   Ftu = 65 x .92 = 60 ksi

Margins of safety at 1.1 factor for yield and 1.5 for ultimate:

Axial M.S.y = 52 / (25 x 1.1) - 1 = 0.89

M.S.u = 60 / (25 x 1.5) - 1 = 0.60

Lateral M.S.y = 52 / (5.5 x 1.1) - 1 = 7.60

M.S.u = 60 / (5.5 x 1.5) - 1 = 6.27

Vertical M.S.y = 52 / (8.3 x 1.1) - 1 = 4.69

M.S.u = 60 / (8.3 x 1.5) - 1 = 3.82

HEIM Bearing WE12 static load capacity:

Axial = 7730 lb

Lateral = 26200 lb

Margins of safety :

Axial M.S. = 7730/(28 x 8.9 grms x 3 x 1.5) - 1 = 7.89

Lateral M.S. = 26200/(28 x 8.9 grms x 3 x 1.5/2) - 1 = 45.0

Therefore the bracket mounting assembly is adequate to support the D4816 tank loaded with 18 lb of CO_2 at the TRD environmental condition.

ABAQUS

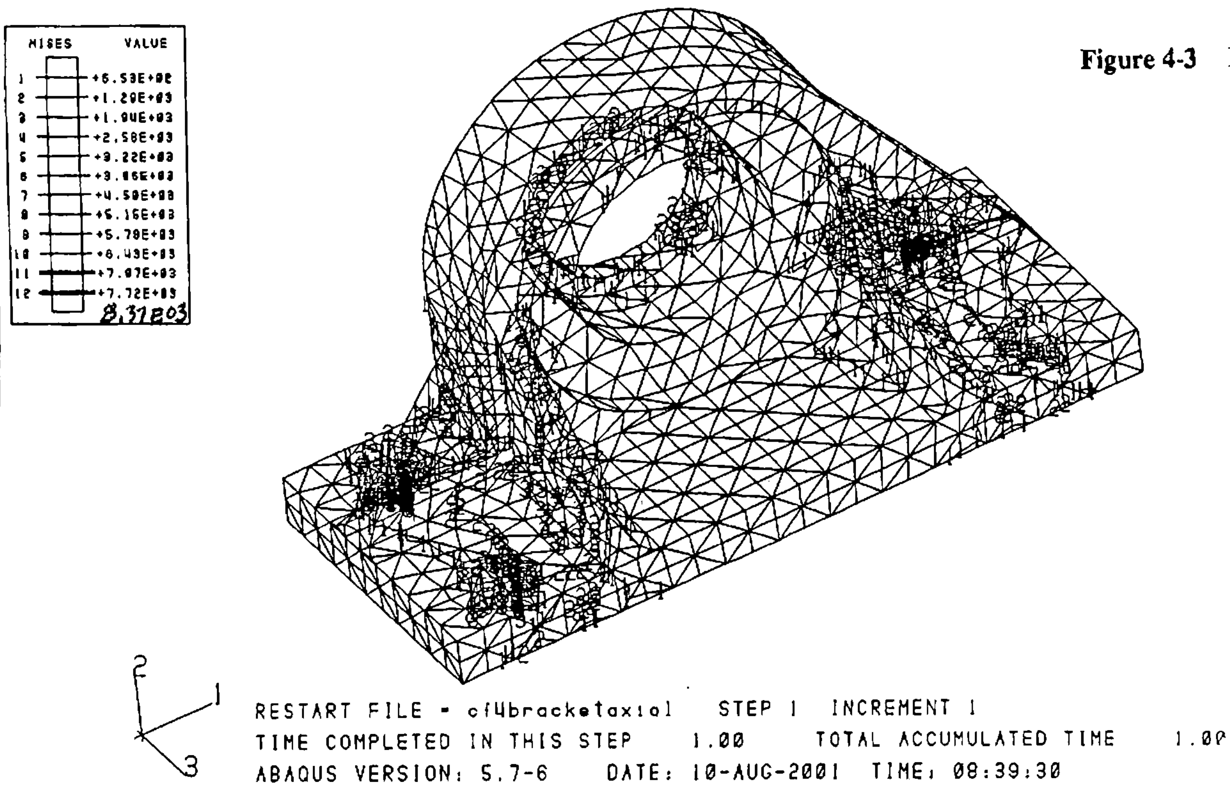
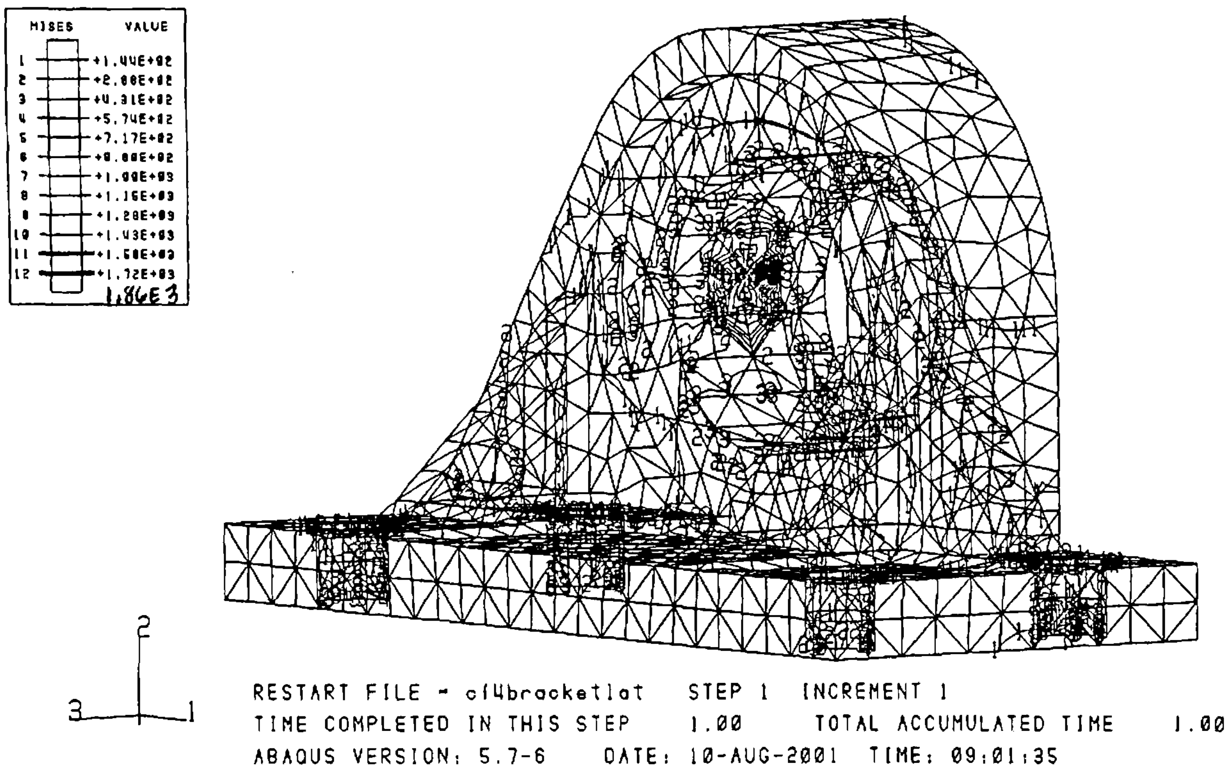


Figure 4-3 BRACKET AT 10G AXIAL (280 LBS)

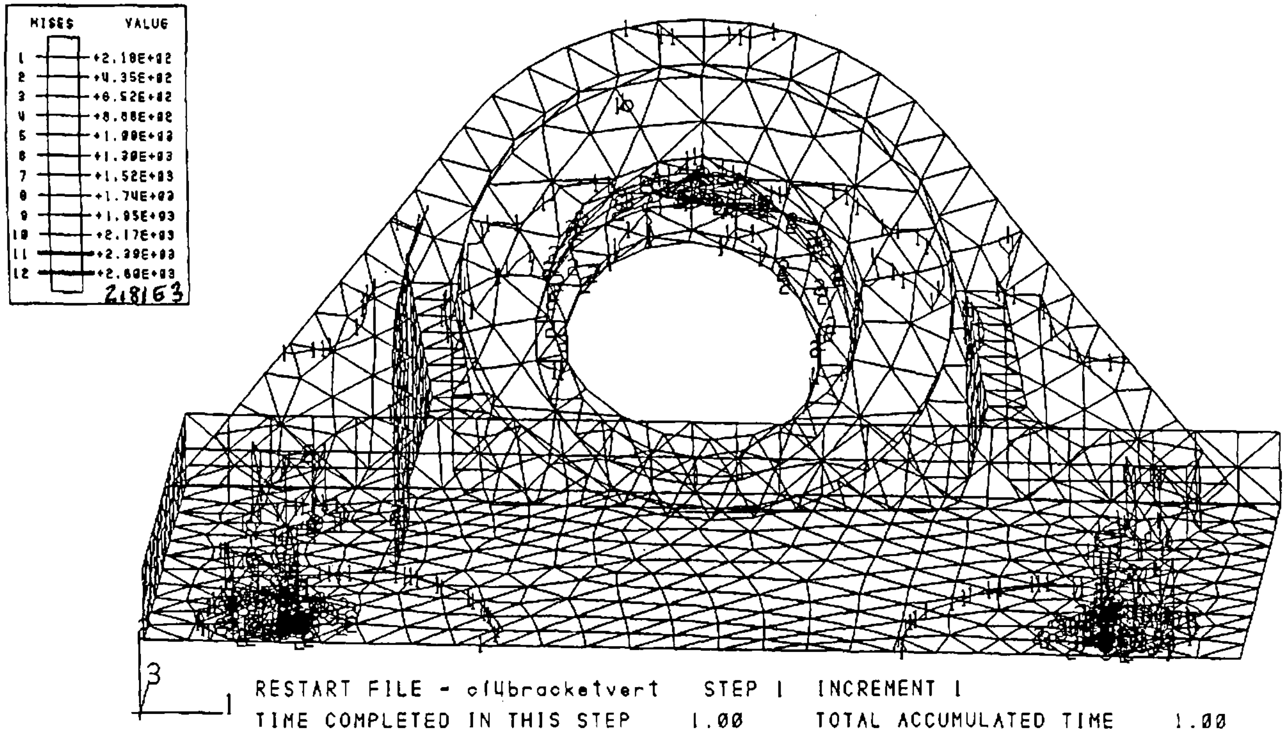
ABAQUS

Figure 4-4 BRACKET AT 10G LATERAL (280/2 = 140 LBS)



ABAQUS

Figure 4-5 BRACKET AT 10G VERTICAL (280/2 = 140 LBS)



RESTART FILE - cf4bracketvert STEP 1 INCREMENT 1
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00
ABAQUS VERSION: 5.7-6 DATE: 10-AUG-2001 TIME: 09:19:07

31

5.0 References

1) ARDE's PN D4683, N/C, Accumulator, Helium

2) ARDE's PM 10070, Statement of Work for TRD Gas Supply System

3) MIL-STD-1522A (USAF), Standard General Requirement for Safe Design and Operation of Pressurized Missile and Space Systems, Department of Defense, May 1984

4) Lockheed Martin Michoud Space System's SCD no. 10550300450, Helium Accumulator

5) ARDE's Fracture and Stress Analyses Report EG 10214, March 1998, for Helium Accumulator, PN D4683.

6) ARDE's Qualification Test Report EG 10221, N/C, for Helium Accumulator, PN D4683.

7) MIL-HDBK-5F, Metallic Materials and Elements for Aerospace Vehicle Structures.