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ANTI-CHAFE HOSE

Richard A. Snyder

Titeflex
Springfield, Massachusetts

February 1974

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DEPARTMENT OF THE ARMY
US ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by the Titeflex Division of Atlas Corporation under the terms of Contract DAAJ02-72-C-0088. It presents the results of an effort to evaluate a proprietary material that is considered a good candidate for a chafe guard for Army aircraft flexible hoses.

The data generated during this evaluation were assessed at different confidence levels to determine the intervals within which values of certain material properties, such as tensile strength and abrasion resistance, would be found. That assessment indicated that the proprietary material would be a reasonably efficient chafe guard for flexible hoses under conditions that are considered representative of Army aircraft operations. The data analysis also indicated that the material properties of interest to this directorate (hardness, abrasion resistance, tensile strength, and percentage of elongation) were nearly constant at each test condition, indicating that the material is reasonably stable and homogeneous.

This report has been reviewed by this directorate and is considered to be technically sound.

The technical monitor for this contract was Mr. Donald R. Artis, Jr., of the Reliability and Subsystems Technical Area of the Military Operations Technology Division of this Directorate.

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ANTI-CHAFE HOSE

Final Report

By
Richard A. Snyder

Prepared by

Titeflex, A Division of Atlas Corp.
Springfield, Massachusetts

for

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13. ABSTRACT

This report presents the results of an R&D program conducted to establish the feasibility of, and the design and test criteria for, a chafe-resistant flexible fluid hose for Army helicopter applications. The vibratory chafing tests developed and conducted under this program demonstrate the feasibility of a flexible high-pressure fluid hose with integral elastomeric chafe guard which provides a tenfold increase in mean-time-between-failures (MTBF) compared to similar unprotected hose subjected to identical chafing conditions at -65°F, +275°F, and +450°F, without sacrifice of other performance parameters. Six chafe-guard-protected assemblies were tested for each of the requirements of MIL-H-38360A, Amend. 2, 8 Jan 73. The hose assemblies with integral chafe guard retained operating pressure for 600 hours under vibratory chafing conditions, provided evidence of wear before failure which was readily apparent to the human eye without physical separation of the hoses, and were capable of operating under vibratory chafing conditions after each of several potentially deleterious pretreatments. Reliability analyses were conducted to determine the 90, 95, and 99 percent confidence intervals for each of the above tests, as well as for the physical properties of the elastomeric chafe-guard material. It was recommended that a full-scale field study be initiated and an economic analysis be conducted to determine the effectiveness of the use of factory-made flexible hose assemblies with permanent fittings and integral chafe guard in reducing system cost by improving reliability, maintainability, and corrosion resistance.

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Chafe Resistant					
Integral Chafe Guard					

SUMMARY

This report presents the results of a research and development program conducted to establish the feasibility of, and the design and test criteria for, a chafe-resistant flexible fluid hose for Army helicopter applications.

The vibratory chafing tests developed and conducted under this program demonstrate the feasibility of a flexible high-pressure fluid hose with integral elastomeric chafe guard which provides a tenfold increase in mean-time-between-failures (MTBF) compared to similar unprotected hose subjected to identical chafing conditions at -65°F, +275°F, and +450°F. This significant improvement was achieved without sacrifice of other performance parameters. Six chafe-guard-protected assemblies were tested for each of the requirements of MIL-H-38360A, Amendment 2, January 8, 1973. The hose assemblies with integral chafe guard demonstrated a capability of retaining the operating pressure for 600 hours under the vibratory chafing conditions specified in the contract, provided evidence of wear before failure which was readily apparent to the human eye without physical separation of the hoses, and were capable of operating under vibratory chafing conditions after each of several potentially deleterious pretreatments. Reliability analyses were conducted to determine the 90, 95, and 99 percent confidence intervals for each of the above tests, as well as for the physical properties of the elastomeric chafe-guard material.

It was recommended that a full-scale field study be initiated and an economic analysis be conducted to determine the effectiveness of the use of factory-made flexible hose assemblies with permanent fittings and integral chafe guard in reducing system cost by improving reliability, maintainability, and corrosion resistance. Savings might accrue through the reduction of aircraft downtime and the lowered logistic support requirements implied by the tenfold increase in MTBF characterizing this chafe-resistant hose.

FOREWORD

This report covers a research and development program to conduct the design, development, and tests necessary to establish the feasibility of, and the design and test criteria for, an anti-chafe flexible fluid hose for Army helicopter applications. These tests were conducted under DA Task IF162205A11906, "Reliability/Environmental Technology", Contract DAAJ02-72-C-0088. This effort is part of the reliability and maintainability effort at the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia, and was undertaken as a result of the recommendations made in USAAMRDL Technical Report 72-1, "Wire Braided Hose Chafing Tests".*

Technical assistance and advice were provided by Mr. Edward LaBoursoliere, Test Laboratory Supervisor, who designed the hydraulic pressure and environmental systems; Mr. Chester Gazda, Materials Engineer, who assisted in the development of the chafe-resistant composition; Mr. Lawrence O'Melia, Chief Chemist, who developed and implemented the material characterization effort as well as the processing techniques; Mr. Donald R. Artis, Jr., Eustis Directorate, USAAMRDL, COTR, who instructed the project engineer in correct statistical treatment of the data and edited this report; Mr. Roger D. Christianson, Project Manager during the early stages of the program; and Mr. James M. Lalikos, Director of Engineering, who ably assisted and advised the project engineer throughout the entire program.

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* Donald R. Artis, Jr., WIRE-BRAIDED HOSE CHAFING TESTS, USAAMRDL Technical Report 72-1, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1972, AD738842.

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E	allowable error
n	sample size
S	standard deviation
$\overline{X}$	sample mean
α	producer's risk or level of significance
$1 - \alpha$	confidence
μ	population mean
$t\ (\alpha/2, n-1)$	100 (α/2) percentage point of the "t" distribution with (n-1) degrees of freedom

INTRODUCTION

During the design and mock-up evaluation phase of an aircraft development program, hydraulic hose locations and routing and the appropriate maintenance practices are established, usually with great skill and forethought. Some of these hoses manage to come in contact with each other or with the aircraft structure and cause chafing, which could result in fluid leakage, which in turn could cause incidents or accidents. Nineteen percent of all Army aircraft mishaps that can be attributed to hydraulic systems are caused by chafed or broken hydraulic lines. Therefore, a substantial reduction in aircraft mishaps could be realized if an effective solution could be found to the hose chafing problem.

The chafing characteristics of wire-braided hoses in an Army helicopter vibration environment were determined and reported in USAAMRDL Technical Report 72-1, "Wire-Braided Hose Chafing Tests", Donald R. Artis, Jr., January 1972. Several interim solutions to the hose chafing problem were recommended; in particular, wrapping nylon coil around existing hose assemblies. A recommendation was also made in that report to initiate a program to develop a chafe-resistant hose for use on future Army aircraft to replace the wire-braided hose currently used.

As a direct result of this recommendation, Contract DAAJ02-72-C-0088 was let to Titeflex, A Division of Atlas Corp., for the purpose of conducting the design, development and tests necessary to establish the feasibility of, and the design and test criteria for, an anti-chafe flexible fluid hose for Army helicopter applications. The replacement hose would be intended for use in aircraft high-temperature fuel, lubricating oil, water-alcohol, chemical-fluid, hydraulic, and pneumatic systems.

The replacement hose would have to conform to the following design requirements:

A. The mean-time-between-failures (MTBF) of the replacement hose was to be at least ten times as long as the MTBF of the MIL-H-38360A hose (two thicknesses of wire braid only) when subjected to vibratory chafing at temperatures ranging from -65°F to +450°F.

B. The replacement hose was to demonstrate a capability of retaining the operating pressure for at least 600 hours under the same vibratory chafing conditions as in requirement A.

C. The hose was to be capable of operating when subjected to the same vibratory chafing as in requirement A after having been subjected to each of the following treatments:

   1. Apply MIL-E-5007C (30 December 1965) sand uniformly over the entire surface of the hoses.

   2. Soak the hose assemblies for 24 hours in MIL-G-5572 fuel (gasoline) immediately prior to testing.

   3. Soak the hose assemblies for 24 hours in MIL-T-5624 fuel (JP-4) immediately prior to testing.

D. The replacement hose was to be compatible with the fluids described in U.S. Army Technical Bulletin 55-9150-200-25 (21 September 1967), MIL-H-5606C (30 September 1971), MIL-H-83282 (16 July 1970), and MIL-H-6083C (17 November 1965).

E. Wear experienced by the hoses was to become readily apparent to the human eye before failure without requiring physical separation of the hoses.

F. The replacement hose was to conform to the requirements of MIL-H-38360A (7 December 1966) and MIL-H-27267A (13 July 1965).

It was proposed to meet the requirements above by extruding a protective elastomeric chafe guard directly onto an otherwise ordinary double-braided tetrafluoroethylene (TFE) hose conforming to MIL-H-38360A. This hose is referred to as the base hose henceforth. The extruded chafe guard would consist of a laminated structure (Figure 1) whose inner layer would be brightly colored in order that any wear produced by a chafing condition would be indicated. The brightly colored wear debris would hopefully adhere electrostatically to the hoses around the wear area and provide the desired indication prior to braid damage.

The required chafe-resistant qualities were to be imparted without adversely affecting other performance criteria. Assuming this to be technically feasible, it was the further purpose of this program to develop the most cost effective replacement hose considering cost, weight, reliability, maintenance, manufacturing considerations or techniques, and overall system cost for an aircraft.

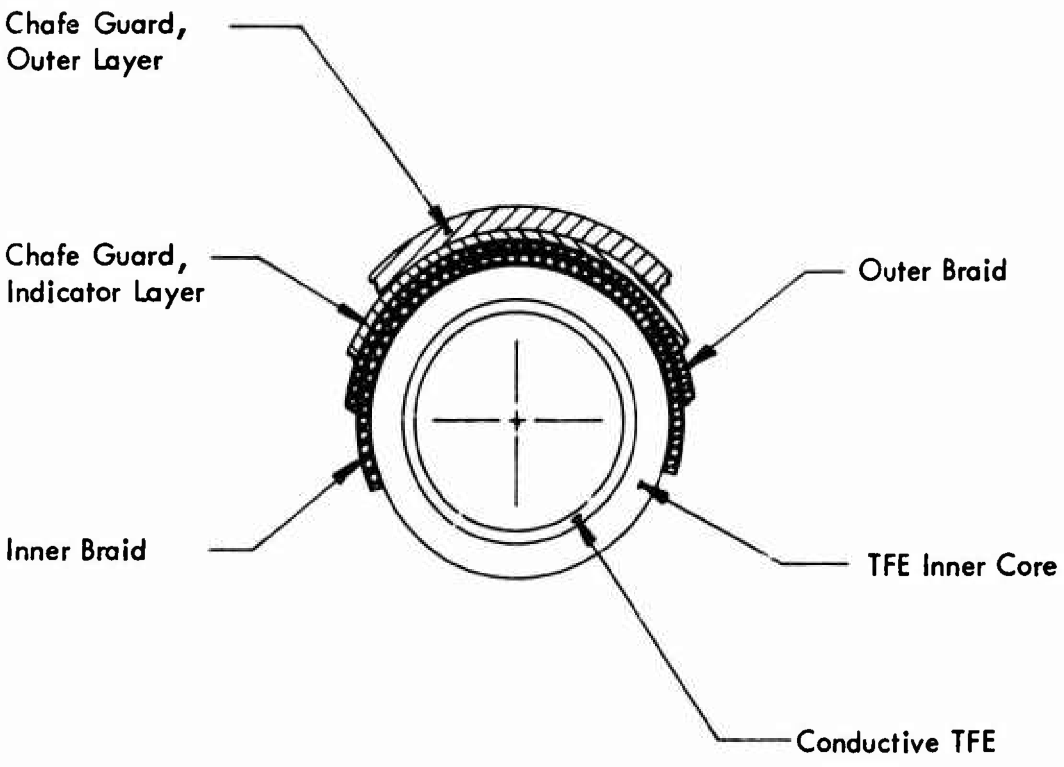

Figure 1. Typical Cross Section, MIL-H-38360A High Pressure Hose With Integral Chafe Guard.

PRELIMINARY MATERIAL EVALUATION

Review of the temperature capabilities of available flexible materials disclosed that the requirement for service at temperatures from -65°F to +450°F severely limits the number of materials from which one may choose. In general, only the silicones, fluorosilicones, fluorocarbons, and fluoroelastomers may be expected to have a reasonable probability of success.

TFE may be eliminated as a candidate matrix material, as it requires a processing operation (sintering) above 630°F to develop its properties. Exposure of the base hose to this temperature would seriously degrade its properties. However, TFE exhibits highly desirable frictional and wear-resistant qualities. To make use of these qualities, various forms of TFE were incorporated into other matrices which could be processed at temperatures not affecting the base hose. These "poly-polymer" composites are considered to be proprietary by Titeflex, having been developed using private funds and disclosed in U.S. Patent Application Serial No. 262,761, filed June 14, 1972, case no. T2-72-100, and British Patent Application No. 38,689/72, filed August 18, 1972, case no. T2-72-105. In order to protect Titeflex's interest, yet present a substantive, useful report, a numerical code system will be used to identify specific compositions. The ingredients and their percentages in all composites studied herein are specified in Appendix III, which is published under separate cover due to the proprietary nature of the data.

All compounds were mixed using a standard two-roll 6-inch x 12-inch rubber mixing mill. Candidate chafe-guard compounds were initially tested at room temperature according to the abrasion Test Specification for Elastomeric Chafe Guard Materials, Appendix I. The results of these tests are presented in Table I. Analysis of these data shows that the best poly-polymer composites exhibit thirty to forty times less weight loss than the neoprene jacketing compound under abrasion test conditions at room temperature. Other conclusions as to the effectiveness of specific ingredients and percentages in providing optimum properties are presented in Appendix IV, also published under separate cover due to the proprietary nature of the data.

As a result of this preliminary test series, base elastomer compounds 1 and 4 and poly-polymer compounds 12, 13, 16, 19, 21, 22, 23, 25, and 29 shown on Table I were selected for additional study as candidate chafe-guard materials at 450°F, after fluid soak, and for extrusion characteristics. The base elastomer compounds 1 and 4 were selected to provide a direct comparison between them

TABLE I. ROOM-TEMPERATURE PROPERTIES OF CHAFE-GUARD COMPOUNDS

COMPOSITION	HARDNESS Shore A*		TENSILE psi		ELONGATION %		ABRASION Weight Loss %	
	PRESS	POST	PRESS	POST	PRESS	POST	PRESS	POST
NEOPRENE								
Std. Compound	55	N.A.**	1550	N.A.	325	N.A.	100.00	N.A.
BASE COMPOUND								
1	50	50	777	907	490	488	24.97	14.50
2	- ***	-	886	1080	589	613	-	-
3	45	-	803	790	500	250	100.00	56.00
4	48	45	448	731	275	325	10.11	25.38
CLASS 1 COMPOSITE								
5	75-80	72-77	168	183	33	23	-	-
6	70-75	72-77	316	318	68	30	-	-
7	78-80	83	179	171	63	25	-	-
CLASS 2 COMPOSITE								
8	65	60-65	467	482	450	287	7.57	5.23
9	65-70	62-67	348	388	338	238	-	-
10	65-70	64-68	445	401	188	225	6.54	6.83
11	65-70	70-75	222	352	188	150	-	-
CLASS 3 COMPOSITE								
12	55-60	62-67	491	484	500	412	5.45	5.89
13	55	55	721	751	600	600	15.41	7.44
14	55	55	672	649	588	500	16.40	6.48
15	55	55	675	556	613	425	31.13	8.45
CLASS 4 COMPOSITE								
16	60-65	60-65	367	366	413	313	6.24	5.79
17	60-65	65-70	378	393	425	338	7.43	5.96
18	60-65	65-70	391	396	425	350	5.68	6.02
19	57	60-65	580	599	600	500	14.40	7.20
20	55-60	55-60	523	481	563	450	4.50	6.33
21	62-67	65-70	400	371	269	212	6.39	5.67
CLASS 5 COMPOSITE								
22	60-65	58-60	240	247	400	325	4.92	6.24
23	60-65	65-70	310	337	350	263	5.17	5.87
24	60-65	60-65	262	248	388	313	5.44	5.75
25	65-70	-	287	253	425	275	6.33	7.11
26	65-70	70-75	309	336	288	275	4.64	5.32
27	65-70	68-73	271	298	313	287	5.90	5.77
28	-	-	-	-	-	-	5.66	8.19
29	60	65-70	421	453	600	550	18.60	26.70
CLASS 6 COMPOSITE								
30	60-65	68-73	195	194	288	188	10.55	8.85
31	70	70	221	215	338	313	10.83	13.46
CLASS 7 COMPOSITE								
32	75-80	70-75	754	690	575	400	12.50	10.17
33	70	70	573	551	175	125	6.47	7.11
34	55-60	55-60	668	627	588	525	2.91	5.42
CLASS 8 COMPOSITE								
35	50-55	-	363	317	313	213	5.12	10.25
36	50	55	340	363	237	200	5.40	7.58
37	50-55	40-60	330	333	75	75	5.40	10.87
38	50-55	50-55	150	166	189	125	5.51	6.06
39	-	-	154	140	300	238	-	-

* Shore A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

** N.A. - Not Applicable.

*** - - No Data.

without the property leveling effect of the addition of TFE. Compounds in classes 1, 2, 6, and 8 were rejected because of poor mechanical properties. Compounds in Class 7 were rejected because of extreme difficulty in mixing. Compounds 13, 19, and 29 were selected because they exhibited the highest tensile strength and elongation values in classes 3, 4, and 5. Compounds 12, 16, 21, 22, 23, and 25 were selected because they exhibited adequate mechanical properties and excellent abrasion resistance. These choices also provided good coverage of the composition range exhibiting the best overall properties.

FINAL MATERIAL EVALUATION AND SELECTION

Each of the successful candidate compounds from the preliminary material evaluation program, together with the base elastomer stocks upon which they were based, was prepared in sufficient quantity to permit extensive testing at elevated temperatures, after fluid soak, and in pilot extrusion runs on the base hose. Each base stock was subjected to every test called out in Abrasion Test Specification for Elastomeric Chafe Guard Materials (Appendix I). The candidate compounds were tested under that specification in the following sequence:

1. High-temperature (450°F) abrasion resistance.
2. Room-temperature (80°F) abrasion resistance after fluid soak.
3. High-temperature (450°F) abrasion resistance after fluid soak.

The fluids selected for fluid compatibility considerations as representative of the anticipated service environment are as follows:

1. Gasoline, Grade 100/120, MIL-G-5572
2. Gasoline, JP-4, MIL-T-5624
3. Hydraulic Fluid, Petroleum Base, MIL-H-5606
4. Hydraulic Fluid, Petroleum Base, MIL-H-6083
5. Hydraulic Fluid, Synthetic Base, MIL-H-83282
6. Oil, Lubricating, MIL-L-7808
7. Oil, lubricating, MIL-L-22851
8. Oil, Lubricating, Synthetic Base, MIL-L-23699
9. Hydraulic Fluid, Fire Resistant, Skydrol 500A

The results of these tests are presented in Table II. Compounds 13, 19, and 29 were eliminated from consideration because of poor abrasion resistance after fluid soak. Compound 23 was eliminated because of poor cut and tear resistance. Of the remaining candidates, compounds 12, 16, and 21 exhibited

TABLE II. SUMMARY - ABRASION RATES AT 450° F AND AFTER FLUID SOAK (ALL POST-CURED)

COMPOUND	ROOM TEMPERATURE REFERENCE				450° F	ABRASION RATE AFTER 24-HOUR SOAK IN FLUID							
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-L-22851	MIL-L-23699
BASE COMPOUND	SHORE A	PSI	%	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL
1	50	1080	613	14.50	9.27	7.08	8.34	13.75	41.5	16.7	11.50	8.91	-
4	45	731	325	11.20	13.81	3.82	18.32	16.85	39.0	10.0	12.70	5.24	-
COMPOSITE													
13	55	751	600	7.44	11.60	35.70	23.10	26.80	-	-	-	-	-
19	60-65	599	500	7.20	-	45.80	40.40	25.50	-	100.0	-	-	-
29	65-70	453	550	26.70	-	34.00	-	20.60	-	-	-	-	-
12	62-67	484	412	5.89	4.43	10.90	8.76	6.80	21.5	-	-	-	-
16	60-65	366	313	5.79	5.10	7.75	6.96	6.64	-	-	-	-	-
21	65-70	371	212	5.87	6.71	5.53	8.19	5.17	38.3	12.7	5.00	6.25	-
25	70	253	275	7.11	8.36	8.03	-	4.99	-	13.9	-	-	-
22	75-80	390	150	7.61	10.69	-	-	-	25.2	-	-	-	-
23	65-70	337	263	5.87	-	4.93	-	-	-	-	-	-	-
40 (Compound No. 1)	60	376	400	6.20	5.54	5.66	5.89	5.91	30.6	16.3	7.57	5.47	-
41	60	368	225	7.14	7.08	6.22	5.65	5.61	35.1	12.7	7.70	8.47	-
42	55-60	325	225	5.15	7.80	6.05	6.56	5.90	37.3	14.4	6.29	6.72	-
43	65-70	314	225	8.14	7.51	8.34	8.34	9.02	21.2	10.6	6.96	9.52	-
44	-	-	-	-	-	-	-	-	22.5	-	8.61	6.04	5.15
45 (Compound No. 2)	60-65	368	275	6.88	7.80	6.66	6.69	5.95	37.9	27.9	7.63	4.98	5.89
46 (Compound No. 3)	-	-	-	-	-	-	-	-	33.0	11.7	5.69	6.54	-
47	-	-	-	6.97	10.38	-	-	-	-	-	-	-	-

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
Shore A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.
\- - No data.

best overall abrasion resistance and were evaluated for vibratory chafe resistance and extrudability.

For economic reasons, a candidate was immediately dropped from consideration if it proved to be seriously deficient in any aspect. Thus the data for some of the compounds is incomplete. For example, compound 13 exhibited abrasion rates several times greater than compounds 12 and 16 after fluid soak in MIL-H-5606, MIL-L-7808, and Skydrol, and additional testing of compound 13 was therefore not performed.

At this juncture, the program was dealt a severe blow in that the manufacturer of the particulate TFE used in all of the chosen compounds discontinued its manufacture. A similar product from another source had to be completely evaluated as a substitute because, although average particle size was equal, size distribution and particle shape differed substantially. Therefore, compounds 40 through 47 were prepared using the new product, bracketing the composition range represented by the chosen compounds. Of these, compounds 40, 45, and 46 were selected for final evaluation; they will be referred to as compounds 1, 2, and 3 respectively. These compounds exhibited the best overall properties and, not surprisingly, are of very similar composition.

All three compounds extruded readily; however, compound 2 produced on integral chafe guard having the smoothest surface and the most uniform wall thickness. Compound 3 was intermediate, and compound 1 was decidedly inferior, producing a chafe guard which was quite rough. Initial room-temperature testing indicated compound 2 to be superior in vibratory chafe resistance also, although verification was necessary for reasons to be discussed later under "Initial Vibration Testing".

To characterize fully the physical and chemical properties of compound 2 pertaining to service as a chafe-guard material for flexible hose, six data points were obtained for each property value called out in the Abrasion Test Specification for Elastomeric Chafe Guard Materials (Appendix I) both in the as-molded condition and after a 24-hour soak in each of the nine fluids above. Abrasion resistance was determined both at room temperature and at 450° F for all the above. Percentage weight gain after fluid soak was calculated after soaking in each fluid. A reliability analysis was conducted to determine the 90, 95, and 99 percent confidence intervals for each of the above values. The results are presented in Tables III through VIII.

TABLE III. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (ULTIMATE TENSILE STRENGTH)

ITEM	ROOM TEMPERATURE				450° F	ULTIMATE TENSILE STRENGTH AFTER 24-HOUR SOAK IN FLUID								
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI
DATA POINT. 1	61	369	275	6.84	6.77	202	269	271	190	172	206	274	311	309
2	61	367	275	6.58	8.32	197	272	262	174	156	205	267	332	309
3	61	369	275	6.98	8.55	208	272	279	169	168	201	275	303	310
4	63	357	275	6.98	6.86	207	267	268	168	172	204	293	337	317
5	63	365	290	6.89	9.28	204	266	266	176	163	204	287	333	314
6	63	366	300	7.05	7.00	208	280	255	183	155	205	264	287	305
SAMPLE SIZE = n = 6														
MEAN = $\bar{X}$	62	366	282	6.88	7.80	204	274	267	177	164	204	277	317	311
STD. DEV. = S	1	4	11	0.17	1.06	4	9	8	8	8	2	11	20	4
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	2	4	3	3	3	1	5	8	2
RELIABILITY ANALYSIS 90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	4	7	7	7	6	1	9	17	3
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	200	267	260	170	158	203	268	300	308
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	208	281	274	184	170	205	286	334	314
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	4	9	8	9	8	2	12	21	4
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	200	265	259	168	156	202	265	296	307
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	208	283	275	186	172	206	289	338	315
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$, $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	7	14	13	14	12	3	19	33	7
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	197	260	254	163	152	201	258	284	304
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	211	288	280	191	177	207	296	350	318

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using shore Durometer, A scale, ASTM D 2240.

TABLE IV. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (ULTIMATE ELONGATION)

ITEM	ROOM TEMPERATURE				450° F	ULTIMATE ELONGATION AFTER 24-HOUR SOAK IN FLUID								
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	%	%	%	%	%	%	%	%	%
DATA POINT: 1	61	369	275	6.84	6.77	150	250	240	100	75	150	225	275	275
2	61	367	275	6.58	8.32	150	250	240	100	63	150	235	300	275
3	61	369	275	6.98	8.55	175	225	230	88	75	140	225	275	275
4	63	357	275	6.98	6.86	160	225	240	88	75	140	250	300	275
5	63	365	290	6.69	9.28	150	225	230	88	75	150	250	300	275
6	63	366	300	7.05	7.00	150	250	250	100	63	160	200	225	275
SAMPLE SIZE = n = 6														
MEAN = $\bar{X}$	62	366	282	6.88	7.80	156	233	238	94	71	148	231	279	275
STD. DEV. = S	1	4	11	0.17	1.06	10	14	8	7	6	8	19	29	0
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	4	6	3	3	3	3	8	12	0
RELIABILITY ANALYSIS														
90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	8	11	6	6	5	6	15	24	0
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	148	227	232	88	66	142	216	255	275
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	164	249	244	100	76	154	246	303	275
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	11	14	8	7	7	8	20	31	0
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	145	224	230	87	64	140	211	248	275
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	167	252	246	101	78	156	251	310	275
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$, $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	17	23	12	11	11	12	31	48	0
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	139	215	226	83	60	136	200	231	275
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	173	261	250	105	82	160	262	327	275

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

TABLE V. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (DUROMETER HARDNESS)

ITEM	ROOM TEMPERATURE				450° F	HARDNESS AFTER 24-HOUR SOAK IN FLUID								
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	SHORE A	SHORE A	SHORE A	SHORE A	SHORE A	SHORE A	SHORE A	SHORE A	SHORE A
DATA POINT: 1	61	369	275	6.84	6.77	46	60	58	28	28	50	61	63	61
2	61	367	275	6.58	8.32	48	58	58	30	28	50	61	63	61
3	61	369	275	6.98	8.55	48	57	58	28	28	50	61	61	61
4	63	357	275	6.98	6.86	48	60	58	30	28	50	62	61	63
5	63	365	290	6.89	9.28	48	56	56	30	28	50	62	61	63
6	63	366	300	7.05	7.00	48	60	60	30	28	50	62	61	61
SAMPLE SIZE = n = 6														
MEAN = $\bar{X}$	62	366	282	6.88	7.80	48	59	58	29	28	50	62	62	62
STD. DEV. = S	1	4	11	0.17	1.06	0	2	1	1	0	0	1	1	1
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	0	1	1	0	0	0	0	0	0
RELIABILITY ANALYSIS														
90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	0	1	1	1	0	0	0	1	1
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	48	58	57	28	28	50	62	61	61
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	48	60	59	30	28	50	62	63	63
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	0	2	1	1	0	0	1	1	1
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	48	57	57	28	28	50	61	61	61
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	48	61	59	30	28	50	63	63	63
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$ $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	0	3	2	2	0	0	1	2	2
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	48	56	56	27	28	50	61	60	60
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	48	62	60	31	28	50	63	64	64

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

TABLE VI. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (WEIGHT GAIN)

ITEM	ROOM TEMPERATURE				450° F	WEIGHT GAIN AFTER 24-HOUR SOAK IN FLUID								
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	%	%	%	%	%	%	%	%	%
DATA POINT: 1	61	369	275	6.84	6.77	12.0	1.37	1.90	73.2	55.3	12.3	1.67	0.242	0.748
2	61	367	275	6.58	8.32	12.0	1.49	1.86	76.1	55.7	12.0	1.69	0.262	0.757
3	61	369	275	6.98	8.55	12.0	1.51	1.89	72.5	55.2	12.1	1.65	0.261	0.750
4	63	357	275	6.98	6.86	12.4	1.44	1.90	66.4	56.2	12.2	1.65	0.255	0.477
5	63	365	290	6.89	9.28	12.3	1.50	1.93	65.4	56.5	12.2	1.60	0.234	0.645
6	63	366	300	7.05	7.00	12.3	1.36	1.90	65.8	56.0	11.9	1.67	0.248	0.658
SAMPLE SIZE = n = 6														
MEAN = $\bar{X}$	62	366	282	6.88	7.80	12.2	1.45	1.90	69.9	55.8	12.1	1.66	0.250	0.673
STD. DEV. = S	1	4	11	0.17	1.06	0.2	0.07	0.02	4.6	0.5	0.2	0.03	0.011	0.108
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	0.1	0.03	0.01	1.9	0.2	0.1	0.01	0.005	0.044
RELIABILITY ANALYSIS														
90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	0.2	0.05	0.02	3.8	0.4	0.1	0.03	0.009	0.089
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	12.0	1.40	1.88	66.1	55.4	12.0	1.63	0.241	0.584
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	12.4	1.50	1.92	73.7	56.2	12.2	1.69	0.259	0.762
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	0.2	0.07	0.02	4.8	0.5	0.2	0.03	0.012	0.113
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	12.0	1.38	1.88	65.1	55.3	11.9	1.63	0.238	0.560
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	12.4	1.52	1.92	74.7	56.3	12.3	1.69	0.262	0.786
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$, $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	0.3	0.11	0.04	7.6	0.8	0.3	0.05	0.018	0.177
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	11.9	1.34	1.86	62.3	55.0	11.8	1.61	0.232	0.496
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	12.5	1.56	1.94	77.5	56.6	12.4	1.71	0.268	0.850

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

TABLE VII. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (ROOM TEMPERATURE ABRASION RATE)

ITEM	ROOM TEMPERATURE				450° F	ROOM TEMPERATURE ABRASION RATE AFTER 24-HOUR SOAK IN FLUID									
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL	% WL
DATA POINT: 1	61	369	275	6.84	6.77	5.92	6.30	5.23	36.9	25.6	8.08	4.71	6.45	6.06
2	61	367	275	6.58	8.32	7.50	7.03	5.65	42.3	28.9	7.63	5.38	5.78	6.23
3	61	369	275	6.98	8.55	5.92	5.93	6.15	37.9	24.7	5.40	4.94	5.35	5.96
4	63	357	275	6.98	6.86	6.70	6.31	6.12	30.2	30.7	7.50	4.76	5.40	5.30
5	63	365	290	6.89	9.28	7.74	6.33	6.17	46.2	27.9	9.75	5.15	6.18	6.29
6	63	366	300	7.05	7.00	6.16	8.25	6.40	33.8	29.6	7.42	4.91	6.20	5.72
SAMPLE SIZE = n = 6														
MEAN = $\bar{X}$	62	366	282	6.88	7.80	6.66	6.69	5.95	37.9	27.9	7.63	4.98	5.89	5.93
STD. DEV. = S	1	4	11	0.17	1.06	0.80	0.84	0.43	5.8	2.3	1.40	0.25	0.46	0.37
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	0.33	0.34	0.18	2.3	1.0	0.57	0.10	0.19	0.15
RELIABILITY ANALYSIS 90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	0.66	0.69	0.35	4.7	1.9	1.15	0.21	0.37	0.30
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	6.00	6.00	5.60	33.2	26.0	6.48	4.77	5.52	5.63
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	7.32	7.38	6.30	42.6	29.8	8.78	5.19	6.26	6.23
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	0.84	0.88	0.45	6.0	2.5	1.46	0.26	0.48	0.39
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	5.82	5.81	5.50	31.9	25.4	6.17	4.72	5.41	5.54
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	7.50	7.57	6.40	43.9	30.4	9.09	5.24	6.37	6.32
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$, $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	1.32	1.39	0.71	9.5	3.8	2.30	0.41	0.75	0.61
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	5.34	5.30	5.24	28.4	24.1	5.33	4.57	5.14	5.32
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	7.98	8.08	6.66	47.4	31.7	9.93	5.39	6.64	6.54

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

TABLE VIII. SUMMARY - PROPERTIES OF CHAFE-GUARD COMPOUND 2 (450° F ABRASION RATE)

ITEM	ROOM TEMPERATURE				450° F	450° F ABRASION RATE AFTER 24-HOUR SOAK IN FLUID								
	HDNS	TENSILE	ELONG	ABRAS	ABRAS	MIL-H-5606	SKYDROL	MIL-L-7808	MIL-G-5572	MIL-T-5624	MIL-H-6083	MIL-H-83282	MIL-L-22851	MIL-L-23699
UNITS	SHORE A	PSI	%	% WL	% WL	% WL	% WL	% WL			% WL	% WL	% WL	% WL
DATA POINT: 1	61	369	275	6.84	6.77	15.1	6.52	13.50			16.5	13.10	8.82	11.75
2	61	367	275	6.58	8.32	16.0	15.75	15.65			18.2	11.13	11.10	12.30
3	61	369	275	6.98	8.55	14.9	7.52	12.80			15.7	11.08	9.88	11.15
4	63	357	275	6.98	6.86	14.4	8.32	13.35			13.5	12.35	11.75	8.99
5	63	365	290	6.89	9.28	16.5	10.08	14.80			14.2	12.05	14.80	14.75
6	63	366	300	7.05	7.00	14.0	9.07	13.00			15.6	11.00	9.90	13.30
SAMPLE SIZE = n = 6														
MEAN = X̄	62	366	282	6.88	7.80	15.1	9.54	13.85			15.6	11.78	11.04	12.05
STD. DEV. = S	1	4	11	0.17	1.06	0.9	3.28	1.13			1.7	0.86	2.11	1.96
STD. ERROR = $S/\sqrt{n}$	0	2	4	0.07	0.43	0.4	1.34	0.46			0.7	0.35	0.86	0.80
RELIABILITY ANALYSIS														
90 PERCENT CONFIDENCE LEVEL: $\alpha = 0.1$, $\alpha/2 = 0.05$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.0150$														
$E = t(S/\sqrt{n})$	1	4	9	0.14	0.87	0.8	2.70	0.93			1.4	0.70	1.73	1.61
INTERVAL														
$\bar{X} - E < \mu$	61	362	273	6.74	6.93	14.3	6.84	12.92			14.2	11.08	9.31	10.44
$\bar{X} + E > \mu$	63	370	291	7.02	8.67	15.9	12.24	14.78			17.0	12.48	12.77	13.66
95 PERCENT CONFIDENCE LEVEL: $\alpha = 0.05$, $\alpha/2 = 0.025$, $n - 1 = 5$, $t(\alpha/2, n-1) = 2.5706$														
$E = t(S/\sqrt{n})$	1	4	12	0.18	1.11	1.0	3.44	1.18			1.7	0.90	2.21	2.06
INTERVAL														
$\bar{X} - E < \mu$	61	362	270	6.70	6.69	14.1	6.10	12.67			13.9	10.88	8.83	9.99
$\bar{X} + E > \mu$	63	370	294	7.06	8.91	16.1	12.98	15.03			17.3	12.68	13.25	14.11
99 PERCENT CONFIDENCE LEVEL: $\alpha = 0.01$, $\alpha/2 = 0.005$, $n - 1 = 5$, $t(\alpha/2, n-1) = 4.0321$														
$E = t(S/\sqrt{n})$	2	7	18	0.28	1.74	1.6	5.40	1.85			2.7	1.41	3.47	3.22
INTERVAL														
$\bar{X} - E < \mu$	60	359	264	6.60	6.06	13.5	4.14	12.00			12.9	10.37	7.57	8.83
$\bar{X} + E > \mu$	64	373	300	7.16	9.54	16.7	14.94	15.70			18.3	13.19	14.51	15.27

HDNS - Hardness.
ELONG - Elongation.
ABRAS - Abrasion rate.
WL - Weight loss.
t - Student's "t" distribution.
μ - Population mean.
SHORE A - Hardness value measured using Shore Durometer, A scale, ASTM D 2240.

EXTRUSION

The original concept for producing a chafe-resistant jacket on wire-braid-reinforced flexible hose was to extrude the jacketing material directly onto the surface of the hose as it passed through a hollow mandrel in a ram extruder. This basic concept proved indeed to be practicable, although the final die bore little resemblance to the original configuration.

The initial attempts at extrusion were made using a standard ram extrusion die equipped with a hollow mandrel through which the hose was passed to be jacketed as shown in Figure 2. A hollow cylindrical billet of chafe-guard material was prepared with two concentric layers having compositions identical in all respects except that a bright red pigment was added to the inner "indicator" layer. It was possible to extrude a satisfactory chafe guard of .090 inch thickness from compound 30 (see Table 1) using this setup if the hose was pulled along as the extruder ram forced the billet through the die. It was evident that very high extrusion pressures were being developed, as material would back-extrude between hose and mandrel if the hose was not pulled forward. When this occurred, the back-extruded compound locked the hose in place inside the mandrel, and continued application of force by the ram collapsed the hollow mandrel.

Proprietary Titeflex techniques were applied to reduce extrusion pressure and thus permit extrusion of integral chafe-guard jackets of thinner wall using compounds having higher viscosity, such as compounds 13, 16, 21, and 25 (see Table 1). The techniques used and results obtained, including the final die configuration, are reported in Appendix V, which is published under separate cover due to the proprietary nature of the data.

The test specimens for final evaluation of compounds 1, 2, and 3 (see Table II) under vibratory chafing conditions and compound 2 for tests per MIL-H-38360A and MIL-H-27267A were produced using the final die configuration shown in Appendix V. This die produced a smooth, integral chafe guard of uniform thickness having the desired two-layered structure. The inner or indicator layer was intimately bonded to the outer layer, and the two could not be separated after vulcanization.

INITIAL VIBRATION TESTING

The vibration test setup as originally conceived is shown in Figure 3. The vertical hoses are pressed over pins which are fixed to the transducer. Radial support above the chafe area is provided by pin extensions which pass through bushings in the top frame. The pin extensions screw down tightly against the vertical hoses, preventing relative motion between pin and hose. Loading is achieved via deadweights as shown in Figure 29 in Appendix II.

Results were extremely erratic and the cause was sought. Some of the hoses were found to have lengthened, decreasing the load, while others had shortened, increasing the load. Any slight twist applied to the hose during final tightening was shown to have a profound effect: the load could easily be doubled or almost entirely removed. In order to continue testing without waiting for the test setup to be rebuilt, each loading was measured and recorded every half hour, after which it was readjusted to the correct value.

The design of the environmental test chamber was altered to allow one end of the hose to rotate and reciprocate within a bulkhead bushing, as shown in Figure 4. Thus, the aforementioned problems would not affect the results to be obtained during qualification tests. This chamber was debugged by running tests on the candidate compounds and on unprotected hose at room temperature, confirming compound 2 as the successful candidate. During the early stages of this test series, another factor was found to cause erratic results. When a failure occurred, a varying amount of lubrication was supplied to the remaining hoses. This problem was solved by modifying the test procedure to provide for cleaning the hoses with Freon after each failure. This could be accomplished without disturbing the position or wear scar of the chafing hoses by spraying with Freon liquid and blowing dry with clean air.

The increased precision of the vibratory chafe test results obtained by use of the above techniques made possible a meaningful analysis of failure cause. It was determined that mean-time-between-failures (MTBF) was significantly greater for the specimens in which the chafe guard was well adhered to the substrate braid. Standard good bonding practices of mechanically abrading or chemically etching the metal surface prior to bonding are precluded by their potentially detrimental effect on fatigue life. A special procedure for preparation of the metal surface was developed, including the use of a noncorrosive organosilicone chemical coupling agent to increase bond strength. Final extrusions were prepared using this technique.

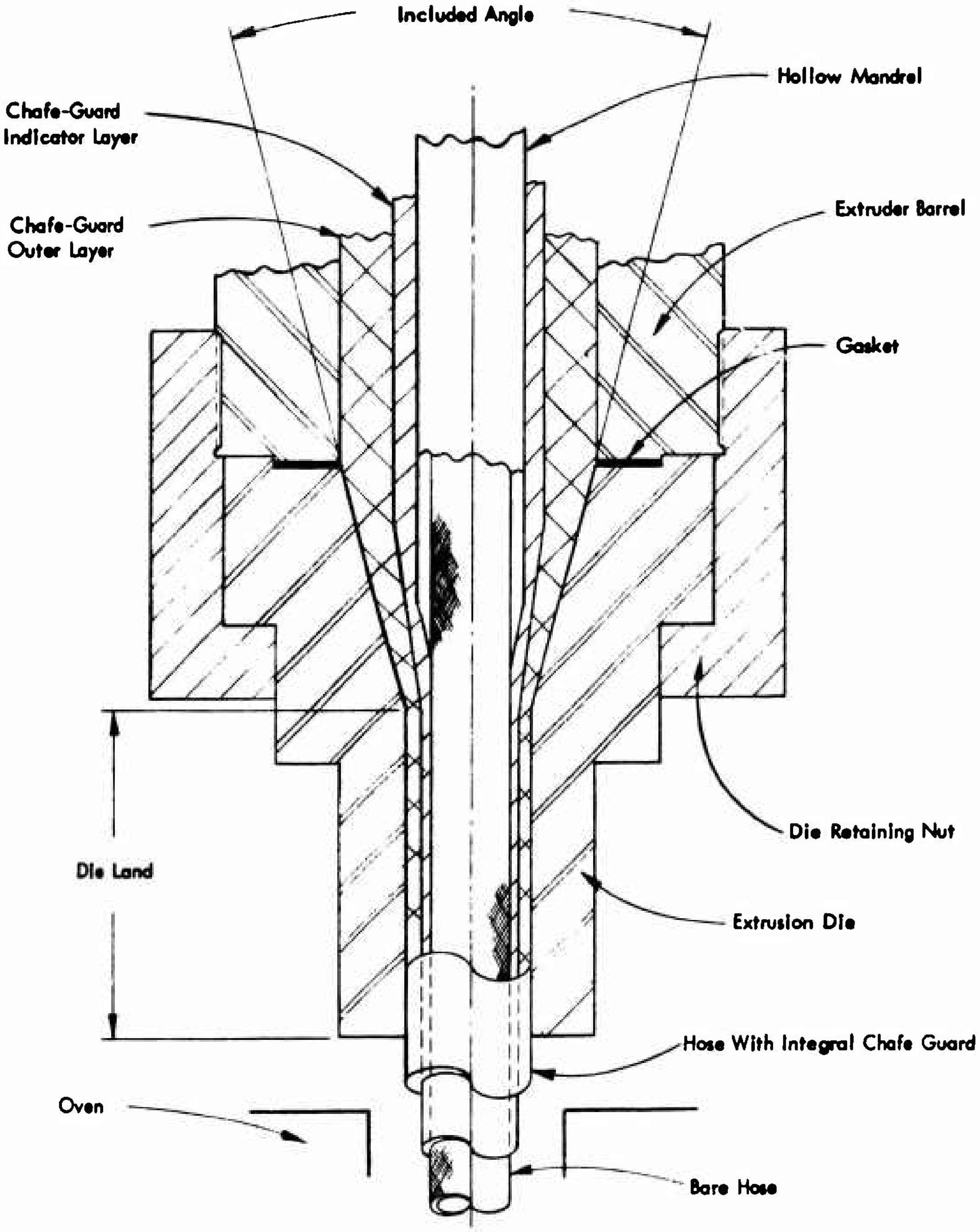

Figure 2. Extruder Setup Showing Initial Die Configuration.

INITIAL VIBRATION TESTING

The vibration test setup as originally conceived is shown in Figure 3. The vertical hoses are pressed over pins which are fixed to the transducer. Radial support above the chafe area is provided by pin extensions which pass through bushings in the top frame. The pin extensions screw down tightly against the vertical hoses, preventing relative motion between pin and hose. Loading is achieved via deadweights as shown in Figure 29 in Appendix II.

Results were extremely erratic and the cause was sought. Some of the hoses were found to have lengthened, decreasing the load, while others had shortened, increasing the load. Any slight twist applied to the hose during final tightening was shown to have a profound effect: the load could easily be doubled or almost entirely removed. In order to continue testing without waiting for the test setup to be rebuilt, each loading was measured and recorded every half hour, after which it was readjusted to the correct value.

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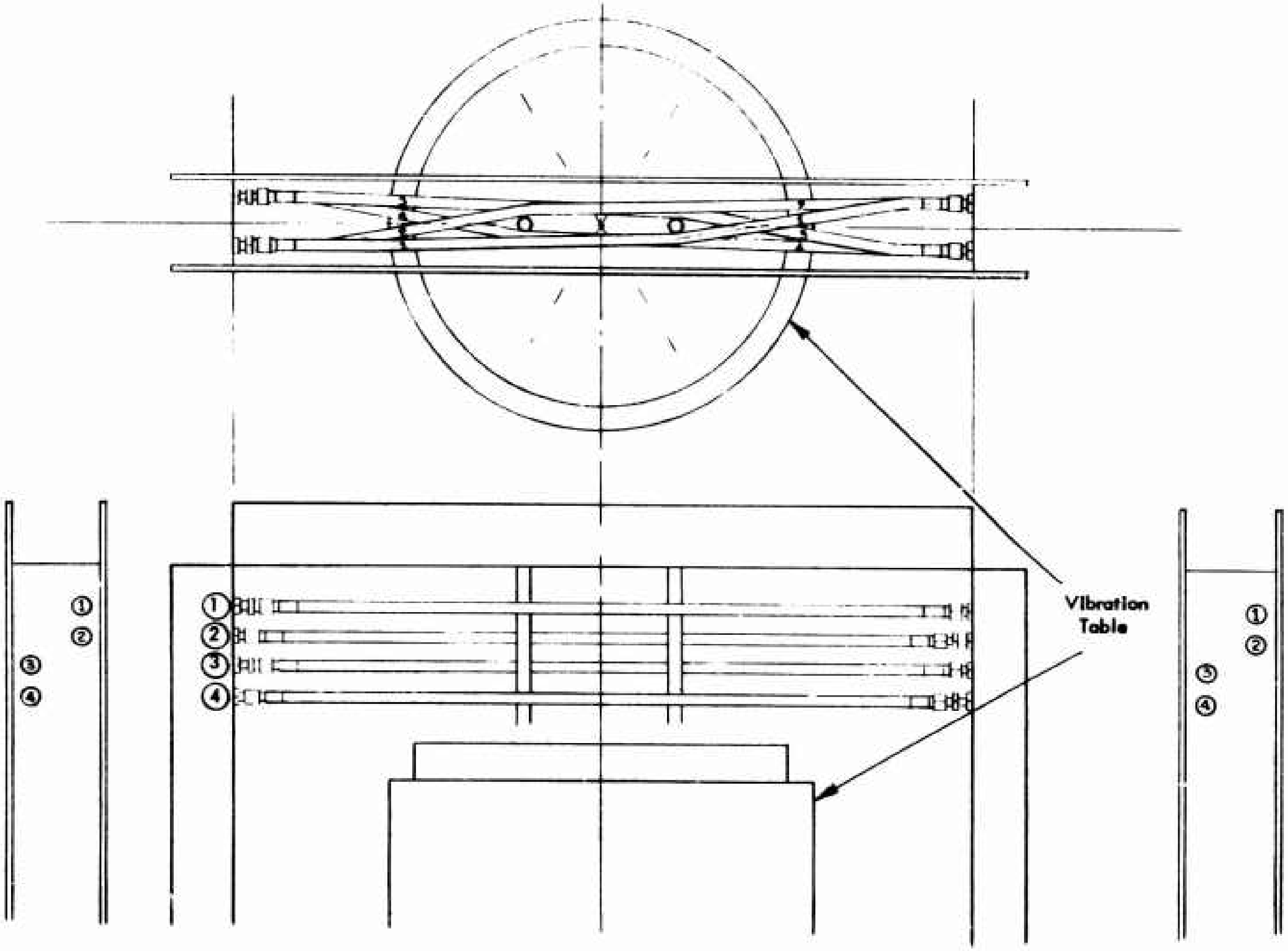


Figure 3. Original Vibratory Chafe Test Setup.

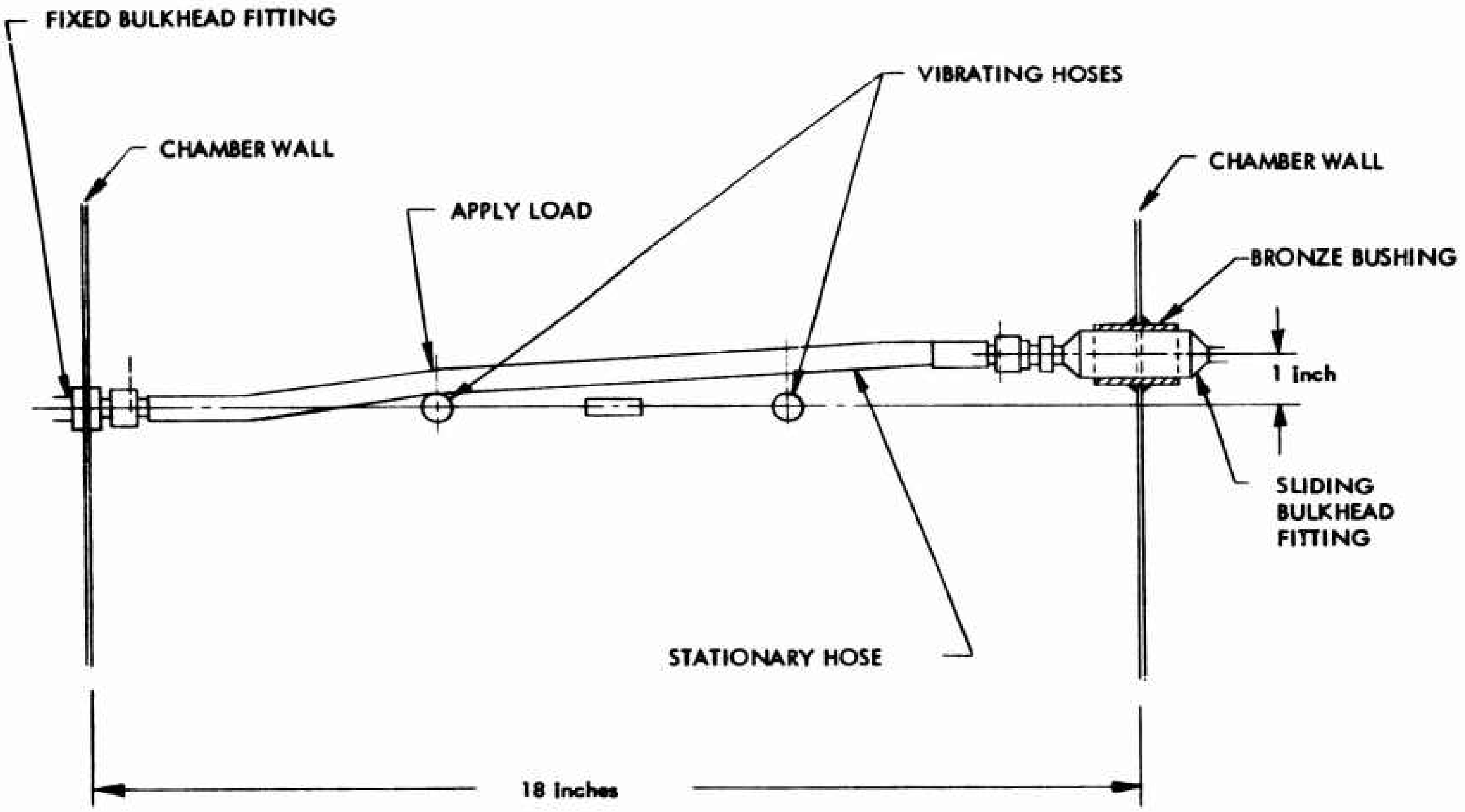


Figure 4. Typical Environmental Test Chamber, Top View, Typical Hose Installation.

VIBRATORY CHAFE-RESISTANCE TESTING

A design requirement for the chafe-resistant hose was that the mean-time-between-failures (MTBF) should be at least ten times as long as the MTBF of the MIL-H-38360A high-pressure hose when subjected to vibratory chafing at ambient temperatures ranging from -65°F to +450°F. To demonstrate compliance with this requirement, a set of six unprotected -4 size hose assemblies and a set of six identical assemblies with integral chafe guard of compound 2 were tested at ambient temperatures of -65°F, +275°F, and +450°F per Vibratory Chafing Test Specification for Flexible Hose Assemblies With Integral Chafe Guard Covers, Appendix II. The -4 size hose was arbitrarily selected as the test hose size. Any size would have been as good as any other.

The test setup is shown in Figure 5. The electrical and hydraulic schematics are shown in Figures 6 and 7 respectively. The accelerated test vibration spectrum described in paragraph 2.3.2.5.2 of Appendix II was used:

Frequency - 20 ± 1 Hertz
Double Amplitude - 0.500 ± 0.010 inch
Vibration Form - Sinusoidal

A contact force of 4.00 ± 0.01 lb was maintained at the point of intersection of the chafing hoses. A flow rate of 0.5 ± 0.05 gallon per minute of MIL-L-7808 oil at 3000 ± 25 psig and 275 ± 10°F was maintained within the samples. The test results are reported in Table IX and are presented graphically in Figure 8 to illustrate the effect of temperature on time to failure. Figures 9 through 15 illustrate typical failed specimens of protected and unprotected hoses at each test temperature. Figure 16 illustrates a typical wear scar of a hose specimen with compound 2 integral chafe guard which did not fail after 40 hours chafing at -65°F. Each photograph shows the pressurized test specimen above and the mating upright below the caption.

The total energy available to produce wear at the point of contact is the sum of the energy provided by the vibrator and the internal thermal energy of the system. Internal energy increases geometrically with temperature at the rate of 10 to 20% for a rise of 1°C (1.8°F).(1) As the energy input of the vibrator is constant for this series of tests, the wear rate should be a power function of the temperature. Another way of expressing this is that the logarithm of the time to failure (MTBF) should vary inversely with the temperature, and a plot of MTBF vs temperature on semilogarithmic graph paper should be linear and have a negative slope.

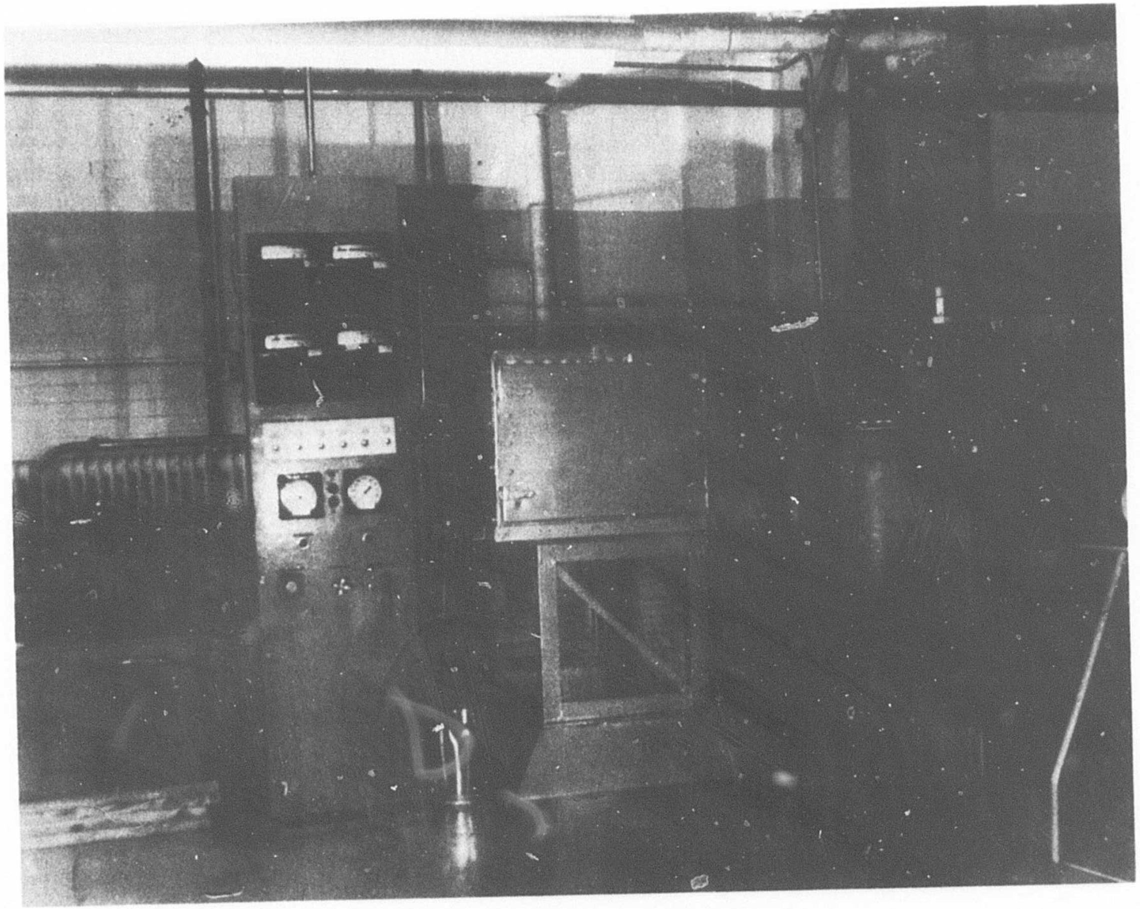


Figure 5. Vibratory Chafing Test Equipment.

This is verified experimentally both for bare hose and for hose protected with integral chafe guard as demonstrated in Figure 8. The difference in slope of the two lines represents the difference in thermal effect on wear resistance inherent in the materials, and the horizontal displacement represents the additional quantity of material which must be worn away to produce failure in the hose assembly protected with integral chafe guard. The fact that the correlation coefficients, r, obtained for the least-squares regression equations of the lines characterizing the experimental data are very close to being equal to 1.0 lends great support to the theoretical analysis above.

This analysis may be used to extrapolate MTBF data for both unprotected hose and hose protected with integral chafe guard for any set of operating parameters selected. We need only experimentally establish a single value of MTBF for either type of hose at any temperature within the range studied using identical fluid conditions together with any desired vibration spectrum and contact force. This is true because the internal energy/wear resistance/temperature relationships are inherent in the system. Only the energy input of the vibrator has been changed, and once the effect of this change on wear rate has been determined at any point on either curve, the entire spectrum of values can be confidently projected.

It was a further requirement that the hoses be capable of operating when subjected to the vibratory chafing conditions above after having been subjected to each of the following treatments:

1. Apply MIL-E-5007C sand uniformly over the entire surface of the hoses.
2. Soak the hose assemblies for 24 hours in MIL-G-5572 fuel (gasoline) immediately prior to testing.
3. Soak the hose assemblies for 24 hours in MIL-T-5624 fuel (JP-4) immediately prior to testing.

The results of these tests, all at 275°F ambient temperatures, are reported in Table X. Figures 17, 18, and 19 illustrate typical failed hose specimens from each of the above tests.

Reliability analyses were conducted to determine the 90, 95, and 99 percent confidence intervals for MTBF at each of the foregoing conditions. The results of these analyses have been reported in Tables IX and X. Figure 8

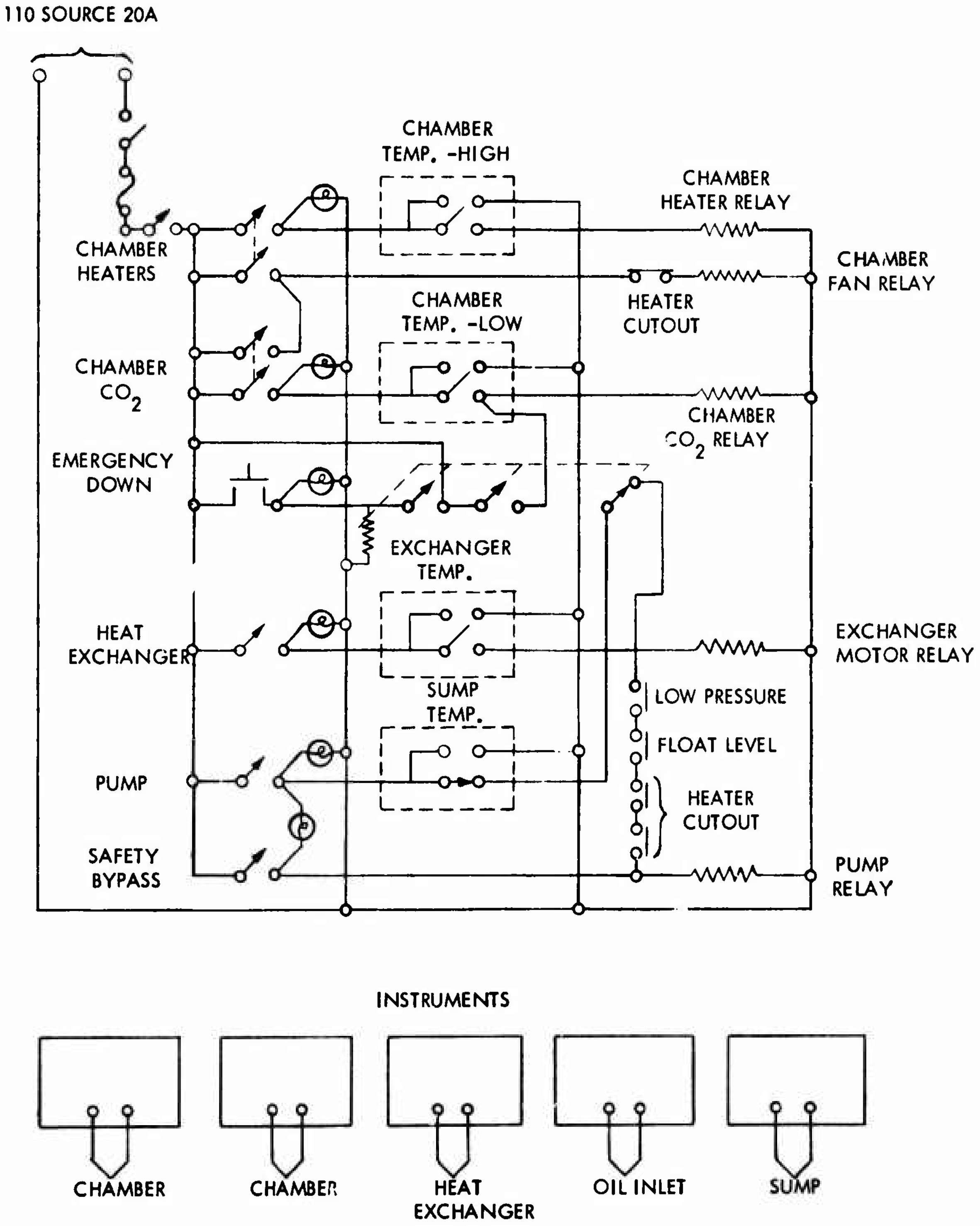
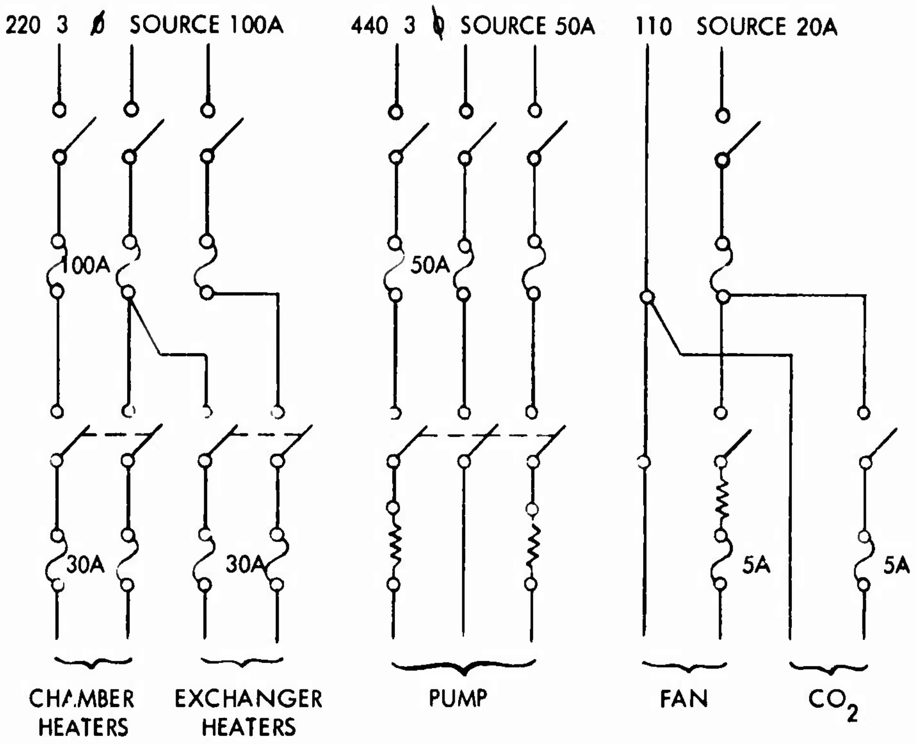
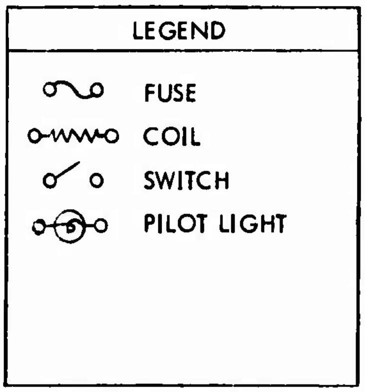


Figure 6. Electrical Schematic


220 3 ø SOURCE 100A
440 3 ø SOURCE 50A
110 SOURCE 20A
100A
50A
30A
30A
5A
5A
CHAMBER HEATERS
EXCHANGER HEATERS
PUMP
FAN
CO2


LEGEND
FUSE
COIL
SWITCH
PILOT LIGHT

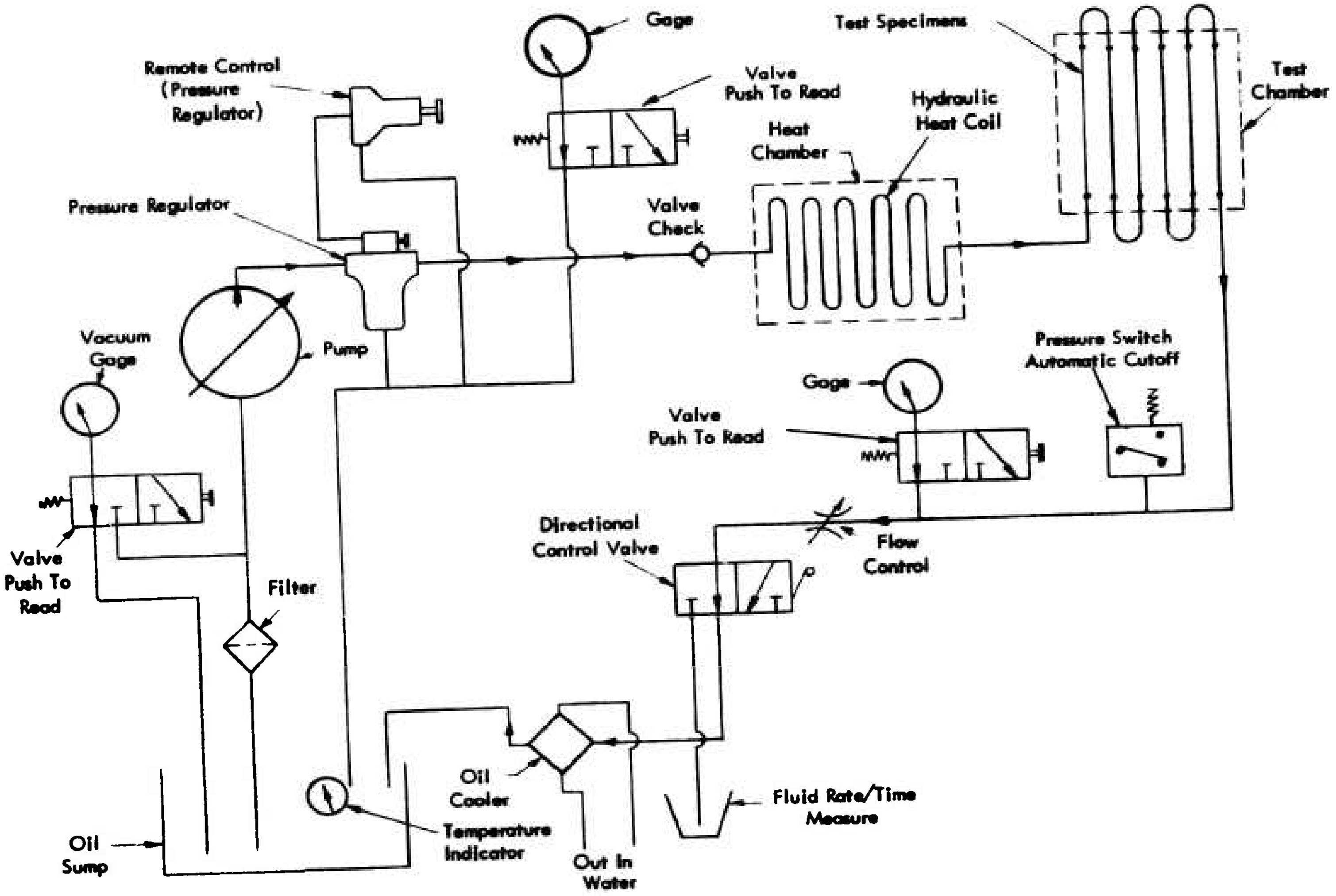


Figure 7. Hydraulic Schematic.

TABLE IX. CHAFE RESISTANCE OF MIL-H-38360A HOSE TIME TO FAILURE, MINUTES (MTBF)

Ambient Temp.	-67° F		+275° F		+450° F	
Chafe Guard	Base Hose None	Cmpd. 2	Base Hose None	Cmpd. 2	Base Hose None	Cmpd. 2
Data Point						
1	*	973	41	235	75	163
2	24	2400**	*	496	21	152
3	162	193	49	572	22	304
4	103	2400**	49	494	11	129
5	164	2400**	58	370	27	464
6	148	2400**	60	469	30	214
Sample Size = n	5	6	5	6	6	6
Mean = $\bar{X}$	120	1794	51	439	31	238
Std. Dev. = S	59	970	8	119	23	127
Std. Error = $S/\sqrt{n}$	26	396	3	49	9	52
	90 % Confidence Level: $\alpha = .01, \alpha/2 = .05$					
$t(\alpha/2, n-1)$	2.13	2.02	2.13	2.02	2.02	2.02
$E = t(S/\sqrt{n})$	56	798	7	98	19	105
Interval						
$\bar{X} - E < \mu$	64	996	44	341	12	133
$\bar{X} + E > \mu$	177	2592	59	538	50	342
	95 % Confidence Level: $\alpha = .05, \alpha/2 = .025$					
$t(\alpha/2, n-1)$	2.78	2.57	2.78	2.57	2.57	2.57
$E = t(S/\sqrt{n})$	73	1018	10	125	24	133
Interval						
$\bar{X} - E < \mu$	47	776	42	314	7	104
$\bar{X} + E > \mu$	194	2813	61	565	55	371
	99 % Confidence Level: $\alpha = .01, \alpha/2 = .005$					
$t(\alpha/2, n-1)$	4.60	4.03	4.60	4.03	4.03	4.03
$E = t(S/\sqrt{n})$	73	1018	10	125	24	133
Interval						
$\bar{X} - E < \mu$	0	197	36	243	0	28
$\bar{X} + E > \mu$	242	3391	67	636	68	447

* Specimen found to be loose; data point deleted.

** Specimen did not fail; test terminated at 40 hours.

t Student's "t" distribution.

μ Population mean.

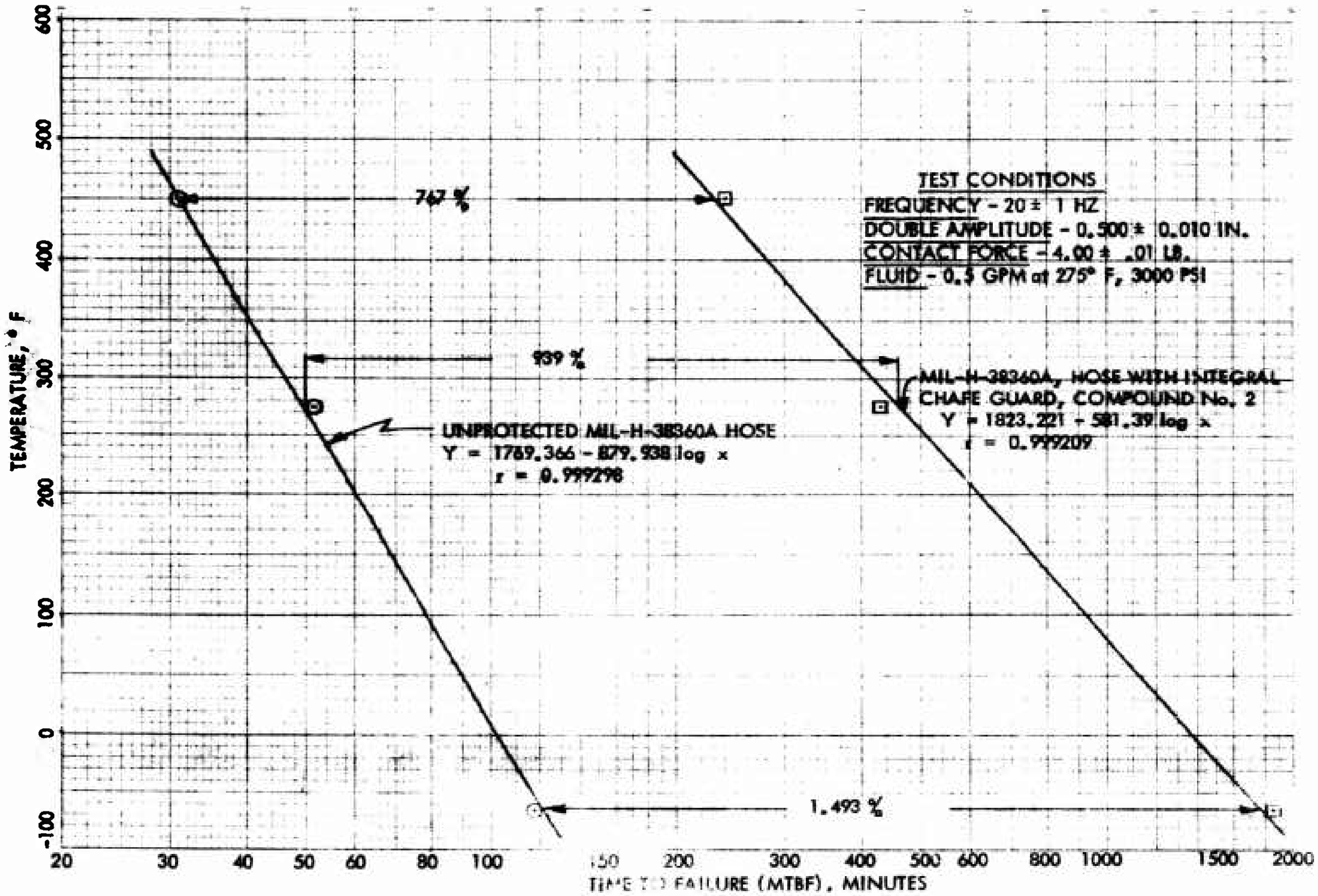


Figure 8. Chafe Resistanc MIL-H-38360A Hose,
Time to Failure at Various Temperatures.

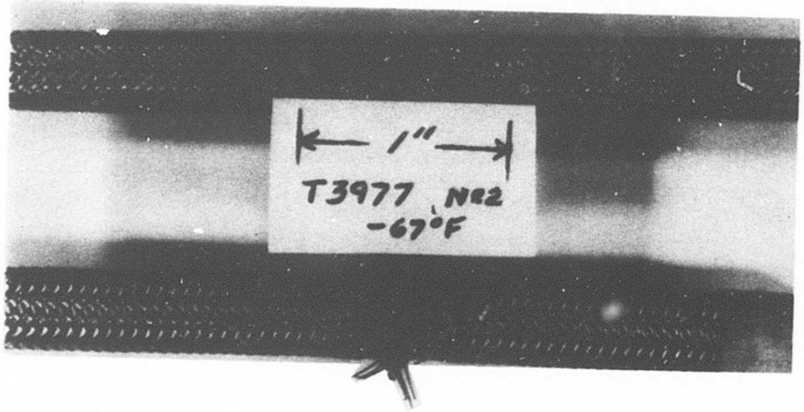


Figure 9. Typical Failed Hose, Unprotected, Ambient Temperature, -67°F.

Figure 10. Typical Failed Hose, Compound 2 Integral Chafe Guard, Ambient Temperature, -67°F.

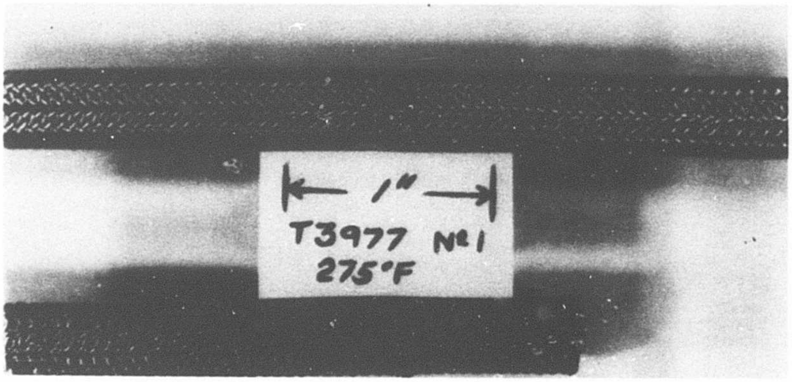


Figure 11. Typical Failed Hose, Unprotected, Ambient Temperature, +275°F.

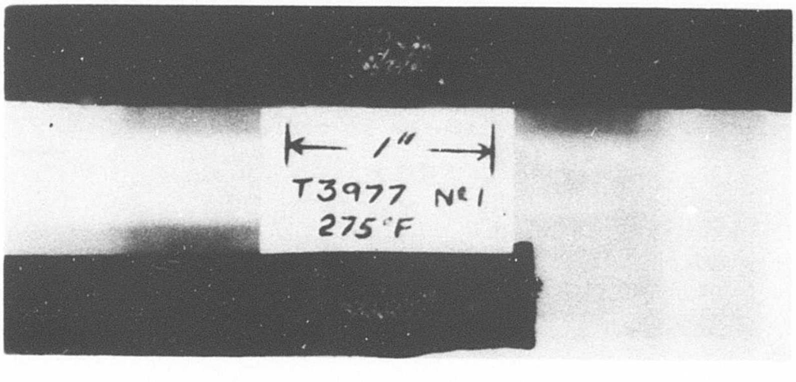


Figure 12. Typical Failed Hose, Compound 2 Integral Chafe Guard, Ambient Temperature, +275°F.

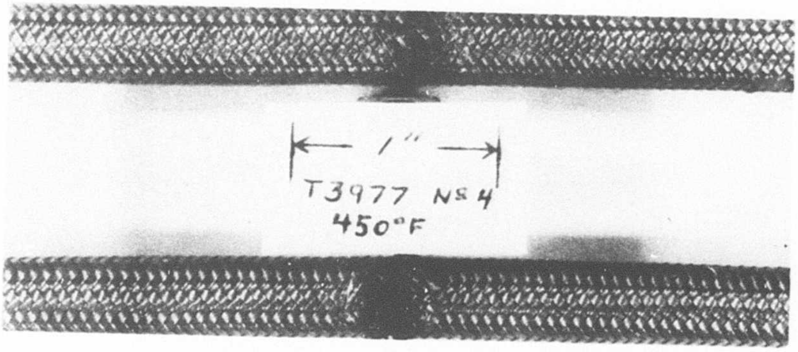


Figure 13. Typical Failed Hose, Unprotected, Ambient Temperature, +450°F.

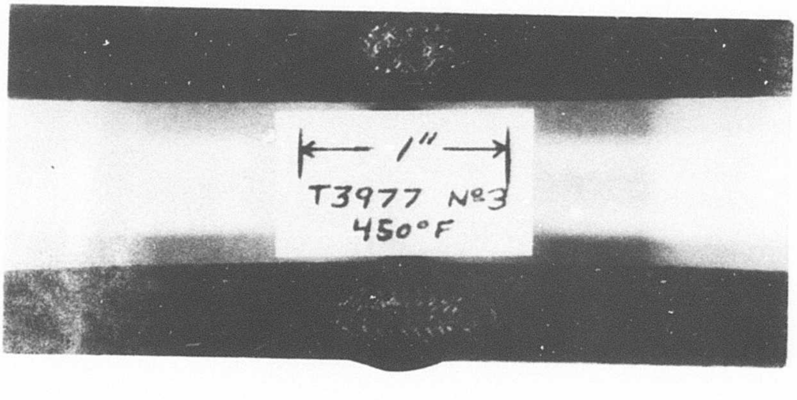


Figure 14. Typical Failed Hose, Compound 2 Integral Chafe Guard, Ambient Temperature, +450°F.

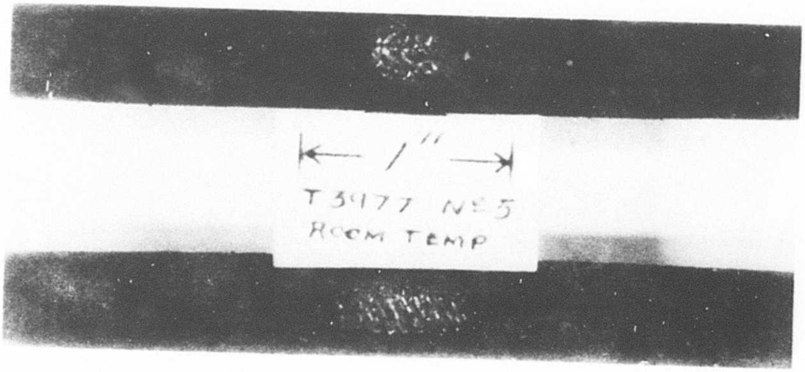


Figure 15. Typical Failed Hose, Compound 2 Integral Chafe Guard, Ambient Temperature, Room Temperature.

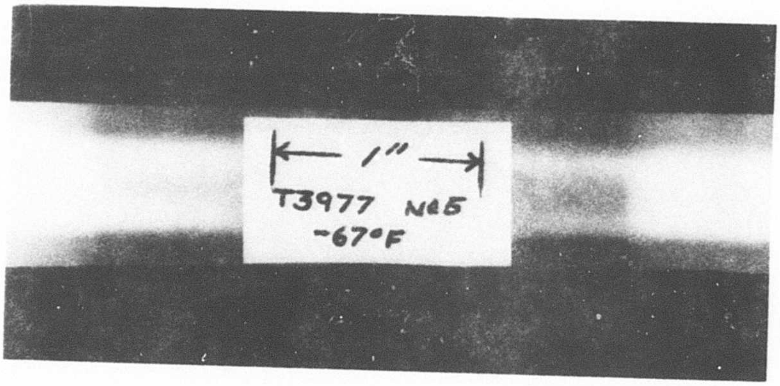


Figure 16. Typical Wear Scar of Tested Hose Specimen With Compound 2 Integral Chafe Guard; Did Not Fail After 40 Hours Chafing at -65°F.

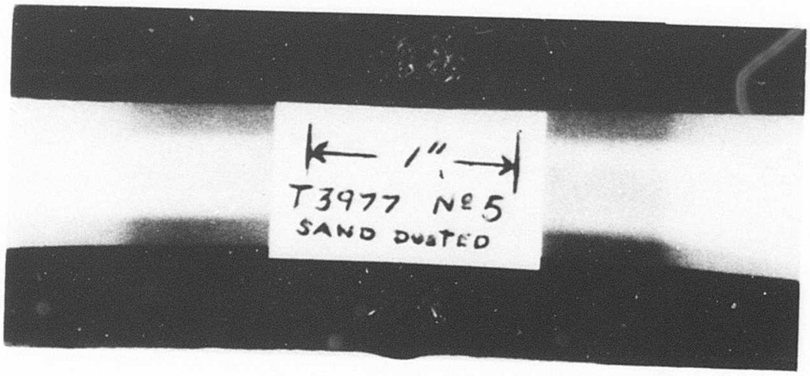


Figure 17. Typical Failed Hose, MIL-E-5007C
Sand Applied Prior to Test.

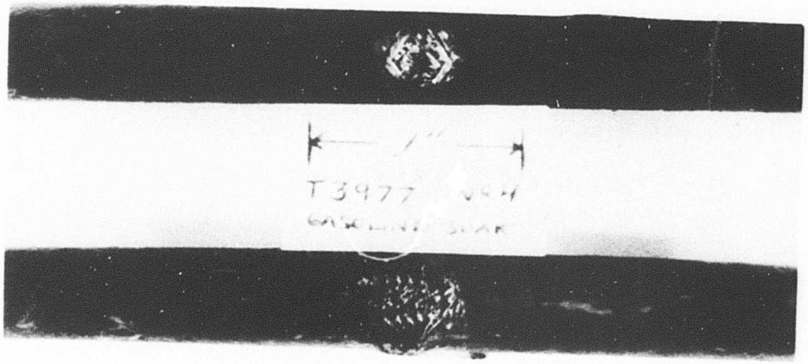


Figure 18. Typical Failed Hose, Fluid
Soaked in Gasoline Prior to Test.

Figure 19. Typical Failed Hose, Fluid Soaked in JP-4 Prior to Test.

TABLE X. CHAFE RESISTANCE OF MIL-H-38360A HOSE WITH INTEGRAL CHAFE GUARD AFTER VARIOUS PRETREATMENTS

Time to Failure, Minutes (MTBF)

Pretreatment	None (Reference)	Cover with MIL-E-5007C Sand	24 Hr. Fluid Soak (JP-4)	24 Hr. Fluid Soak (Gasoline)
Ambient Temp.	+275° F	+275° F	+275° F	+275° F
Data Point				
1	235	387	464	346
2	496	420	216	548
3	572	525	321	410
4	494	498	506	192
5	370	260	350	249
6	469	475	428	408
Sample Size = n = 6				
Mean = $\bar{X}$	439	428	381	359
Std. Dev. = S	119	96	106	127
Std. Error = $S/\sqrt{n}$	49	39	43	52
90 % Confidence Level $\alpha = .1, \alpha/2 = .05, n-1 = 5, t^*(\alpha/2, n-1) = 2.015$				
$E = t(S/\sqrt{n})$	98	79	87	105
Interval				
$\bar{X} - E < \mu$ **	341	348	293	254
$\bar{X} + E > \mu$	538	507	468	463
95 % Confidence Level $\alpha = .05, \alpha/2 = .025, n-1 = 5, t(\alpha/2, n-1) = 2.570$				
$E = t(S/\sqrt{n})$	125	101	112	133
Interval				
$\bar{X} - E < \mu$	314	326	269	225
$\bar{X} + E > \mu$	565	529	492	492
99 % Confidence Level $\alpha = .01, \alpha/2 = .005, n-1 = 5, t(\alpha/2, n-1) = 4.032$				
$E = t(S/\sqrt{n})$	196	158	175	209
Interval				
$\bar{X} - E < \mu$	243	269	206	149
$\bar{X} + E > \mu$	636	586	556	568

* t Student's "t" distribution

** μ Population mean

shows that under the vibratory chafing conditions studied, the hoses with compound 2 integral chafe guard had approximately a fifteen-time increase in MTBF at 65°F, a nine-time increase at 275°F, and an eight-time increase at 450°F when compared to unprotected hose. It is also evident that the presence of MIL-E-5007C sand at the point of contact did not have a significant effect on MTBF. The data of Table X show that hose assemblies protected with compound 2 integral chafe guard subjected to vibratory chafing after being soaked for 24 hours in JP-4 or gasoline immediately prior to testing exhibit an MTBF less than 20 percent lower than the MTBF of unsoaked assemblies.

The final requirement for chafe resistance to be demonstrated by the replacement hose was to retain operating pressure for at least 600 hours when contacting a similar hose in a vertical plane at a single point of contact with a 1-pound contact force at the vibration conditions described in MIL-STD-810B, 20 October 1969, Notice One, Test Method 514.1, equipment category C, procedure 1, curve M.

A resonance search was conducted as required by the above procedure, and as no resonant frequencies were found, 110 Hertz at 5 g was selected as the operating point for the 600-hour duration of the test. During this test, observations were made every 12 hours until the wear experienced by the chafing hoses became readily apparent to the human eye before failure without requiring physical separation of the hoses as required by the contract. A measurement was taken over the hoses at the points of contact at these times to plot wear against time (Figure 20). The appearance of red wear debris clinging to each of the chafing hoses was noted at 52 hours (Figure 21). All specimens of hose with integral compound 2 chafe guard successfully completed the 600-hour test.

After completion of the 600-hour test, photographs of a typical wear scar were taken at actual size (Figure 22) and at 20X magnification (Figure 23). Figure 23 clearly shows the formation of a protective film of TFE over the outer braid of the hose, preventing metal-to-metal contact. The wires are intact, and no wear whatsoever is apparent. The penetration of the chafe guard compound into the interstices of the braid and its excellent adhesion to the wires are also shown. This penetration provides a ready supply of fresh lubricant to renew the protective film should it be worn away during a period of extreme vibration.

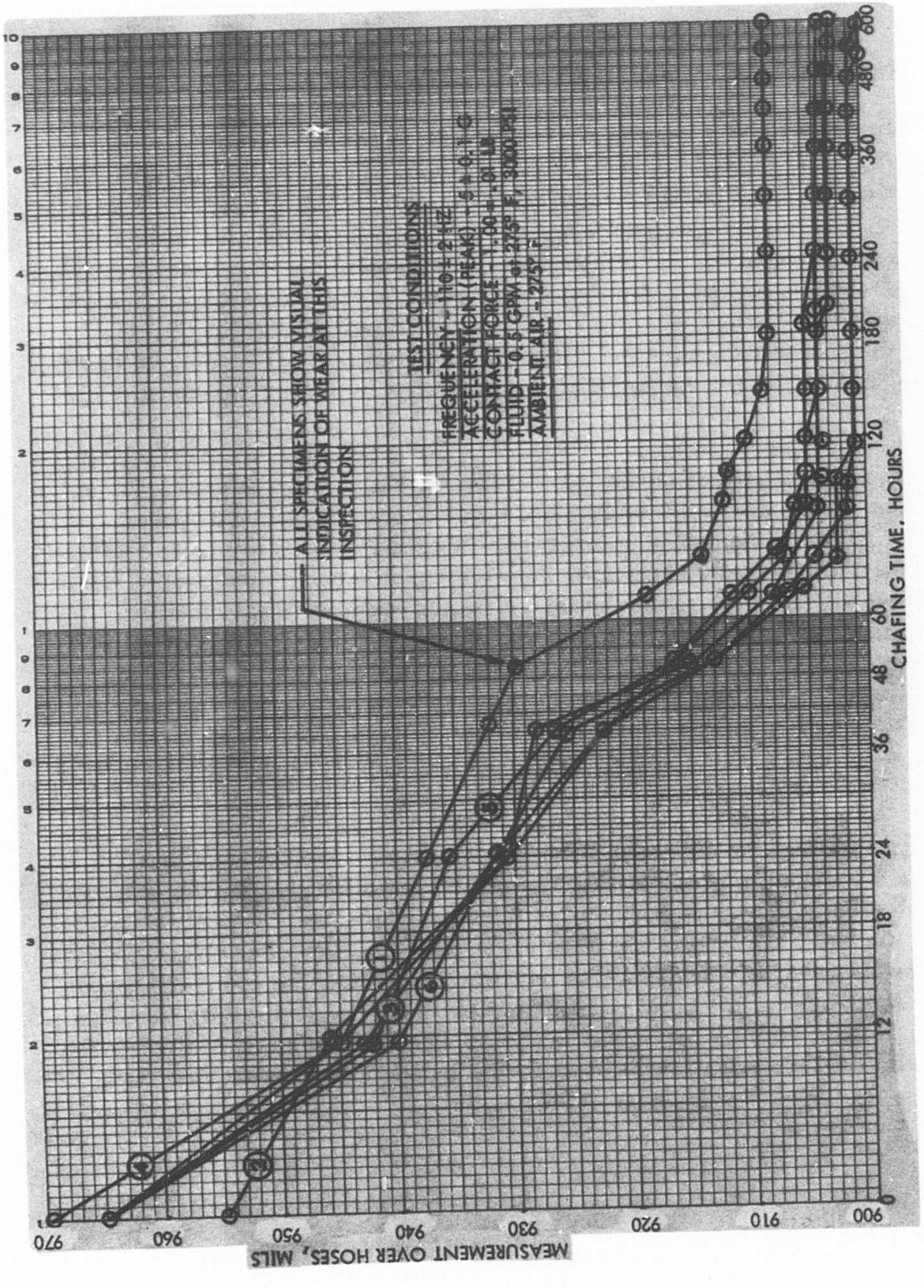


Figure 20. Wear vs. Time, 600-Hour Vibratory Chafe Test.

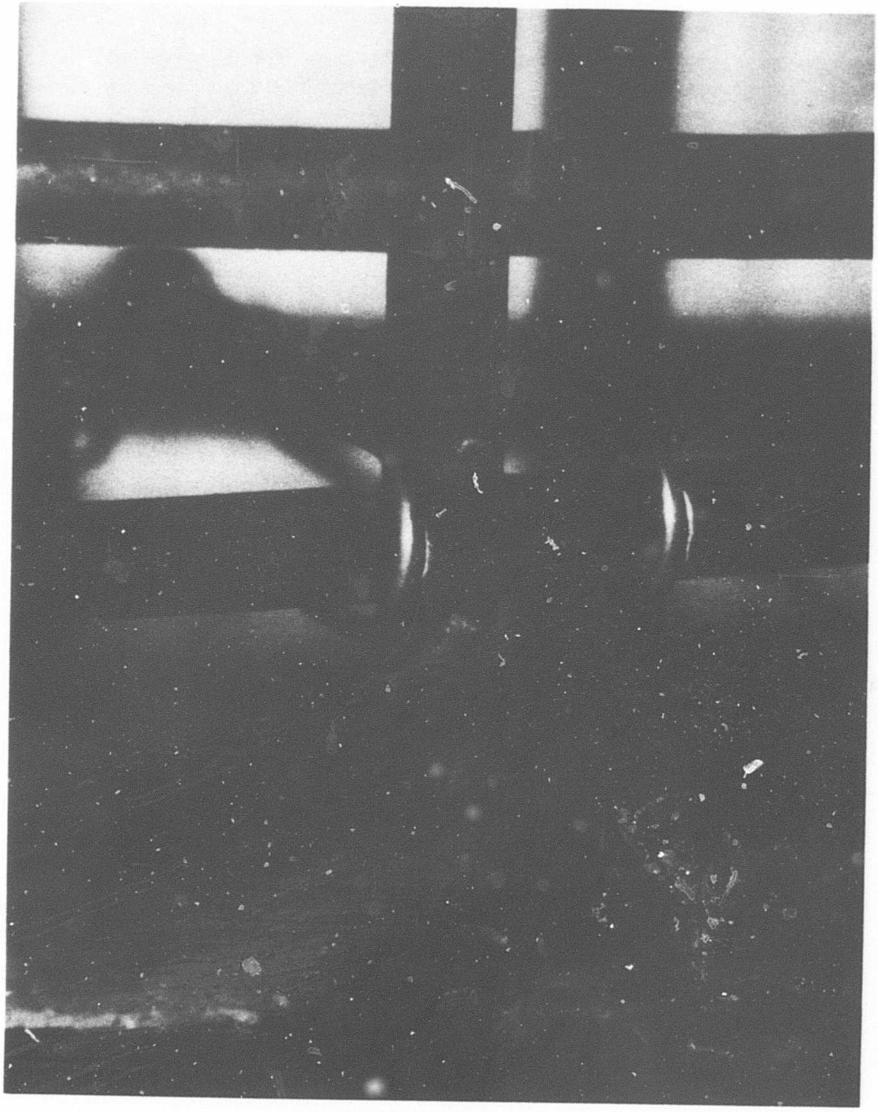


Figure 21. Wear Debris Clinging to Chafing Hoses, 600-Hour Vibratory Chafe-Resistance Test.

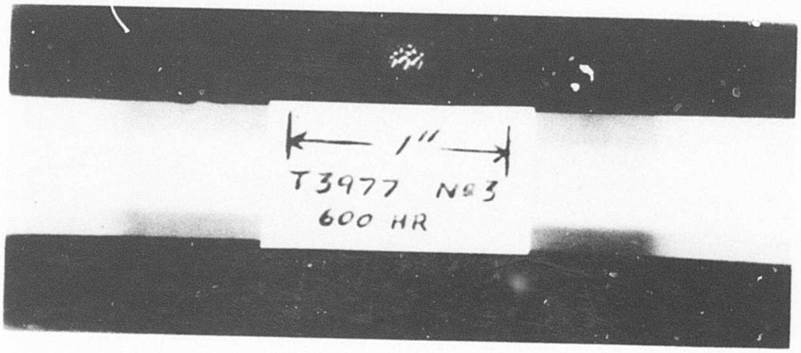


Figure 22. Typical Wear Scar After 600-Hour Chafe Test, Actual Size.

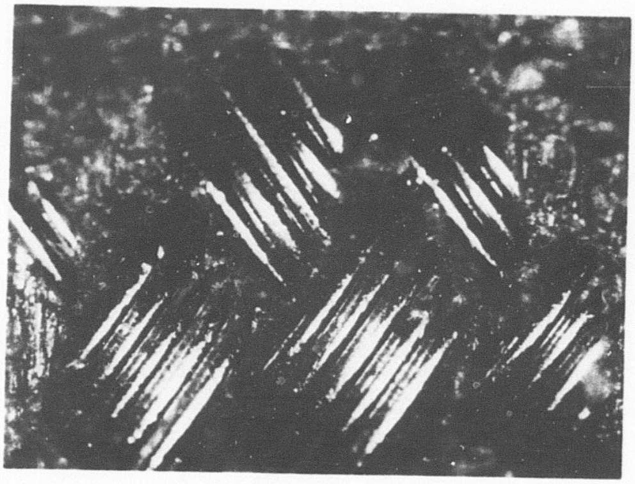


Figure 23. Typical Wear Scar After 600-Hour Chafe Test, 20X Magnification.

TESTS PER MIL-H-38360A and MIL-H-27267A

The hose with integral compound 2 chafe guard was next tested using the most severe conditions noted in MIL-H-38360A or MIL-H-27267A for each of the parameters listed in the following paragraph to assure that the integral chafe guard had not produced any deleterious effect on the basic hose (MIL-H-38360A, -4 size).

Fifty-four hose assemblies were prepared and tested according to the qualification test sequence of Table XI. A reliability analysis was conducted to determine the 90, 95, and 99 percent confidence intervals for those results, such as burst pressure, wherein numerical values were generated (numbers 4, 8, 9, and 11 listed below). These results are reported in Table XII.

1. Operating Temperature: -65°F to +450°F

2. Operating Pressure: 3000 psi

3. Proof Pressure: MIL-H-38360A, paragraph 3.5.2.1. Hose assemblies 1 through 54 were filled with water and pressurized to 6000 psi for 1 ± 0.1 minute. No evidence of leakage or other malfunction was noted.

4. Burst Pressure: MIL-H-38360A, paragraph 3.5.2.5. Hose assemblies 13 through 18 were filled with water and subjected to a pressure rise of 20,000 ± 5000 psi per minute until burst occurred. No evidence of leakage or other malfunction was noted prior to burst. Burst pressures all exceeded the specified 16,000 psi and are reported in Table XII.

5. Ozone Resistance: Hose assemblies 31 through 36 were exposed to ozone at a concentration of 120 parts per million for 60 minutes at 100° ± 5°F while in minimum bend radius. No cracking, checking, or other adverse effects were observed.

6. Fuel Resistance: MIL-H-27267A, paragraph 3.6.2.11. Hose assemblies 49 through 54 were filled with MIL-J-5624 fuel and maintained at 260°F for 48 hours at the operating pressure (3000 psi). The assemblies were then drained, cooled, and refilled with TT-S-735, Type III fluid at room temperature and pressurized to the operating pressure (3000 psi) for 2 hours. No leakage or other evidence of malfunction was observed.

TABLE XI. TEST SEQUENCE BY MILITARY SPECIFICATION PARAGRAPH NUMBER

Sample No.:	1-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54
	*3.6.1.6	4.6.1	4.6.1	4.6.1	4.6.1	4.6.1	4.6.1	4.6.1	4.6.1
	*3.6.1.3	4.6.4	4.6.4	4.6.4	4.6.4	4.6.4	4.6.4	4.6.4	4.6.4
		4.6.5	4.6.6	4.6.7	4.6.12	4.6.7	4.6.10	*3.6.2.12	*3.6.2.11
		4.6.11	4.6.14	4.6.9	4.6.13	4.6.15		**	*3.6.2.8
		*4.6.13	4.6.8						**

* Test per MIL-H-27267A, Amendment 3, dated June 11, 1971.

** Chafe resistance per Appendix II.

All other testing per MIL-H-38360A, Amendment 2, January 8, 1973.

Note: Samples 19, 20, 21, 37, and 38 were also air-aged according to paragraph 4.5.2, MIL-H-38360A; samples 39 and 40 were oil-aged according to paragraph 4.5.3, MIL-H-38360A.

TABLE XII. TEST RESULTS, HOSE ASSEMBLIES WITH INTEGRAL COMPOUND 2 CHAFE GUARD

MIL-H-38360A Paragraph	3.5.2.5	3.5.2.2	3.5.2.2	3.5.2.3	3.5.2.6
Description	Burst Pressure	Elongation + Contraction (Pressurized)	Elongation + Contraction (Released)	Volumetric Expansion	Thermal Shock
Units	psi	in.	in.	cc/in.	psi
Data Point					
1	17500	0	+.032	.0289	14400
2	16800	-.046	0	.0286	13900
3	17200	-.015	0	.0293	14000
4	16500	-.156	-.032	.0284	14300
5	17500	-.062	-.016	.0288	14250
6	17300	-.046	0	.0286	14100
Sample Size=n=6					
Mean = $\bar{X}$	17060	-.054	-.003	.0288	14160
Std. Dev. = S	400	.055	.016	.0003	190
Std. Error = $S/\sqrt{n}$	180	.024	.007	.0001	90
90 % Confidence Level $\alpha = .1, \alpha/2 = .05, n-1 = 5, t^{*}(\alpha/2, n-1) = 2.0150$					
$E = t(S/\sqrt{n})$	360	.049	.014	.0003	170
Interval					
$\bar{X} - E < \mu$ **	16700	-.103	-.017	.0285	13990
$\bar{X} + E > \mu$	17420	.005	.012	.0291	14330
95 % Confidence Level $\alpha = .05, \alpha/2 = .025, n-1 = 5, t(\alpha/2, n-1 = 2.5706$					
$E = t(S/\sqrt{n})$	460	.062	.018	.0004	220
Interval					
$\bar{X} - E < \mu$	16600	-.117	-.021	.0284	13940
$\bar{X} + E > \mu$	17520	.018	.015	.0292	14380
99 % Confidence Level $\alpha = .01, \alpha/2 = .005, n-1 = 5, t(\alpha/2, n-1) = 4.0321$					
$E = t(S/\sqrt{n})$	730	.098	.028	.0006	340
Interval					
$\bar{X} - E < \mu$	16330	-.152	-.031	.0282	13820
$X + E > \mu$	17790	.044	.026	.0294	14500

* t Student's "t" distribution

** μ Population mean

7. Assembly Flex: MIL-H-38360A, paragraph 3.5.2.8. Hose assemblies 7 through 12 were pressurized and flexed at the minimum bend radius (3") at 70 ± 10 cycles per minute for a total of 400,000 cycles at the following conditions without leakage, burst, fitting blow-off, or other evidence of malfunction:

   a. The test assemblies were soaked with no pressure or flexing at a room temperature of -67° ± 2°F for a minimum of 1 hour.

   b. With no flexing, the assemblies were pressurized to the proof pressure (6000 psi) for a minimum of 5 minutes (first cycle only).

   c. Flexing was begun with the test assemblies pressurized to the operating pressure (3000 psi) with the temperature still at -67°F for a minimum of 4000 cycles.

   d. With the pressure reduced to zero psi, flexing continued for 1000 cycles at -67°F.

   e. The temperature was increased to 400°F, and the assemblies were flexed for 1000 cycles at zero psi. The pressure was increased to 3000 psi with the temperature held at 400°F, and flexing continued until a total of 80,000 was reached.

   f. Steps a, c, d, and e were repeated for a total of five test sequences or 400,000 total cycles.

   g. After completion of step f and with no flexing, the assemblies were pressurized to 6000 psi with the temperature still at 400°F for a minimum of 5 minutes (last cycle only).

8. Elongation and Contraction: MIL-H-38360A, paragraph 3.5.2.2. Hose assemblies 7 through 12 were held in a straight, unpressurized condition and a 10-inch gage length marked off. The test assemblies were then pressurized to the operating pressure (3000 psi) for 5 minutes minimum, and the gage length was remeasured while still pressurized. Changes in length were all less than the specified ± 0.20 inch and are reported in Table XII.

9. Volumetric Expansion: MIL-H-38360A, paragraph 3.5.2.3. Hose assemblies 13 through 18 were tested in accordance with ASTM D571. The volumetric expansion values were below the specified 0.065 cc/in. and are reported in Table XII.

10. Leakage: MIL-H-38360A, paragraph 3.5.2.4
Hose assemblies 19 through 24 were pressurized to 70 percent of minimum room-temperature burst pressure (16,000 x 0.7 = 11,200 psi) for 5 minutes minimum. The pressure was then reduced to zero psi, after which it was raised to 11,200 psi for an additional 5 minutes. No evidence of leakage, burst, fitting blow-off, or other malfunction was observed.

11. Thermal Shock; MIL-H-38360A, paragraph 3.5.2.6
Hose assemblies 19 through 24 were subjected to this test. Assemblies 19 through 21 were aged in air 7 days at 400°F prior to testing; assemblies 22 through 24 were unaged.

a. The test assemblies were mounted, empty, in a test chamber and soaked at an ambient temperature of -65°F ± 2°F for a minimum of 2 hours. At the end of this period, while still at this temperature, MIL-L-7808 oil at a temperature of 400°F and a pressure of 50 psi was suddenly introduced. Immediately after the hot oil filled the assembly, the pressure was raised to the proof pressure (6000 psi) for a minimum of 5 minutes.

b. The pressure was then reduced to 75 ± 25 psi, and the assemblies were soaked at an ambient temperature of 400°F for 1 hour minimum. At the end of this period, while still at this temperature, the assemblies were pressurized to the proof pressure (6000 psi) for a minimum of 5 minutes. The pressure was then released, and while still maintaining 400°F, the pressure was increased at a rate of 20,000 ± 5000 psi per minute until burst occurred.

During step a and the proof portion of step b, no evidence of leakage, burst, fitting blow-off, or other malfunction was observed. The burst pressures were all in excess of the specified 12,000 psi and are reported in Table XII.

12. Impulse: MIL-H-38360A, paragraph 3.5.2.7
Hose assemblies 37 through 42 were subjected to this test. Assemblies 39 and 40 were filled with MIL-L-7808 oil and aged in an air oven at a temperature of 400°F for 7 days. Assemblies 37 and 38 were aged in air for 7 days at 400°F. Assemblies 41 and 42 were unaged.

a. The assemblies were subjected to the proof pressure (6000 psi) for a minimum of 5 minutes.

b. The assemblies were fixed to rigid supports in the minimum bend radius (3 inches) at the apex of the bend.

c. The test assemblies were subjected to 250,000 impulse cycles at a rate of 70 ± 10 cycles per minute. The ambient and test fluid (MIL-L-7808 oil) temperatures were cycled a minimum of two times from room temperature to 400°F with a minimum of 80 percent of the impulses at 400°F. An electronic measuring device was used to determine and control the pressures to the following magnitudes during the cycle: the pressure rose to a peak of 150 percent of operating pressure (3000 x 1.5 = 4500 psi) at a rate of 175,000 psi per second minimum during the initial 15 percent of the cycle; the pressure was then maintained at the operating pressure (3000 ± 100 psi) for the balance of the first 50 percent of the cycle; the pressure was then released within 5 percent of the cycle to zero psi (maximum back pressure, 150 psi) for the balance of the cycle.

No evidence of leakage or other malfunction was observed during the test.

13. Stress Degradation: MIL-H-38360A, paragraph 3.5.2.9
Hose assemblies 25 through 30 were subjected to this test.

a. The test assemblies were filled with MIL-L-7808 oil and placed in an oven at 400°F. The assemblies were pressurized to the operating pressure (3000 psi) for 20 hours.

b. The pressure was gradually released, and the assemblies were removed from the oven, drained, and cooled to room temperature.

c. The assemblies were then filled with MIL-H-5606 oil and pressurized to the operating pressure (3000 psi) for a minimum of 2 hours at room temperature.

d. Steps a, b, and c were repeated for a total of three cycles.

e. After the final 2-hour pressurization, the assemblies were drained, flushed with trichloroethylene, and oven dried for 1 hour at 160° ± 10°F.

f. The assemblies were then removed from the oven, cooled to room temperature, and subjected to an air-underwater test.

g. Each assembly was immersed in a water bath containing no wetting agent and pressurized with air to the operating pressure (3000 psi) for 15 minutes to allow any entrapped air to escape.

h. The pressure was held an additional 5 minutes during which the effused gas was collected from the test assembly, including the hose-to-fitting junctures.

The average rates of effusion were less than the specified 2.0 cc/in./min for each test assembly.

14. Pneumatic Surge: MIL-H-38360A, paragraph 3.5.2.10
Hose assemblies 25 through 30 were subjected to this test subsequent to the stress degradation test above.

a. Each test assembly was installed between two MIL-F-8815 air filters.

b. The test assembly was then pressurized with air to the operating pressure (3000 psi) for 25 minutes at room temperature.

c. After this period of pressurization, a quick-exhaust valve was opened within 50 milliseconds to permit rapid discharge of the pressurized gas.

d. After 5 minutes, the exhaust valve was closed and the test assembly was repressurized per step b and discharged per step c for a total of 16 cycles.

No tube collapse, sponging of the inner tube, or other malfunction was noted upon sectioning the hose assemblies. The downstream filter was examined after testing each assembly, and no evidence of inner tube degradation was found.

15. Pneumatic Effusion: MIL-H-38360A, paragraph 3.5.2.11
Hose assemblies 13 through 18 were immersed in a water bath containing no wetting agent and pressurized with air at the operating pressure (3000 psi) for 1 hour. During the last 30 minutes of the test, the effused gas was collected from the test assembly, including the hose-to-fitting junctures. The total effusion was less than the specified 8.0 cc/ft.

16. Tensile Strength: MIL-H-27267A, paragraph 3.6.1.2
The longitudinal tensile strength of the inner tubes of hose assemblies 1 through 6 exceeded the 3000 psi minimum specified.

17. Conductivity of Inner Core: MIL-H-27267A, paragraph 3.6.1.6
The conductivity of the inner tubes of hose assemblies 1 through 6 exceeded the specified minimum of 10 microamperes when a test potential of 1000 volts dc was applied to the inner surface.

18. Vacuum: MIL-H-27267A, paragraph 3.6.2.8
Hose assemblies 49 through 54 were placed in an air oven at 450°F in the minimum bend radius, and a negative pressure of 28 inches of mercury was maintained for 4 hours. No evidence of collapse or other malfunction was observed.

19. Corrosion: MIL-H-27267A, paragraph 3.6.2.12
Hose assemblies 43 through 48 were cycled by soaking 5 minutes in a 2-1/2 percent salt solution followed by a 25-minute dry-out period in air at 140°F. This cycling was repeated for 172 hours, after which the assemblies were pressurized to the proof pressure (6000 psi) for 5 minutes minimum. No leakage or other evidence of malfunction was observed.

20. Overtightening Torque: MIL-H-38360A, paragraph 3.5.2.12

a. Hose assemblies 31 through 33 were assembled onto a flared fitting end of corrosion-resistant steel construction designed in accordance with MS 33656. The fittings were lubricated prior to assembly with MIL-H-5606 oil. The fittings were tightened to the specified (overtightened) torque value of 160 pound-inches and then were loosened. This sequence was repeated 15 times. There was no evidence of failure or deformation of the fitting assemblies, and the swivel nuts were free enough to turn on the nipple by hand.

b. Hose assemblies 34 through 36 were assembled onto a flareless fitting end of corrosion-resistant steel construction designed in accordance with MS 33514. Lubrication and torque values were the same as for flared fittings above. No evidence of failure or deformation of the fitting assemblies was noted.

21. Hose Dimensions: MIL-H-27267A, paragraph 3.5.2
All 54 hose assemblies conformed to the specified dimensions.

OTHER DESIGN CONSIDERATIONS

The hose with integral compound 2 chafe guard is capable of being cut to any length, assembled, and proof tested with its fitting using only the tools found at the Army aviation direct support maintenance level as described in U.S. Army Supply Catalog 4920-99-CL-A06, July 1971. The integral chafe guard is simply removed in the fitting area, and standard fitting installation procedures are used. Hose fittings are as specified in Military Standards (MS) or Air Force - Navy Aeronautical Standards (AN). Hose clamps are as specified in Military Standard 21919 and Air Force - Navy Aeronautical Standard 742.

The hose has essentially an infinite life during storage and/or transit at the temperatures and humidity extremes shown in Table XIII.(2) (3)

TABLE III. STORAGE AND TRANSIT CONDITIONS

Induced Air Temperature, °F	Induced Relative Humidity, %
160	85
160	2
80	95 to 100
-65	Tending toward saturation

Compatibility of the cleaning materials listed in Table XIV with hose assemblies having integral compound 2 chafe guards was determined by chemical resistance considerations.(3)(4) Each material listed was also discussed with technical personnel of the suppliers of raw materials used in compound 2. Although none of these materials would cause a catastrophic failure of the chafe guard, the use of the items marked with asterisks, which are basically organic solvents, is not recommended.

TABLE XIV. CLEANING MATERIALS

Nomenclature	Specification Number
Cleaning compound, alkaline water base, Type I (liquid concentrate)	MIL-C-25769
Cleaning compound, alkaline water base, Type II (powder form)	MIL-C-25769
Denatured alcohol	MIL-A-6091
Detergent, anionic, synthetic	MIL-D-26937
Detergent, nonionic	MIL-D-16791
Disinfectant	O-D-406
Dope and lacquer thinner*	TT-T-266
Kerosene*	VV-K-211
Paint remover*	TT-R-248
Soap, laundry	P-S-579
Soap, laundry	P-S-585
Soap, mild	P-S-620
Soap, paste	P-S-560
Sodium bicarbonate, technical	O-S-576
Solvent*	MIL-S-11090
Steam cleaning compound	P-C-437

* The use of this cleaning material is not recommended.

ECONOMIC CONSIDERATIONS

Economics play a major role in any decision concerning the implementation of a solution to a problem. The following question must, therefore, be answered: "Is the additional initial cost of a hose assembly protected with an integral chafe guard justified by its longer life, improved reliability, and lowered maintenance and logistical support cost?" To answer this question, we must first establish how much additional cost is being considered.

Addition of an integral chafe guard will add between 20 and 30 percent to the acquisition cost of an unprotected hose, depending on the size. The cost of the end fittings would remain the same. In the case of a hose assembly 2 feet long with permanent, swaged straight fittings, approximately 50 percent of the assembly cost is represented by the fittings; therefore, the cost of the assembly with integral chafe guard would be 10 to 15 percent higher than an identical assembly without chafing protection. The cost of an identical assembly protected with polyolefin shrink tubing would be approximately the same as the assembly with an integral chafe guard, but it would be limited to a maximum service temperature of 200°F as opposed to 450°F. Chafe protection achieved via installation of perfluoro-ethylene-propylene shrink tubing increases the temperature capability to only 400°F and is substantially more expensive than the integral chafe-guard-protected hose.

If we consider a hose assembly 2 feet long with permanent, swaged elbow fittings, the portion of assembly cost represented by the hose drops below 40 percent. Thus a hose assembly of this type protected with an integral chafe guard would cost only 7 to 12 percent more than an unprotected assembly. If non standard fittings are specified, the percentage cost increase for the protected assembly would be even lower. For longer hoses, of course, the percentage cost increase would be higher, up to a maximum of 20 to 30 percent in the case of infinite length.

Based upon the established history for frequency of hose failures on Army helicopters resulting from braid chafe damage, the tenfold increase in MTBF for hoses with integral chafe guards should justify the cost increase discussed above. Of even greater importance is the total potential savings to be realized in the reduction of downtime for aircraft equipped with hoses with the integral chafe guard described in this report.

The economic advantages can be maximized by using permanent end fittings which are lighter, smaller, less expensive, and more reliable than their reusable counterparts. This would be made possible by the low number of hose replacements which would be required due to the large (eight to fifteen times) increase in MTBF which would characterize hose assemblies with integral chafe guards compared to non-chafe-guard-protected hoses.

Use of complete assemblies should reduce downtime due to maintenance for aircraft because they should be available for installation as needed; they do not have to be made after the need is known. However, this saving in downtime may be offset by supply constraints.

A significant improvement in corrosion resistance may be achieved through the use of a standard factory-installed swaged fitting incorporating a corrosion shield as shown in Figure 24. This shield prevents corrosive substances, such as salt spray, from coming into contact with the braid wires and greatly reduces or eliminates the possibility of hose failure due to corrosion damage, as the chafe-guard material is itself highly resistant to acids, alkalis, and salts.

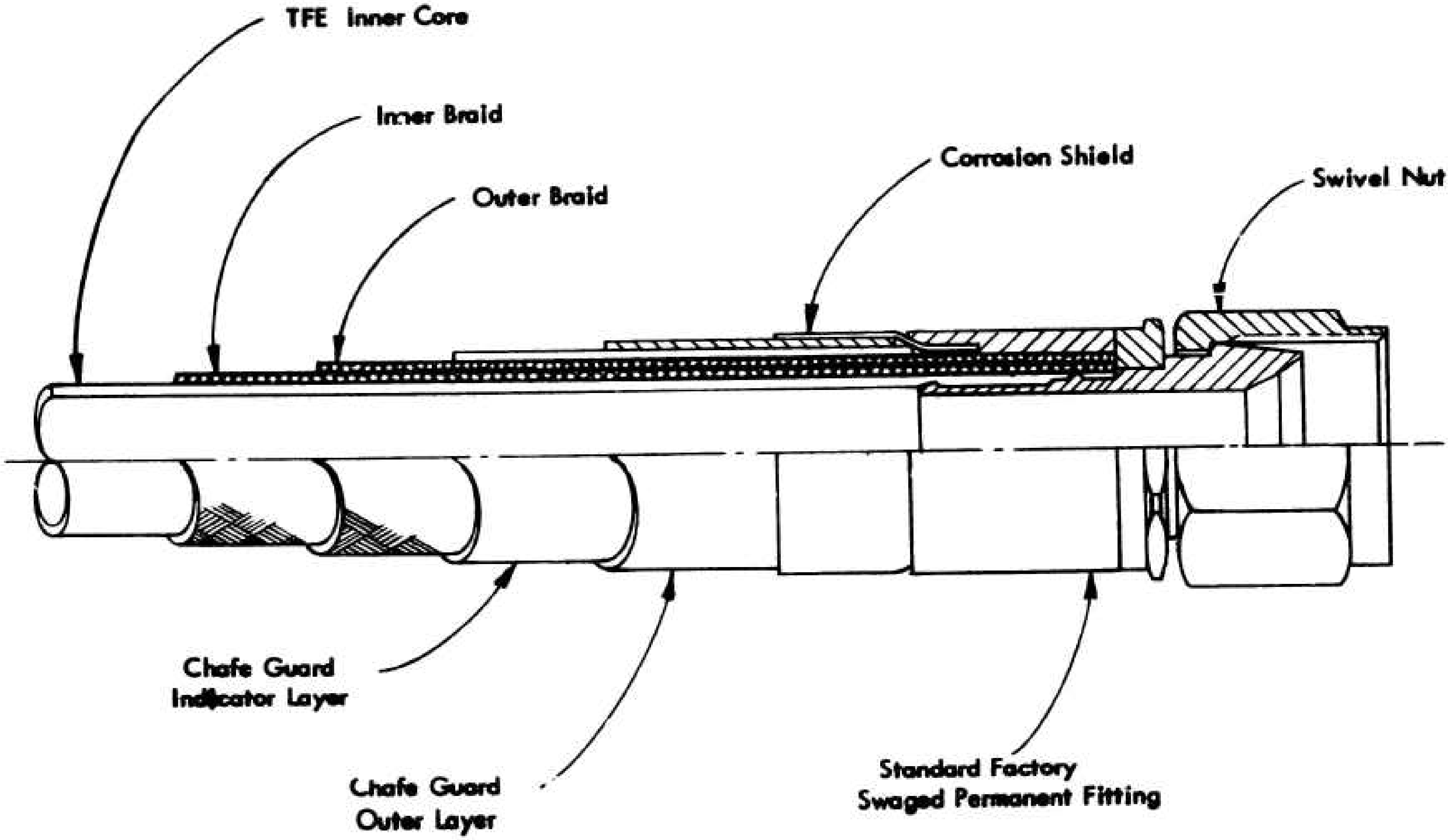


Figure 24. Hose-to-Fitting Assembly With Corrosion Shield.

CONCLUSIONS

It is concluded that:

1. A chafe-resistant flexible fluid hose has been developed which provides a large (eight to fifteen times) increase in mean-time-between failures (MTBF), compared to unprotected hose subjected to identical vibratory chafing conditions.

2. The large increase in MTBF of the integral chafe-guard protected hose involved in this program was achieved without sacrifice in other performance criteria specified in MIL-H-38360A and MIL-H-27267A. The service temperature range of -65°F to +450°F is not compromised by the incorporation of the integral chafe guard.

3. The chafe-resistant flexible fluid hose is capable of retaining operating pressure for at least 600 hours under the vibratory conditions specified in the section of this report entitled "Vibratory Chafe-Resistant Testing". Wear experienced by the hoses under these vibration conditions is readily apparent to the human eye before failure without requiring physical separation of the hoses. The coloring pigments used to indicate wear prior to braid damage do not affect abrasion resistance significantly.

4. The chafe-resistant flexible fluid hoses are capable of operating under the chafing conditions described above after being covered with MIL-E-5007C sand, after being soaked in MIL-G-5572 fuel (gasoline), and after being soaked in MIL-T-5624 fuel (JP-4).

5. Compound 2 is compatible with all the fluids studied, and has excellent abrasion resistance under a wide diversity of conditions.

6. Compound 2 is highly stable; it is not subject to large property changes due to day-to-day processing variables.

7. [illegible] test specifications and criteria which were developed under this program and were used to evaluate the feasibility of candidate chafe-resistant flexible fluid hose coverings can be adapted to industrial use.

8. The incorporation of a stainless steel corrosion shield and a factory-installed, permanent-swaged end fitting should greatly reduce or eliminate corrosive attack on the wire braid.

RECOMMENDATIONS

The following recommendations are made to reduce or eliminate the problems of chafing and corrosion of wire-braided hoses in future-generation Army aircraft:

1. Amend those standards and specifications (such as MIL-H-27267A and MIL-H-38360A) that describe design and test requirements for wire-braided hoses used on Army aircraft to account for chafing characteristics of those hoses that are qualified under those specifications for use by future Army aircraft system developers.

2. Initiate a full-scale field study of flexible hose assemblies with the integral chafe guard (compound 2) involved in this program to measure their effectiveness in improving the reliability and maintainability of the fluid systems of Army helicopters in an actual operating environment.

3. Conduct an economic analysis of an Army aircraft to determine the change in system cost which may accrue through the use of flexible fluid hose assemblies with the integral chafe guard (compound 2) and using either field-installed fittings, or corrosion shields and factory-swaged end fittings. Items to be considered in this analysis should include life-cycle cost, weight, reliability, maintainability, and manufacturing consideration, as well as aircraft downtime and required logistic support.

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3. M. A. Rudner, FLUOROCARBONS, Reinhold Publishing Corp., 1958, pp. 9-16.

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APPENDIX I

ABRASION TEST SPECIFICATION FOR ELASTOMERIC CHAFE-GUARD MATERIALS

1.0 SCOPE

1.1 Scope - This specification defines the standard test criteria for evaluating elastomeric chafe-guard materials.

1.2 Purpose - The purpose of this specification is to provide standard criteria for testing and evaluating the abrasion resistance of elastomeric materials for use as chafe guards for flexible hose.

2.0 REQUIREMENTS

2.1 Test Samples

2.1.1 Buttons - Six molded test buttons shall be prepared from each candidate material in accordance with ASTMD395, paragraph 5b, Note 2. Three buttons shall be in the as-molded condition and three shall be treated with the recommended post-cure for the particular material. Additional buttons shall be prepared and post-cured for high-temperature and fluid-aged testing as required.

2.1.2 Tensile Test Specimens - Four tensile test specimens shall be prepared in accordance with ASTMD412, die C, from a test slab molded from each candidate material in accordance with ASTMD15, Figure 1. Two shall be in the as-molded cure condition and two shall be treated with the recommended post-cure for the particular material. Additional test specimens shall be prepared for fluid-aged testing as required.

2.2 Molding Temperature - Molding temperature shall be as recommended by the manufacturer of the particular elastomer.

2.3 Post-Cure Temperature - Post-cure temperature shall be as recommended by the manufacturer of the particular elastomer.

2.4 Test Parameters and Setup for Abrasion Test

2.4.1 Test Setup - The abrasion test setup shall be in accordance with Figure 25.

2.4.1.1 Grit Size - No. 320 grit silicone carbide sanding belts 6 in. wide x 48 in. long.

2.4.1.2 Velocity of sanding belt - 7.5 ft/sec (450 ft/min) ±10%.

2.4.1.3 Deadweights - Deadweights (see Figure 26) shall have a weight of 1.000 ± .005 lb.

2.4.1.4 Temperature - Test temperature will be as specified ±10°F.

2.5 Test Requirements

2.5.1 Hardness - The Shore A hardness (hardness value measured using Shore Durometer, A scale, ASTMD2240) of four tensile test specimens (two mold-cured and two post-cured) of 2.1.2 shall be determined in accordance with ASTMD2240 and recorded. This test shall also be performed on fluid-aged specimens when fluid-aged testing is required.

2.5.2 Tensile and Elongation - The ultimate tensile strength and elongation of four tensile test specimens (two mold-cured and two post-cured) of 2.1.2 shall be determined in accordance with ASTMD412 and recorded. This test shall also be performed on fluid-aged specimens when fluid-aged testing is required.

2.5.3 Abrasion Test - The following abrasion tests are designed to compile comparative data on different materials to analyze and select the most abrasion-resistant material. The room-temperature tests should be used quite extensively to weed out obviously inferior materials and reduce the number of materials to be tested at increased temperatures and after fluid aging.

2.5.3.1 Room Temperature - The test buttons of 2.1.1 (three mold-cured and three post-cured) shall be weighed with an accuracy of ± .01 gram and the weight recorded. The buttons shall be installed in the test apparatus as shown in Figure 25. A new, unused grit belt shall be used for each test. The belt shall be run for 30 ±.5 minutes. The samples shall be removed from the holding block and any evidence of tackiness, reversion, or other noticeable characteristic recorded.

Each button shall be weighed with an accuracy of ±.01 gram and the weight recorded. The percentage weight loss (% WL) shall be computed using the following formula and recorded:

$$\% \text{ WL} = \frac{\text{Original weight} - \text{Final weight}}{\text{Original weight}} \times 100$$

2.5.3.2 High Temperature (450°F) - The testing of 2.5.3.1 shall be repeated except the sample size shall be six, all post-cured, and the temperature of the test buttons and holding block shall be maintained at 450° ±10°F.

2.5.3.3 Room Temperature and Fluid Aged - The final selected materials shall be subjected to the test procedure of 2.5.3.1 except the sample size shall be twenty-seven, all post-cured. Prior to running this test, sample lots of three buttons shall be subjected to a 24-hour soak at room temperature in each of the test fluids.

After removal from the test fluid, the buttons shall be stored in airtight containers to minimize evaporation losses prior to testing.

Each button shall be weighed with an accuracy of ±.01 gram and recorded. The percentage weight increase after fluid soak

(% WI) shall be computed according to the following formula and recorded:

$$\% \text{ WI} = \frac{\text{Final weight} - \text{Original weight}}{\text{Original weight}} \times 100$$

In certain cases the dimensional increase may be such that the fluid-aged buttons will not slide freely into the holding block. In such cases, the O.D. shall be ground down to provide a loose fit, and the button shall be reweighed and recorded.

The percentage weight loss shall be computed and recorded using the weight after fluid soak (after grinding when necessary) as the original weight in the formula of 2.5.3.1.

2.5.3.4 High Temperature and Fluid Aged - The final selected materials shall be subjected to the test procedure of 2.5.3.3 except the temperature of the buttons and the holding block shall be 450°F.

3.0 EVALUATION AND SELECTION

3.1 Evaluation - Evaluation of the materials shall consist of review of all test data accumulated from the tests performed herein. The chafeguard materials shall be rated with respect to the following criteria, which are listed in the order of their importance:

a. Room-temperature abrasion resistance.

b. High-temperature abrasion resistance.

c. Average room-temperature abrasion resistance after fluid aging.

d. Average high-temperature abrasion resistance after fluid aging.

e. Tensile strength (no fluid age).

f. Elongation (no fluid age).

g. Durometer (no fluid age).

h. Tensile strength after fluid aging.

j. Elongation after fluid aging.

k. Durometer after fluid aging.

3.2 Selection - One or more materials shall be selected for hose chafeguard vibration abrasion testing. These materials shall be selected with respect to the following criteria, which are listed in the order of their importance:

a. Abrasion test evaluation rating of 4.1.

b. Weight.

c. Material cost.

d. Degree of difficulty of compounding the material.

e. Degree of difficulty of extruding onto hoses.

f. Degree of difficulty of post-curing.

4.0 DEVIATIONS

Deviations from this specification shall be coordinated with the procuring agency prior to initiation of testing.

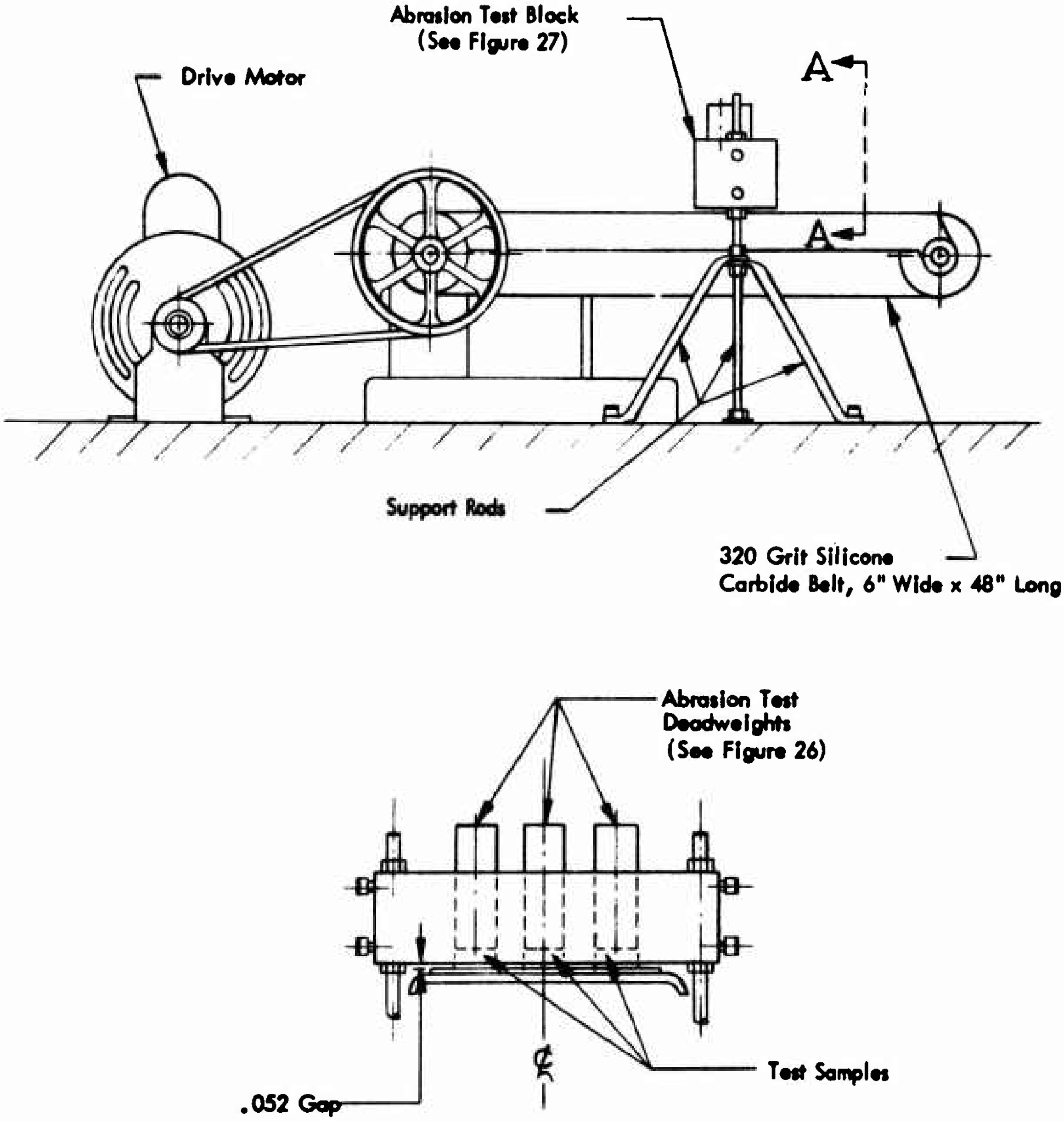
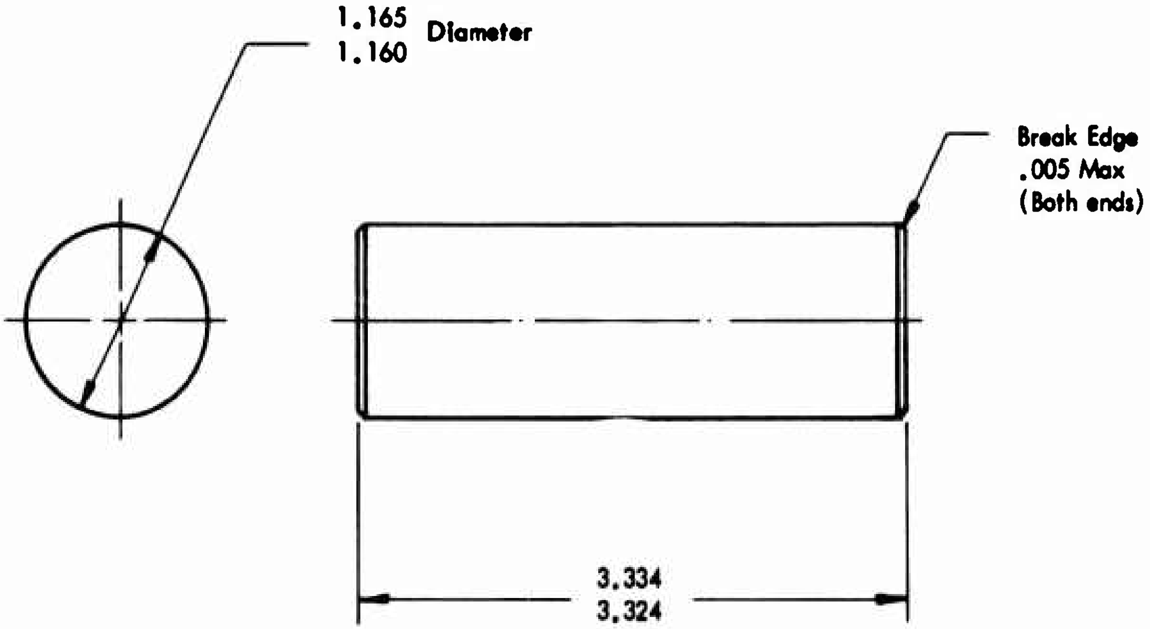


Figure 25. Abrasion Test Setup.

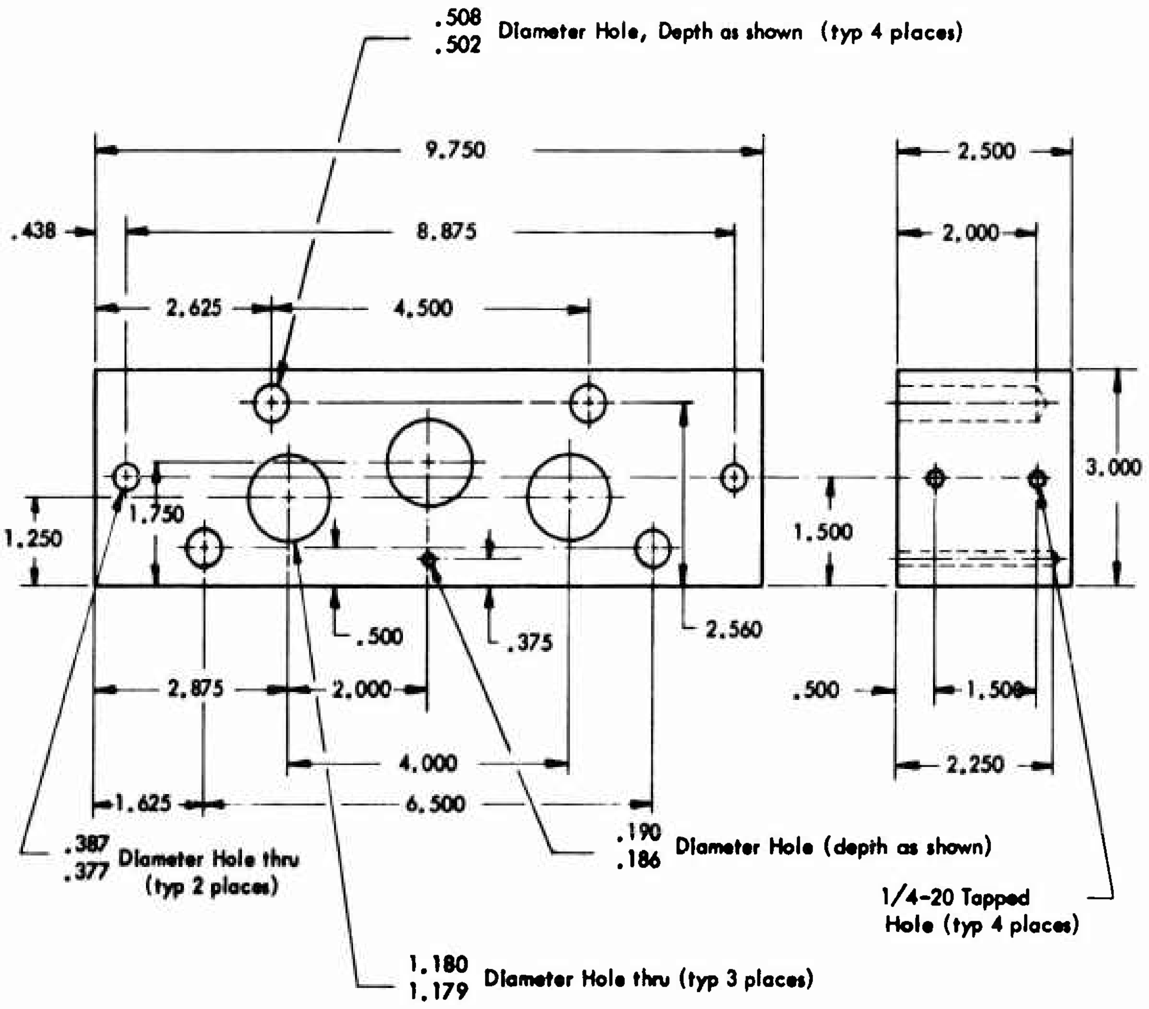


Material: 321 Stainless Steel

Weight: 1.000 ± .010 lb (ref.)

NOTE: All values in inches

Figure 26. Abrasion Test Deadweight.



$\begin{smallmatrix}.508\\.502\end{smallmatrix}$ Diameter Hole, Depth as shown (typ 4 places)

$\begin{smallmatrix}.387\\.377\end{smallmatrix}$ Diameter Hole thru (typ 2 places)

$\begin{smallmatrix}.190\\.186\end{smallmatrix}$ Diameter Hole (depth as shown)

1/4-20 Tapped Hole (typ 4 places)

$\begin{smallmatrix}1.180\\1.179\end{smallmatrix}$ Diameter Hole thru (typ 3 places)

Material: Aluminum - Anodize natural color (yellow)
Tolerances: ± .010 unless otherwise specified
Note: All values in inches

Figure 27. Abrasion Test Block.

APPENDIX II

VIBRATORY CHAFING TEST SPECIFICATION FOR FLEXIBLE HOSE ASSEMBLIES WITH INTEGRAL CHAFE-GUARD COVERS

1.0 SCOPE

1.1 Scope - This specification defines the standard test criteria for evaluating the chafe-resistance qualities of flexible hose assemblies with an integral external chafe guard.

1.2 Purpose - The purpose of this specification is to provide standard criteria for chafe resistance of flexible hose assemblies with integral chafe-guard covers.

2.0 REQUIREMENTS

2.1 Environmental Test Chamber - Vibration/environmental testing shall be performed within an insulated chamber as shown in Figures 28 through 31 and Figure 4.

This chamber is suitable for simultaneous chafe testing at six data points at a given set of environmental test parameters for the -4 size flexible hose (1/2-inch outside diameter). Ideally, a viewing port is provided in the cover(s) for observation during testing, although this is not required.

The test chamber shall be mounted above a transducer capable of producing the vibration spectrum of 2.3.2.5. It is intended that this chamber shall be used for initial screening tests at room temperature in order that only the most promising compositions shall be tested in extreme environments.

2.2 Test Samples

2.2.1 Horizontal members shall consist of hose assemblies with straight end fittings. Hose assembly length shall be as required by the test fixture, as shown in Figure 28.

2.2.2 Vertical members shall consist of hoses without fittings assembled to supporting mandrels.

2.3 Test Parameters and Setup

2.3.1 Test Setup - The test setup shall be as shown in Figure 28.

2.3.2 Test Parameters

2.3.2.1 Ambient Temperature - The ambient air within the test chamber shall be maintained at the following test temperatures:

Low temperature: -65°F ±10°F

Medium temperature: 275°F ±10°F

High temperature: 450°F ±10°F

2.3.2.2 Fluid temperature - The temperature of the test fluid shall be 275°F ±10°F.

2.3.2.3 Pressure - The horizontal members of 2.2.1 shall be pressurized to 3000 ±25 psig.

2.3.2.4 Flow Rate - The flow rate of the test fluid shall be 0.5 ±0.05 gpm.

2.3.2.5 Vibration Spectrum

2.3.2.5.1 Standard Test - The vibration spectrum of the vertical members shall be as described in MIL-STD-810.

2.3.2.5.2 Accelerated Test - To accumulate comparative data on numerous candidate materials in as short a time as practicable, the following vibration spectrum may be used:

Frequency: 20 ±1 hertz

Double Amplitude:
0.500 ±0.010 inch

Vibration Form: Sinusoidal

2.3.2.6 Contact Force - The horizontal members of 2.2.1 shall contact the vertical members of 2.2.2 with a constant force provided by deadweights applied at the point of intersection as shown in Figure 4.

2.3.2.6.1 Standard Test - The deadweight shall be 1.00 ± .01 pounds.

2.3.2.6.2 Accelerated Test - The deadweight shall be 4.00 ± .02 pounds.

2.4 Test Sample Installation Procedure

The horizontal members shall be installed in the stationary test chamber as shown in Figure 4. The interconnections between the hoses shall be made using flexible hose assemblies and the sliding bulkhead fittings in order to minimize extraneous forces on the test specimens.

The vertical members shall be fixed to the vibratory head. The covers shall be closed and the deadweight loading applied. The sliding bulkhead fittings shall be checked for free axial movement and rotation. The test parameters of 2.3.2 shall be stabilized for 30 minutes prior to starting vibration.

2.5 Test Requirements

The vertical members shall be vibrated against the stationary horizontal members per 2.3.2.5 until failure. Failure is defined as loss of operating pressure and/or fluid leakage at the point of contact of the hoses. Time to failure for each sample shall be recorded.

After each failure, the failed sample shall be removed. Fluid leakage shall be removed from the remaining samples as necessary without disturbing their positions or wear scars by spraying with Freon liquid and blowing dry with clean air.

The test parameters shall be restabilized for 30 minutes prior to resuming vibration. The test samples shall be examined and any visual evidence of wear recorded at no more than 12-hour intervals. Vibration shall be stopped for this examination if a failure has not occurred during the preceding 12 test hours.

The test shall be terminated after failure of all the hoses or at the maximum test time specified by the procuring agency. The vertical members shall be removed from the vibratory head, and the wear scars of test samples shall be photographed following each failure or following the maximum test time, whichever comes first.

3.0 EVALUATION AND SELECTION

3.1 Evaluation - The mean-time-between-failures (MTBF) and standard deviation shall be computed for unprotected hose assemblies and for each candidate integral chafe-guard composition. A reliability analysis shall be conducted to determine the 90, 95 and 99 percent confidence interval for each of the temperatures of 2.3.2.1.

3.2 Selection - An integral chafe guard for flexible hoses shall be considered acceptable which provides a fivefold (minimum) increase in failure time over identical unprotected hose when tested in accordance with this specification.

4.0 DEVIATIONS

Deviations from this specification shall be coordinated with the procuring agency prior to initiation of testing.

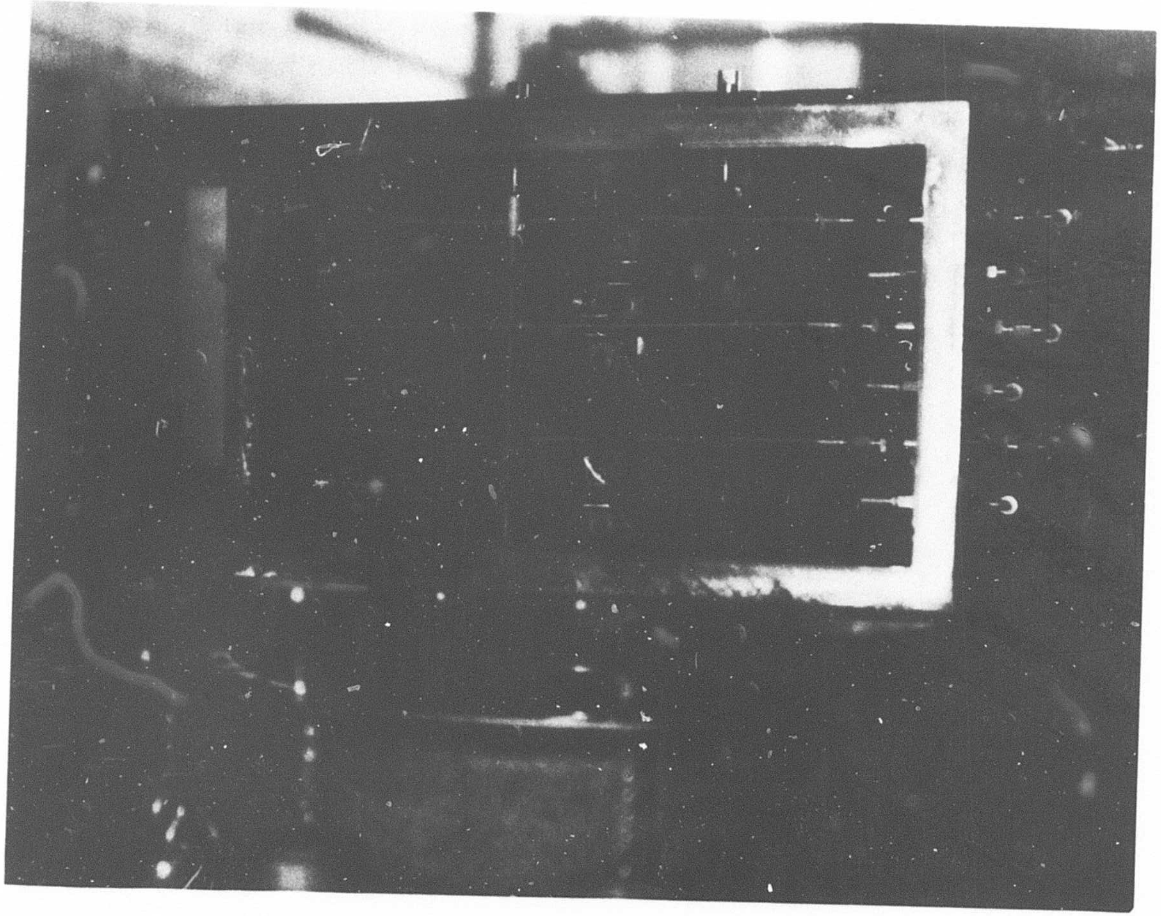


Figure 28. Typical Environmental Test Chamber
With Test Samples Installed, Front Cover Open.

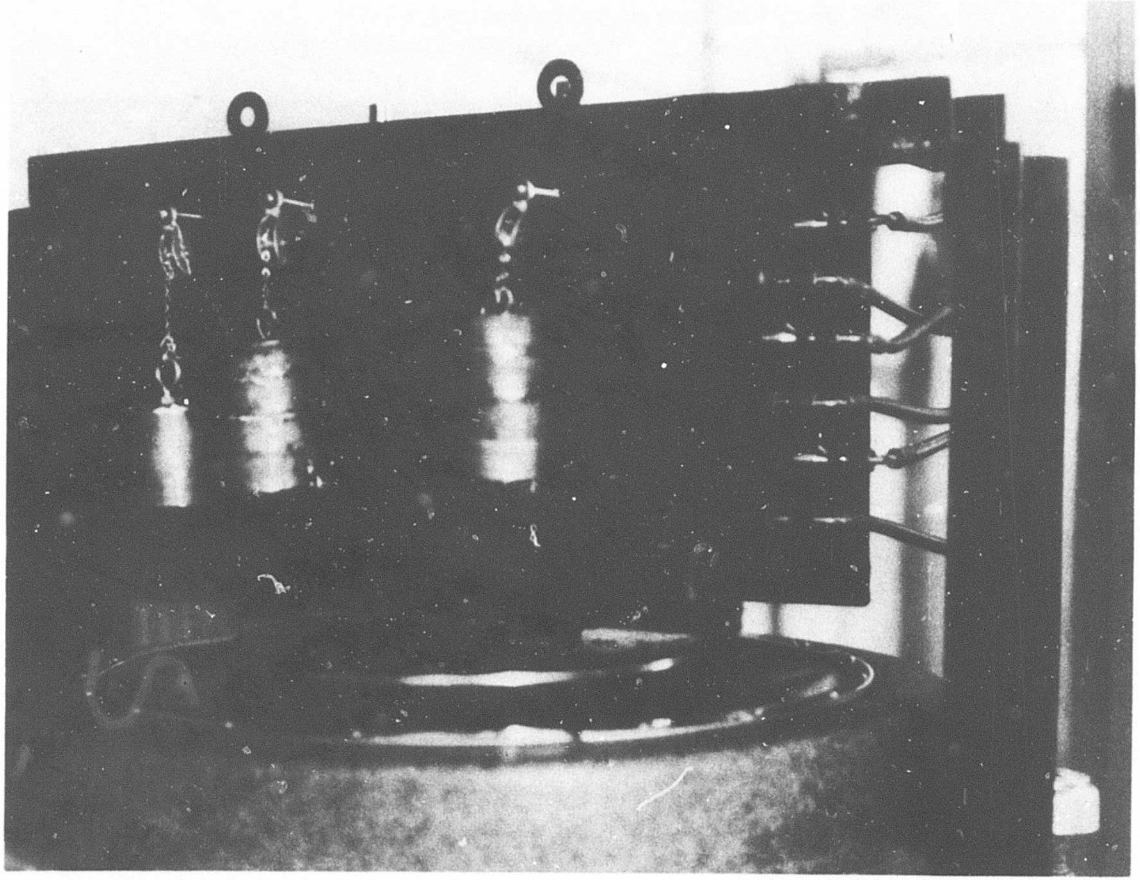


Figure 29. Typical Environmental Test Chamber With Front Cover Closed and Deadweights in Place.

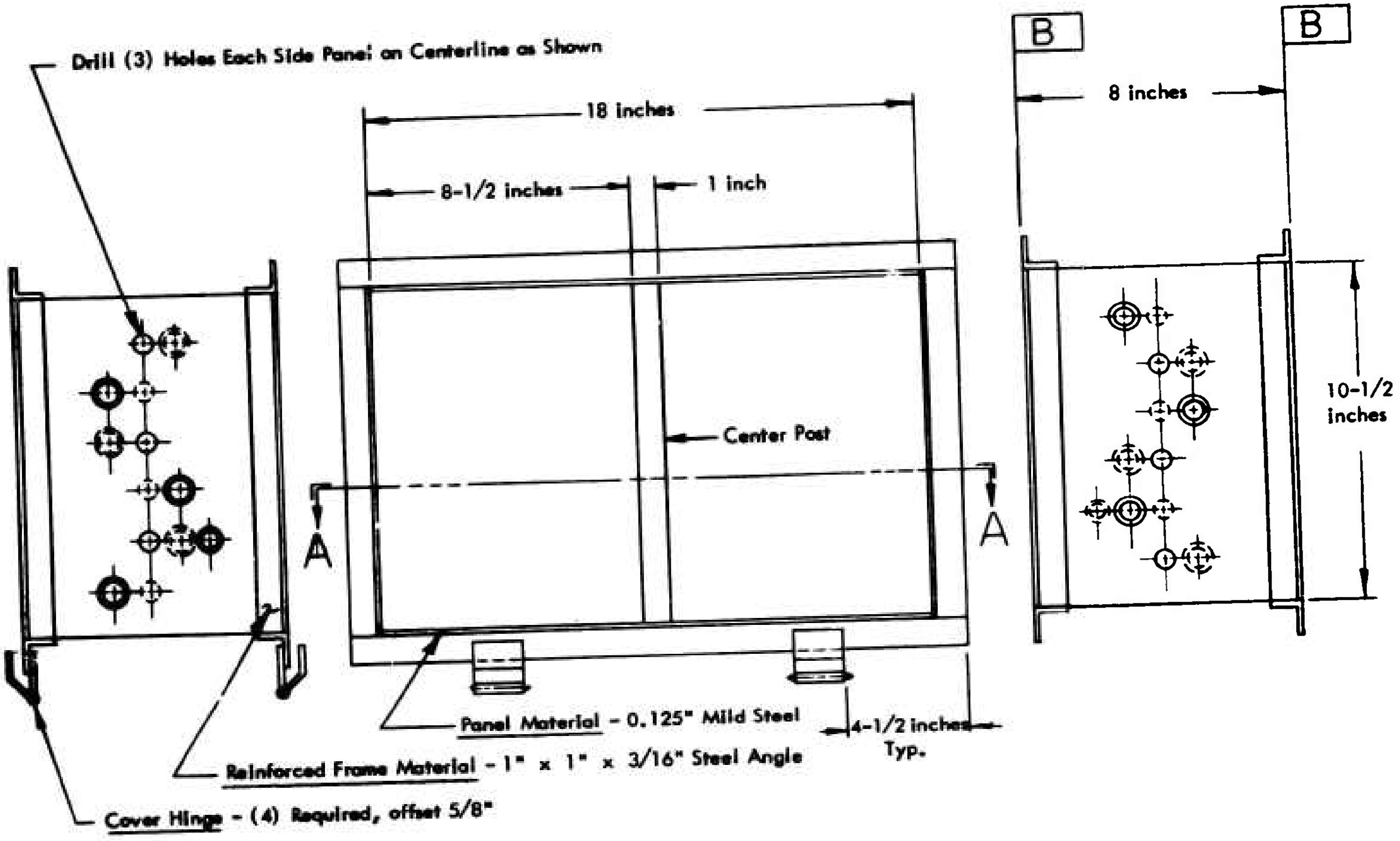


Figure 30. Typical Environmental Test Chamber, Front and Side Views, Covers Removed (Sized for -4 Hose).

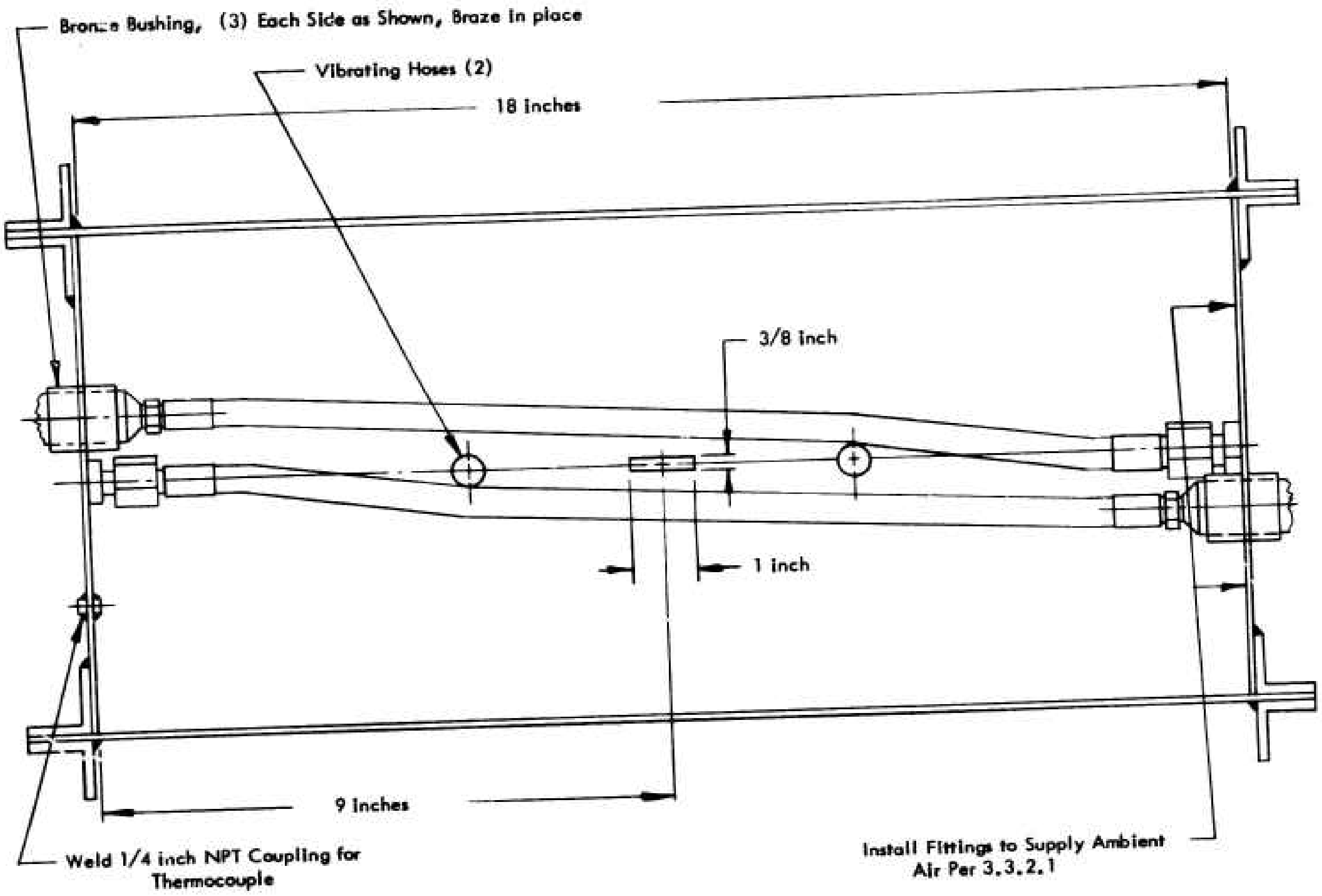


Figure 31. Typical Environmental Test Chamber, Top View, Covers in Place (Sized for -4 Hose).