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VOLUME VII

IMPROVED RADIATOR COATING ADHESIVES TESTS

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VOUGHT SYSTEMS DIVISION
LTV AEROSPACE CORPORATION

SHUTTLE ACTIVE THERMAL CONTROL SYSTEM DEVELOPMENT TESTING

VOLUME VII

IMPROVED RADIATOR COATING ADHESIVES TESTS

Report No. T169-28

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Submitted By

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To

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Houston, Texas

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FOREWORD

This volume is one of a series of reports describing the development tests conducted on a candidate Shuttle heat rejection system at the National Aeronautics and Space Administration - Johnson Space Center during the period from March to July 1973. The complete test series are reported in the following volumes:

Volume I	Overall Summary
Volume II	Modular Radiator System Tests
Volume III	Modular Radiator System Test Data Correlation With Thermal Model
Volume IV	Modular Radiator System Test Data
Volume V	Integrated Radiator/Expendable Cooling System Tests
Volume VI	Water Ejector Plume Tests
Volume VII	Improved Radiator Coating Adhesives Tests
Volume VIII	Tube Anomaly Investigation

The tests were conducted jointly by NASA and the Vought Systems Division of LTV Aerospace Corporation under Contract NAS9-10534. D. W. Morris of the NASA-JSC Crew Systems Division was the contract technical monitor. Mr. R. J. Tufte served as the VSD Project Engineer.

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1.0 SUMMARY

Vought Systems Division (VSD) of LTV Aerospace Corporation has produced and tested silver/Teflon thermal control coatings on a Modular Radiator System projected for use on the Space Shuttle. Seven candidate adhesives have been evaluated in a thermal vacuum test on radiator panels similar to the anticipated flight hardware configuration. Several classes of adhesives based on polyester, silicone, and urethane resin systems were tested. These included contact adhesives, heat cured adhesives, heat and pressure cured adhesives, pressure sensitive adhesives, and two part paint on or spray on adhesives. The panels were tested at the NASA/JSC Space Environmental Simulation Laboratory - Chamber A during the July 9-20, 1973 time span.

The coatings attached with four of the adhesives, two silicones and two urethanes, had no changes develop during the thermal-vacuum test. The two silicone adhesives, both of which were applied to the silver/Teflon as transfer laminates to form a tape, offered the most promise based on application process and thermal performance. Each of the successful silicone adhesives required a heat and pressure cure to adhere during the cryogenic temperature excursion of the thermal-vacuum test.

2.0 INTRODUCTION

The use of silver/FEP Teflon* film as a thermal control surface for space radiators is based on a favorable solar absorptance/emittance ratio in the 0.08 to 0.1 range, a stable solar absorptance varying between 0.06 and 0.08, high transparency, and minimal degradation in the charged particle-ultraviolet radiation environment of near-space[1]. The combination of properties available in the silver/FEP film could result in both area and weight reductions for the Modular Radiator Panels currently being considered in Shuttle Orbiter vehicle design studies which use Z93 white paint as the thermal control surface. The silver/FEP thermal control material consists of FEP Teflon film, type A, with a layer of silver deposited on one side by vacuum evaporation to a thickness of 1000-2000 A.U. The silver is protected by an evaporated overlay of Inconel 600** to a thickness in the 1000-2000 A.U. range. The Inconel serves to retard chemical attack on the silver, aids the handleability of the film, prevents mechanical damage to the silver, and furnishes a bondable surface for the film. The silver/FEP functions as a second surface mirror since the attachment from the radiator panel is to the metallized surface of the FEP; this leaves the bare FEP exposed as the radiating surface. The favorable hemispherical emittance, $\epsilon = 0.8$ typically of the FEP is thus retained. The FEP absorbs relatively little in the solar wavelength region, meaning that the solar absorptance, $\alpha = 0.08$ typically of

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the silver/FEP film will be essentially that of the silver. Alternate thermal control materials include paint systems, fused silica sheets with evaporated metal coatings, and dielectric coated metals. Paint systems are limited by relatively high solar absorption and deterioration of properties (primarily increased absorption) with exposure to the charged particle-ultraviolet radiation environment. The optical properties of the metallized silica sheets are excellent, but their application to large, irregular surfaces poses a severe economic and technological problem. The dielectric coated metals, typically silicon monoxide coated aluminum, do not have optimum optical properties, and are difficult to apply to contoured areas of the design likely to be required by the radiator panels of the Shuttle Orbiter vehicle(2). Technical problems with silver/FEP in previous work on flight hardware scale radiator panels in thermal-vacuum tests extending into the cryogenic temperature regime have been numerous(3). These include (a) thermal expansion mismatch between the aluminum radiator and the silver/FEP film, (b) adhesive bond failure between the aluminum and the silver/FEP film, and (c) delamination of the metallized layer(s) from the FEP film.

For the radiator to function efficiently, the emittance should be the maximum which can be optimized from thickness vs emittance considerations. Figure 1, which is a plot of normal emittance (ε_N), and α/ε ratio vs FEP film thickness, shows that the change in ε_N is slight for thicknesses greater than 0.005 in.(4). The α/ε ratio of silver/FEP is a minimum in the 0.005 in. thickness range. Hence, the selection of 0.005 in. FEP Teflon, type A, as the basic film in this work.

Degradation of 0.005 in. silver/FEP due to ultraviolet radiation in the 350-400 mm wavelength range is considered minimal. Increases in α by less than 0.01 after 800 equivalent sun hours exposure have been demonstrated[5]. Electron and proton exposure has caused negligible, 0.01, to major, 0.13, changes in the α of silver/FEP. Conservative estimates of one to three years in orbit without significant change in α are made from these data [6,7].

3.0 PURPOSE

The key objectives of the present investigation are to (a) establish bonding materials and processes for the silver/FEP thermal control material to Shuttle radiator panels and (b) thermal-vacuum test the radiator panels to environments predicted for the Shuttle Orbiter vehicle.

4.0 ADHESIVE SELECTION

Prior work on silver/FEP as a thermal control material for radiator panels of the type required by the Shuttle Orbiter vehicle was disappointing. Even though supplier experience and recommendations regarding adhesive and application process were positive, an off-the-shelf silver/Teflon film separated from the radiator skin during a full scale thermal-vacuum test[8]. With this experience in mind, a concerted push was needed toward solution of the attachment problem of the silver/FEP film to the aluminum radiator panel. A multiple effort, with both industry and NASA laboratories contributing to attachment method screening and selection, was undertaken. LTV Aerospace Corp., Vought Systems Division (VSD) was selected to have overall responsibility for evaluation of screening test results, applying candidate silver/FEP-adhesives to the modular radiator panel test articles, thermal-vacuum test conduct, and analysis of test data.

The NASA-JSC philosophy was to obtain adhesive material and process recommendations from organizations with experience in spacecraft surface temperature control and/or silver/FEP thermal control material.

Organizations contributing to the program initially and specific adhesives recommendations were as follows:

(a) NASA Langley Research Center
  - (1) Mystic A117 Silicone
  - (2) Thiokol Solithane 113 urethane
  - (3) Narmco Uretnane
  - (4) Mystic 7366 Silicone Double-Backed Tape

(b) NASA Goddard Spaceflight Center
  - (1) Gelva 263 Acrylic

(c) NASA-JSC - Structures and Mechanics Division (SMD)
  - (1) Emerson & Cuming 2651 Stycast epoxy

(2) Shell Epon 828 epoxy/DETA Catalyst

(3) G. E. RTV 566 Silicone

(d) G. T. Schjeldahl Co.

(1) Dow Corning 282 Silicone

(2) G-401903 Polyester

(e) LTV Aerospace Corp., Vought Systems Division

(1) G. E. RTV 560 Silicone

(2) DuPont Adiprene L-167 urethane/VSD modified catalyst

(3) Crest 7344/7119 Urethane

(4) Furane 5712 Urethane

(5) Crest 7343/7139 Urethane

Various attachment concepts were proposed and are included in the above recommendations. These included:

adhesive bonding, (A) two part paint on or spray on adhesives,

(B) heat cured adhesives,

(C) heat and pressure cured adhesives,

(D) contact adhesives, and

(E) pressure sensitive adhesives

and heat bonding. All of the attachment concepts were evaluated in laboratory scale element tests.

Screening tests consisted of immersion of bonded panels in liquid nitrogen followed by a thaw cycle to ambient temperature. The test panels consisted of 0.020" 6061-T6 aluminum sheet, 2" x 10", as the adherend. Silver/FEP strips, 1" x 4" or 1" x 8" x 0.005", were bonded to these adherend sheets to form the element test panels. Numerous adhesives other than those included in the initial recommendations were evaluated by each organization in screening tests. Those screened in a cursory manner by VSD included: (a) Dow Corning 280A, 281 and XR-4-3135 silicones, (b) 3M 467 acrylic and 3515 urethane, (c)

Permacel 6962 double backed Kapton*/silicone, (d) Emerson & Cuming 45 flexible epoxy, CPC-16 urethane, and CPC-6 urethane, (e) Crest 3170/7133 epoxy. NASA Goddard evaluated such adhesives as; (a) Crest 3170 and 3725 epoxies as well as 7344 urethane, (b) Dupont L-100 urethane, (c) Thiokol 113 urethane (several different catalysts), (d) Morgan 9626 double backed polyester/acrylic and MOCTAC double backed paper/polyster, (e) 3M 665 double backed cellulosic/polyester, (f) Fasson 230 double backed paper/polyester, and (g) Kasen Circle K double backed paper/polyester. It is understood that the other laboratories involved went through similar screening efforts of short term duration.

Final selection of adhesives to be included in the thermal vacuum test of the 6' x 12' modular radiator panels was based on peel tests at cryogenic, ambient, and elevated temperatures as well as cryogenic soak tests. Outgassing data were also taken on the selected candidates, but due to the lack of absolute standards and specific requirements for the Orbiter Vehicle, this data was not used for disqualification of a promising adhesive. The peel strength and outgassing data were taken on the adhesives that the individual laboratories felt were most promising from their internal screening tests. Each organization prepared peel test and outgassing specimens to NASA-JSC-SMD specifications using adherend substrates prepared by VSD. Results of the peel tests run at NASA-JSC-SMD are given in Table 1. Note that three adhesives from McDonnell-Douglas Co. - East (McDAC) are included, since they requested an opportunity to participate prior to final adhesive selection. Only the following adhesives of those listed in Table 1 had measurable peel strengths at -300°F: Adiprene L-100 urethane, RTV 560 silicone, and Permacel 6962 double backed Kapton/silicone. Peel strengths generated at VSD agreed well with NASA-JSC-SMD data as noted in Table 2.

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The Mystic 7366 double backed Kapton with silicone adhesive, which was recommended in the literature (9), did not perform well in screening tests. However, a similar material, Permacel 6962, was a very reliable performer; this led to its inclusion in the full scale tests.

The outgassing data taken at NASA-JSC-SMD on the various adhesives are included in Table 3 for reference purposes only; absolute outgassing limits for the Orbiter Vehicle and its payload are yet to be established.

Representatives from NASA/JSC-Crew Systems Division and Structures and Mechanics Division, NASA/Langley, NASA/Goddard, VSD, McDAC, and Rockwell International participated in the final selection of adhesives. A prime consideration in choosing adhesives was to get the widest variety of chemical types which might function in the anticipated -280°F to +175°F thermal environment. The following adhesives were selected for evaluation on the modular radiator panels;

IDENTIFICATION	TYPE/APPLICATION	INVESTIGATOR
RTV560	silicone/2 part brush	VSD
Mystic A117	silicone/contact	Langley
SR585	silicone/transfer laminate	McDAC
Permacel 6962	silicone-Kapton/transfer laminate	VSD
Crest 7343	urethane-aluminum/2 part hot mix	Langley
Adiprene L-100	urethane/2 part hot mix	Goddard
Adiprene L-167	urethane/2 part ambient mix	VSD
G401903	polyester/transfer laminate	Schjeldahl

Variations in the size of the silver/FEP film as it influenced handling and coating operations were also investigated. For this reason silver/FEP film was specified from the supplier, G. T. Schjeldahl, in various widths from 1" to 48". Three of the adhesives, Permacel 6962, SR585, and G401903 were applied to the silver/FEP by Schjeldahl on a laminating machine to form a tape. The resulting laminates could be handled as tape with tack varying from nil (G401903) to moderate (Permacel 6962) to very high (SR 585). Each of the adhesives was applied by VSD per instructions from and under the direct supervision of the contributing laboratory.

5.0 ADHESIVE BONDING PROCEDURES

Application of each adhesive used to bond the silver/FEP to the aluminum radiator panels will now be detailed as to specific processes and steps leading to the coated test article. Comments on advantages, disadvantages, and problem areas which became apparent as the panels were coated are also included in this section. The design of the modular radiator panels used in this work is shown in Figure 2. The panels were configured for one side radiating in this test. The coated radiating surface is opposite the heat exchange tubes; it is a smooth surface broken by a longitudinal weld, section B-B, and two reinforcing channel ("hat") sections, Detail Z. Figures 3 and 4 show coated surface and heat exchange tube sides of a modular radiator panel, respectively. The hat sections on each panel were coated with the silver/FEP, since a determination of the feasibility of coating contoured surfaces was required.

Surface preparation for the 6061 alloy used as the radiator material consisted of the following steps:

a) strip existing 3M white velvet epoxy coating with Penn Walt 732 stripper (the panels had been previously tested with the 3M coating)
b) de-ionized water rinse
c) wet sand with 120 grit aluminum oxide abrasive cloth
d) wet rub with Scotch-Brite pad, Type A
e) wet wipe with methyl ethyl ketone/cheesecloth
f) wipe dry with cheesecloth
g) air dry for 1/2 hour minimum before application of primer or adhesive.

The heat exchange tube side of the panels was masked during the stripping, surface preparation, and coating operations, so that existing instrumentation on the panels would be undisturbed. An overlay, Mystic PD 570A which consists of a blue Mylar* film with low tack adhesive, was used to protect the FEP surface from handling damage during shipping, bonding, and post bonding operations. Wrinkles were often present between the overlay and FEP which caused problems during application of the film, particularly in the 12" and 48" widths.

The selection of adhesives from three general types; i.e., silicone, urethane, and polyester, allowed a wide variation in application processes to be evaluated. The silicone adhesives (and suppliers) evaluated were RTV 560 (G.E.), A117 (Mystic), SR 585 (G.E.), and 6962 (Permacel).

The RTV 560 is a two part, room temperature curing silicone elastomer. It was applied by brushing or troweling with a notched spreader onto radiator panel No. 2, after thorough mixing of the catalyst with the silicone resin. Difficulty in maintaining uniform bond line thicknesses was encountered. The slight surface irregularity found in the modular radiator panels accentuated this problem. The dibutyl tin dilaurate catalyst required a seven day cure cycle with 50% relative humidity, ambient temperature environment. Other catalysts evaluated had specific limitations; for example tin octoate had short pot life of 1-5 minutes, and RTV 9811 paste catalyst would not cure reliably in the thin bond lines required for optimum heat transfer. The coated panels with tin dilaurate catalyst would tolerate moderate handling after 16 hours cure time. A vacuum bag was required for conformal coating of contoured surfaces; flat surfaces with the silver/FEP upright did not require

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vacuum bagging for successful bonding. Realignment of the silver/FEP film was readily accomplished after it was placed on the wet surface of 560 on the radiator panel. Priming of both adherend surfaces, i.e., the Inconel on the silver/FEP and the aluminum, was mandatory to obtain bonding. G.E. SS-4155 was more reliable than G. E. SS-4004 as a primer. Brush coating was the method of application. The Mylar overlay caused wrinkles to be transferred to the FEP surface during 560 cure. Removal of the overlay was necessary to obtain a wrinkle-free application of silver/FEP with 560 adhesive. Delaminated areas between the FEP and silver, 3-6 inches in diameter, developed between application and receipt of this panel at NASA/JSC some 4-5 weeks later. A field refurbishment procedure with ambient temperature and pressure was demonstrated using RTV 560 after shipment of the coated radiator panels to NASA/JSC. This refurbished panel, with approximately 75% of the silver/FEP replaced, was used as the test article in the thermal-vacuum test in SESL-Chamber A.

The A-117 is a contact type silicone adhesive with extremely high tack at the air dry step in processing. A prime coat of AP-134 was applied to the Inconel and aluminum adherend surfaces by spraying. The A-117 was brushed onto the primed surfaces of panel No. 7 to a uniform appearance and texture. The resin dried to a high tack in a few minutes; this made recoat or overcoat application difficult. The dried A-117 often tended to pull from the aluminum when a wet brush was used to overcoat. After air drying for 1-1/2 hours, the adhesive had high tack. The use of a slip sheet between the A-117 coated Inconel and aluminum was not feasible due to the tack of the air-dried adhesive. Since the A-117 was a contact type adhesive, the correct alignment between the silver/FEP film and radiator panel was necessary as the film was placed on the panel. Lifting the film after contact was made with the panel resulted in adhesive pulling from either the panel or the Inconel surface. The Mylar overlay was removed before application to the panel was started. White gloves were used to handle the silver/FEP after overlay removal in this and all cases. The application technique consisted of supporting the silver/FEP above the radiator panel while one edge of the film was aligned on the panel. The film was lowered carefully to contact the panel so that a minimum number of air bubbles were trapped as the surfaces were brought together. The entrapped air was removed by puncturing the bubble in the film with a sharp implement. This allowed air to escape as the film was pressed to contact the panel. The final bond was formed by curing at 225°F for four hours in a vacuum bag.

SR 585 is a silicone resin which develops adhesive properties based on elimination of a solvent, followed by heat cure or catalyst addition with subsequent heat cure. A prime use of the resin is in manufacture of pressure sensitive, glass backed or Teflon film tapes. The 585 was applied to the silver/FEP film on transfer laminating equipment to form a pressure sensitive tape. 0.5% benzoyl peroxide catalyst was added during the laminating process. Skived TFE was used as a release liner, preventing adhesion of the 585 to the Mylar overlay. The liner was stripped from the 585 as the laminate was unrolled. The tape was then applied to radiator panel No. 3 by hand smoothing. The Mylar overlay was removed from approximately 20% of the silver/FEP/585 laminate prior to application. This was in wrinkled areas between the Mylar and FEP film which prior experience showed would transfer to the silver/FEP after bonding. The tack of 585 is high, making lift-off difficult if bubbles are entrapped during application. Lift-off to work out small areas of trapped air, e.g., 1-2 square inches, was possible without causing apparent damage to the silver/FEP film at that time or after cure. The cure cycle consisted of vacuum bagging followed by heating to 275°F with a 30 minute soak. The vacuum bagging was necessary to prevent bubble formation during cure. In spite of the high tack demonstrated by 585, ambient temperature and pressure application of this adhesive did not result in a bond usable in anticipated Orbiter Vehicle environments.

The 6962 laminate consists of silicone pressure sensitive adhesive on each side of a 0.001" Kapton film backing to form a double-faced tape. The 6962 tape was attached to the silver/FEP film on transfer laminating equipment. Removal of the Mylar overlay was not required before application of silver/FEP/6962 laminate to radiator panel No. 5. A cloth release liner is used to prevent adhesion of the 6962 to the Mylar overlay on the rolled laminate. The release liner is removed as the laminate is unrolled and hand smoothed onto the aluminum panel. Since the 6962 has only moderate tack, trapped bubble removal was accomplished by lift-off of the laminate after initial contact. No damage to the silver/FEP was apparent after the lift-off to reposition or after cure. The cure consists of heating to 290°F with a one hour soak at temperature. Vacuum bagging is required during cure to prevent bubble formation at the adhesive-aluminum interface. The protective overlay was left on the FEP surface during bagging, cure, and post cure handling. This served to protect the FEP from mechanical damage during the severe handling phases of the bonding. No wrinkles were induced in the FEP from the overlay during bonding. Ambient temperature and pressure application of 6962 laminate will not result in a bond usable for the cryogenic temperature extreme predicted for the modular radiator panels. In addition to the full panel, 9 square feet of panel No. 4 and 3 square feet of panel No. 3 were coated with 6962 laminate due to slight under-runs while producing these two adhesives as laminates.

Urethane adhesives evaluated included 7343 (Crest Products) and Adiprene L-100 and L-167 (DuPont).

Crest 7343 is a two part, room temperature curing urethane resin system designed for cryogenic environments after cure. The curing agent for 7343 was methylene (bis) orthochlor analine (MOCA) which was solid at ambient temperature. The MOCA was melted by slow heating to the 250°F range. The 7343 resin required de-airing by heating in vacuum to 230°F. This vacuum de-airing was most effective if cycled two to three times to ambient pressure. Both resin and curing agent were cooled to 160-180°F and mixed gently to minimize bubble formation. Aluminum powder (Alcan MD105) was added to the catalyzed resin in amounts of 17%. This increased the thermal conductivity of the adhesive while decreasing the thermal expansion mismatch between the 6061 aluminum (C.T.E. = 1.2×10^{-5} in/in/°F typ at -100°F) and the FEP teflon film C.T.E. = 4.6×10^{-5} in/in/°F typ at -100°F). A primer, Z-6040, was sprayed on both the aluminum and Inconel adherend surfaces. Although the pot life of the 7343 was approximately 4 hours, the viscosity increased rapidly as the mixed adhesive cooled. The warm mix was spread onto radiator No. 6 by squeegee to a depth of about 4 mils. The adhesive was allowed to stand for approximately 2.5 hours after the resin and curing agent were mixed before the adherends were joined. Numerous bubbles were observed to rise and burst in the adhesive during this period. A working life of some 30 minutes was found for spreading the adhesive on the panel. The primed silver/FEP laminate was lowered onto the moderately tacky 7343, taking care not to entrap bubbles between the adhesive and film. The bond line was difficult to maintain at a uniform thickness. The mixing process and outgassing cycles for the adhesive system required meticulous judgement and attention by the operator to provide reproducible batches. The CO_2 gas evolved during cure of the isocyanate collects to form large bubbles in the adhesive. Bubbles continued to form during the 150°F post cure even with a moderate (50°F/hr) temperature increase. The MOCA curing agent was ruled potentially carcinogenic per OSHA Standard 1910.93C during the course of this work. This means the handling procedures in future work would be even more complex and tedious than in the present work.

The Adiprene L-100 is a two part room temperature curing urethane resin similar to Crest 7343. The MOCA, used as a curing agent, was melted at 250°F and added to the hot, 200°F L-100 resin. The problems in mixing and handling the resin/curing agent system were similar to those found for the 7343. The mixed resin was applied to the radiator panel by squeegee to a depth of some 5 mils. An attempt was made to use notched spreaders to obtain uniform bond line thickness. The viscosity of the L-100 increased too rapidly for the adhesive to flow to the uniform thickness desired. Panel No. 8 was pre-heated to prevent premature cooling of the L-100 mix during spreading operation. The low thermal mass of the radiator panel prevented the preheating from being a significant aid in application of the hot mix adhesive. It was extremely difficult to spread the L-100 to the desired uniform bond line thickness since the working life of the mix was 5 to 15 minutes. Bubbles in sizes varying up to 1" formed in the adhesive for up to 24 hours after application of the silver/FEP film. Small bubbles, less than 0.25" diameter, formed during the three hour, 210°F post cure. The carcinogenic curing agent, MOCA, adds to the severe handling and mixing problems with this adhesive system.

The Adiprene L-167 is an aromatic isocyanate with somewhat higher equivalent weight than the L-100 urethane; both were applied to equal areas of panel No. 8. The curing agent, MOCA, was dissolved in acetone to give a two-part liquid urethane adhesive system amenable to ambient temperature mixing and application. A major advantage with this two-part liquid system was that no viscosity increase occurred when the mixed adhesive was spread on the panel. A working life of two hours, coupled with the low viscosity, allowed a relatively uniform bond line to be established by brushing. Contact between the silver/FEP and adhesive was established at one edge. The FEP film was then lowered onto the wet adhesive layer taking care not to entrap bubbles. Lift-off of the film from the adhesive was easily accomplished to re-position the film for better fit or to release bubbles. The cure cycle was ambient temperature and pressure for 24 hours; no post cure was required. CO_2 gas evolved during cure collects to form large bubbles at the adhesive-film interface. The trapped bubble problem common to each of the urethane systems could be alleviated to a degree with perforated silver/FEP film. The perforations formed an escape path for the CO_2 evolved during cure. The MOCA curing agent was easier to handle when dissolved, but it remains a serious health hazard per OSHA Standard 1910.93C.

The G401903 (Schjeldahl) polyester adehsive had favorable test data not reported herein at temperatures in the -200°F range. This led to its inclusion in the test program to supplement the silicone and urethane adhesives. Transfer laminating equipment was used to form a tape of the silver/FEP film and polyester adhesive. Handling, storage, and transportation of the laminate was done in dry ice to prevent premature cure of the G401903. Application of the laminate consisted of positioning on radiator panel No. 4 and heating with a hand heat gun. This heating caused sufficient tack to develop in the adhesive to allow vacuum bagging for cure. It was necessary to remove the Mylar overlay prior to heating the laminate to promote adhesion. Meticulous operator attention was necessary during the heat gun cycle to prevent wrinkling of the silver/FEP due to excess heat. A thermal cycle of 250°F for one hour while vacuum bagged was used to cure the G401903 polyester.

The adhesives and application techniques to bond the silver/FEP to the modular radiator panels are summarized in Table 4. In general the two-part mix and contact adhesives presented severe application difficulty as measured by the appearance of coated radiator panels. Non-uniform bond line thickness, wrinkles, and trapped bubbles were the major flaws apparent with these two-part and contact adhesives. The transfer laminates produced coatings with excellent optical appearance and no visible defects, although a vacuum bag cure was required in each case. Figures 5 and 6 illustrate the appearance of a typical two-part adhesive panel and a typical transfer laminate adhesive panel, respectively.

6.0 THERMAL-VACUUM TEST PANEL

Phase 4 Testing*

The objective of the modular radiator coating evaluation was to determine the ability of the coating to adhere to the panels over a wide range of modular radiator Shuttle operational conditions. A timeline, shown in Figure 7, was devised to accomplish this objective. The timeline was designed for 100 hours of testing and included test simulation of maximum and minimum heat load operation under environments simulating:

1. Typical orbital cyclic environments (0 degree inclination solar oriented, 270 n.m.)
2. Maximum orbital flux expected for steady state
3. Minimum orbital flux expected for steady state
4. Deep space simulation with LN_2 temperature environment

The worst combinations of maximum and minimum heat load and the four simulated environments were tested to provide as wide a range of panel temperatures as possible with these conditions. The panels were mounted for the thermal-vacuum tests with the silver/Teflon coated surface down facing the IR simulator panels as illustrated in Figure 8. The philosophy of the test was to as nearly as possible subject all seven panels to the same conditions in order to provide an equitable test for each adhesive. For this reason the seven panels were flow connected in parallel. In order to evaluate the coating condition throughout the test, a baseline performance point with LN_2 environment and 163°F inlet temperature was established at the start of the test and repeated at regular intervals. A comparison of the heat rejection of the panels at

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* Phases 4 and 3A refer to segments of a 6 month overall radiator test program conducted under the subject contract.

these points along with video monitor observations gave an indication of any change in the state of the coating. The test conditions began with nominal panel temperature variations and proceeded to more severe temperature conditions to determine limits on the adhesives. The actual test sequence followed the planned time line closely with only minor time adjustments at steady state conditions except for the last low to high load sequence. It was decided not to increase the environment as was planned for this point, and to ramp the inlet temperature from 53°F to 163°F as quickly as possible in order to subject the panels to a more severe thermal shock. The ramp was conducted in 20 minutes rather than the two hours planned for the time line.

Phase 3A Testing

It had been planned to test the panels at temperatures as low as -250°F during the Phase 4 testing; however, the temperature fell to only about -230°F during the Phase 4 cold soaks. It was decided to extend the coatings test into the Phase 3A test, which was scheduled immediately after the Phase 4 testing. This allowed lower temperatures to be achieved by exposing both sides of the panels to LN_2 environment for longer times. The test sequence planned for these tests is illustrated in Figure 9 and consisted of high load (163°F inlet temperature) baseline performance points and low load (53°F inlet temperature) soaks,both with LN_2 environment. Two baseline points were obtained for panels 3-8 during phase 3A testing, while three baseline points were taken for panel 2.

7.0 TEST RESULTS

7.1 Thermal Performance Evaluation

Phase 4

The Phase 4 test panel outlet temperatures for the eight baseline performance points are compared in Table 5. The panel outlet temperature is a function of the heat rejected by the panel and will therefore indicate changes in the condition of the coating. Should the coating dislodge from the aluminum panel or should the Teflon delaminate from the silver, the thermal emissivity of the panel would be reduced from the 0.80 value for the silver/EP Teflon, to about 0.25 for bare aluminum or silver. The dislodged/delaminated portion would act as a radiation shield. This would reduce panel heat rejection significantly and result in an increase in panel outlet temperature. This data indicates a degradation in performance of panels 4 and 6 between baseline points 2 and 3 and 7 and 8. The second point was just prior to the first cold soak and the third was just after. Between points 7 and 8 a longer cold soak with the rapid recovery was conducted as discussed earlier. The thermal performance of the other five panels did not degrade during the phase 4 test. The data of panel 4 correlated with visual observation via TV which indicated some of the coating dislodged between the second and third baseline points. The TV observations of panel 6, however, did not clearly indicate a change in in the coating. Some dislodgement of corners of coating strips were noted on panel 7; however, this was never apparent from the thermal performance during Phase 4. In comparing the outlet temperatures of the seven panels, it is noted that there was a range of 30°F variation in the first baseline point prior to any degradation of coatings. This difference was due to flow rate differences between panels. Although the seven panels were connected in parallel there were differences in the flow lines to the panels. Only panels 2, 5 and 7 had flowmeters and flow adjustments such that the flow could be balanced directly. The flow in the remaining four panels could not be adjusted nor read directly. In order to determine the flow to these panels, a pressure drop-flow rate curve was generated for each panel. The pressure drop was measured during the test and flow rate determined from these curves. A curve of outlet temperature as a function of flow rate was generated from an analytical thermal model of the panel for the baseline performance point inlet temperature and environment. The Phase 4 test data baseline points are compared to these analytical results in Figures 10-17. These plots give an indication of the performance of the panels with the various adhesives. The first baseline point (Figure 10) indicates all panels are performing close to analytical predictions except Panel 2. This correlates with the fact that panel 2 coating was damaged prior to testing as was discussed in Section 4.0. The trend of this data was that panels 4 and 6 performance began degrading after the number two baseline point and continued to degrade during the test. Another definite step downward in performance between points seven and eight was noted. As well as indicating that panel 2 began with an inferior coating, there is indication that this condition degraded somewhat during the test with the outlet temperature increasing from an average of 5 degrees above the analytical value for the first four baseline points to an average of 10 degrees for the last four. In the last baseline point all the panel outlet temperatures were above the analytical prediction. The trend of the data, however, at the end of the Phase 4 test timeline indicates Panel 4 performance had degraded significantly, Panel 6 somewhat, and Panels 2 and 7 indicated the possibility of some damage. This correlated well with the post test examination of the coatings which indicated the only undamaged panel coatings were panels 3, 5 and 8. The data of Figures 10-17 indicated degradation of the panel 2 and 7 coatings which was not obvious from the Phase 4 outlet temperature data of Table 5 since the panel outlet temperatures did not increase significantly.

The following conclusions resulted from the analysis of the thermal performance of the panels during the Phase 4 coatings test.

1. The heat rejection of the panels was nominal for an undamaged silver/FEP Teflon coating regardless of the adhesive used.
2. There was no change in any of the panel coatings during the Phase 4 test until the panels were exposed to temperatures below -200°F.
3. The only panels with undamaged coatings after Phase 4 testing were Panel 3 (SR 585), Panel 5 (Permacel 6962) and Panel 8 (Adiprene L-100 and L-167).

Phase 3A

The outlet temperature data for Phase 3A tests are also given in Table 5 along with those from the Phase 4 tests. The second baseline point in the phase 3A test appeared to have some differences in flow rates from the first points. The outlet temperature increased about 10°F for panel 2 from the first to the second baseline point, by 12°F for panel 5 and 13°F for panel 7. Panel 6 outlet temperature, however, decreased by 24°F, Panel 8 by 5°F and Panel 3 by 3°F. This combination of increases and decreases in panel outlet temperature precludes drawing conclusions regarding the state of the coating from the outlet temperature data except for Panel 2. No pressure drop data were obtained in the second baseline point due to instrumentation problems; therefore, no flow rate data were available to resolve the outlet temperature changes between the first and second baseline points. An analytical curve for the phase 3A test, similar to that generated for the phase 4 test, is compared to the test data for the first baseline point in Figure 18. Also included is the third baseline point for panel 2. This data could be expected to match the analysis more closely for damaged coatings than the phase 4 data, since half of the radiating area with two sides radiating is coated with white paint rather than the silver/Teflon coating. Damage to the silver/Teflon coating would have less effect on total panel heat rejection and therefore on outlet temperature. Figure 18 shows all the outlet temperatures close to the analytical value except the heavily damaged panel 4. The panel 7 coating, which suffered some loss of adhesion in phase 4 test, was restuck to the panel by hand prior to phase 3A testing, thus explaining the improved performance of this panel. The third baseline point for panel 2 indicates a possibility of some futher degradation of this coating in Phase 3A testing with the outlet temperature increasing from 1° below the analytical value to 3° above between the first and third baseline point. Phase 3A testing was not completed due to leaks which developed in the Freon 21 cooling loop.

No degradation of the three undamaged panels was observed from the thermal data of Phase 3A. Further degradation of the damaged panel coatings could not be determined from Phase 3A thermal data except in the case of Panel 2.

7.2 Coatings/Adhesives Evaluation

No change in the silver/FEP coating on any of the radiator panels occurred during the normal cyclic conditions of on-orbit simulation. This result is supported by (a) video monitor sweep over the panels in real time during the thermal-vacuum test, (b) limited direct visual observation of the panels, (c) stable thermal performance thru the normal cyclic portion of the test. Coating failures, evidenced by video or thermal indications, occurred during the initial cold soak/recovery cycle. Limited data available indicates the failed area on certain panels progressed with subsequent cold soak/recovery cycles.

Failures were apparent in four of the adhesives (560, A117, 7343, G401903) at the conclusion of the eight 6 hour cold soak/recovery cycles (Phase 4). No failures in the remaining four adhesives (585, 6962, L-100, L-167) during the two subsequent Phase 3A 12 hour cold soak/recovery cycles were noted. The extent of the failed areas increased during the 12 hour cold soak/recovery cycle on the panels with 560, A117 and 7343 adhesives as determined by visual observations. The condition of the silver/FEP coating on each radiator panel before and after the thermal-vacuum test is discussed below.

The RTV 560 panel (#2) had spotty delaminations and trapped bubbles in both original bond and refurbished areas before test. Approximately 50% of the panel area had delaminated at the inspection following the eight 6 hour cold soak/recovery cycles of Phase 4. This delamination had increased to 75% of the area by the conclusion of the Phase 3A test. No difference between refurbished and original bond was apparent in terms of relative amount of failed area. The failure mode was primarily silver/FEP separation. Some discoloration of the silver was noted in delaminated areas. The solar absorptance of the delaminated areas was measured after test. A change from an original value of 0.06 to 0.22 range was found. Some 4 square feet of the FEP film separated completely away from the radiator panel. No correlation was found between failed areas in the 560 and the width of the coating strips.

The SR585 panel (#3) had excellent appearance before and after test. No delaminations or changes in solar absorptance from the original 0.06 range were found.

The G401903 panel (#4) had excellent appearance prior to thermal-vacuum test. The FEP film separated from the silver over 98% of the panel area during the first cold soak/recovery cycle of Phase 4. Figure 19 shows panel #4 in the test fixture after Phase 4 and 3A thermal vacuum cycling. Note the clear FEP Teflon hanging from the panel after separation from the silver.

The 6962 panel (#5) had excellent appearance before and after test. A separation of some 3 square inches between adhesive and aluminum was noted on the inlet side of the panel. Since this area is relatively warm and experiences the least severe thermal transients, the separation is considered an adhesive manufacturing or surface preparation anomaly. The silver/FEP/6962 coating, used to complete panels #3 and #4 when insufficient SR585 and G401903 laminate was available, had excellent appearance before and after test. A total area of 84 square feet of 6962 laminate was thus tested successfully. The versatility of the 6962 adhesive was illustrated by the different cure conditions for panels #3 and #4 which produced usable coatings. Solar absorptance remained in the 0.06 to 0.08 range after test. Figure 20 shows panel #5 after Phase 4 and 3A thermal-vacuum cycling.

The 7343 panel (#6) had many bubbles in the 0.25-1.0 inch diameter size range which formed during cure in the adhesive. The silver/FEP coating showed some delamination during the initial Phase 4 cold soak/recovery cycle.

Complete separation of the FEP from the silver occurred during the Phase 3A 12 hour cold soak/recovery cycles. The failure was localized in the mid-region of the panel, which comprises 50% of area. The 7343 adhesive was mixed in batches. The mid-region of the panel was bonded separately from the inlet and outlet region. Temperature extremes were most severe in the outlet region, hence failure would be expected initially in that area. This failure may be related to the adhesive batches used to bond the mid-region. Reproducibility of batches of 7343 has been a problem in past work[10]. The appearance and solar absorptance of the coating on inlet and outlet regions of the panel were essentially unchanged after the thermal-vacuum test.

The A117 panel (#7) had wrinkles, folds and creases in the silver/FEP film after bonding. These resulted from the extremely high tack of the adhesive at the application stage. Failure of the bond occurred over most of the panel except a 7 square foot area along the relatively warm inlet manifold. Evidence of failure was seen by video scan during the initial Phase 4 6 hour cold soak/recovery cycle. Complete separation of the coating over 90% of the panel occurred during the Phase 3A 12 hour cold soak/recovery cycles. The failure was adhesive in nature, primarily at the A117-aluminum bond line.

The L-100 and L-167 areas of panel #8 had similar appearances with numerous 0.25" to 1.0" bubbles present. The L-100 bond area had ripples introduced by the Mylar overlay into the silver/FEP film. These carried through as bond line thickness variations. No change in appearance or solar absorptance occurred in either L-100 or L-167 portion of Panel #8 during the thermal-vacuum test. The panel is pictured in Figure 21 after Phase 4 and 3A testing; the ripples in the mid-region coated with L-100 are clearly seen.

Table 6 summarizes the appearance of the various coated radiator panels after test. The width of the FEP film did not influence or induce coating failure with any of the adhesives investigated. The handleability and ease of application with a particular adhesive can be used as major criteria for film width selection.

8.0 CONCLUSIONS

Four coatings/adhesives, two silicones and two urethanes, were carried through the test sequences successfully.

The most promising adhesives were the silicones, Permacel 6962 and G.E. SR585, which were applied to the silver/FEP Teflon film to form a laminate tape.

The urethanes have the disadvantages of a potentially carcinogenic curing agent and difficult application process.

The laminate adhesives in tape form required a vacuum bag/heat cure to adhere during the cryogenic temperature excursion.

Adhesives with attractive thermal performance properties may be impractical for application to hardware for reasons such as high tack or bubble formation during cure.

9.0 REFERENCES

(1) James B. Heaney, "Suitability of Metallized FEP Teflon as a Spacecraft Thermal Control Surface", ASME publication 71-AV-35, 1971.

(2) Ibid, p. 1

(3) J. Brian Dietz, M. L. Fleming, R. J. Tufte, and D. W. Morris, " Modular Radiator System Development for Shuttle and Advanced Spacecraft", ASME publication 72-ENAv-34, 1972, p. 12

(4) Heaney, ASME 71-Av-35, p. 4

(5) Heaney, ASME 71-Av-35, p. 4

(6) L. B. Fogdall and S. Cannady, "Dependance of Thermal Control Coating Degradation Upon Electron Energy", NAS5-11164, May 1969, NASA-Goddard

(7) L. B. Fogdall and S. Cannady, "Protons and Electron Effects in Thermal Control Degradation", NAS5-11219, May 1970, NASA-Goddard

(8) Dietz, et.al., ASME 72-ENAv-34, p. 12

(9) Heaney, ASME 71-Av-35, p. 6

(10) Wayne S. Slemp, private communication, 1973.

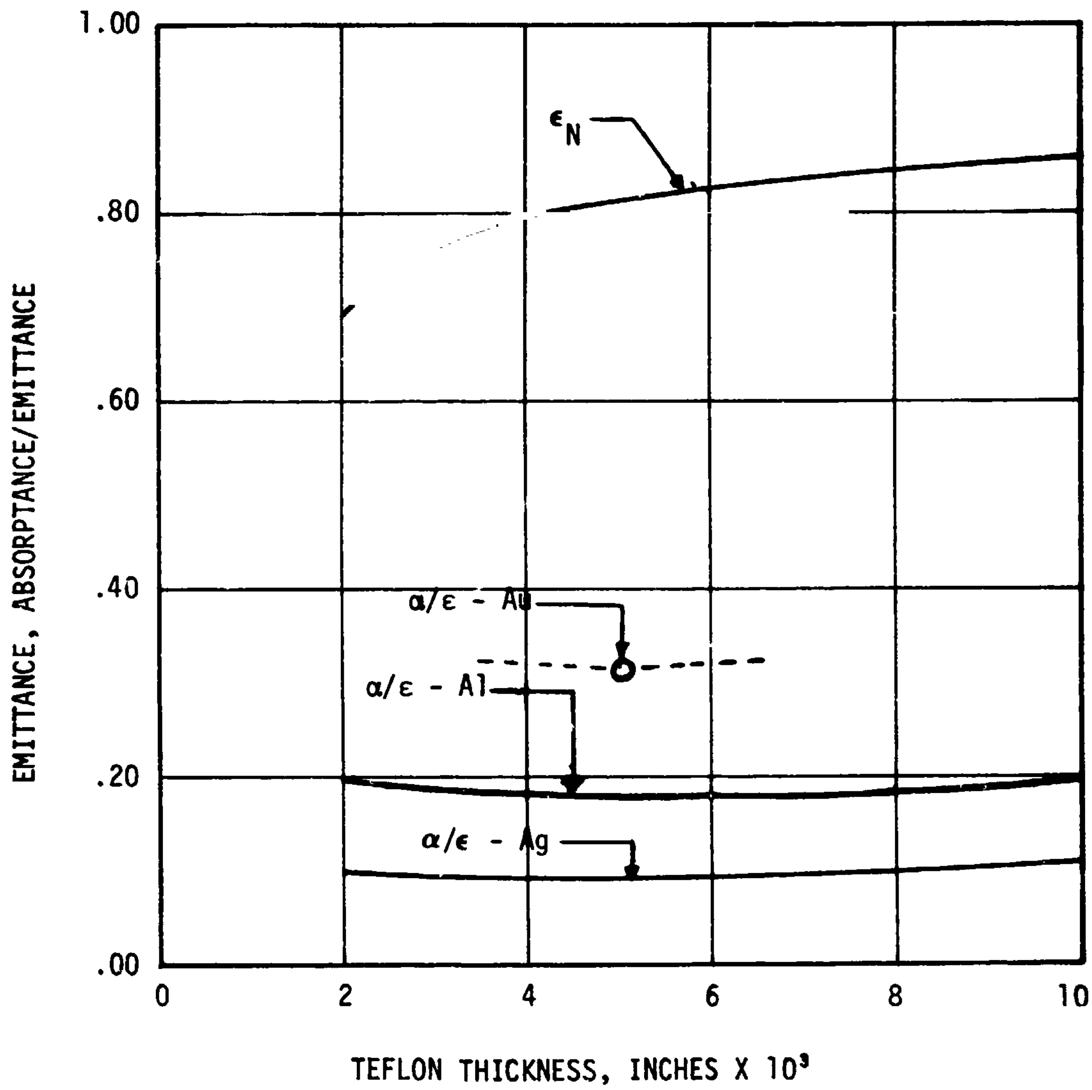
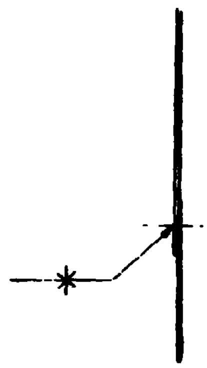


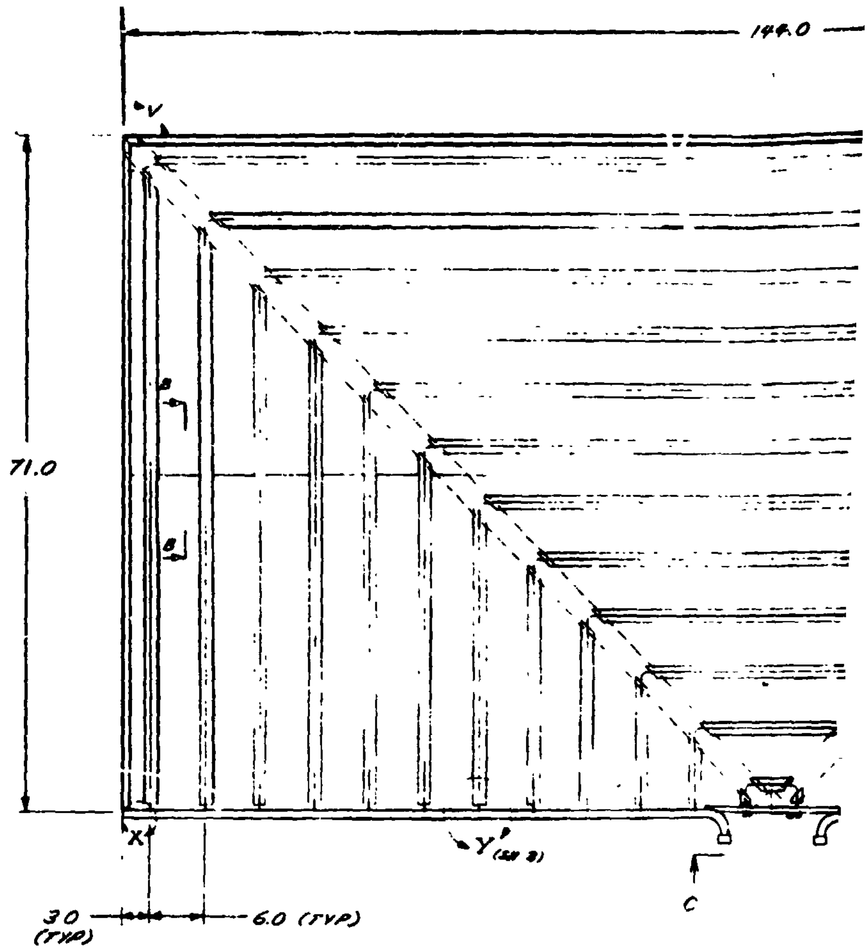
FIGURE 1

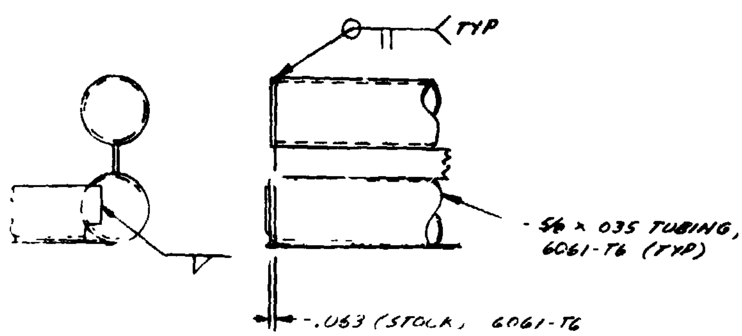
NORMAL EMITTANCE AND ABSORPTANCE/EMITTANCE FOR SILVER/FEP TEFLON FILMS AS A FUNCTION OF THICKNESS

FOLDOUT FRAME

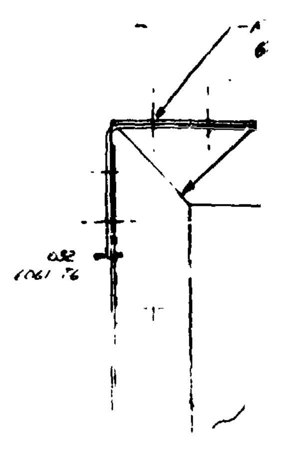


FULL SCALE
SECTION B-B





DETAIL X
FULL SCALE
(SAME FOR OPPOSITE END EXCEPT FOR TUBE ORIENTATION)



DETAIL

FOLDOUT FRAME 2

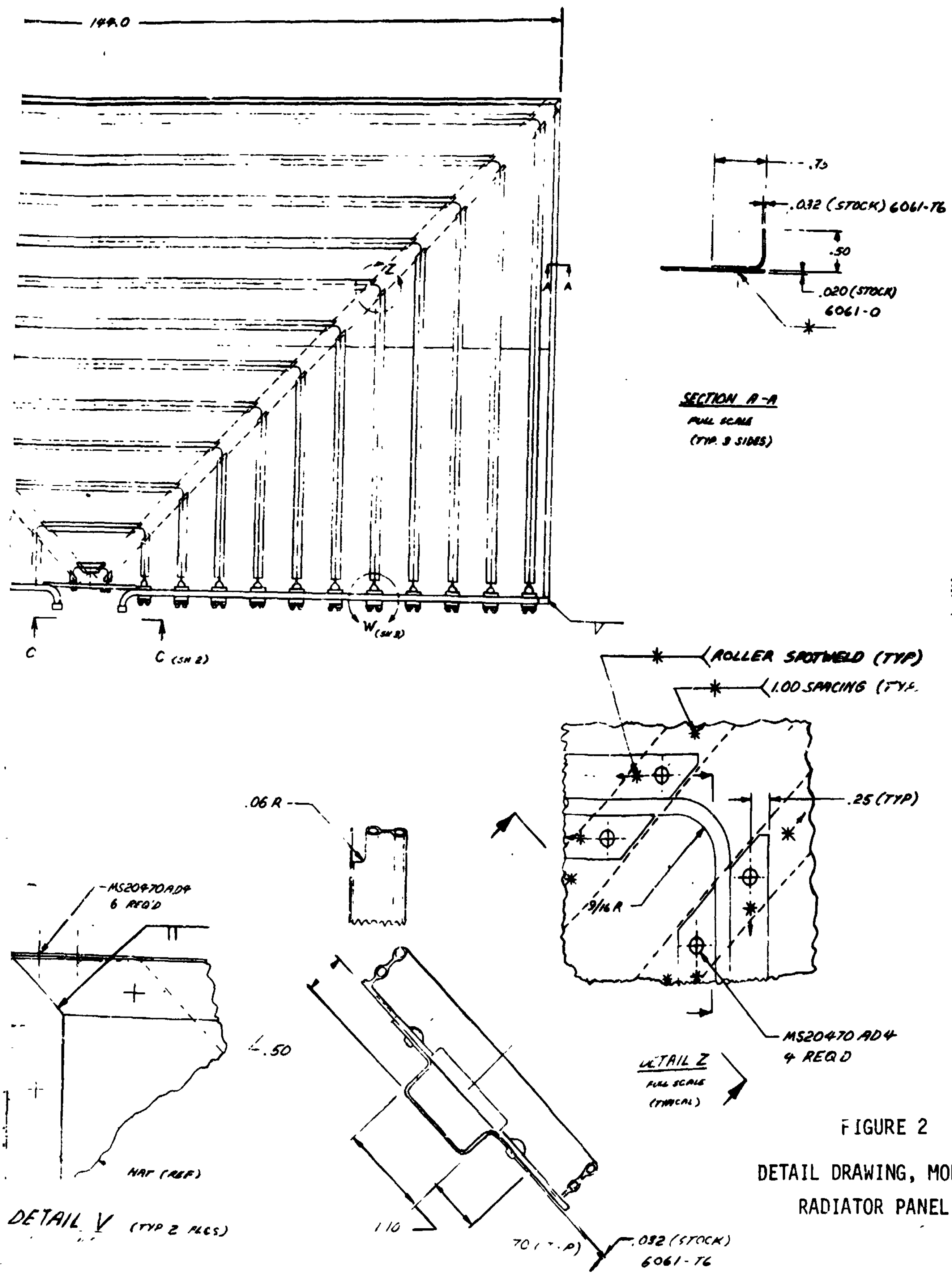


FIGURE 2

DETAIL DRAWING, MODULAR RADIATOR PANEL

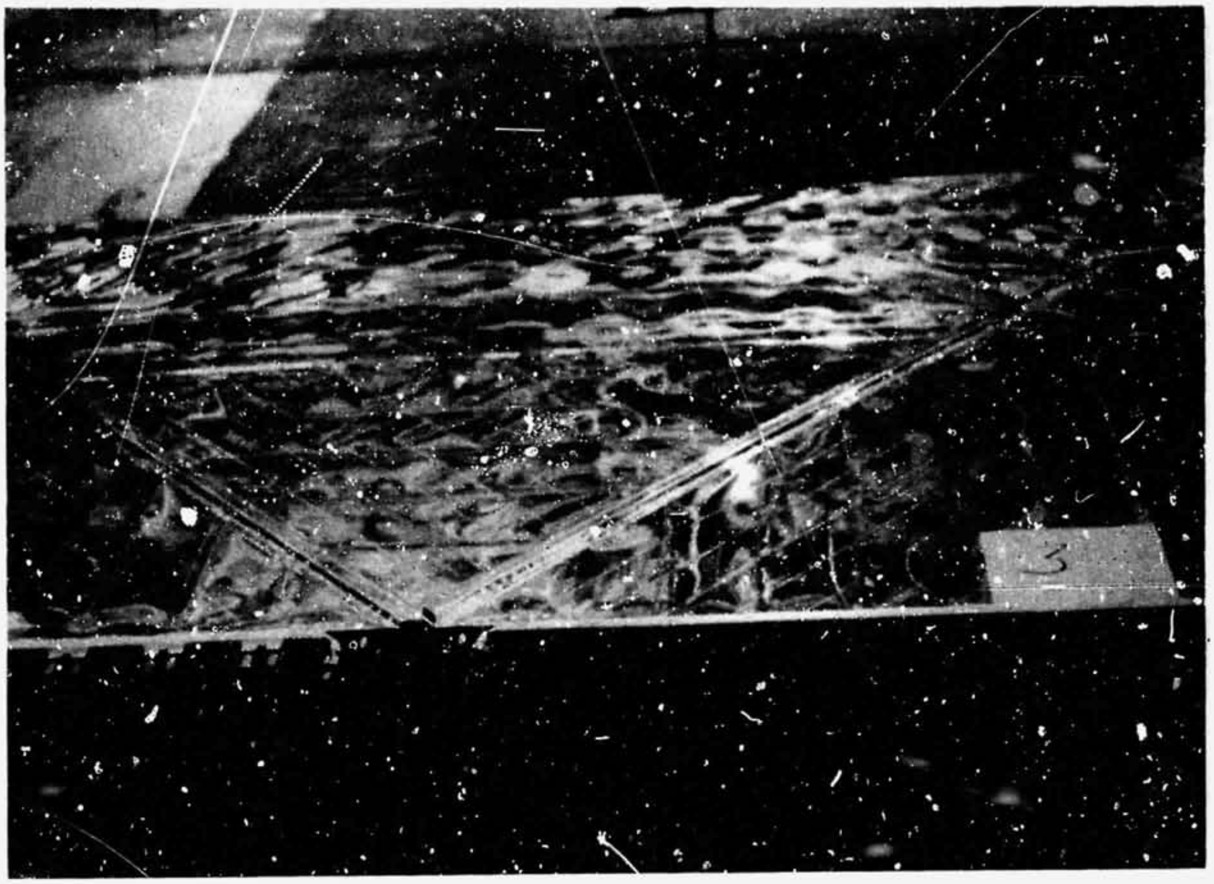


FIGURE 3 COATED SURFACE OF MODULAR RADIATOR PANEL

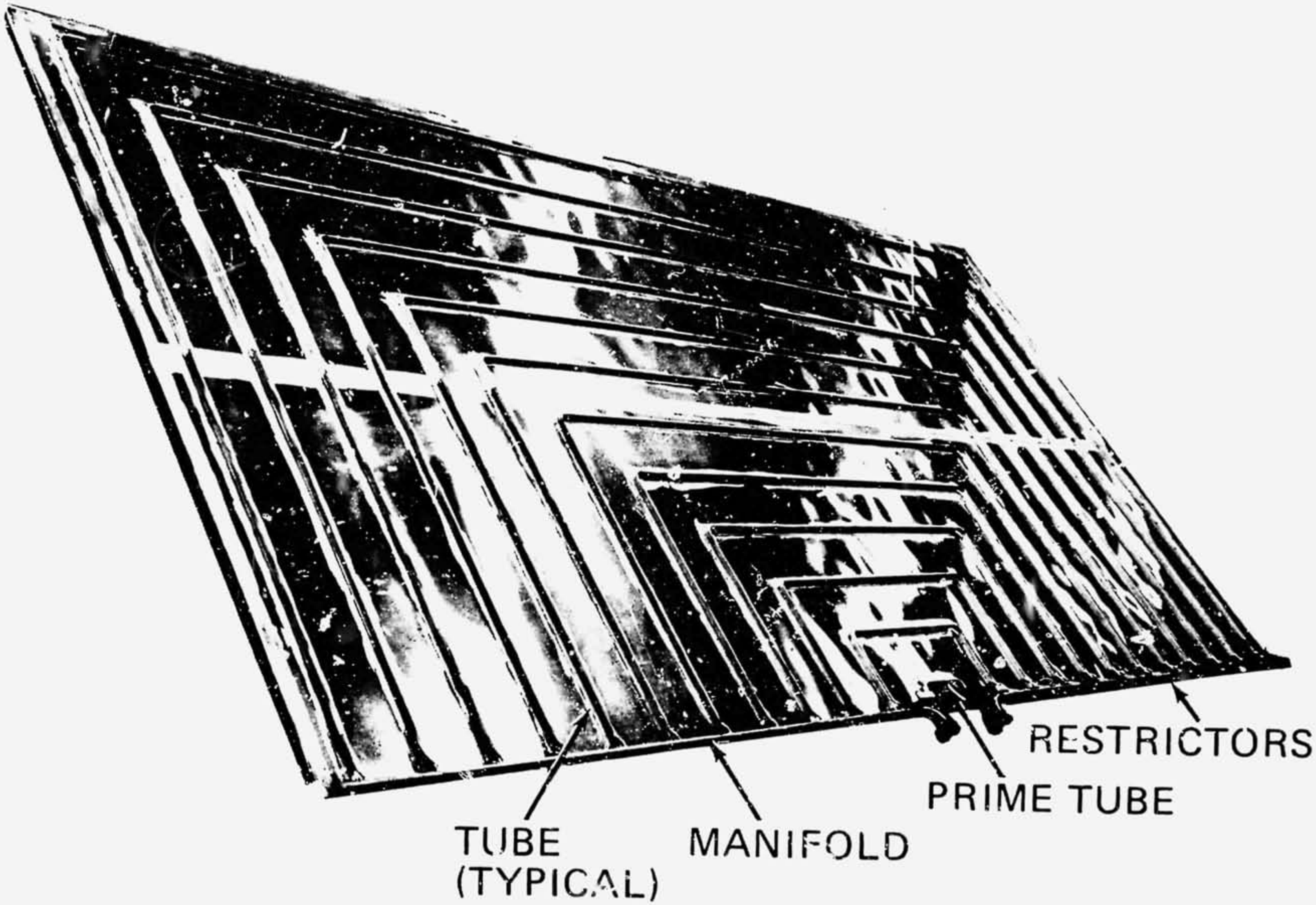


FIGURE 4 HEAT EXCHANGE TUBES ON MODULAR RADIATOR PANEL

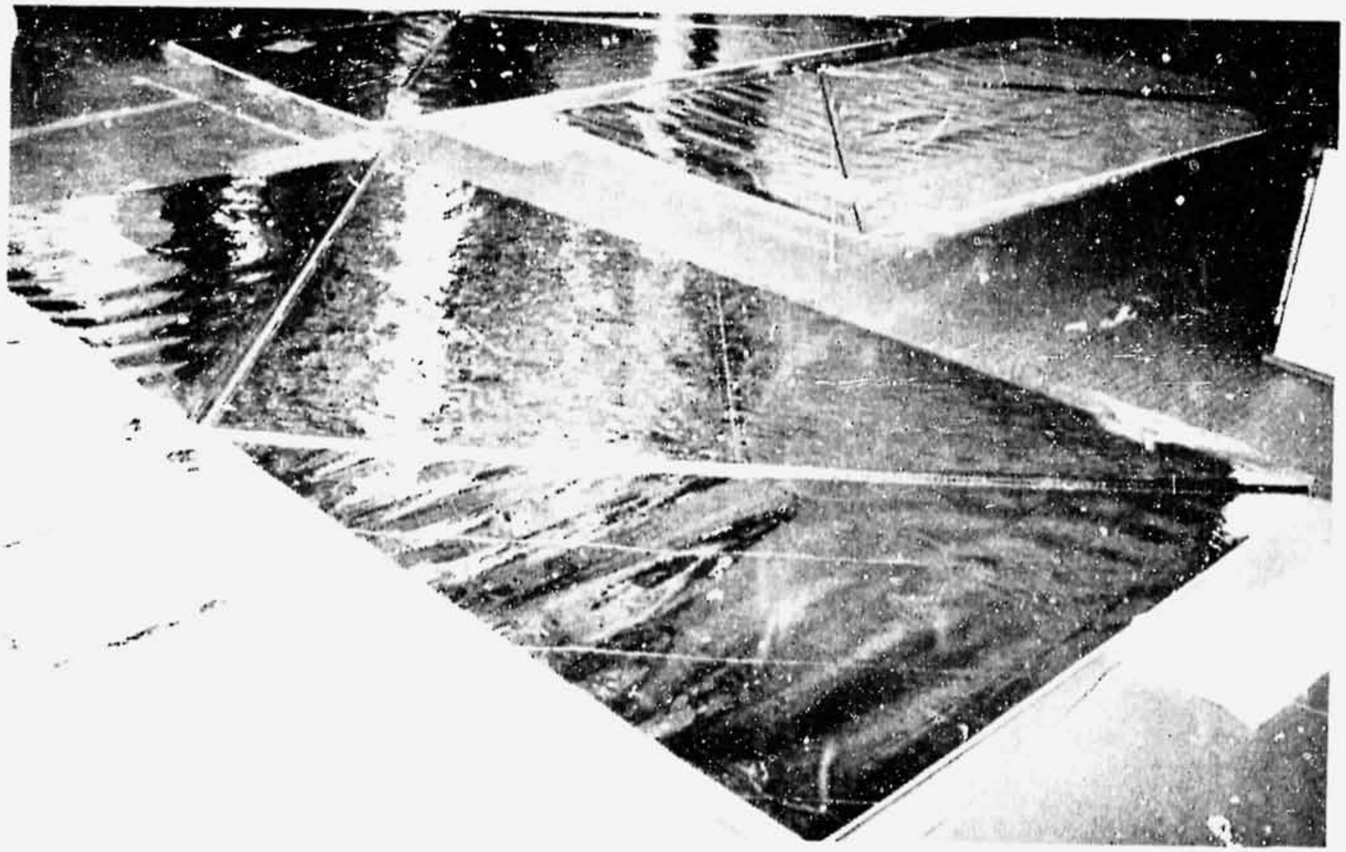


FIGURE 5 L-100/L-167 PANEL PRIOR TO THERMAL-VACUUM TEST

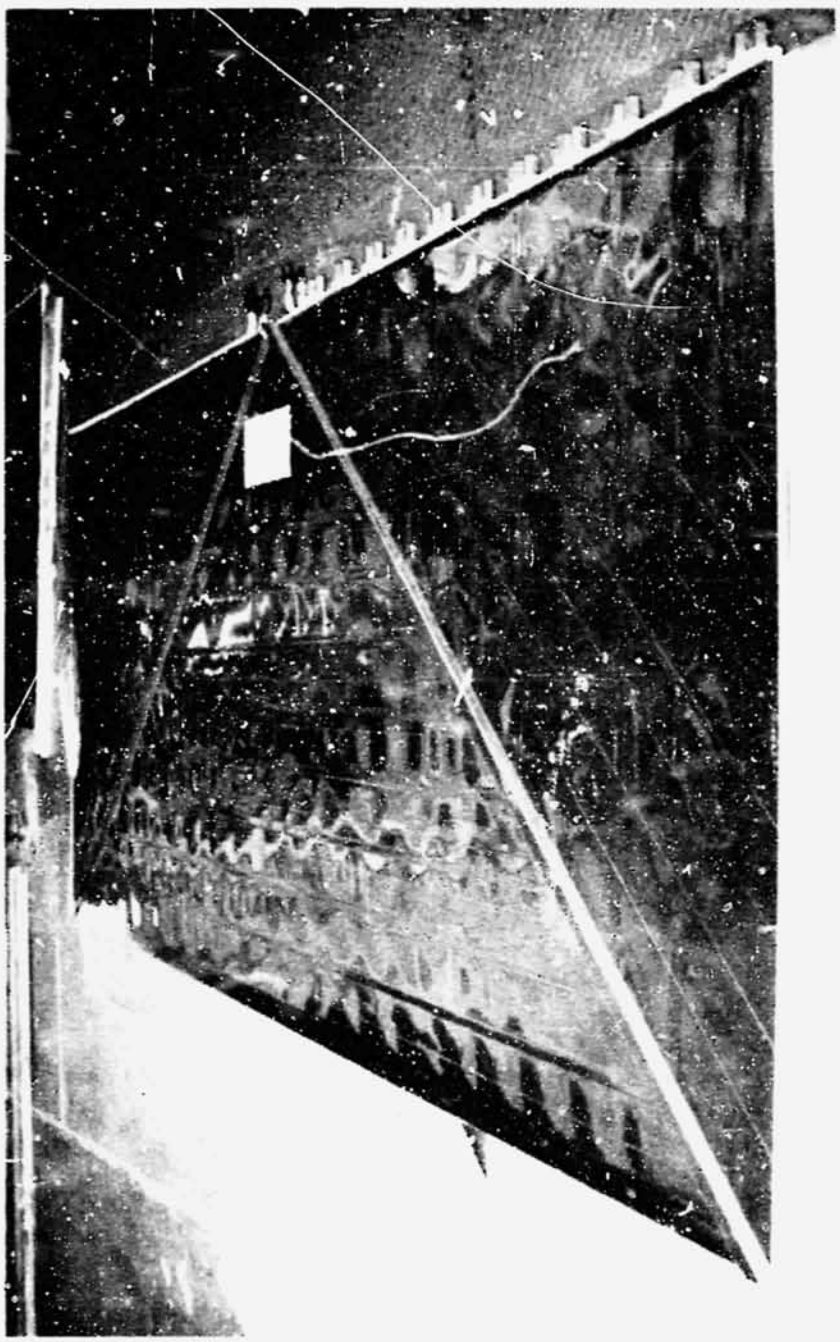


FIGURE 6 G401903 PANEL PRIOR TO THERMAL-VACUUM TEST

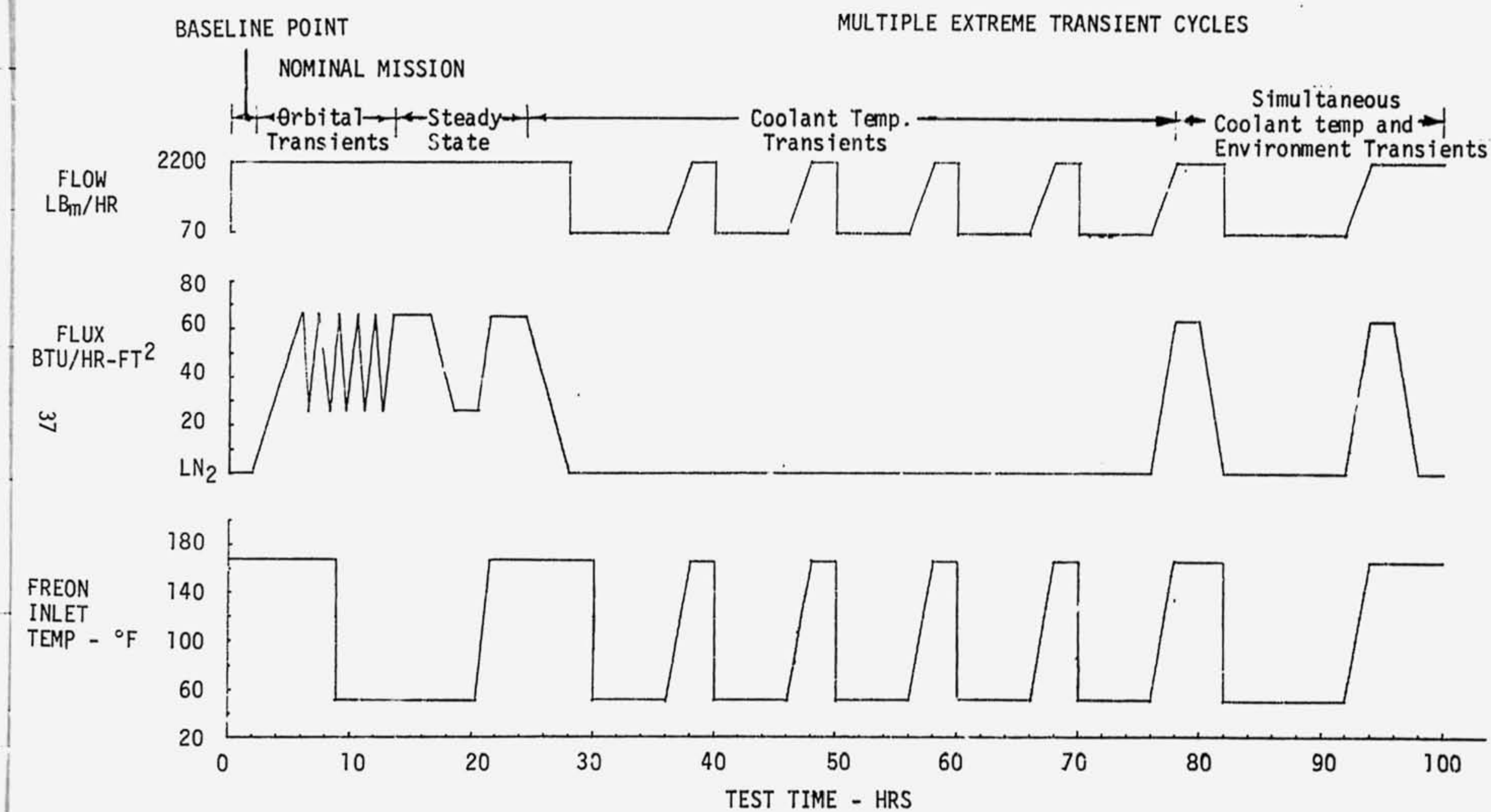


FIGURE 7 TEST TIMELINE, PHASE 4 TESTING OF SILVER/FEP TEFLON THERMAL COATING ON MODULAR RADIATOR PANELS

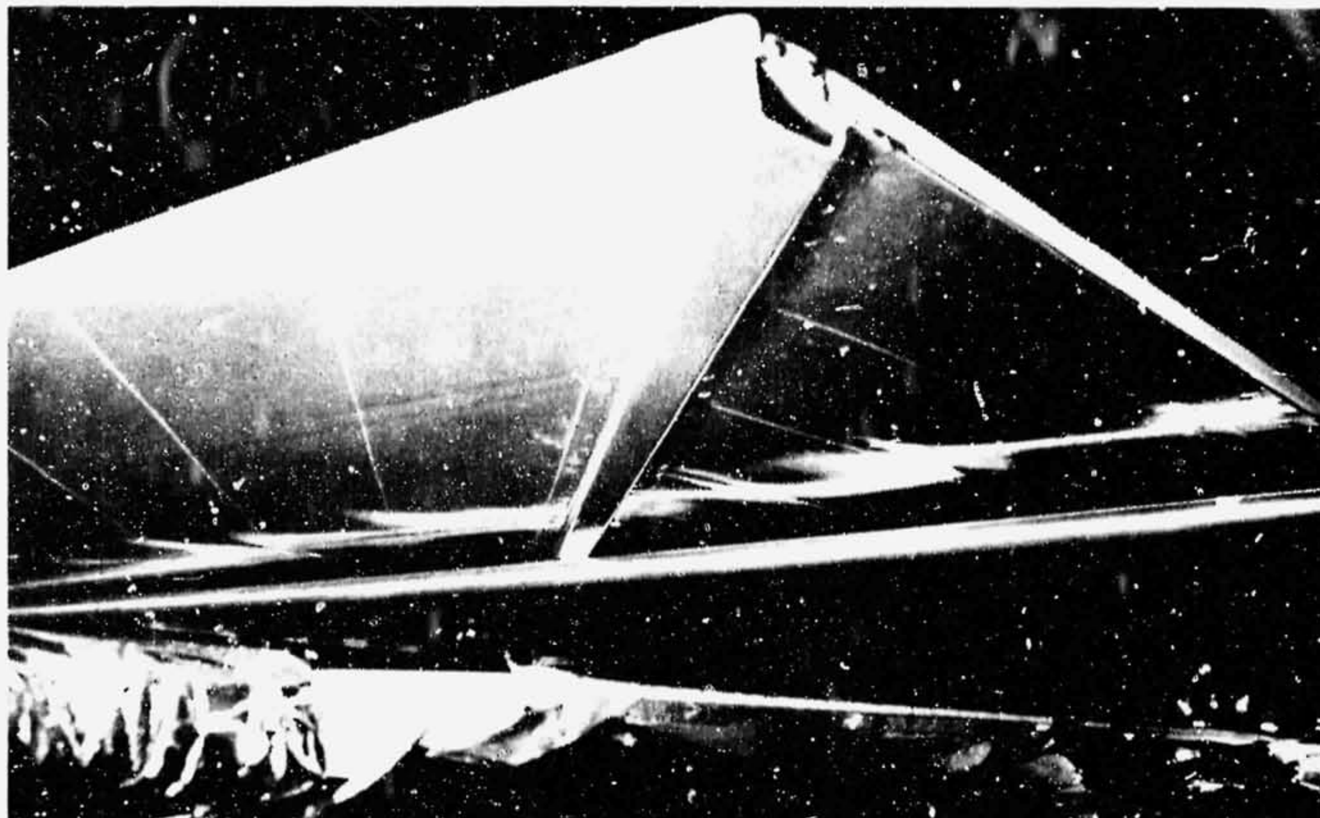


FIGURE 8 MODULAR RADIATOP PANEL - UPPER, AND INFRARED SIMULATION PANEL - LOWER, IN VACUUM CHAMBER FOR TEST

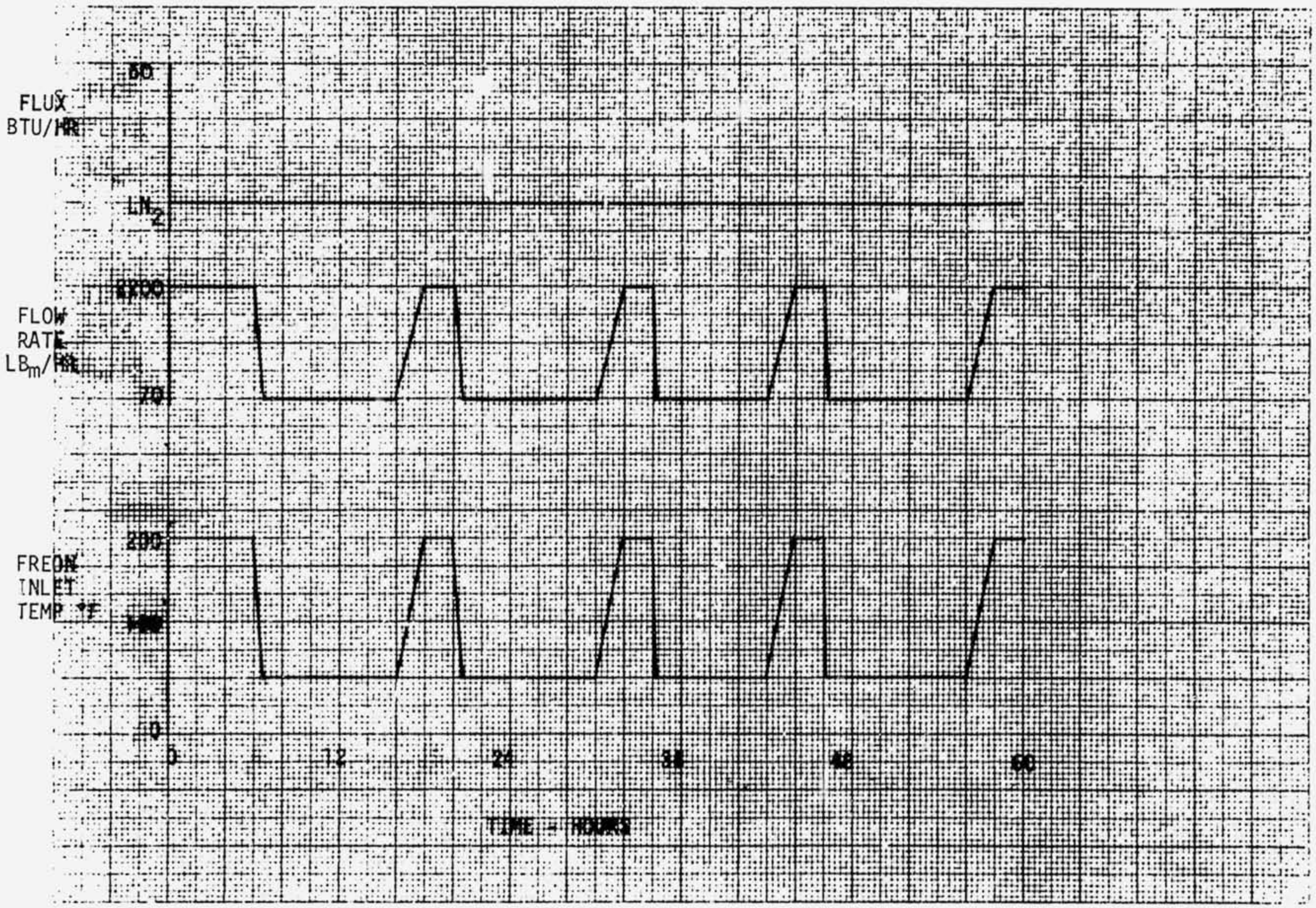


FIGURE 9 MRS COATING TEST TIMELINE - PHASE 3A

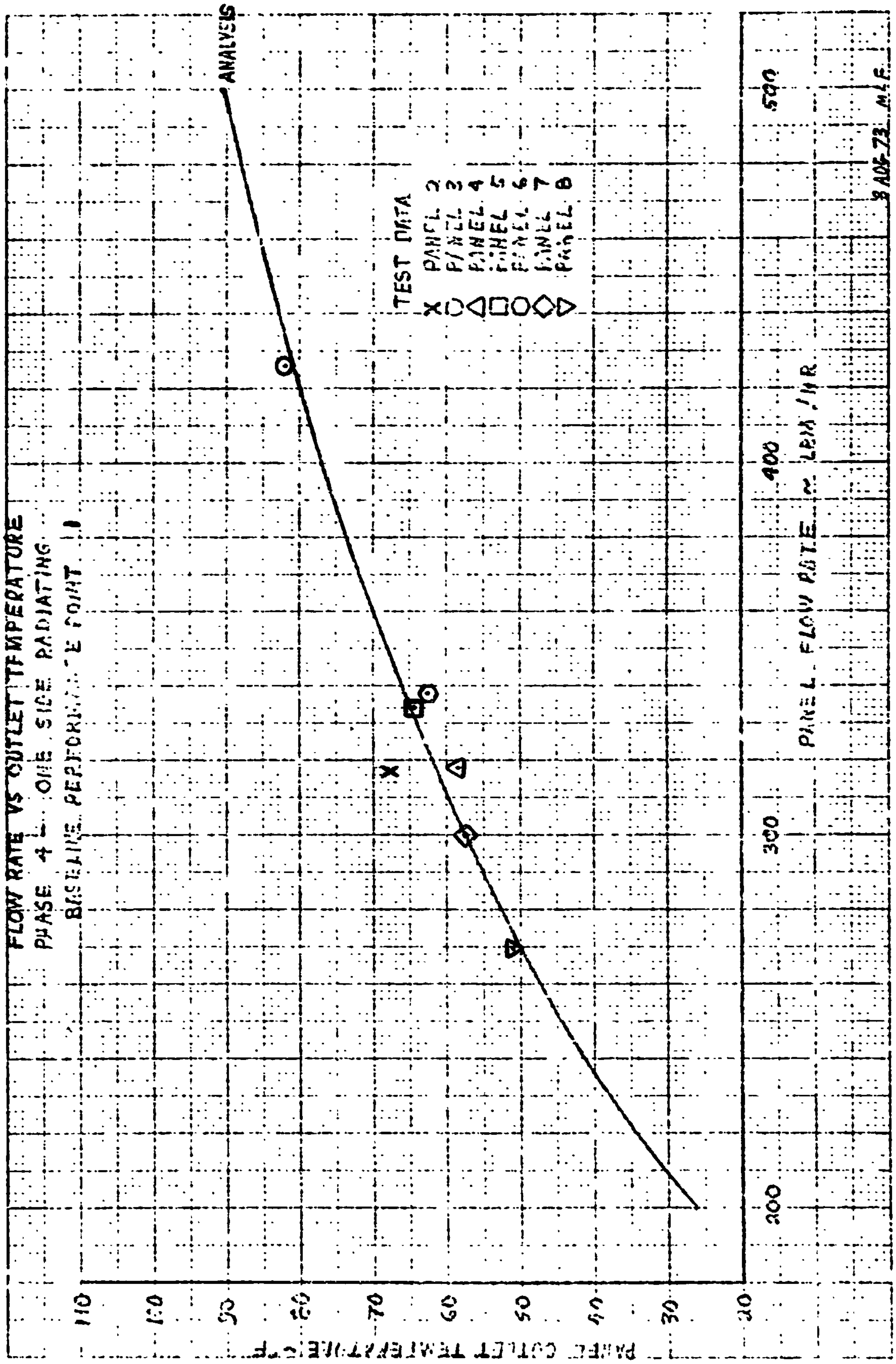


FIGURE 10 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

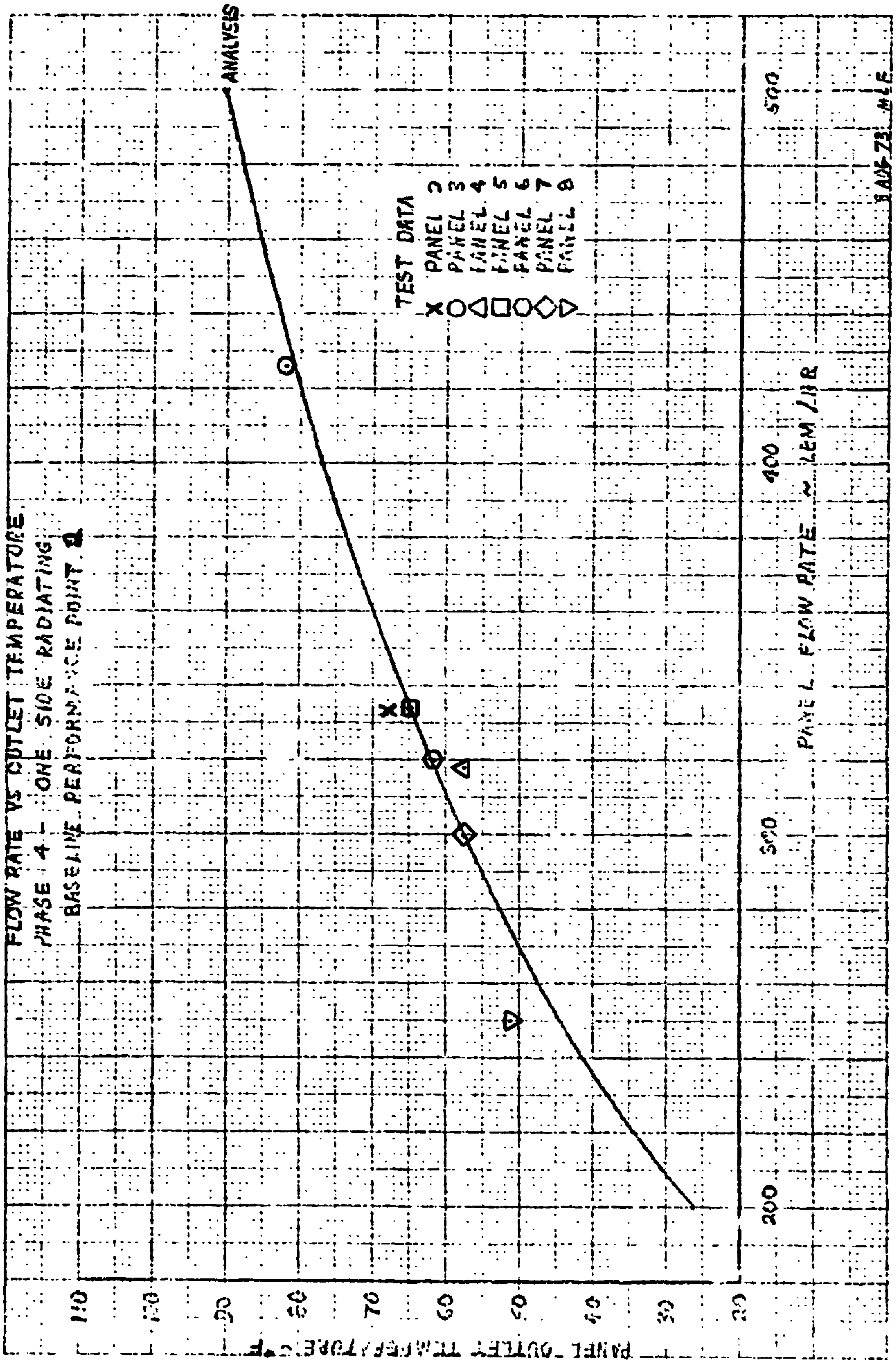


FIGURE 11 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

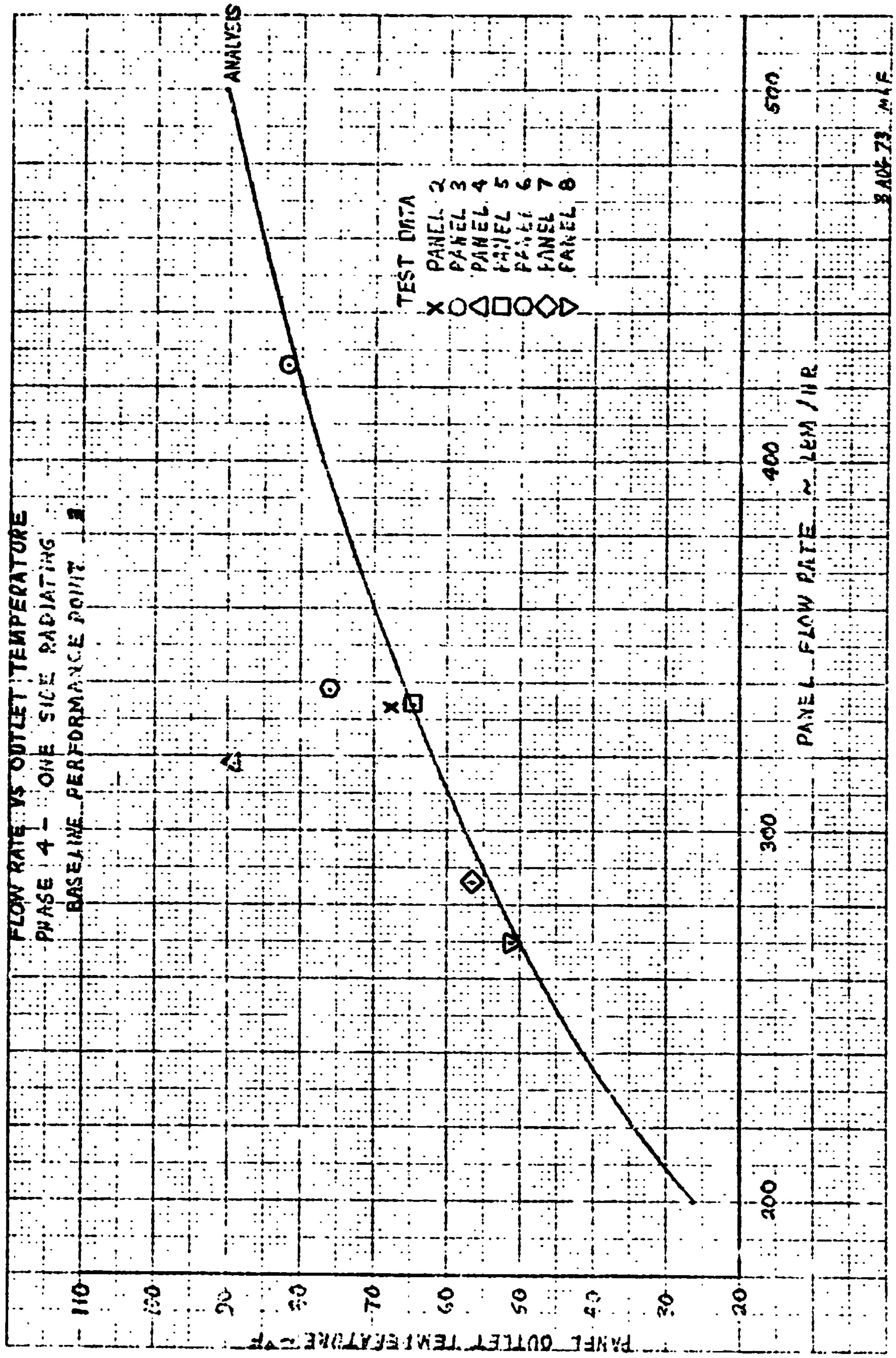


FIGURE 12 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

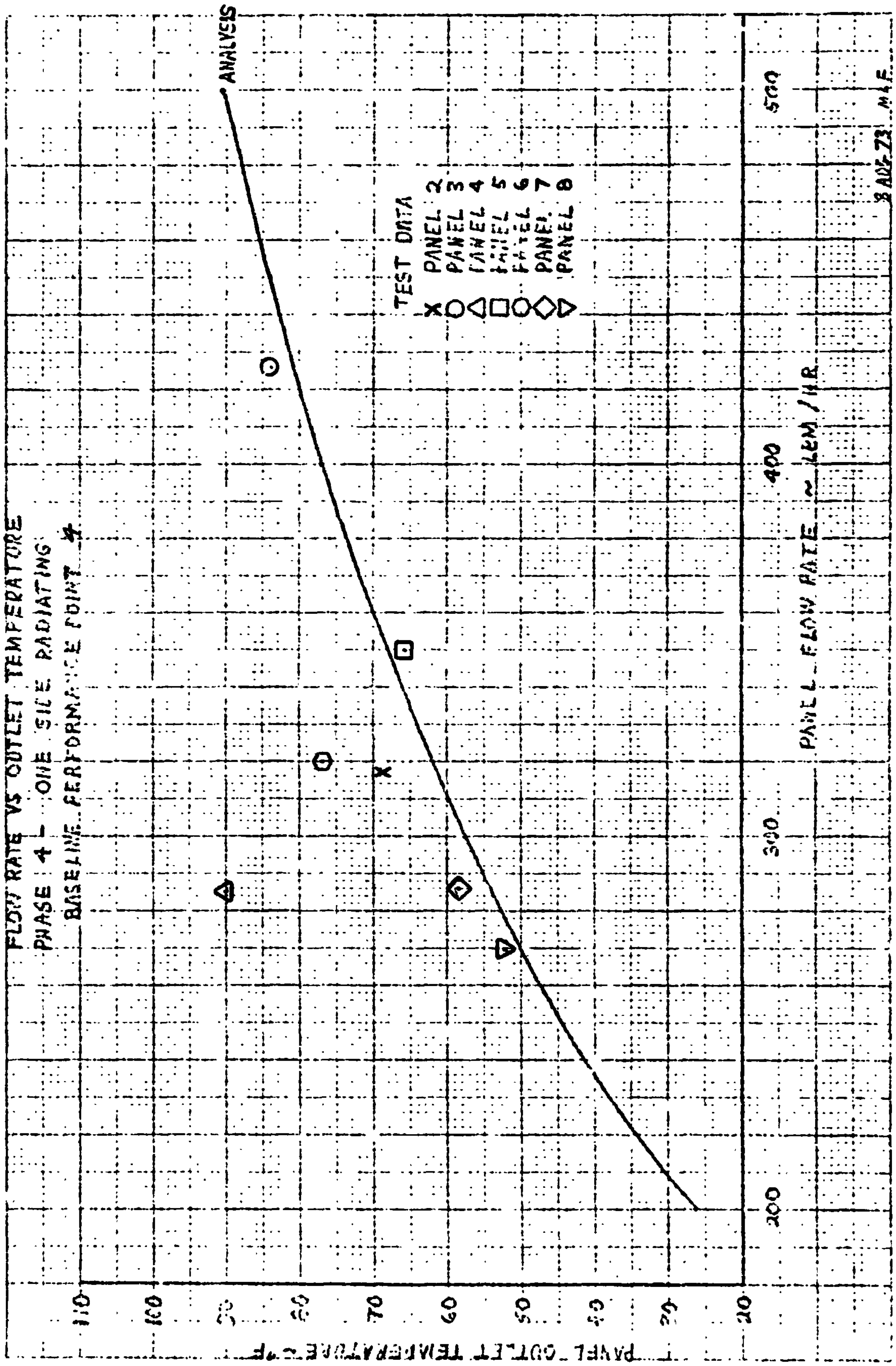


FIGURE 13 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

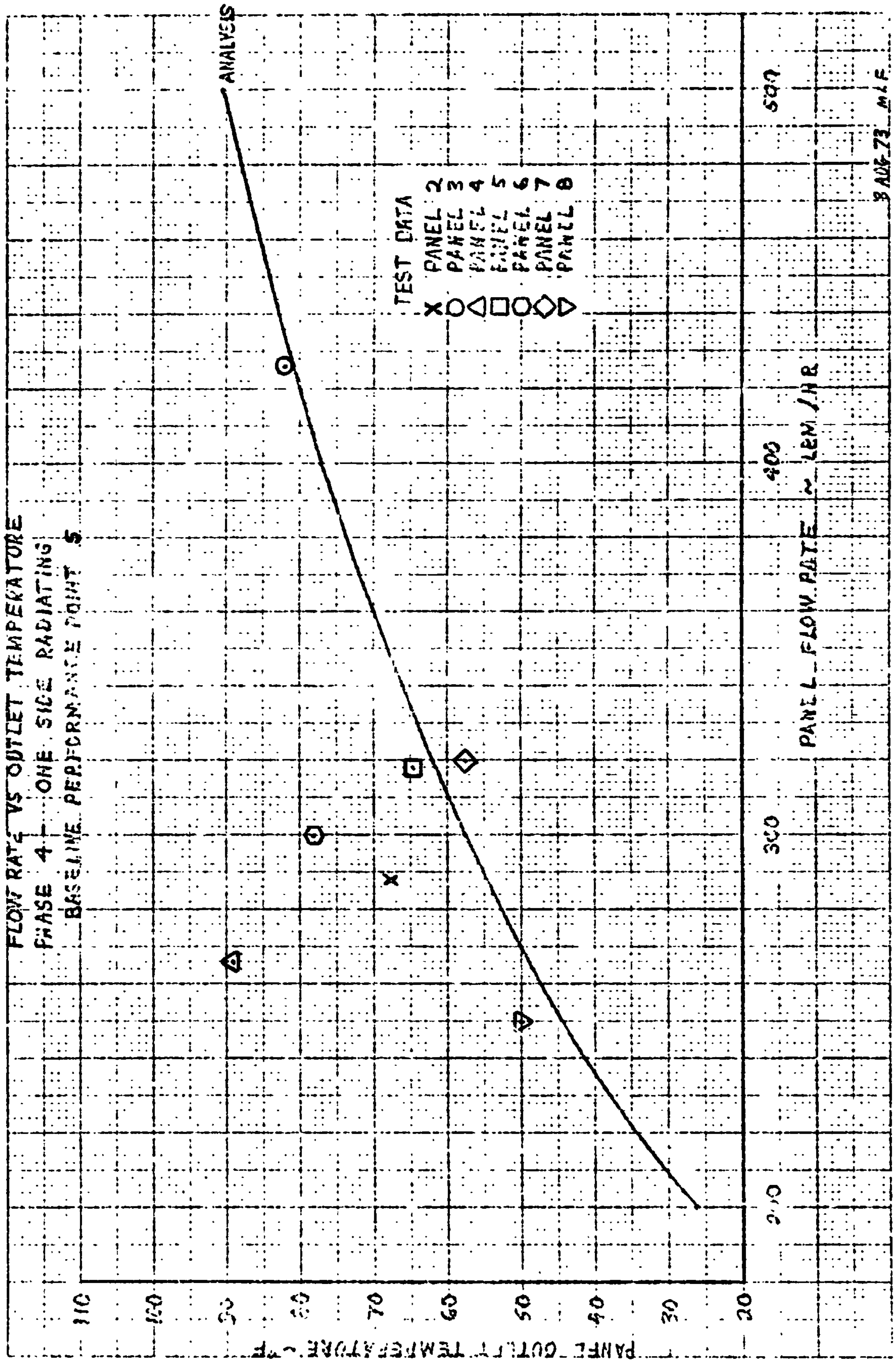


FIGURE 14 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

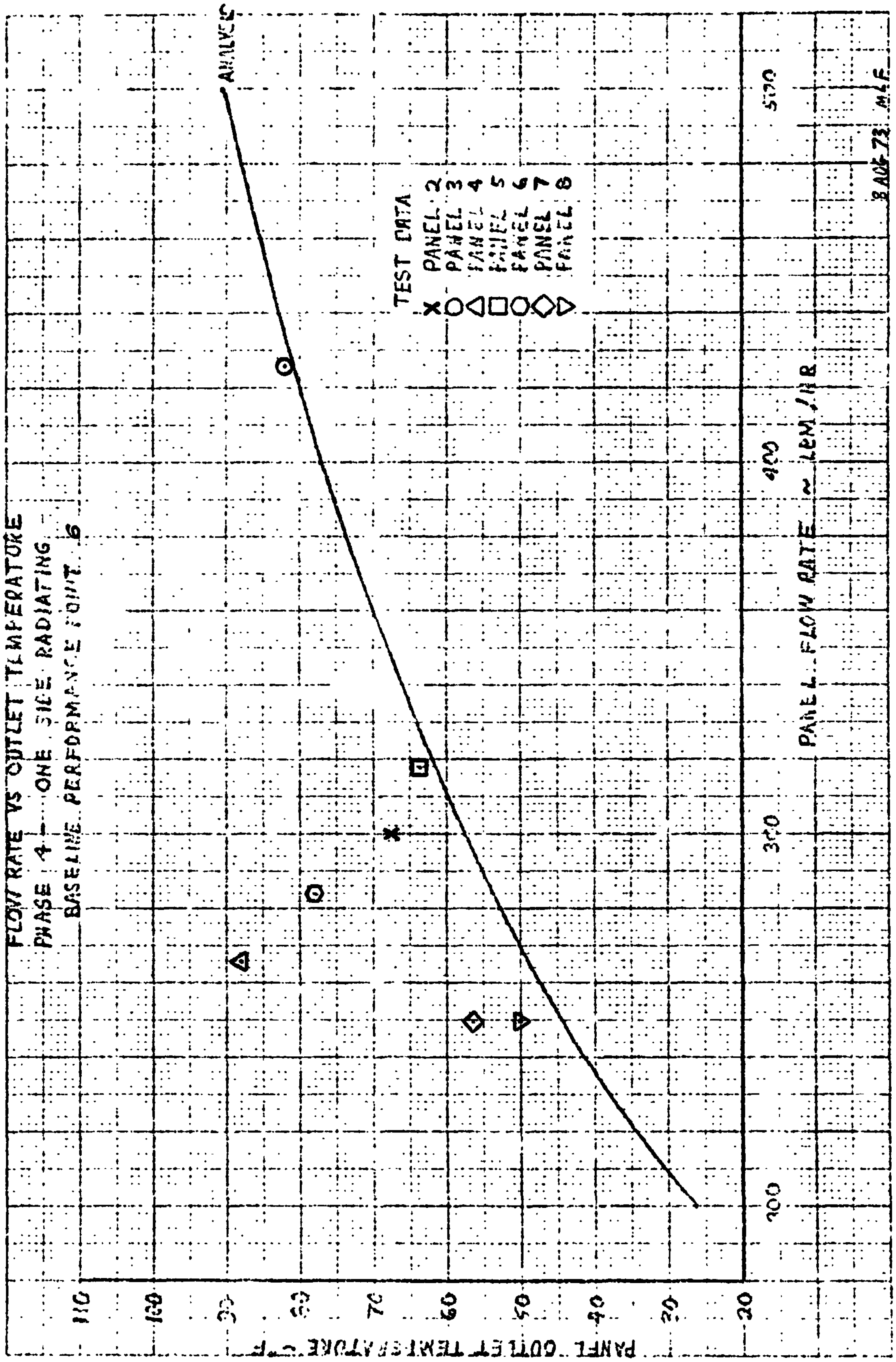


FIGURE 15 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

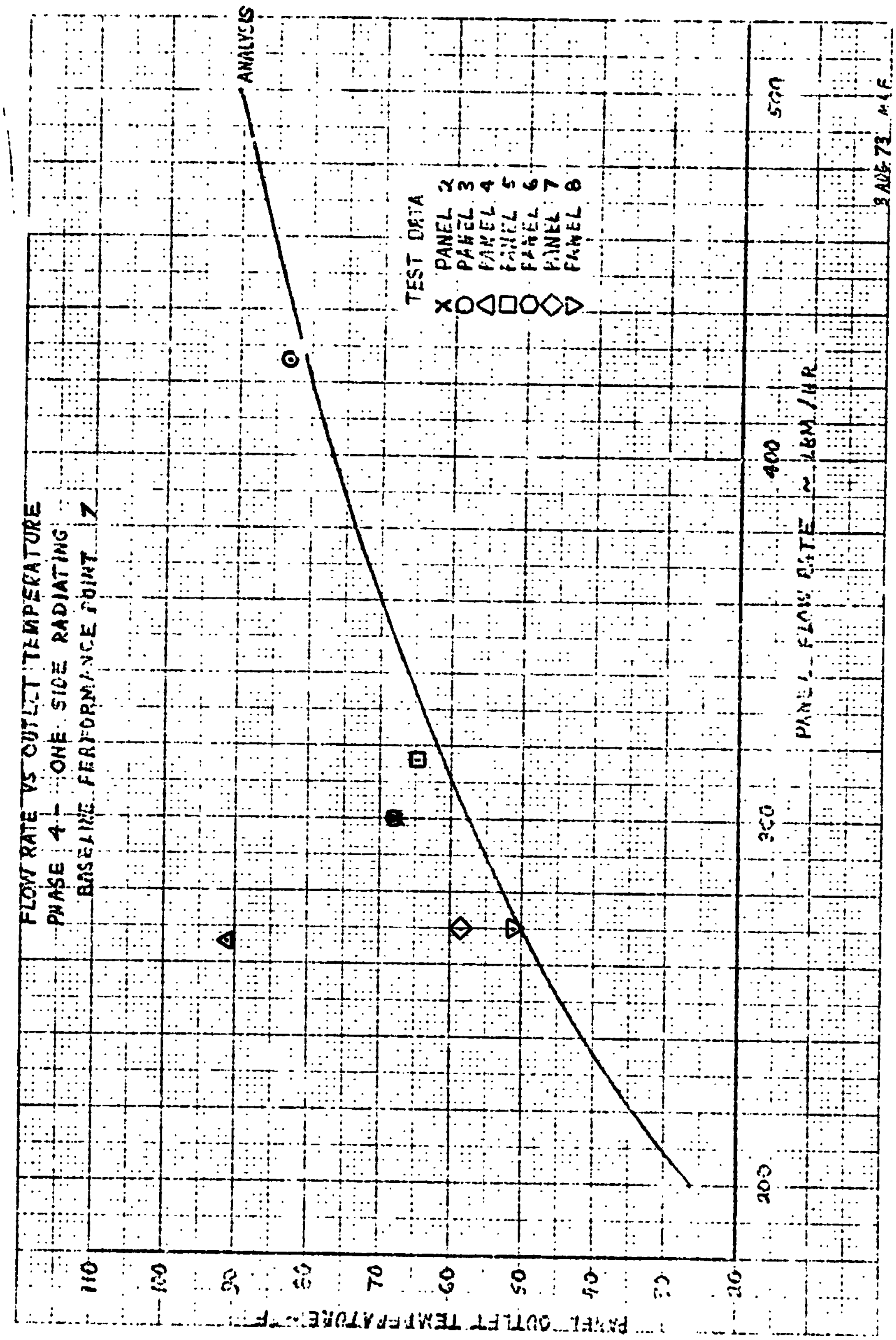


FIGURE 16 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

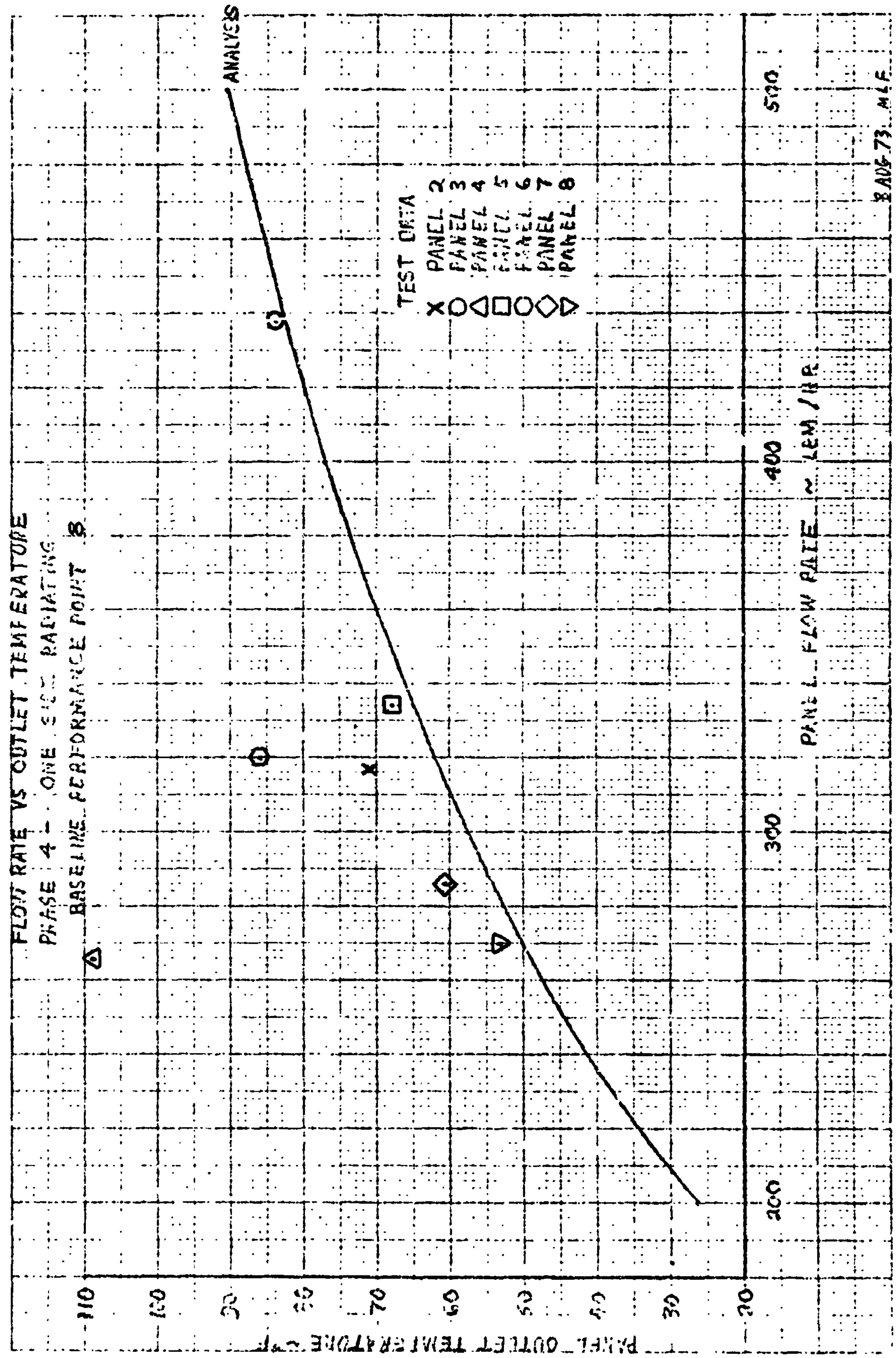


FIGURE 17 COMPARISON OF PHASE 4 TEST RESULTS WITH ANALYTICAL PREDICTIONS

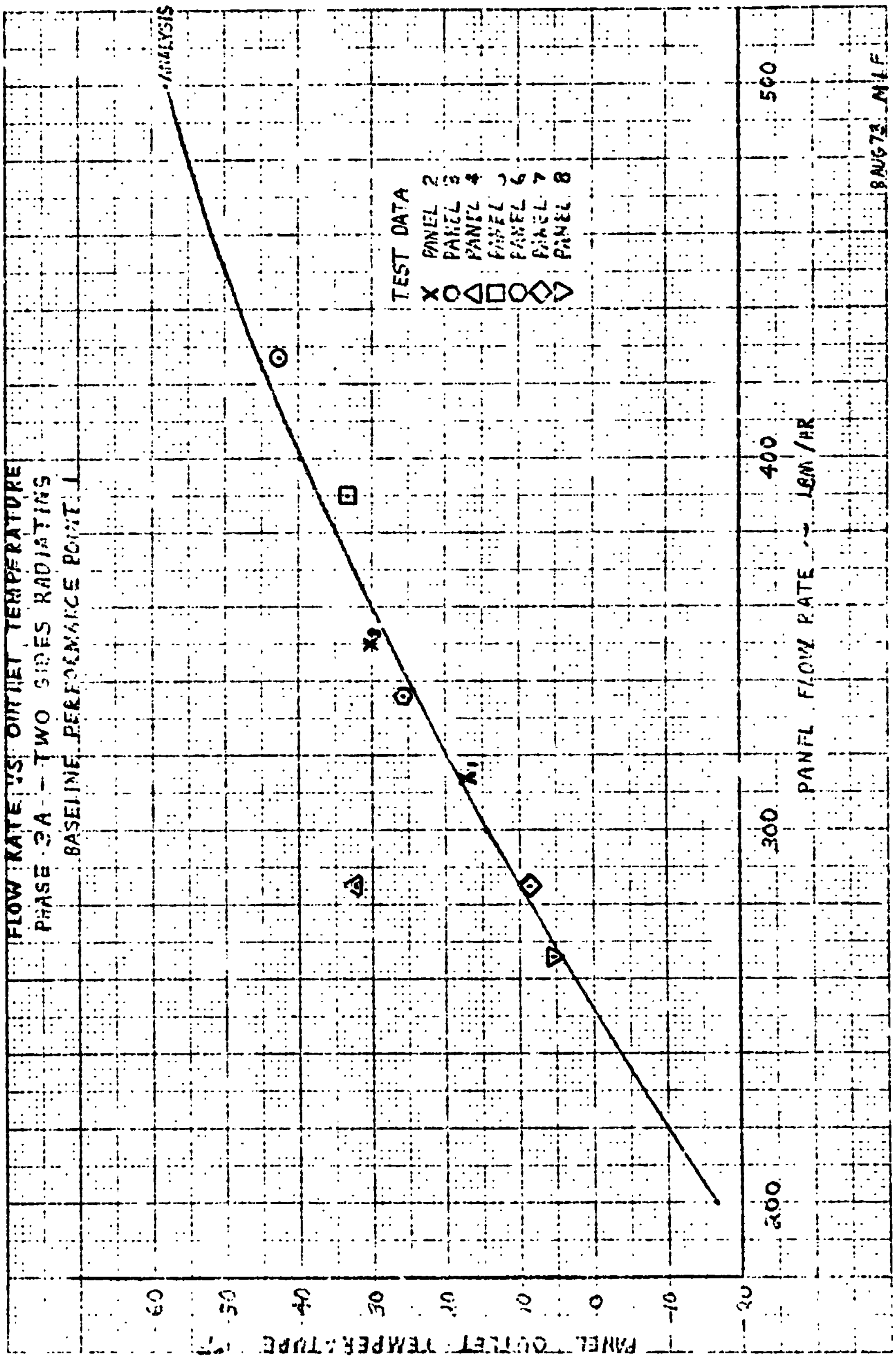


FIGURE 18 COMPARISON OF PHASE 3A TEST RESULTS WITH ANALYTICAL PREDICTIONS

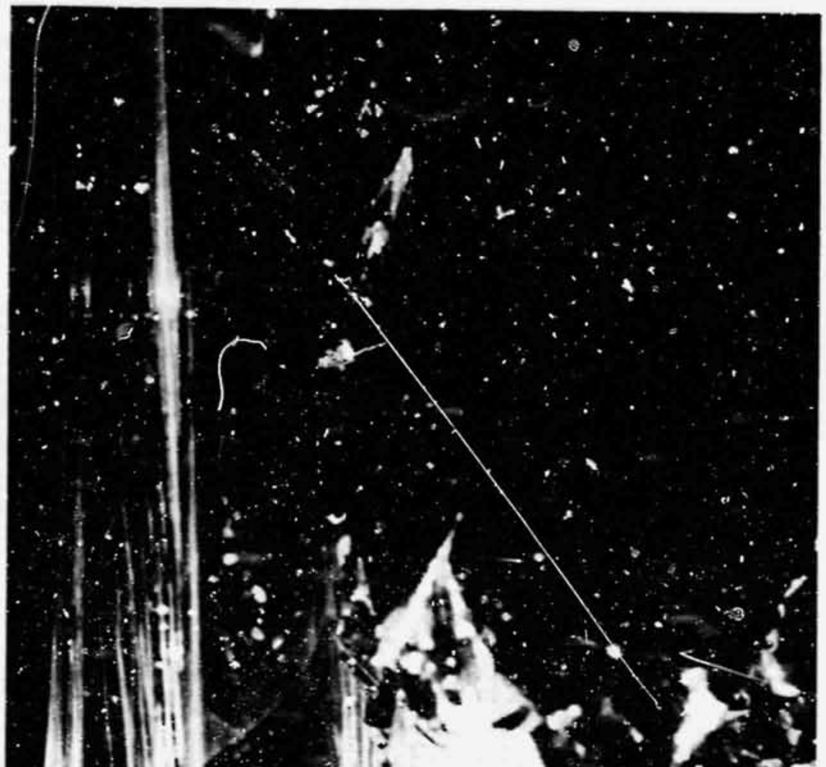


FIGURE 19 G401903 PANEL AFTER THERMAL VACUUM TEST

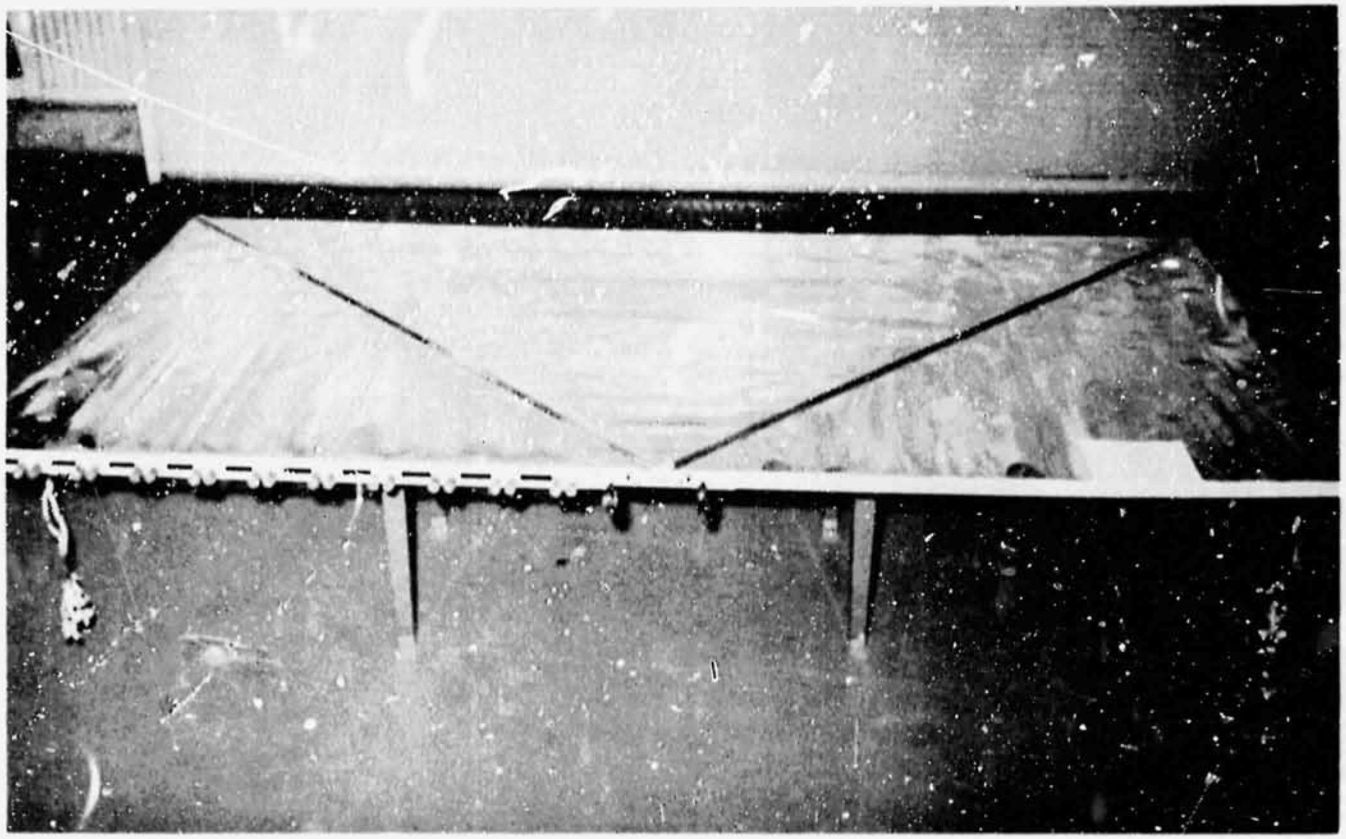


FIGURE 20 6962 PANEL AFTER THERMAL VACUUM TEST

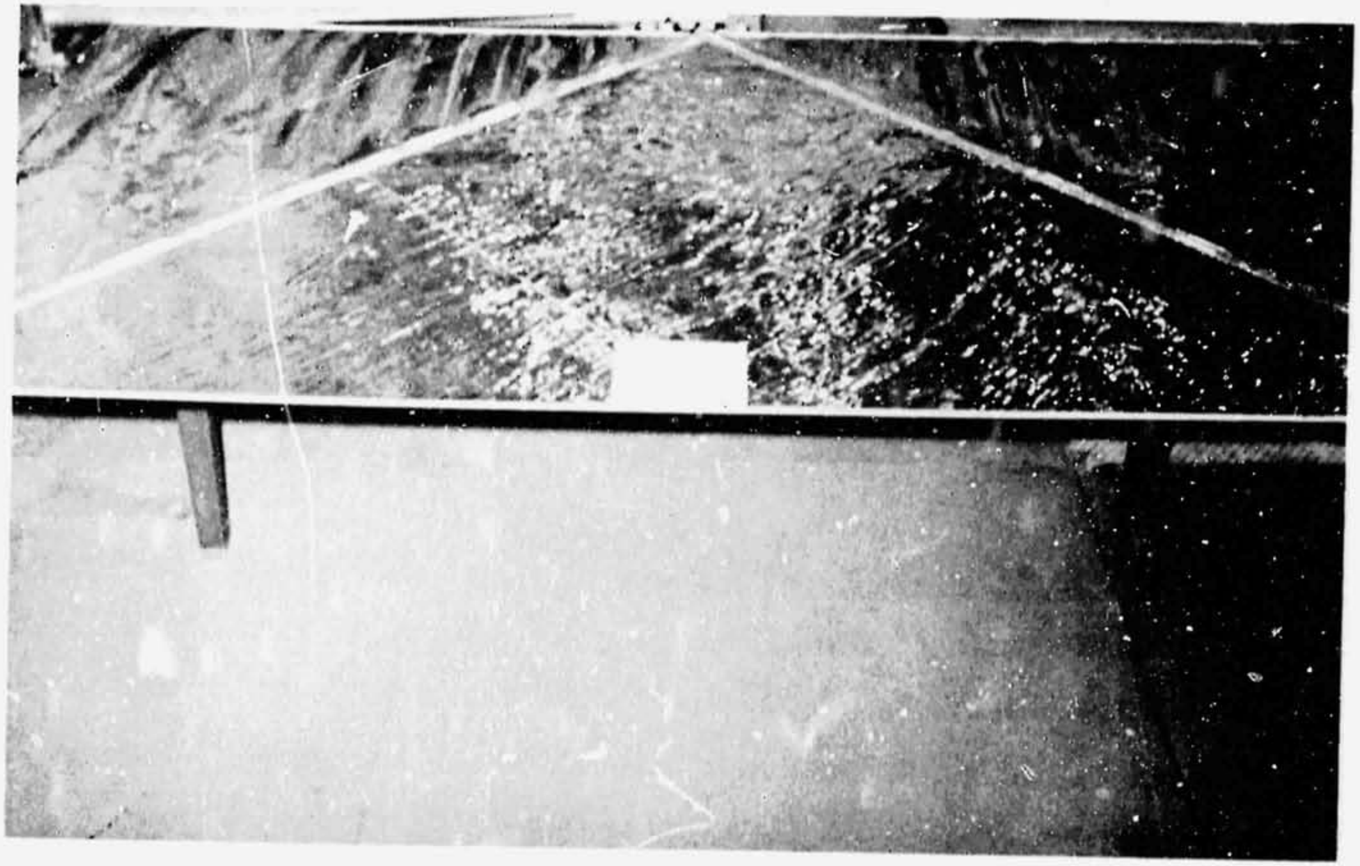


FIGURE 21 L-100/L-167 PANEL AFTER THERMAL-VACUUM TEST

TABLE 1 PEEL STRENGTHS OF SILVER FEP TEFLON BONDED TO 6061-T6 ALUMINUM ADHEREND

NASA-JSC-SMD DATA

ADHESIVE IDENTIFICATION (ORGANIZATION) CLASS	PEEL STRENGTH* lbs/in		
	-300°±5°F	72±2°F	+300±5°F
MYSTIC A117 (LANGLEY) SILICONE	Failed(1)	4.6(5)	0.18(5)
	Failed(1)	5.6(5)	0.20(5)
E/C CPC-6 (VSD) URETHANE	Failed(2)	2.36(1)	0.28(1)
	Failed(2)	2.36(1)	0.30(1)
ADIPRENE L-167 (VSD) URETHANE	Failed(2)	2.16(1)	0.02(1)
	Failed(2)	2.20(1)	0.07(1)
RTV 560 (VSD) SILICONE	1.9(2)	1.50(2)	0.12(2)
	2.4(2)	1.52(2)	0.16(2)
PERMACEL 6962 (VSD) DOUBLE BACKED KAPTON/SILICONE	0.4(3)	0.74(3)	0.16(3)
	0.2(3)	0.76(3)	0.08(3)
DC 282 (SCHJELDAHL) SILICONE	Failed(3)	2.0(3)	0.3(3)
	Failed(4)	1.8(3)	0.4(3)
G-401903 (SCHJELDAHL) POLYESTER	Failed(2)	1.1(2)	0.3(2)
	Failed(4)	1.6(2)	0.4(2)
ADIPRENE L-100 (GODDARD) URETHANE	2.44(2)	2.08(1)	0.36(1)
	0.0(2)	2.20(1)	0.32(1)
STYCAST 2651 (JOHNSON) EPOXY	Failed(1)	0.32(1)	0.12(1)
	Failed(1)	0.34(1)	0.15(1)
EPON 828 (JOHNSON) EPOXY	Failed(4)	0.50(1)	0.18(3)
	Failed(4)	0.88(1)	0.12(3)
SOLITHANE 113 (LANGLEY) URETHANE	Failed(1)	0.64(1)	0.06(3)
	Failed(1)	0.80(1)	0.04(3)
CREST 7343/7139 WITH ALUMINUM POWDER(LANGLEY)URETHANE	Failed(2)	1.12(2)	0.06(2)
	Failed(2)	1.16(2)	0.10(2)
CREST 7343/7139 WITHOUT ALUMINUM POWDER	Failed(2)	1.14(2)	0.08(2)
(LANGLEY) URETHANE	Failed(2)	1.26(2)	0.08(2)
SR 537 (MDAC) SILICONE	Failed(1)	0.76(5)	0.03(5)
	Failed(1)	1.08(5)	0.02(5)
SR 585/MOD 1 (MDAC) SILICONE	Failed(1)	2.24(4)	0.04(5)
SP 7-12	Failed(1)	2.68(4)	0.05(5)
SR 585/MOD 2 (MDAC) SILICONE	Failed(1)	2.24(4)	0.04(5)
SP 1-6	Failed(1)	2.68(4)	0.[illegible]

1. Partial failure between silver and Teflon.
2. Failure between silver and Teflon.
3. Failure between silver and adhesive.
4. Failure between aluminum & adhesive.
5. Failure between aluminum and silver-cohesive failure.

* Federal Test Method Std #175, Method 1041.1

TABLE 2 PEEL STRENGTHS OF SILVER/FEP TEFLON BONDED TO 6061-T6 ALUMINUM ADHEREND

VSD DATA

ADHESIVE IDENTIFICATION	PEEL STRENGTH lb/in*	PEEL STRENGTH lb/in(avg. of 4)
RTV560, surface prep: wet sand/ 180 grit Al_2O_3, MEK wet wipe, wipe dry	1.65	
	1.90	
	2.00	
	1.70	1.81
RTV560, surface prep: Penn Walt841	1.70	
	1.85	
	1.90	
	1.60	1.76
Emerson & Cumming #6 surface prep: wet sand/180 grit Al_2O_3, MEK wet wipe, wipe dry	2.35	
	2.30	
	2.40	
	2.35	2.35
Permacel 6962 surface prep: wet sand/180 grit Al_2O_3, MEK wet wipe, wipe dry; overlay removed before cure	0.76	
	0.76	
	0.78	
	0.74	0.76
Permacel 6962, surface prep: wet sand/180 grit Al_2O_3, MEK wet wipe, wipe dry; cured with overlay on FEP	0.8	
	0.8	
	0.8	
	0.8	0.8

Test Temperature: 75°F

*Federal Test Method Std. #175, Method 1041.1

TABLE 3 OUTGASSING DATA FOR ADHESIVES

TML : TOTAL MASS LOSS
VCM : VOLATILE CONDENSABLE MATERIAL

CONDITIONS : TML @125°C, 24 hrs, 1×10^{6} TORR
VCM @125°C, 25°C CONDENSING SURFACE

MATERIAL	TYPE	SUPPLIER	CURE INFORMATION	SILVER/FEP TEFLON/ADHESIVE/ALUMINUM					ADHESIVE ONLY		
				Original Adhesive Weight(g)	TML %	TML Wt (g)	Original Adhesive Weight(g)	VCM %	CURE INFORMATION	TML %	VCM %
1. Mystic A117 with AP-134	Silicone	NASA-LaRC		0.1353	4.31[a]	.00583	0.1626	0.23[b]			
2. RTV 560	Silicone	VSD		0.2010	3.94	.00791	0.1567	2.12[c]			
3. Permacel 6962	DBL Backed Tape Silicone/Kapton	VSD		0.1133	1.64	.00186	0.2221	0.56[d]			
4. G-401903	Polyester	Schjeldahl		0.040863	1.60		0.040863	0.25[e]			
5. DC 282	Silicone	Schjeldahl		0.102159	0.57	.00058	0.102159	1.24[f]			
6. Solithane 113 50% Resin 113 50% C113-300	Urethane	NASA-LaRC	Resin Deg. @80°C, In Vac						20 hrs@ 70°C	0.29 -0.39	0.03 -0.09
7. Crest 7343/7139	Urethane	NASA-LaRC[g]								1.41	0.17
8. RTV 566	Silicone	LaRC/VSD[h]							24 hrs @ 25°C	0.23	.030
9. E/C CPC-6	Urethane	VSD[i]								5.78	2.01
10. Adiprene L-167	Urethane	VSD								3.23	0.97
11. Adiprene L-100 /MOCA 100/10 by weight	Urethane	NASA-GSFC							7 da @ RT 3 hr @ 100°C	1.15 1.06	0.15 0.06
12. SR 537	Silicone	MDAC[k]							+50%Toluene	10.37	5.09
13. SR 585	Silicone	MDAC[l]									
Mystic 7366	DBL Backed Tape Silicone/Kapton	--							72 hrs @55°C in vacuo	1.3	0.94
Stycast 2651	Epoxy	JSC							8 hr @ 25°C	0.37	0.03
Epon 828	Epoxy	JSC							3 da @ 25°C	0.505	0.012
Crest 7344/7119	Urethane	--							21 da @ RT	2.78	0.66

NOTES: (a) TML ok, run after bearing surf clean; (b) VCM Quest. (Run L); (c) Sample delaminated; (d) Good data; (e) Good data; (f) Below inst-capab; (g) Unrec; (h) Contingency ; (i) In Test; (j) Questionable; (k) Unreceived; (l) Unreceived

TABLE 4 SILVER/FEP TEFLON ADHESIVE SUMMARY

MR PANEL NO.	ADHESIVE NAME (VENDOR)	ADHESIVE TYPE	SIZE OF COATING STRIPS	ADHESIVE APPLICATION TECHNIQUE	ADHESIVE CURE TECHNIQUE
2	RTV 560 (G.E.)	Silicone	48" 15" 4" 1"	2 part mix; trowel/ brush	ambient temp./pressure for 16 hours minimum
3	SR 585 (G.E.)	Silicone	3"	transfer laminate (tape)	275°F for 0.5 hours in vacuum bag
4	G401903 (Schjeldahl)	Polyester	4"	transfer laminate; heat gun for initial adhesion	250°F for one hour in vacuum bag
5	6962 (Permacel)	Silicone Double-backed Kapton	4-1/2"	transfer laminate (tape)	290°F for 1 hour in vacuum bag
6	7343 (Crest)	Urethane	12" 48"	2 part mix; hot melt catalyst/hot resin	ambient temp/pressure, plus 150°F for 8 hours
7	A117 (Mystic)	Silicone	12"	1 part contact cement; both surfaces coated	225°F for four hours in vacuum bag

TABLE 4 SILVER/FEP TEFLON ADHESIVE SUMMARY (CONTINUED)

MR PANEL NO.	ADHESIVE NAME (VENDOR)	ADHESIVE TYPE	SIZE OF COATING STRIPS	ADHESIVE APPLICATION TECHNIQUE	ADHESIVE CURE TECHNIQUE
8	Adiprene L-100 (DuPont)	Urethane	48"	2 part mix; hot melt catalyst/hot resin	ambient temperature for 16 hours
	Adiprene L-167 (DuPont)	Urethane	15"	2 part mix; ambient catalyst/resin	ambient temperature/ pressure for 16 hours

NOTE: Subsequent to adhesive cure, each panel subjected to outgassing cycle consisting of 150°F for 8 hours in a circulating air oven.

TABLE 5

OUTLET TEMPERATURE DATA

MIXED OUTLET TEMPERATURE FROM EACH PANEL, °F

FOLLOWING EACH HEAT LOAD TRANSIENT

PANEL	Phase 4 Baseline Performance Point No. 1	2	3	4	5	6	7	8	Phase 3A Baseline Performance Point No. 1	2	3
2 RTV 560 (VSD)	68	68	68	69	67	67	68	71	17.4	26.9	30.1
3 SR585 (MDAC)	82	82	82	84	82	82	83	84	42.7	39.5	-
4 G401903 (Schjel)	57	57	89	90	89	88	91	109	32.2	33.2	-
5 Permacel 6962 (VSD)	65	65	65	66	64	64	65	68	33.2	44.8	-
6 Crest 7343 (LaRC)	63	62	76	77	78	77	78	86	25.8	1.9	-
7 Mystic A117 (LaRC)	57	57	57	58	57	56	58	60	8.7	21.6	-
8 Adiprene (VSD/GSFC)	51	51	51	52	50	50	51	53.2	5.3	- .3	-

TABLE 6 CONDITION OF SILVER/FEP TEFLON THERMAL CONTROL COATING

Solar absorptance of as-received silver/FEP teflon = 0.050-0.085

MR PANEL NO.	ADHESIVE NAME (VENDOR-TYPE)	CONDITION OF COATING AS-BONDED	CONDITION OF COATING POST-TEST (SOLAR ABSORPTANCE)
2	RTV560 (G.E.-silicone)	Spotty delamination in both original bond and refurbished areas	75% delaminated between silver and FEP. 4 square feet of FEP separated completely from panel (α = 0.06-0.22)
3	SR585 (G.E.-silicone)	Excellent	no apparent change (α = 0.06-0.07)
4	G-401903 (Schjeldahl-polyester)	Excellent	98% of FEP separated completely from silver which remained bonded to the panel (α = 0.06-0.07)
5	6962 (Permacel-silicone)	Excellent	no apparent change except 3 square inches lost adhesion to aluminum (α = 0.06-0.08)
6	7343 (Crest-urethane)	Many bubbles in adhesive	complete separation of FEP from silver in mid-region of panel. No apparent change in inlet and outlet regions. Possible batch mixing variation (α = 0.06-0.08)
7	A117 (Mystic-urethane)	Many folds, wrinkles, creases in FEP film	90% failure at aluminum-adhesive bond line. 7 square feet of silver/FEP intact along "warm" inlet manifold. (α = 0.05-0.06)
8	L-100, L-167 (DuPont-urethane)	Many bubbles in adhesive; ripples in L-100 bond area	no apparent change (α = 0.06-0.07)