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SUPPLEMENT TO

FINAL REPORT

MEASUREMENT OF THERMAL CONDUCTANCE OF MULTILAYER AND OTHER INSULATION MATERIALS

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MEASUREMENT OF THERMAL CONDUCTANCE OF MULTILAYER AND OTHER INSULATION

A.1 INTRODUCTION

This report is provided in partial fulfillment of Contract NAS9-3685, Modification No. 6. It is presented as an addendum to the final report of the preceding phase of this contract, "Measurement of Thermal Conductance of Multilayer and other Insulations," General Electric Company Report No. 67SD4388, dated September 1967 (Reference 1).

The work performed during the current phase of this contract, covering the period March 21, 1968,to June 21, 1968,was similar to that of Task 2 of Reference 1. The same test apparatus and measurement techniques were used in this new Task 7A as were previously used in Task 2 and are described in detail in Reference 1.

The objective of Task 7A was to obtain thermal conductance measurements for additional spacesuit thermal insulation candidates under varying degrees of compression. Boundary temperatures varied from -320 to +285°F with the body side temperature held at about 70°F in all cases.

The majority of test points at test conditions of interest were obtained for a laminated aluminized 1/2-mil Kapton - Beta - glass marquisette insulation made by Schjeldahl.* One repeat point of a Task 2C layup and tests of a gold on mylar layup were also made for a total of 21 valid steady state conductance tests. A schematic of the various layups tested is shown in Figure A-1.

A.2 RESULTS AND DISCUSSION

The test results are tabulated in Table A-1 in a manner similar to that of Table 2-4 of Reference 1 to permit comparison of data. The test run numbers and configuration designations follow sequentially from this table for ease of reference. These data are also shown graphically in the curves of Figures A-2 and A-3.

*X-993 Aluminized Kapton Laminated with Beta Glass Marquisette.

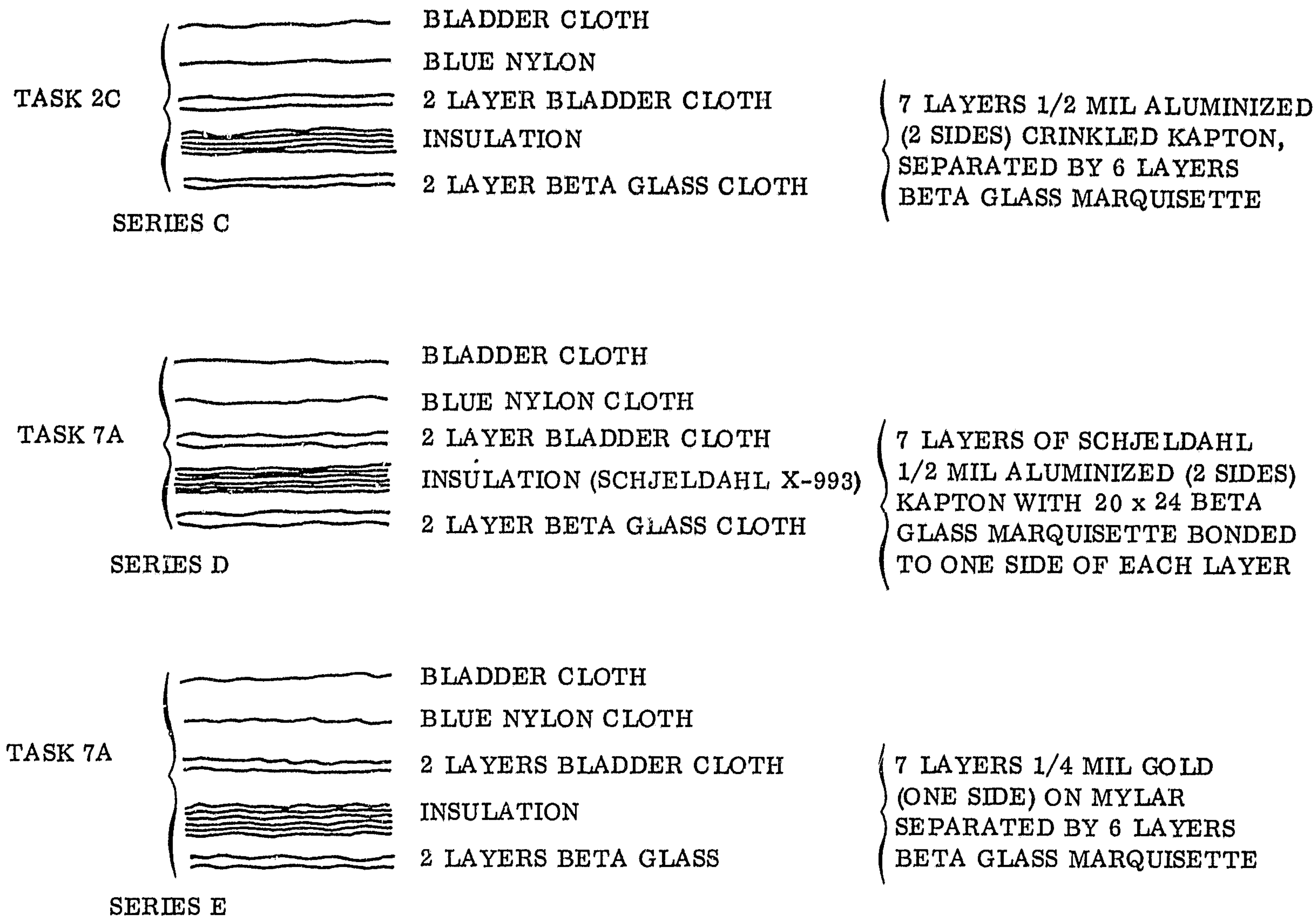

Figure A-1. Schematic of Insulation Layups

Table A-1. Task 7A Test Data Summary

Task	Config.	Run	Compressed Thickness x (In)	Compressed Thickness x^1 (Ft)	Thermal Conductivity K (Btu/Hr-Ft^2-^{o}F/ Ft)	Thermal Conductance K/ΔX (Btu/Hr-Ft^2-^{o}F)	Temperatures Avg (^{o}R)	Temperatures Hot (^{o}R)	Temperatures Cold (^{o}R)	Chamber Pressure (mm Hg)	Electric Power Input (Watts)	Nonequilib. Corrections (% of Power Input) dt/dt	Nonequilib. Corrections (% of Power Input) ΔT	Run Time Total/Data (Hours)	Comments
7A	C	32	5/32	.0130	1.72×10^{-4}	1.32×10^{-2}	633.3	736.5	530.2	1.5×10^{-5}	.7521	0	1.8	5/2.0	Re-run of Series C - Run 26
7A	D	33	6/32	.0156	1.89×10^{-4}	1.21×10^{-2}	582.3	634.5	530.1	8.0×10^{-6}	.3662	4.4	0.4	5.6/2.3	
7A	D	34	6/32	.0156	2.68×10^{-4}	1.71×10^{-2}	635.2	740.2	530.2	1.6×10^{-6}	.9680	2.4	0.2	27.5/2.5	
7A	D	35	6/32	.0156	1.02×10^{-4}	6.50×10^{-3}	446.7	529.9	363.5	1.4×10^{-6}	2990	0.7	0.5	7.8/2.3	
7A	D	36	6/32	.0156	5.82×10^{-5}	3.73×10^{-3}	337.7	529.5	146.0	4.0×10^{-8}	.3963	0.3	0.2	27/2.0	
7A	D	37	5/32	.0130	5.24×10^{-5}	4.08×10^{-3}	336.6	529.2	144.0	8.0×10^{-7}	.4244	0	0.4	23/3.3	
7A	D	38	5/32	.0130	8.88×10^{-5}	6.82×10^{-3}	334.0	531.3	363.5	5.0×10^{-7}	.3132	0.3	0.1	27.5/3.0	
7A	D	39	5/32	.0130	1.81×10^{-4}	1.39×10^{-2}	583.3	634.1	532.5	1.2×10^{-6}	.3872	0	0.7	8.0/1.5	
7A	D	40	5/32	.0130	2.25×10^{-4}	1.73×10^{-2}	639.0	745.8	532.2	1.7×10^{-6}	1.0192	0	0.1	6.5/2.0	
7A	D	41	4/32	.0104	1.63×10^{-4}	1.56×10^{-2}	583.8	635.0	532.5	1.0×10^{-6}	.4441	0.3	0.1	24/2.0	
7A	D	42	4/32	.0104	2.11×10^{-4}	2.03×10^{-2}	638.5	745.3	531.7	1.2×10^{-6}	1.1977	0.6	0.3	25/2.0	
7A	D	43	4/32	.0104	---------	---------	-----	-----	-----	---------	------	---	---	------	Data System Malfunctioned
7A	D	44	4/32	.0104	7.20×10^{-5}	6.92×10^{-3}	443.0	530.1	355.9	3.0×10^{-7}	.3362	1.5	0.3	22.5/3.0	
7A	D	45	4/32	.0104	4.06×10^{-5}	3.90×10^{-3}	334.0	529.1	140.0	2.0×10^{-7}	.4459	6.0	0.1	24/3.0	
7A	D	46	7/64	.0091	1.02×10^{-4}	1.12×10^{-2}	334.0	528.5	140.0	6.0×10^{-7}	1.2016	0	0	6.5/2.5	
7A	D	47	7/64	.0091	6.50×10^{-4}	7.14×10^{-2}	637.0	743.2	530.8	5.0×10^{-6}	4.1861	0.2	0.1	25/2.5	
7A	D	48	3/32	.0078	1.83×10^{-3}	2.34×10^{-1}	637.6	742.9	532.3	1.0×10^{-6}	13.6040	0	0	5.5/2.0	
7A	D	49	3/32	.0078	8.44×10^{-4}	1.08×10^{-1}	335.9	528.7	143.0	6.8×10^{-7}	11.5010	0	0	29.5/3.0	
7A	D	50	9/64	.117	4.34×10^{-5}	3.70×10^{-3}	334.2	528.5	140.0	9.0×10^{-7}	.3982	0.9	0.6	8.0/2.0	
7A	D	51	11/64	.143	2.42×10^{-4}	1.69×10^{-2}	636.6	743.2	530.0	1.0×10^{-6}	1.0072	1.5	0.1	25.5/3.5	
7A	E-1	52	5/32	.0130	3.63×10^{-4}	2.79×10^{-2}	638.7	747.5	529.9	5.5×10^{-7}	1.6948	0.7	0.4	29.0/2.0	Gold-Mylar Batch #1
7A	E-2	53	5/32	.0130	2.10×10^{-4}	1.62×10^{-2}	638.1	746.3	529.9	5.5×10^{-7}	.9594	0.4	0.2	25.0/2.0	Gold-Mylar Batch #2

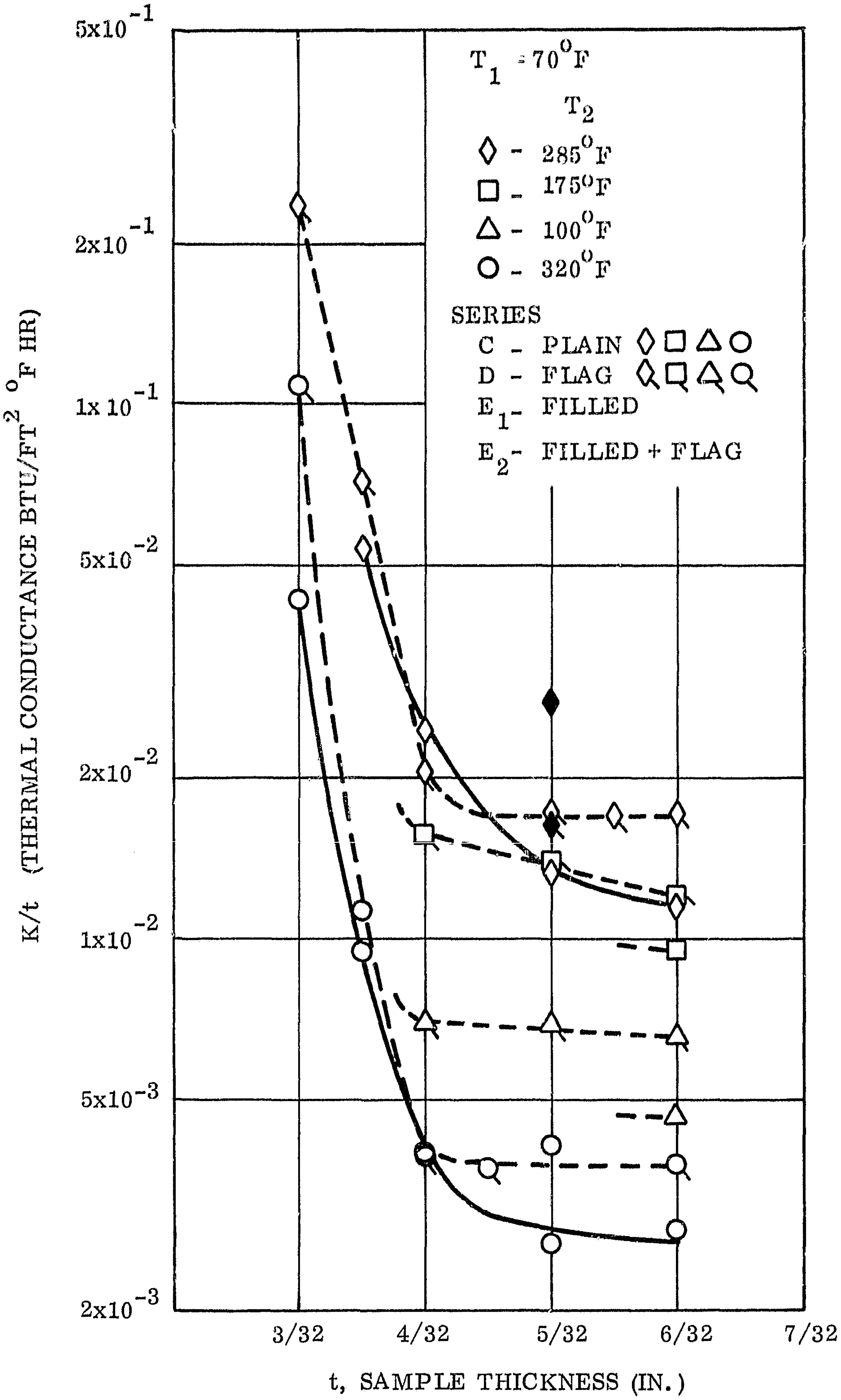

Figure A-2. Effective Thermal Conductance Versus Sample Thickness

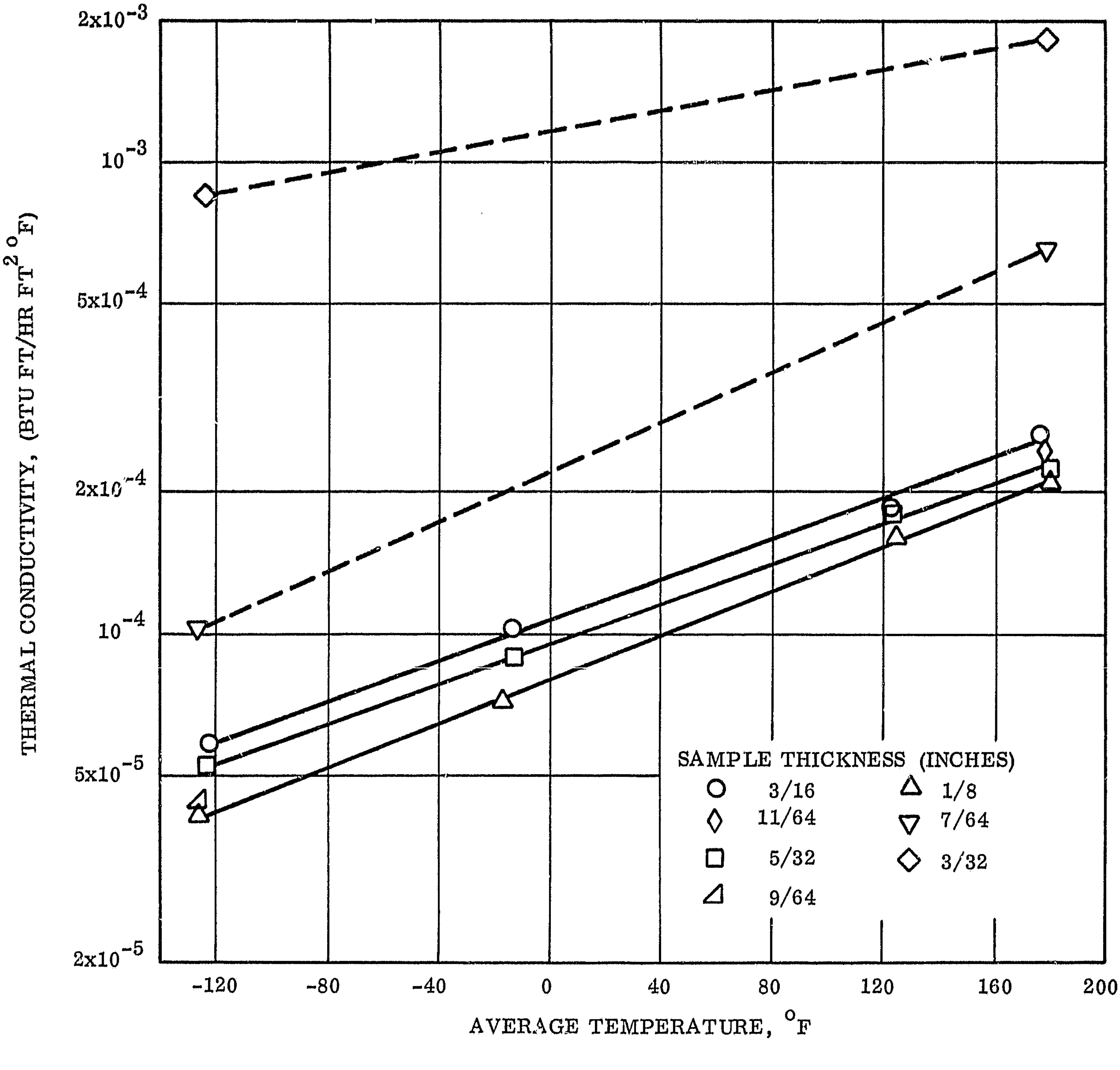

Figure A-3. Thermal Insulation Conductivity versus Average Temperature

Because the test apparatus had not been used for some time, a repeatability test was performed to check the apparatus and the instrumentation. The Test Series C layup material was used and Test Point 26 conditions were repeated. The results of Run 32 were identical to those of Run 26.

The same layup constituents were then used for Series D, except that the individual layers of crinkled aluminized Kapton and Beta-glass marquisette were replaced by a bonded, aluminized Kapton - Beta glass marquisette lamina made by Schjeldahl* The marquisette was a 20 x 24 mesh fabric and was bonded to the aluminized Kapton. The adhesive added approximately 1/2 mil to the 1/2 mil thickness of the Kapton film.

A brief preliminary analysis indicated that the Series D layup (X-993) thermal conductance should be higher than that for the Series C layup, because the bonding as well as the absence of crinkling had removed one significant thermal resistance from this assembly. It was further surmised that the thermal conductances should approach each other for Series C and D, when the sample thickness decreased; i.e., the effects of interface resistance in Series C becomes negligible due to compression of the sample.

As can be seen in the curves of Figure A-2, the conductance was indeed higher at low compression of the sample. It was also interesting to observe that this conductance was fairly constant for several degrees of compression from 3/16 inch to 1/8 inch. Upon further compression, the conductance rose steeply, approaching that of Layup C, but still slightly higher. These differences could be explained as follows:

At low compression the Layup D insulation remained essentially unchanged, because it was not in a crinkled and fluffy state, which could be compressed. Thus no additional contact heat flow points could be produced by compression, as would be the case for Layup C. As compression was increased, the differences between Layup C and D vanished, because the additional resistance of a separate Beta-glass marquisette interface in layup C as compared to Layup D no longer was significant. These insulation characteristics were observed in a reproducible pattern for the four temperature ranges of interest.

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*Schjeldahl X-993

The repeatability of the test data was checked for two test points (Runs 50 and 51) and was found to be within experimental accuracy. It should be noted that the construction of Layup D is very unlikely to exhibit "hysteresis" effects, because there are no crinkles in the aluminized Kapton which can be flattened out. Thus, the repeatability of thermal conductance should be good after repeated compression. This is in contrast to the crinkled insulation of Layup C, where some of this flattening of crinkles occurs before repeatability can be ensured. No tests were performed for reproducibility, because material for only one sample pair was available.

A.3 GOLD ON MYLAR TEST

Because of the possible degradation of vapor-deposited aluminum on thin film material due to presence of water vapor, a number of investigators have recommended vapor-deposited gold, which has been shown not to degrade. For this reason, two tests were performed on goldized 1/4-mil Mylar.

The goldized Mylar was obtained from residual material of a previous insulation program carried out at General Electric. The gold was vapor-deposited on Mylar (one side) by National Metallizing Corporation. The crinkling of the metallized film and the perforation of the film for venting purposes was performed at General Electric, at the time the material was originally obtained.

In contrast to aluminum, gold in its vapor-deposited state on Mylar is rather soft and scratches easily. This was noted on both test samples used in this program.

The material used in these tests came from two different lots. Unfortunately, since this was residual material, no further identification was possible. The goldized Mylar had been perforated on 8-inch centers with 1/8-inch diameter holes for venting purposes. In order to work with uniform materials, the samples were recrinkled using a Teflon die as shown in Figure A-4. Figure A-5 shows the sample in its crinkled state after it had been cut to size. The samples were then assembled into a layup (Series E) by using the test Series C layup, but replacing the aluminized Kapton with goldized Mylar, as shown in the schematic of

Figure A-4. Crinkling of Insulation by Drawing Through Teflon Die

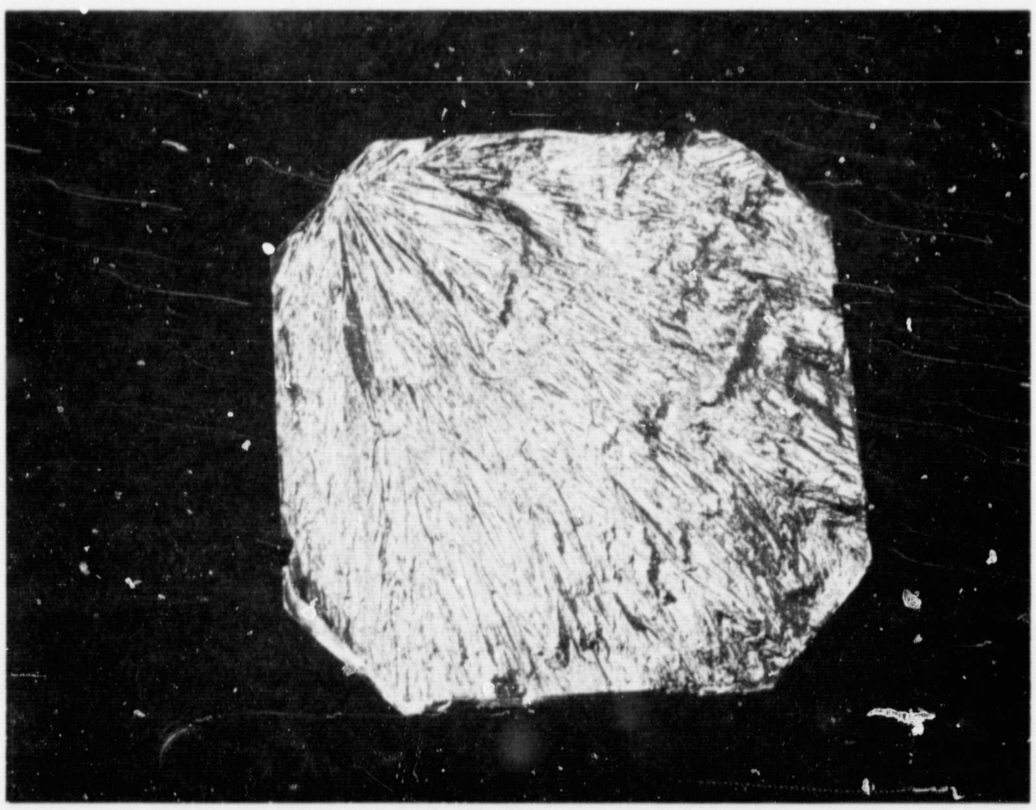

Figure A-5. Gold-on-Mylar after Crinkling

Figure A-1 and the photograph of Figure A-6. Two such layups were made and tested and are reported in Table A-1 as Runs 52 and 53. These data also are shown in Figure A-2. The large difference in results for the two tests, for what appeared to be similar samples, required further investigation. The appearance of the goldized Mylar after test is shown in Figure A-7. Since both samples were tested and crinkled under similar conditions and their post-test appearance was similar, the differences were assumed to be in the vapor-deposited gold characteristics and thickness.

Emissivity measurements were performed on the two samples and helped to explain the differences. The goldized Mylar sample for Run 52 had an emissivity of 0.08; whereas, that for run 53 had an emissivity of 0.03. Since the emissivity measurement areas evaluated on the samples were rather small in relation to the entire goldized Mylar area under test (0.1 percent), any conclusions made are only approximations. Time and funding limitations prevented any detailed investigation or more tests.

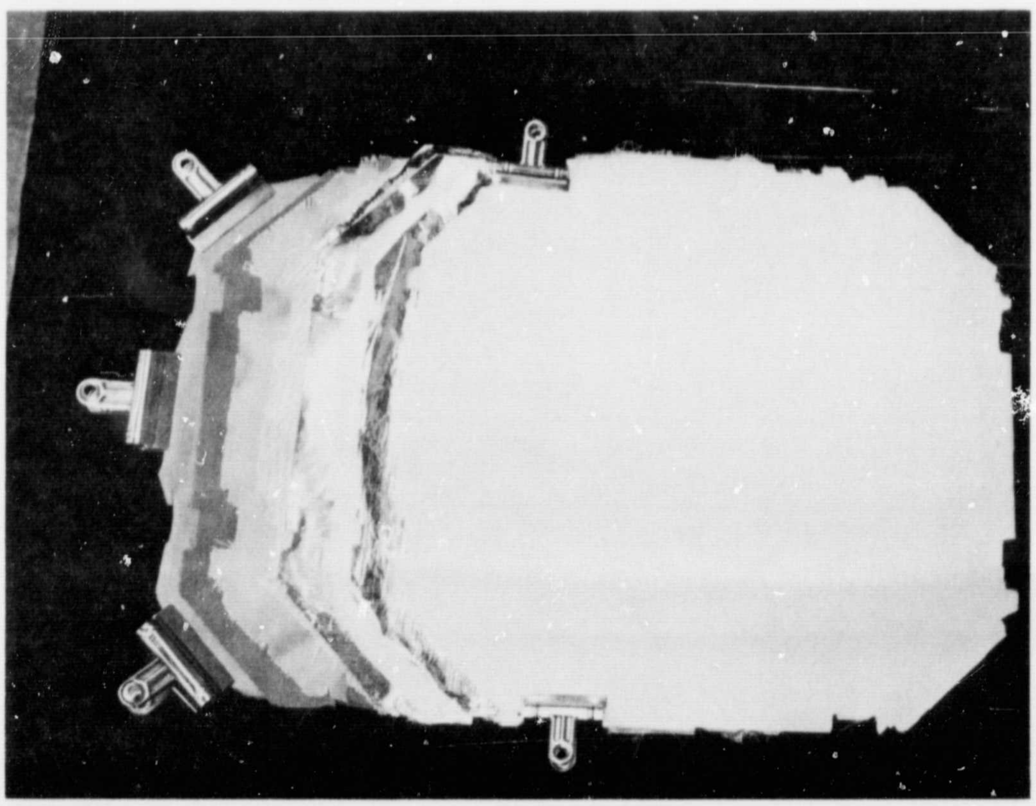

Figure A-6. Exploded View of Test Sample Layup

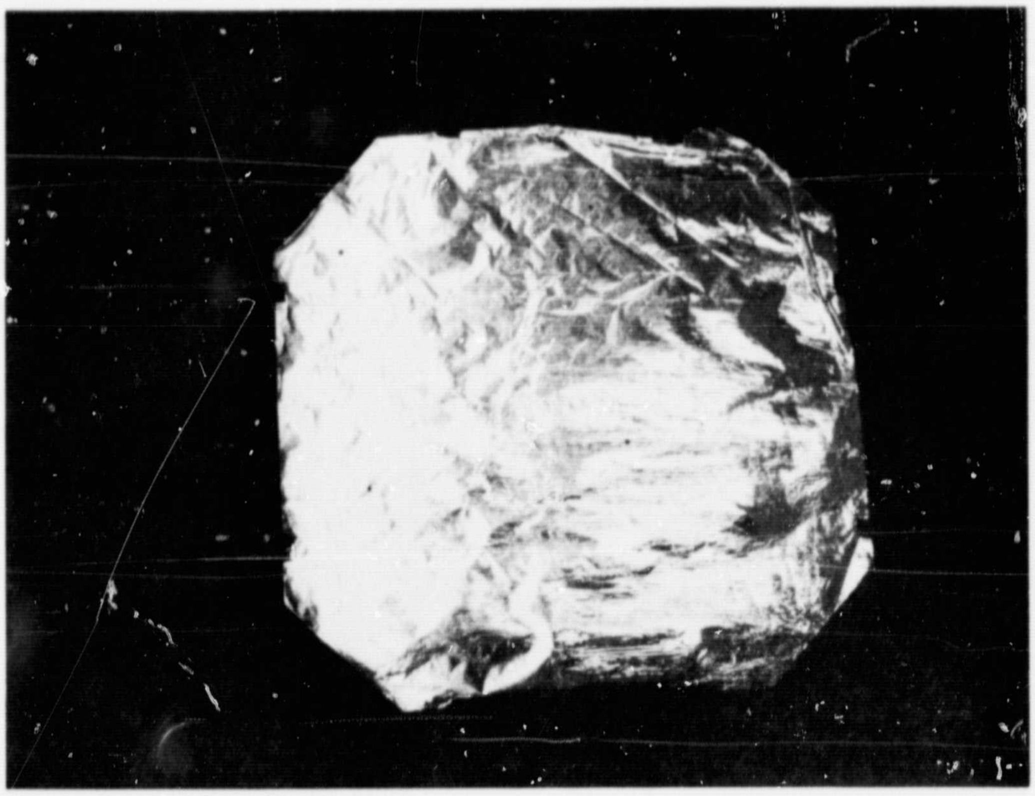

Figure A-7. Gold-on-Mylar After Test

It would appear that the sample used in Run 52 came from an exploratory vapor deposition lot of insulation; whereas, the sample used in Run 53 was from a regular sample lot.

While not as good as the double aluminized Kapton of test Series C, the single side goldized Mylar performed about as well as the Series D insulation. All this is based on a single sample experiment with its attendant uncertainty. Based on past experience (Reference 2), goldized Mylar should perform very similar to aluminized Mylar, when used as multilayer thermal insulation.

A.4 CONCLUSIONS

From this investigation the following can be concluded:

a. The use of the Schjeldahl bonded insulation is likely to provide better repeatability of thermal performance after several space suit layup compression and release cycles. This is due to the absence of film crinkling which could be "ironed out."

b. Handling of the bonded Beta - glass/aluminized Kapton layup, Series D, is simpler than that of Series C due to fewer components and less bulk.

c. The thermal insulation performance of the Series D layup, although poorer than Series C, should be more easily predictable due to the lack of crinkling.

d. The possibility of metal film abrasion should be reduced with the Series D layup, resulting in less likely degradation after long term use, since there should be no relative motion at the bonded surface.

e. The thermal performance of the goldized Mylar can be expected to be close to that of the other insulations in Series C and D. However, the exploratory tests performed are not sufficient to make a selection or recommendation.

A. 5 RECOMMENDATIONS

From the foregoing investigations the following is concluded:

a. The Schjeldahl X-993 insulation should be considered a series contender for space suit application, if the poorer insulation performance can be accepted when compared to series C.

b. Additional tests should be performed to evaluate the possible improvement in thermal performance if this material is crinkled or 1/4-mil Kapton is used.

c. If long term space suit use and the attendant moisture problem between layers degrades the aluminum film, the use of goldized Kapton should be considered. In that case, test data should be obtained for goldized Kapton layups in Series D and Series E type configurations.

d. The emissivity of the metallized film used for spacesuits should be monitored to avoid the use of inadequate thickness of metal. An electrical resistivity test could also be utilized for this purpose.

A. 6 REFERENCES

1. Fried, E., Karp, G., Hobbs, R., and Hieser, G., Measurement of Thermal Conductance of Multilayer and Other Insulation Materials, Final Report on Contract NAS9-3685, GE Document No. 67SD4388, September 1967.

2. Planetary Vehicle Thermal Insulation Study, Phase I Summary Report, JPL Contract 951537; GE Document No. 67SD4289, April 1967.