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INVESTIGATION OF APPLICATION PARAMETERS AND TESTING OF RAIN ERO--ETC(U)
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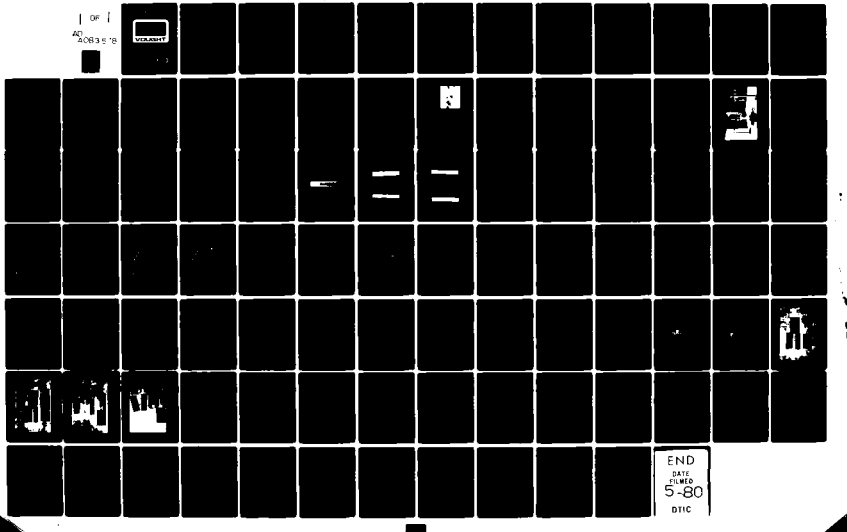

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VOUGHT CORPORATION

INVESTIGATION OF APPLICATION PARAMETERS AND TESTING OF RAIN EROSION COATINGS

FINAL TECHNICAL REPORT
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FOREWORD

This program was designed to study parameters affecting the successful application of organic coatings on reinforced nonmetallic composite substrates for the purpose of protecting these substrates from the deleterious effects of rain droplet impact at high speed. The program was sponsored by the Naval Air Systems Command under Contract N00019-78-C-0125. Technical administration was initially the responsibility of Mr. David P. Hornick, subsequently, Mr. John Gurtowski was the responsible administrator of the Engineering Division of the Materials Acquisition Group of the Naval Air Systems Command.

The rain erosion coating material evaluation work was completed in the Vought Corporation's Engineering Materials and Process Laboratory, and the radar signal attenuation tests were completed by Mr. George Dorsett and associates of the Vought Corporation's electronics range.

Valuable technical contributions are hereby acknowledged from each of these contributors.

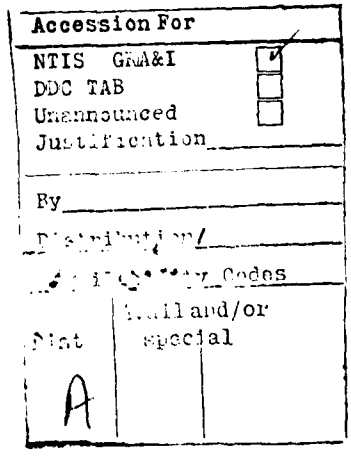


TABLE OF CONTENTS

TABLE OF CONTENTS
(CONTINUED)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

(CONTINUED)

1.0 INTRODUCTION

This program was sponsored in order that the performance of selected rain erosion coatings might be evaluated and that those parameters affecting the performance of these materials might be studied with the goal in mind to upgrade rain erosion coatings for use on high performance aircraft. In order to realize this goal, the following characteristics of two select polyurethane materials were evaluated:

- o Coating adhesion to the reinforced composite substrates.
- o Solvent evaporation rates or "solvent release" from each select rain erosion coating material for the purpose of reducing coating porosity of the cured material
- o A polymerization study related to the chemical reactivity of these moisture reactive materials after exposure to known quantities of free water.
- o A coating familiarization study for each of the rain erosion coating materials.
- o Radar signal attenuation studies to determine signal losses through the rain erosion coating.
- o High-speed erosion tests for selected coating materials and primer combinations.

2.0 SUMMARY

A familiarization study was completed for each coating material selected for use in this test effort. Flat test panels were sprayed and the buildup rate per spray pass, cure time, and the pot life of each coating material were determined. Viscosity curves were drawn for use in determining sprayable limits of the coating materials.

Adhesion of each rain erosion coating was determined utilizing the standard 180^{0} adhesive peel and by the blister test method. Adhesion of each coating material/primer combination was determined on a fiberglass reinforced epoxy laminate and a quartz fiber reinforced polybutadiene laminate. Adhesion of each coating/primer combination on each type substrate was determined by both methods before and after exposure to MIL-H-5606 hydraulic fluid.

Adhesion strength values were calculated, and the mean and standard deviation for each set of values were computed. The percentage adhesive strength loss was also calculated for all specimens before and after exposure using both methods.

Correlation of adhesive strength, as measured by each method, was not as good as expected. Values of strength found to be relatively high by the 180^{0} peel test were not all found to be high as determined by the blister method. Some values were comparable in all respects for both methods with respect to adhesive strength before and after test and percentage adhesive strength loss as a result of exposure to the MIL-H-5606; others were disproportionate in these respects.

Solvent evaporation studies completed during the course of this program revealed a method of quantitative evaluation of the degree of coating porosity. Measurement of porosity was accomplished by spraying films diluted with various solvents onto release plates, curing, then mounting and observing the edge of the coating film. Microscopic examination of each coating film permitted determination of the number of voids per unit area within the coating.

Photomicrographs of each film made with the various diluents were made, and the actual void count was recorded.

A polymerization study was conducted using the Vought diamine cured coating. The moisture sensitive component of this coating was contaminated with known quantities of free water. After mixing the contaminated moisture sensitive component with the amount of diamine required for a full stoichiometric equivalent reaction with the uncontaminated material, the contaminated admixture was used to make test films. Samples of the test films were tested for tensile strength, ultimate elongation, by differential thermal analysis and by thermal gravimetric analysis for the purpose of developing a method by which the partially contaminated or marginal quality polyurethane can be detected before use.

The test results indicated that tensile strength and tensile modulus are more definitive of partially cured polyurethane materials due to moisture contamination than the differential thermal analysis or thermal gravimetric analysis. The tensile strength and elongation of these materials were reduced considerably by addition of only 10% of that amount of free water required to react all of the isocyanates in the base component.

The results of these tests illustrate the importance and necessity of excluding all forms of free water from the moisture reactive isocyanate component of polyurethane rain erosion materials during the manufacture, packaging or reclosure of opened containers.

Radar signal attenuation studies were completed for two select rain erosion coating materials. Flat reinforced plastic test panels were constructed per MIL-R-7705 as specified in MIL-C-83231. Rain erosion coatings were applied over primer and over the unprimed panels. One panel was left uncoated for use as a baseline standard. The cured coated panels were subjected to microwave power measurements at incidence angles from -30^{0} to $+30^{0}$, using parallel and perpendicular polarization of the incident energy. Measurements were made over the 60^{0} range described above at longitudinal increments of 0.1 inch through a 1.0 inch range. The microwave power transmission frequency was 9.375 gigahertz.

The percent transmission for each test point was calculated as follows:

$$\frac{T^2 \text{ sample}}{T^2 \text{ blank}} \times 100 = \% \text{ transmission}$$

Where T^2 sample = power transmission of coated panel

T^2 blank = power transmission of uncoated panel

All transmission values ranged from approximately 95% to 93% for the full range for perpendicular polarization. The full range of values for transmission for parallel polarization was from approximately 99% to 93.5%. Individual specimens had narrower ranges of transmission efficiencies.

High-speed erosion tests were conducted to determine the rain erosion resistance of select materials. Simulated leading edge shapes were coated and exposed to test velocities of 500 M.P.H. with a simulated one inch per hour rainfall. Coating thickness of specimens submitted to NAVAIR for testing on the B. F. Goodrich whirling arm test apparatus ranged from 10 to 15 mils dry film thickness.

Results of the high-speed erosion tests will be made available to recipients of this report when these tests are complete.

3.0 TEST METHODS

3.1 ADHESION MEASUREMENTS BY BLISTER TEST METHOD

The Blister Test Method application to coating adhesion which was developed under a previous program[1] was utilized to determine adhesion characteristics of organic coatings to anodized surfaces. This is a relatively simple test in which the adhesion is measured by applying fluid under pressure through a hole in the substrate under the coating. From the pressure required to lift the coating from the substrate and the blister-height, the adhesion strength can be determined.

The Blister Test Method had been utilized to measure adhesive strengths of other materials. A similarity between certain problems of adhesion and fracture was discussed by Williams (2,3). It was noted that in both cases, if one considers the elastic stress analysis in the neighborhood of a sharp crack (or slight region of non-adhesion), a singularity in stress is found to exist. In the case of a central finite length crack in an infinite sheet subjected to tension, the classic Griffith problem gives a local stress variation which is proportional to the inverse square root of the distance from the crack tip.

Since this (mathematical) infinite stress exists for even the smallest loading, it appears that instantaneous fracture would occur and that stress analysis would not be useful for predicting a finite stress which the film could withstand before fracture. However, Griffith (4) developed an overall energy balance, which incorporated the integrable stress singularity, by equating the reduction in strain energy to the energy required to create new surfaces. The result was the prediction of a finite applied tensile stress, σ_{cr} needed to initiate fracture, namely:

$$\sigma_{cr} = \frac{2E\,\sigma_c}{\pi\, a}$$

where E and σ_c are the Young's modulus and energy to create new fracture surface, respectively, and 2a is the finite length of the crack in the thin film. Thus, the use of the integrated energy balance circumvented the question of how infinite the stress need become before fracture. It also

suggests the way in which other problems in stress analysis having stress singularities can be attacked in order to predict a finite stress at failure notwithstanding an infinite stress at the origin of the fracture initiation.

The character of elastic stress singularities to be expected for various geometric discontinuities was investigated by Williams and later applied to the specific situation of the interface between dissimilar media. In this case, too, when a crack existed along a line of demarcation of the two materials, the stress singularity was likewise singular and the similarity between cohesion and adhesive failure becomes clear. In the Griffith problem the finite length of the central crack 2a lies along the x axis, with the upper and lower half planes occupied by the same material; in the second case, the materials above and below the x axis are different.

The adhesive mechanics approach is straightforward and consists of two parts:

- o Conduct the stress analysis for the bonded materials including a flaw at the interface.
- o Express the incremental new surface energy (γ_a) as the crack extends.

Williams developed the treatment for the blister test, first proposed by Dannenberg (5) but without the fracture mechanic statement, for determination of the strength of an adhesive (i.e. γ_a).

The samples are easily constructed. The pressure uniformly distributes itself in the flaw, thus reducing alignment problems. The tests can be conducted with apparatus generally available in research and testing laboratories. To determine the strength of an adhesive only the critical pressure for failure, the flaw size, the system geometry, and the material properties are required. For a circular plate of incompressible elastic material bonded to a rigid plate, with air injected through a hole in the rigid member into a circular unbonded area (see Figure 1), the following relationship was developed:

$$P_c = \left[\frac{32}{3(1-\sigma^2)} \left(\frac{h}{a}\right)^3 \right] \sqrt{\frac{E\,\gamma_a}{a}} \qquad (1)$$

where P_c = pressure necessary to initiate adhesive fracture

E = Young's Modulus
h = Plate thickness (coating)
σ = Poisson's Ratio
a = Radius of unbond
γ_a = Adhesive surface energy density

H. B. Jones, and Williams (6) did additional work which showed that the equation could be written in terms of the center plate deflection as:

$$P_c W_0 = 2\gamma_a \text{ (plate)} \qquad (2)$$

where W_0 = center plate deflection (see Figure 1) which is a convenient description for an experimental test since both the pressure necessary to *initiate adhesive fracture* and the center deflection at that pressure can be measured directly. The adhesion surface energy density is then calculable. For the same plane form, if the plate is thin and deflections are large, the mid-plane stretching or membrane stresses predominate and criticality can be defined (reference 7).

$$P_c W_0 = 2.4\gamma_a \text{ (membrane)} \qquad (3)$$

or $$P_c = 1.532 \left(\frac{h}{a^{(3/4)}}\right)^4 \frac{E\alpha_a}{a} \qquad (4)$$

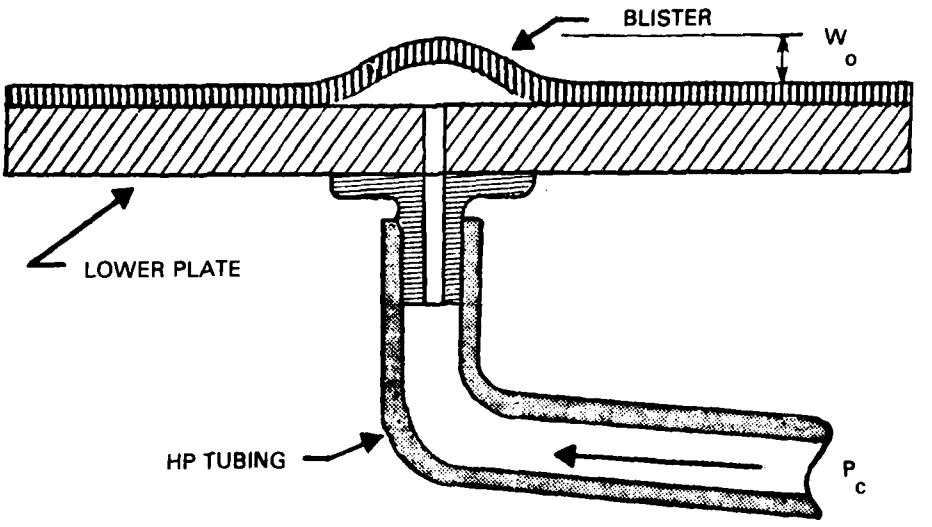


Figure 1. Schematic of Adhesive Test Specimen

Tests using filled and unfilled elastomers indicate that the response of a specimen undergoes a rather smooth transition from plate to membrane behavior over a relatively narrow range of increasing deflections. This transition is indicated by the x's on Figure 2. This orderly transition in behavior, then, appears to present no insurmountable difficulty relative to the analysis of blister test data.

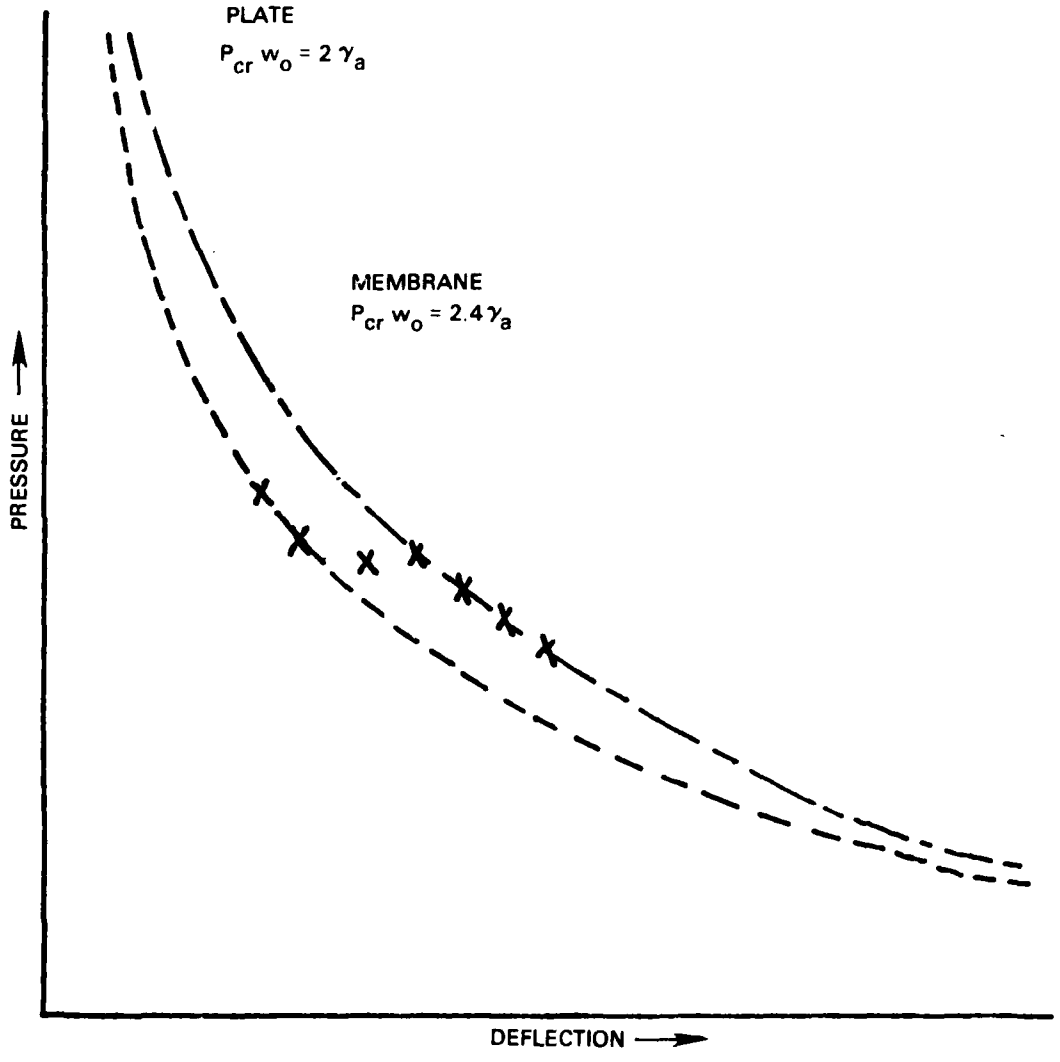


Figure 2. Characteristic Specimen Pressure — Deflection and Fracture Behavior

During repeated tests on a specimen, where deflections may range from small to large, there will, of course, be intermediate values for which neither the plate solution nor the membrane solution is valid.

The analysis has also been developed for other geometries such as a bond between two disks of different elastic properties (double blister), for two rigid plates bonded together by an adhesive and for multiple layers of elastic materials bonded to a rigid plate. All of these can be handled mathematically and according to Williams (8) since the value determined is γ_a and the relationship includes this thickness, it is not necessary that the test specimens have the same thickness as the practical coating.

Depending on the system to be studied the test apparatus may be as simple as that shown in a paper by Williams, et al (9), or a more sophisticated one such as that diagrammed in Figure 3. This was used at Vought in previous study (1).

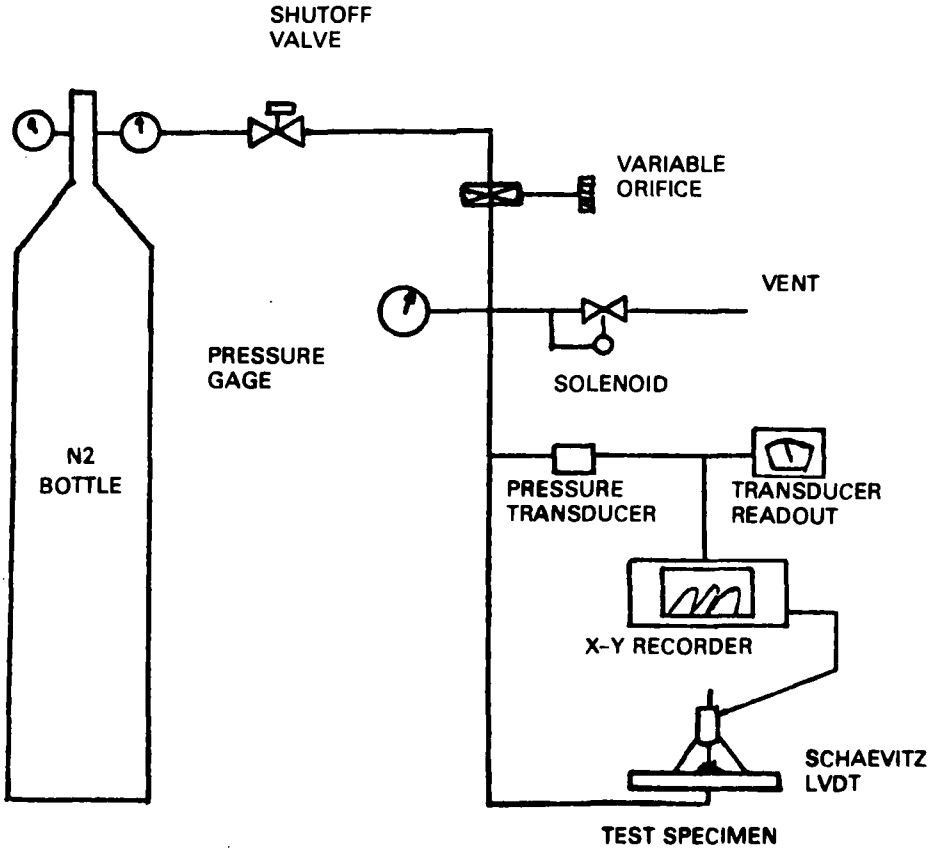


Figure 3. Diagram of Apparatus For Blister Test

3.2 DESIGN AND ASSEMBLY OF TEST EQUIPMENT

The "Blister Test" apparatus was assembled as diagrammed in Figure 3 using a Statham Instrument, Inc., strain gauge, model UC3 in a body shell adapter, model U6P4-B in which selected diaphrams may be installed. A Statham Universal Readout, model SC1001 was attached to the pressure transducer and then relayed to a Hewlett Packard X-Y recorder, model 7004B. The system was pressurized with cylinder nitrogen through a cylinder pressure gauge/regulator, cutoff valve and a micrometering valve, model 1B22RS4. System pressure was also monitored, and calibrated with a Ashcroft 0-60 psig test gauge which had previously been calibrated. A 110 volt solenoid operated pressure release valve and specimen holder, Figure 4, completed the pressurization side of the apparatus.

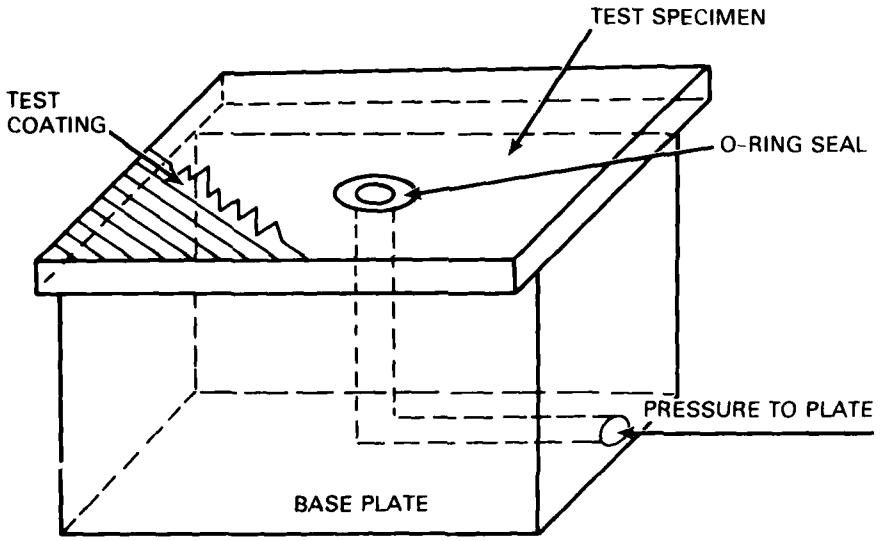


Figure 4. Schematic of Specimen Holder and Specimen

The blister height measurement utilized a Schaevitz Liner Displacement Transducer (LVDT) which operated on 32 volts DC supplied by a Lambda Electronics Corporation regulated power supply, series LCS-4. The transducer which is mounted in a tripod holder to place on the specimen (Fig. 5), was then connected to the X-Y recorder. The entire system was powered through a Freed 115 volt power regulator to minimize line voltage fluctuations.

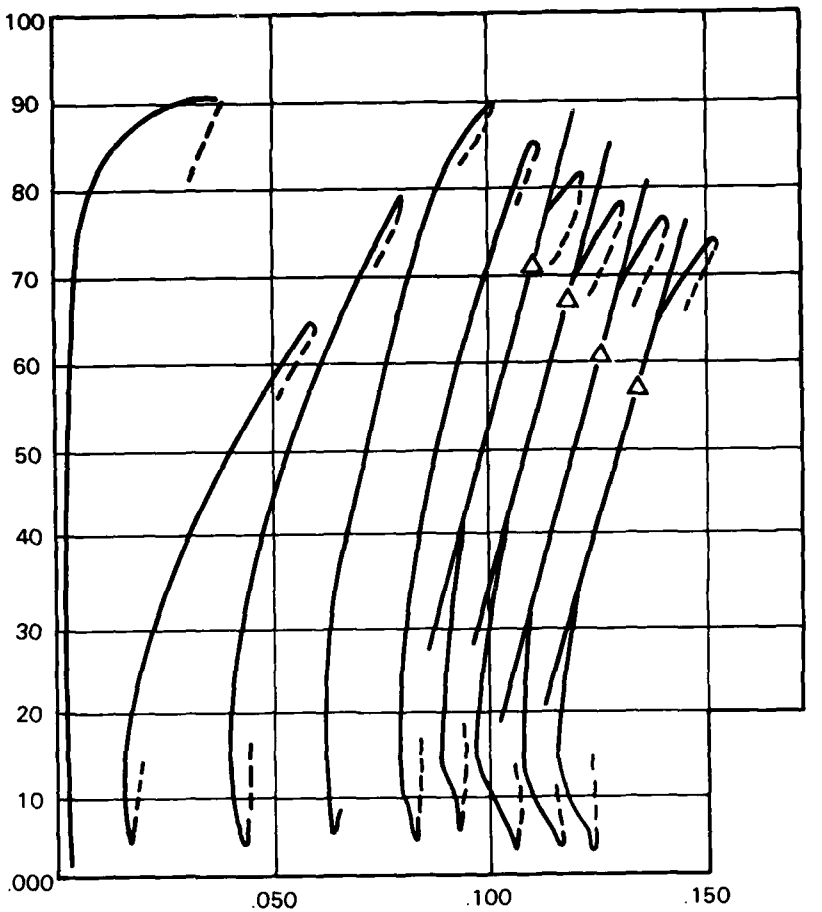


Figure 5. Example of Blister Test Data

	P_{cr}	W_0	a
1	70.0	.109	3.2
2	66.2	.118	3.3
3	60.3	.125	3.1
4	56.3	.133	3.1

3.2 Average

Figure 5. Transducer on Adhesion Specimen

3.3 ADHESION MEASUREMENTS BY THE 180° PEEL METHOD

This method describes a laboratory procedure for determining the adhesive strength and characteristics of peel properties of cured-in-place elastomeric materials. This procedure is described fully in ASTM-C-795-75. The method was followed, except that fiberglass reinforced or quartz reinforced composites were used as substrates. A cotton reinforcement material of 12.1 oz/yd^2 was used in the peel attachment straps.

Figure 6 is a sketch of the adhesive peel test set-up.

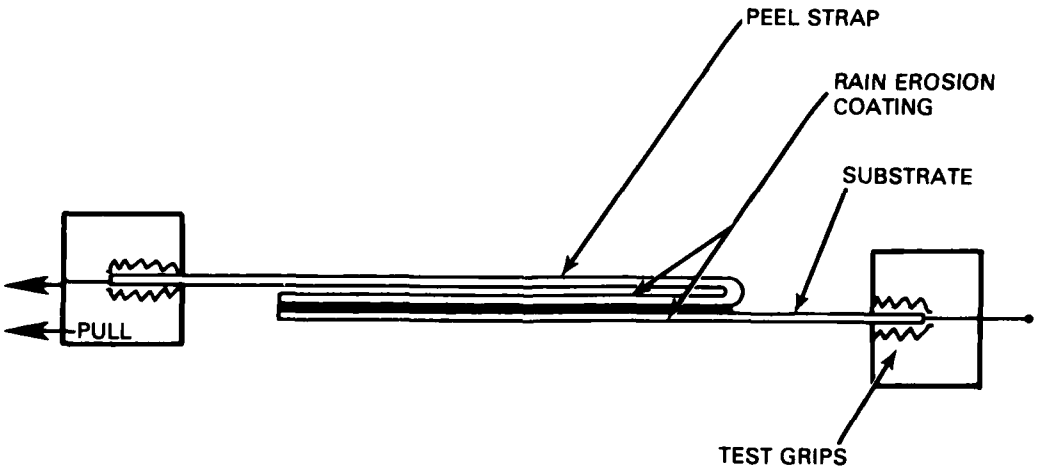


Figure 6. Sketch of 180° Peel Test

3.4 SIGNAL TRANSMISSION EFFICIENCY TEST METHOD

Microwave signal transmission efficiency tests were conducted for rain erosion materials of the Type I (nonelectrically-conductive) per MIL-C-83231. Test panel substrates used for this test procedure conformed to requirements of MIL-R-7705 as required per MIL-C-83231.

Figures 7 and 8 show a schematic of the test set up and Figure 9 is a photograph of the actual test setup.

3.5 SIMULATED RAIN EROSION TEST METHOD

The rain simulation was conducted at the B. F. Goodrich Research Center at Brecksville, Ohio. The "whirling arm" of the simulator is located in the basement while the controls are on the ground floor of the "O" building. For convenience and ease of identification, odd numbered specimen were installed on blade 1 and even numbered specimen were installed on blade 2.

To protect the edges of the specimen holders and complete the testing on all specimens, a polyurethane tape was used. Specimen failure was considered when the substrate showed through.

The conditions selected for the tests were (ref. 10):

1. Specimen rotational speed of 500 miles per hour.
2. A 1" per hour rainfall.
3. Time intervals of 5 and 10 minutes.

A typical test procedure consisted of the following:

1. Install specimen and apply polyurethane tape over the specimen edges which face the airstream.
2. Bring whirling arm up to speed.
3. Check speed with stroboscope.
4. Simultaneously energize water valve and stopwatch.
5. Make fine adjustments to water flow as necessary.
6. At end of selected time interval, simultaneously de-energize water valve and stopwatch.
7. Allow arm to come to a full stop.
8. Inspect specimen.
9. Record results.

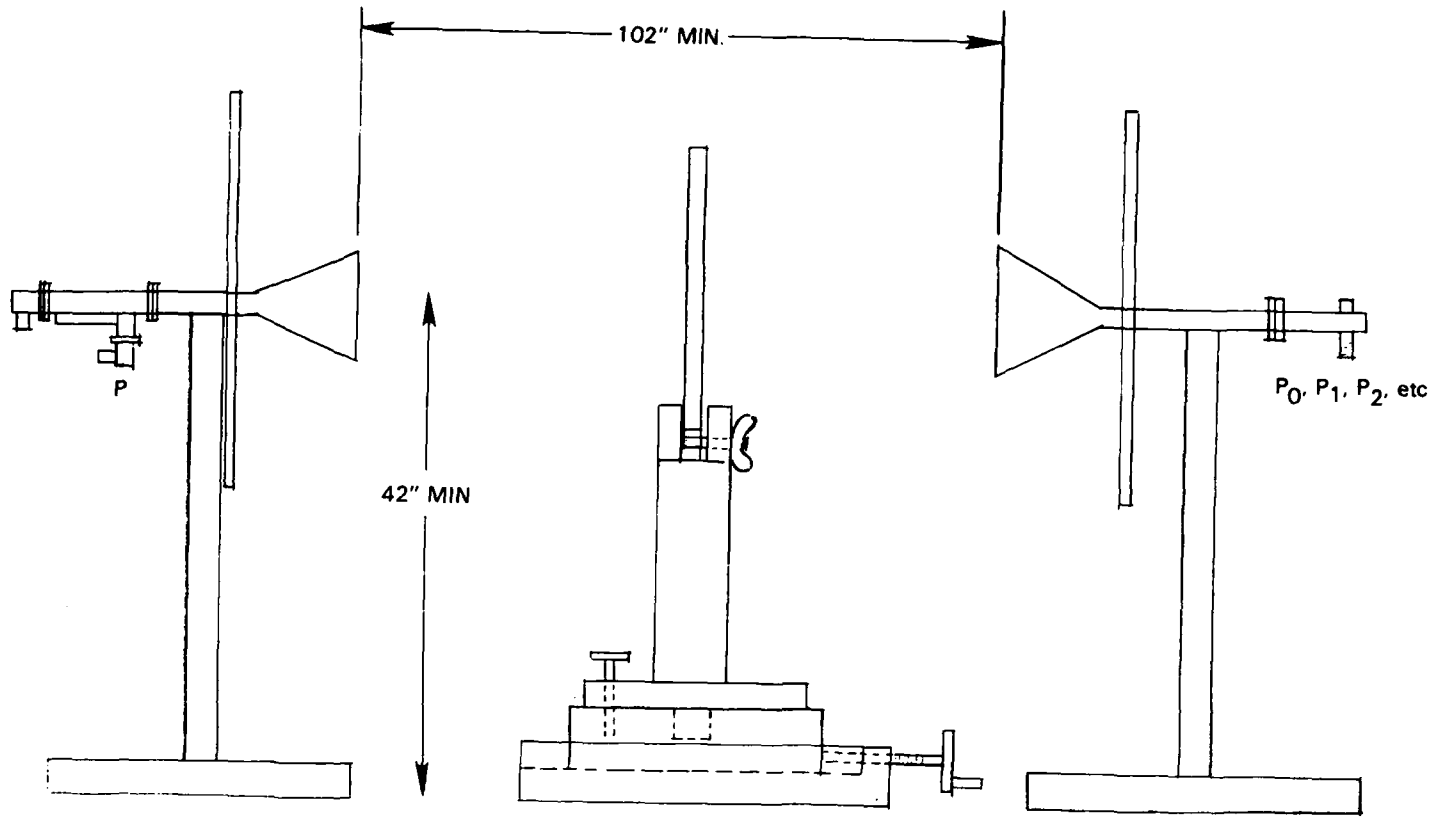


Figure 7. Signal Transmission Test Specimen Set Up

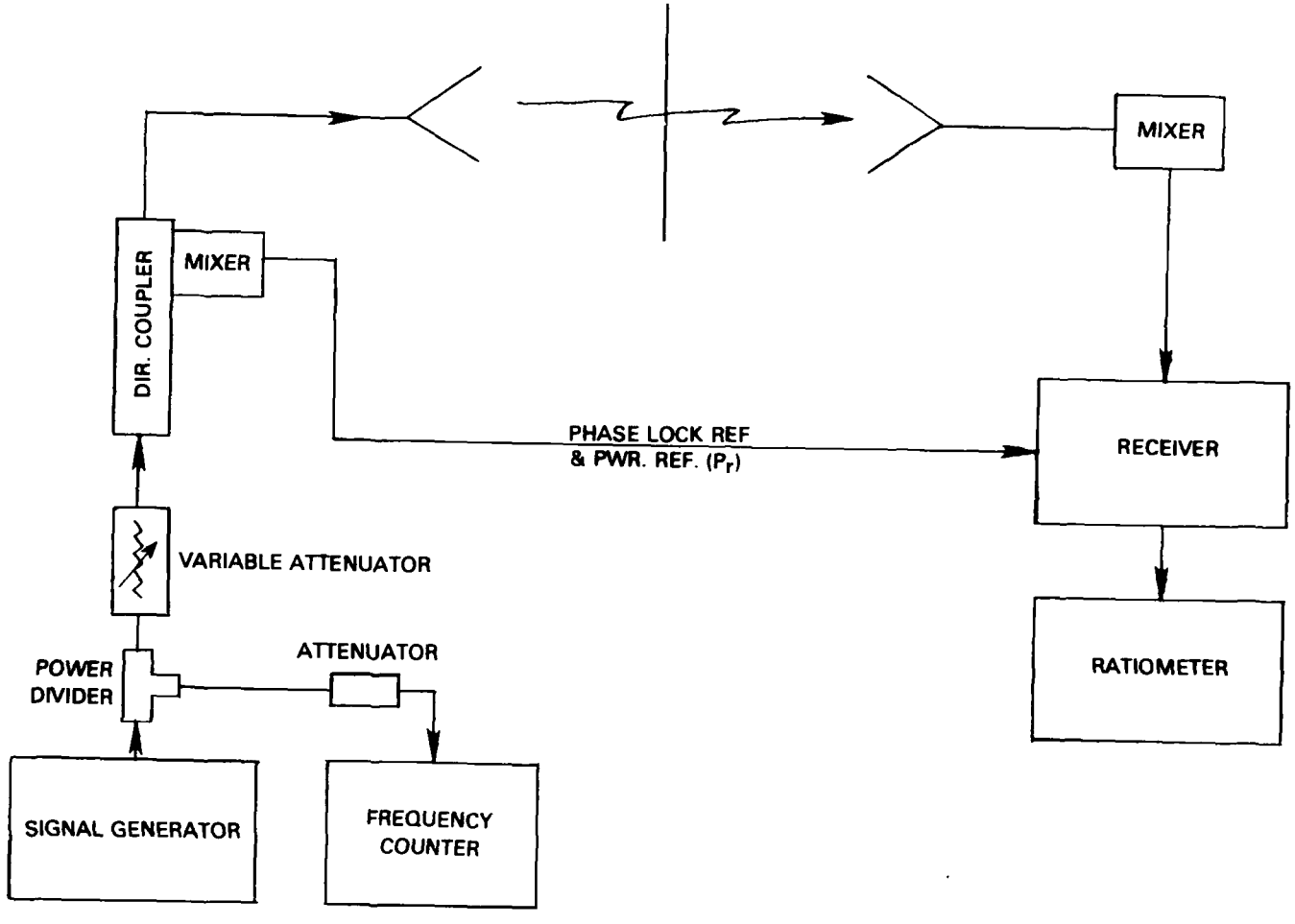


Figure 8. Sketch of Electronic Equipment Set Up

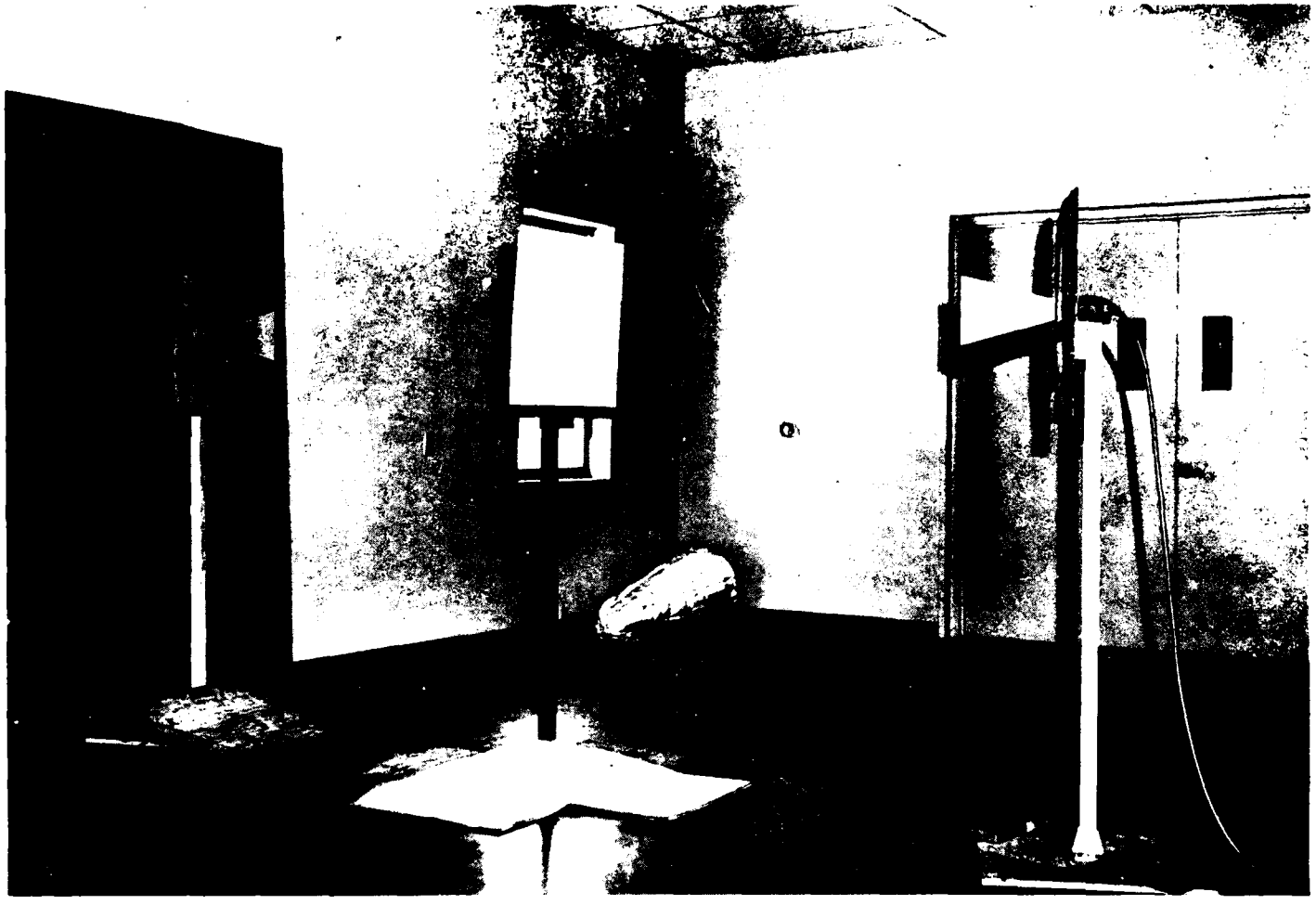


Figure 9. Transmission Efficiency Test Set Up

The following is a typical data sheet and data collected during a test performed earlier by B. F. Goodrich:

RAIN EROSION TEST RESULTS

Sample Description: (compound number, gauge, construction, etc.)

VOUGHT SYSTEMS DEVELOPMENT – SET NO. 1

MPH 500 RPM 1400 AM'T. OF RAINFALL .9 per min

DATE TESTED Aug 4, 1975 OPERATOR B. Isaacs

XA NO. LTV TYPE HOLDER Fiberglass

TYPE ADHESIVE _____ BLADE NO. 1 SAMPLE NO. H-1

MINUTES					
INTERVAL	ACCUM.	Erosion	Pitting	Chunking	REMARKS
10	10	0	A	A	
10	20	0	D	A	
5	25	0	—	C	

4.0 TEST RESULTS

4.1 RESULTS OF THE COATING FAMILIARIZATION STUDY

Results of the coating familiarization study indicated that the M213 and the 207-9-427 coating materials were easily applied to properly prepared reinforced composite substrates with a minimum of difficulty. Although the M213 coating requires the presence of water (atmospheric moisture) to initiate the cure, this material was found to cure well, even if recoated 15 minutes after the first application. Some reduction in workable pot life was observed when the M213 material in the container was allowed to absorb moisture from the air between spray applications. The usable pot life of the M213 was found to be only approximately 15 minutes if exposed to the air 4 to 5 minutes during mixing. If the 213 material was rapidly transferred and mixed by shaking in a closed container, the usable pot life was found to be approximately 25 minutes. The 207-9-427 coating material was found to have a usable pot life of about 90 minutes, and since this material is crosslinked with a diamine, no reduction of the pot life of this coating was observed due to exposure of the materials to atmospheric moisture during mixing. Both coatings produced continuous films with very smooth surfaces. The M213 coating produced a dry film thickness of 2.5 mils per cross pass and the 207-9-427 produced a dry film thickness of 3.0 mils per cross pass. M213 produced a slightly smoother surface finish than the 207-9-427 did; however, both materials produced very smooth coatings when applied with suction feed spray equipment. No special spray equipment was required in applying these coatings.

To summarize the results of the coating familiarization and application study, the following significant findings should be noted:

- The M213 coating is somewhat limited by a relatively short pot life.
- The M213 material should not be applied in rapid subsequent applications under conditions of low relative humidity.
- M213 should be transferred into a closed container as quickly as possible and mixed by shaking on a power shaker.

Operators should only mix that amount of material required to make one spray application or to spray for a time period not to exceed 15 minutes.

- o The 207-9-427 coating is sprayable for approximately 90 minutes after mixing in an environment of 70-80^{o}F and 40-60% R. humidity.
- o The 207-9-427 material should be mixed in a closed container on a power shaker, although it is not sensitive to small amounts of moisture that may be absorbed during mixing.
- o Both coating materials had build rates of 2.5 to 3.0 mils dry film thickness per cross coat pass.

Figure 10 depicts the increase in the viscosity of these coating materials after mixing.

4.2 RESULTS OF COATING ADHESION TESTS

Results of the adhesion study were very variable. Considerable spread was noted in the data obtained via the blister method and the standard 180^{o} adhesive peel method. The blister method indicated that all coatings were well above minimal adhesion values before and after exposure to MIL-H-5606 hydraulic oil. (Values of 1.0 to 1.5 inch-lb/inch^{2} are the reported minimum values for good adhesion via the blister method.) Most values ranged well above 2.0 inch-lbs/inch^{2} for the blister method. Values for adhesion by the standard 180^{o} peel methods were found to be slightly below minimum requirement values before exposure to the MIL-H-5606 (a value of 15 lbs/inch width peel is considered minimum for good rain erosion coating performance by the 180^{o} peel method.) Adhesion losses were greater after exposure to MIL-H-5606 hydraulic fluid when measured by the blister method. The percentage loss was less for the same specimens as tested by the 180^{o} peel method in most cases.

The following pertinent facts were observed concerning the adhesion study:

- o Data obtained by both methods did not all agree.
- o Although the mean values obtained varied considerably, the standard deviation values were relatively small, indicating a small variation between specimen within a given set.

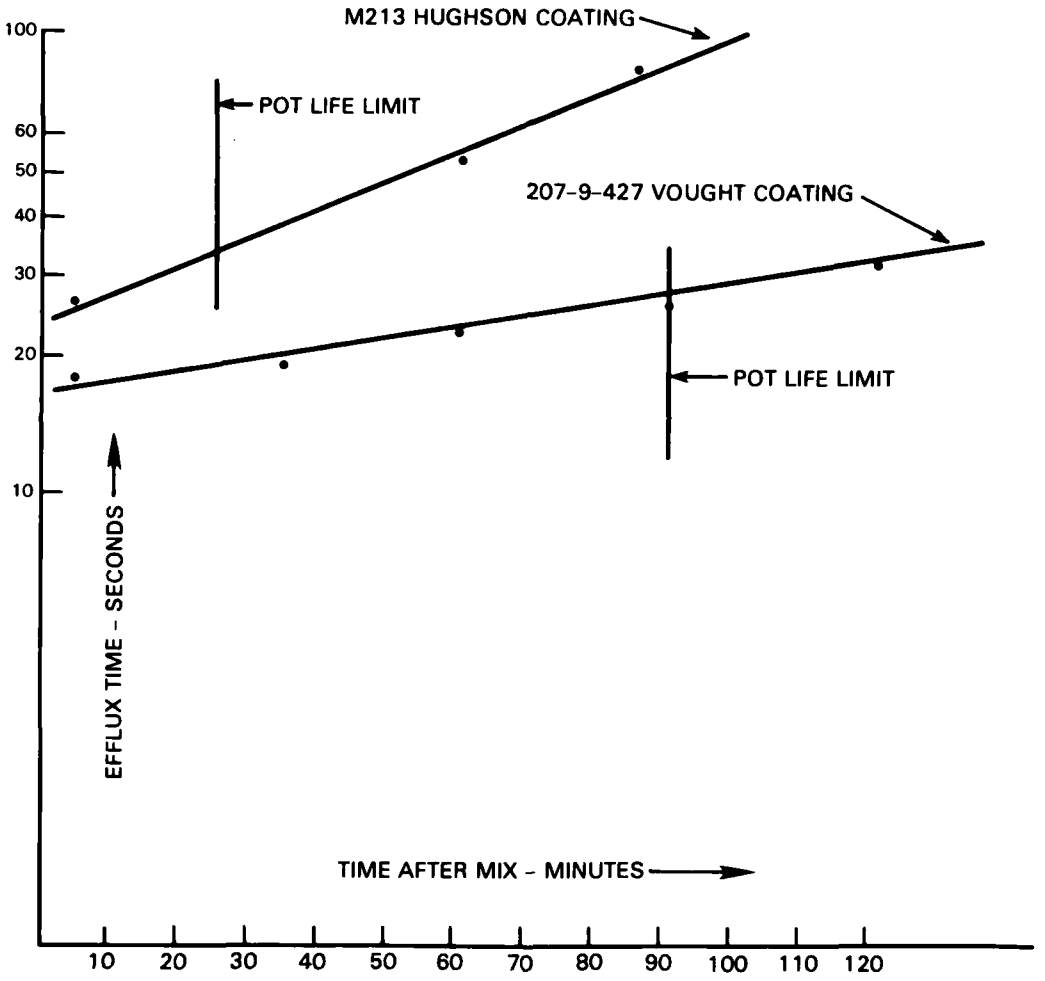


Figure 10. Viscosity vs. Time After Mixing No. 2 ZAHN Cup - 77°F

TABLE 1

COMPARISON OF 180° ADHESIVE PEEL AND BLISTER ADHESION DATA(1)

Specimen I.D.(2)	180° Peel - lbs./in. Width			Blister Adhesion Density in.-lbs./in.^{2}		
	Before	After	Δ % Loss	Before	After	Δ % Loss
HFP	14.75 / 0.05	14.29 / 0.30	3.12	2.83 / 0.38	1.69 / 0.21	40.28
VFP	20.21 / 0.58	19.08 / 0.02	5.59	3.45 / 0.66	2.42 / 0.18	29.86
HFU	33.77 / 3.39	30.25 / 1.77	10.42	2.46 / 0.18	2.05 / 0.27	16.67
VFU	38.11 / 9.02	24.64 / 2.77	13.47	3.46 / 0.86	3.16 / 0.39	8.67
HQP	13.20 / 0.43	7.09 / 1.43	46.29	2.97 / 0.29	2.04 / 0.19	31.31
VQP	15.75 / 1.05	14.29 / 0.40	9.27	3.33 / 0.56	2.33 / 0.07	30.03
HQU	14.98 / 0.68	14.35 / 1.10	4.21	2.34 / 0.39	2.23 / 0.23	4.70
VQU	23.83 / 1.65	15.81 / 1.03	33.68	2.72 / 0.60	2.71 / 0.14	0.37

(1) Values given represent $\frac{\text{Mean}}{\text{Std. Deviation}}$ for each test condition.

(2) Identification code: First letter H = Hughson, V = Vought coating; second letter F or Q, F = Fiberglass reinforced plastic laminate, Q = Quartz reinforced laminate. The third letter P or U = primed or unprimed, respectively. Hence HFP = Hughson coating on fiberglass reinforced plastic laminate with primer between the laminate and the rain erosion coating. Primer for the Hughson material was MIL-C-8514 wash primer. Primer used for the Vought coating was MIL-P-23377 epoxy-polyamide.

- o Results for the peel tests were more realistic than the values obtained for the blister test method. Values of 38 lbs./inch width peel are moderate by high values, whereas 3.5 inch-pounds/ $inch^2$ is an exceptional high blister adhesion density.

Adhesion data were compiled in Table 1.

4.3 RESULTS OF SOLVENT EVAPORATION STUDY

Results of the solvent evaporation study indicated that the amount of porosity within a cured coating film can be detected and measured microscopically by examining the cross section of the cured coating. Casting of the cured coating films onto a plastic mount piece and polishing the coating permitted counting voids within the coating, (reference figures 11, 12, and 13). Various solvents were used for reducing the viscosity of the rain erosion coatings. Coating films were sprayed up, and various porosities resulted. Slow release solvent (high boilers) such as xylene and cyclohexanone reduced the porosity of cured coating films. Reference Table 2 for these data. Application of coating passes at 15 minute intervals did not increase the porosity within the coating films. M213 produced cured films that were slightly less porous than the 207-9-427 material. Reference Table 3 and Figures 11, 12, and 13 for these data.

Observations concerning porosity of cured rain erosion coatings revealed the following:

- o The M213 coating was observed to have slightly less porosity than the 207-9-427 coating, comparable ratios of 2.32 to 4.4, respectively.
- o The M213 coating was found to have a slightly smoother surface finish than the 207-9-427 material when fully cured.
- o Application of up to five cross coat spray passes with 15 minute dry time between passes produced coating films without increased amounts of porosity in either coating.

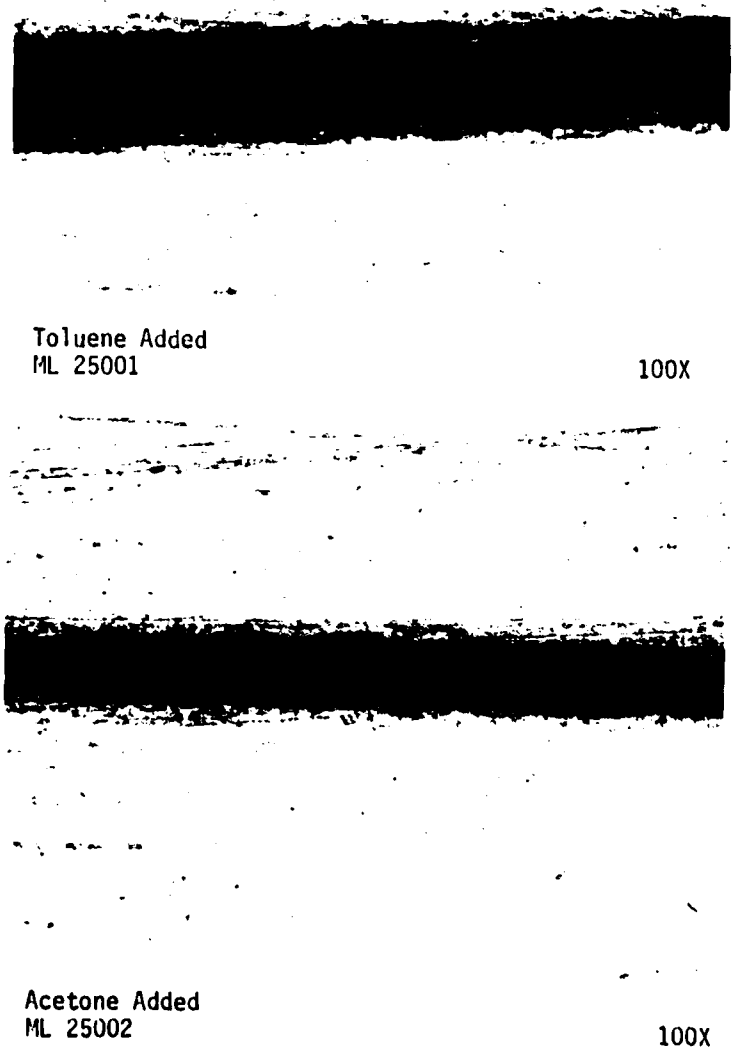
4.4

Results of the polymerization work were impressive and point out the necessity of maintaining complete dryness of all materials used in production of moisture sensitive polyurethane coatings. Introduction of only small amounts of moisture into the moisture reactive component of these

TEST SPECIMEN

Figure 3. Diagram of Apparatus For Blister Test

Figure 11. Photomicrograph of M213 Coating Applied in Five Cross Coats MIL 25000



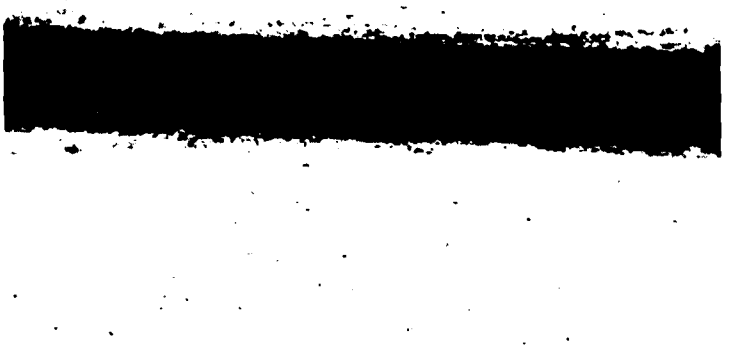
Toluene Added
ML 25001 100X

Acetone Added
ML 25002 100X

Figure 12. Photomicrographs of 207-9-427 Coating.

MIL 24998

100X



MIL 24999

100X

Figure 13. Photomicrographs of Cured Coating Films Showing Porosity.

TABLE 2

"ADD" SOLVENTS USED IN REDUCING
207-9-427 POLYURETHANE COATING(1)

Solvent	Dry Film Thickness per Cross-Coat - mils	Relative Rank for Porosity Reduction 1 = Best (3)
Acetone	2.54	6
Cyclohexanone	3.23	2
Methyl-ethyl-ketone	2.73	5
Methyl-isobutyl-ketone	2.08	N.T.(2)
Methylene Chloride	3.46	N.T.
Mesityl Oxide	3.74	4
P-Dioxane	3.52	3
Petroleum Ether	2.40	3
TF Freon	3.40	N.T.
Tetrahydrofuran	3.14	3
Xylene	2.51	1
Toluene	2.74	7

(1) The "add" solvent used to reduce this coating was 8.0% by weight of the total mixture.

(2) N.T. indicates that the value was not determined for this test condition.

(3) Refer to Table 3 for porosity density of various cured coating films.

TABLE 3

POROSITY DENSITY OF VARIOUS CURED COATING FILMS

Sample I.D.	Number of Cross Coat Passes (1)	Avg. Number of Pin Holes per Unit Area
M213	1	4.0
M213	2	2.3
M213	3	2.3
M213	4	2.3
M213	5	0.7
207-9-427	1	5.3
207-9-427	2	4.0
207-9-427	3	3.7
207-9-427	4	5.0
207-9-427	5	4.0

(1) Subsequent cross coat passes applied at 15 minute intervals. Relative humidity 45 - 47% at 81°F during coating application.

materials produced a significant reduction of the ultimate tensile strength in the 207-9-427 coating. The tensile modulus at 100% elongation was also reduced by the same order of magnitude. (Reference Figures 14 and 15, respectively for these data.)

Tensile strength and tensile modulus data appeared to be the most reliable method investigated to detect partially moisture contaminated materials. Thermogravimetric analysis (TGA) and differential thermal analysis (TGA) and differential thermal analysis (DTA) showed some differences between contaminated and noncontaminated materials; however, these analyses did not differentiate between the degrees of contamination as clearly as did the simple tensile strength tests.

Tensile strength and tensile modulus data were included in Figures 14 and 15, respectively. Ultimate tensile strength in PSI was plotted along the ordinate and the percent contamination was plotted along the abscissa. "Percent contamination" represented that amount moisture required to react with the moisture reactive isocyanate sites within the polyurethane prepolymer; thus a 10 percent water contamination would react only 10 percent of the reactive isocyanate groups, leaving 90 percent of those isocyanate groups to react with the diamine crosslinking agent. The percent contamination of 10 percent of the reactive isocyanate was very small as compared to 10 percent of the total material component. A 10 percent moisture contamination reduced the tensile strength approximately 62 percent; tensile modulus values were reduced proportionally.

TGA curves for contaminated and control specimens were included in Figures 16 through 21. DTA data for these same specimens were included in Figures 22 through 27.

Observations concerning the polymerization study data:

- Polyurethane materials and materials used in compounding these rain erosion coatings must be virtually free of water in order for the coating material to remain stable in the container after manufacture.
- Ultimate tensile strength and tensile modulus are two dependable means of detecting moisture contaminated polyurethanes. These methods require considerable time for cure before performing these tests.

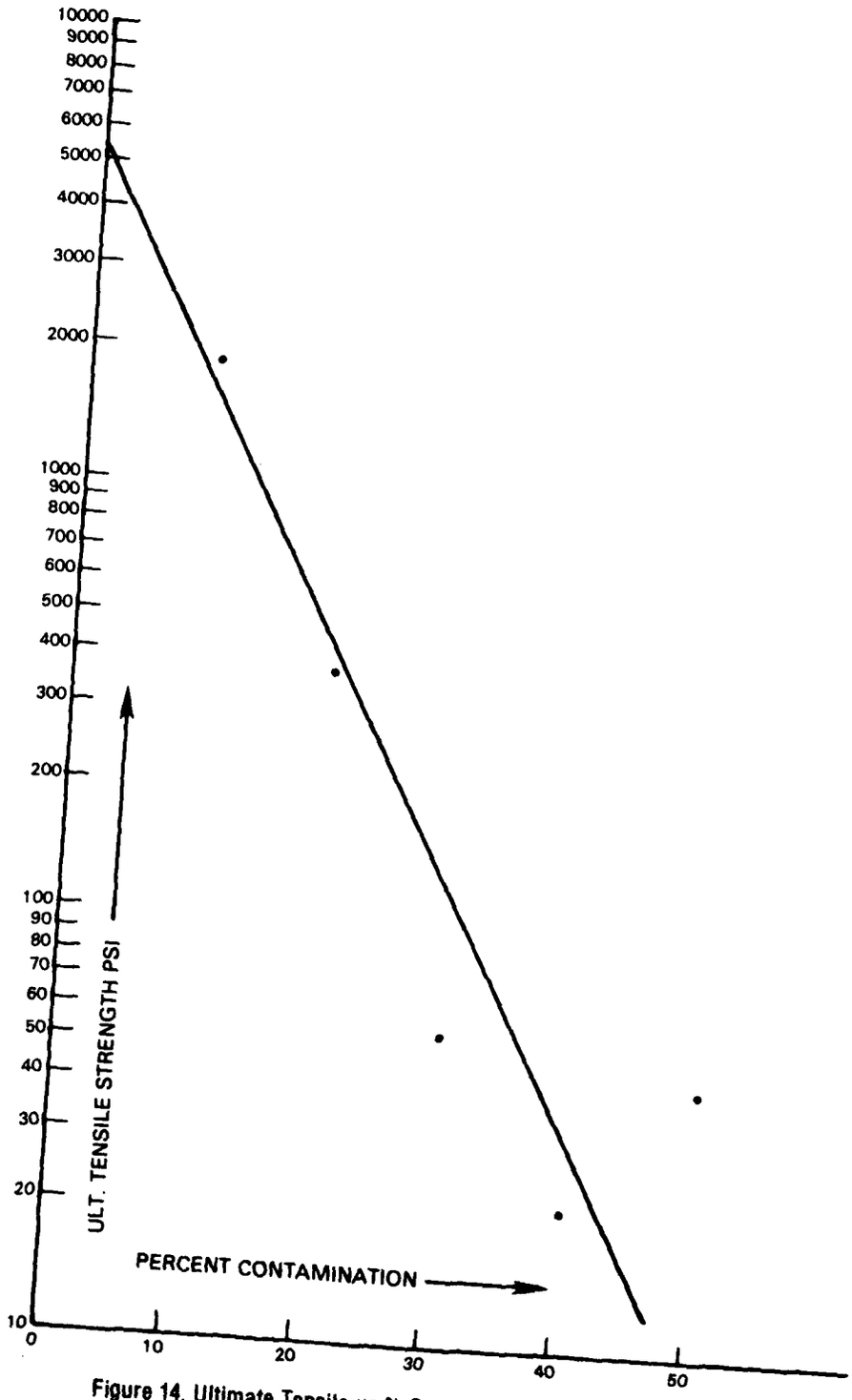


Figure 14. Ultimate Tensile vs % Contamination — Vought Coating

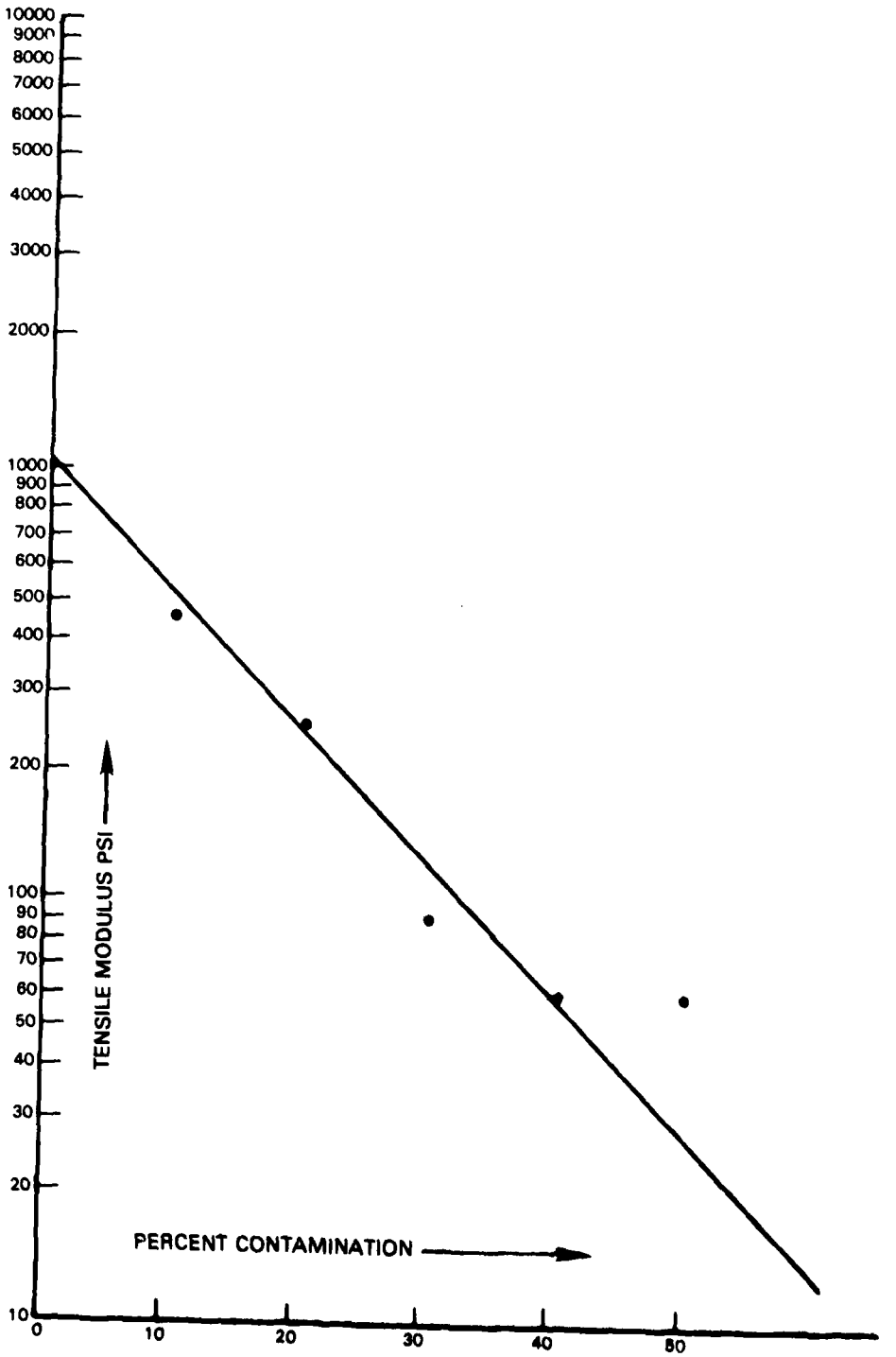
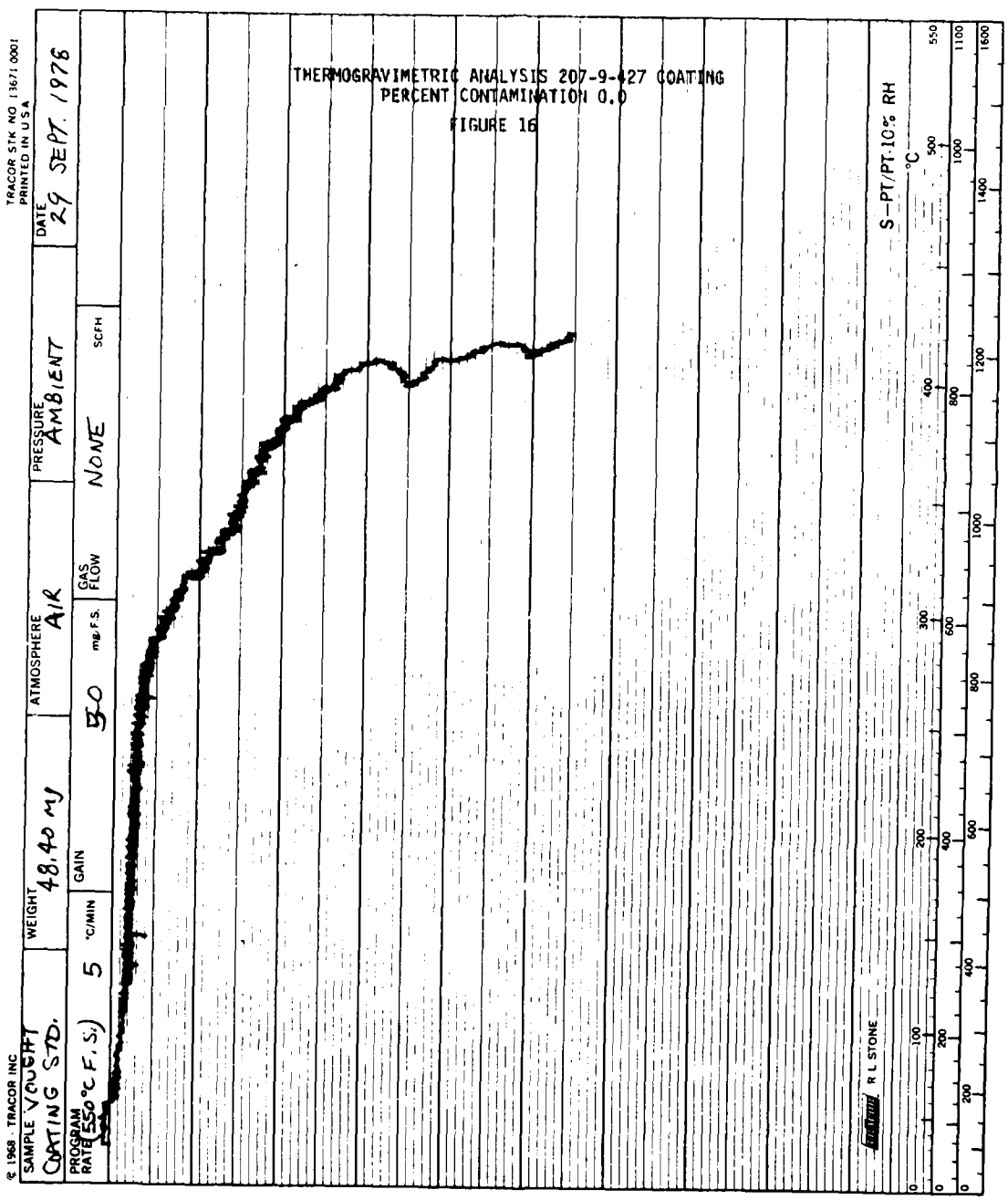
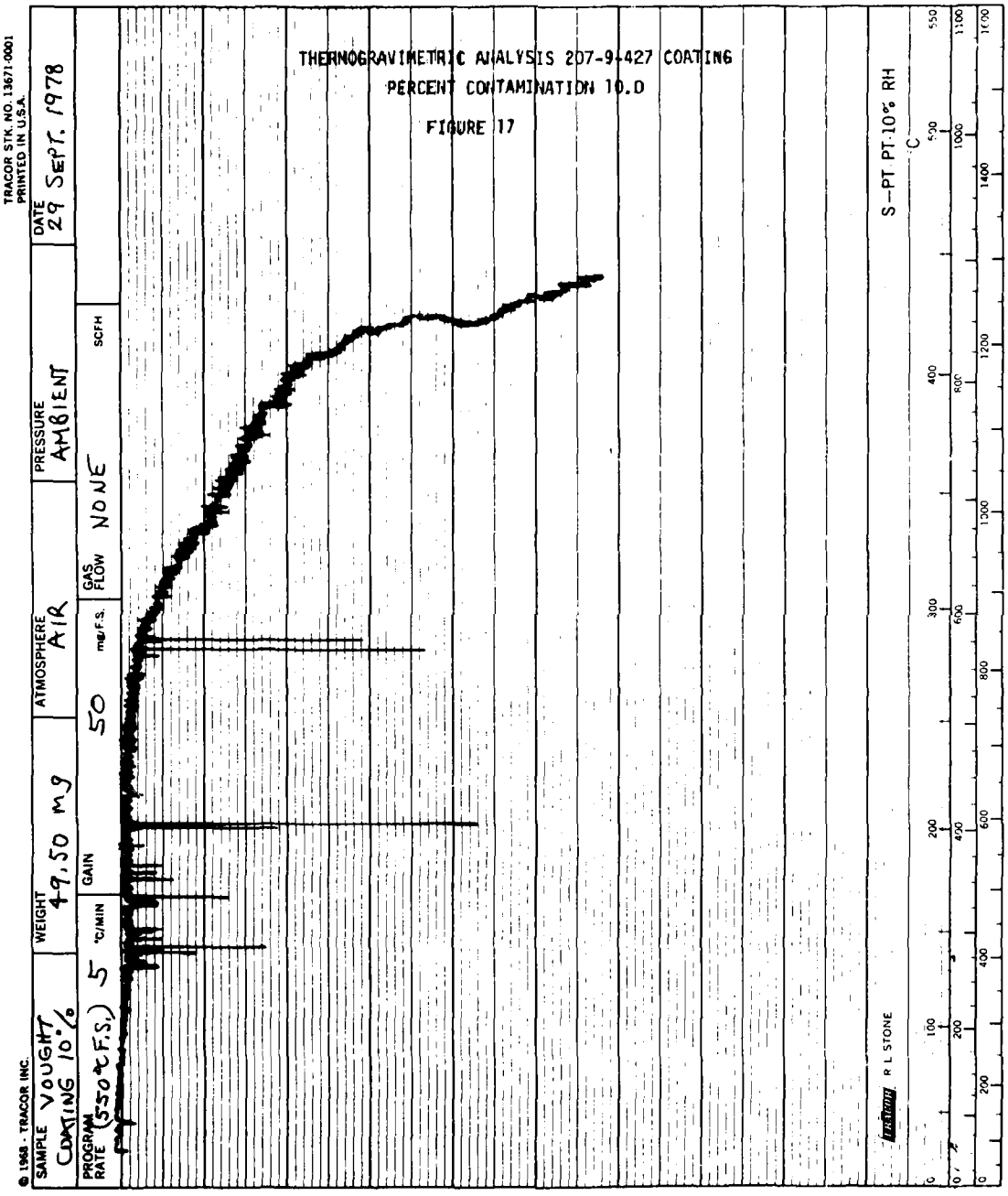
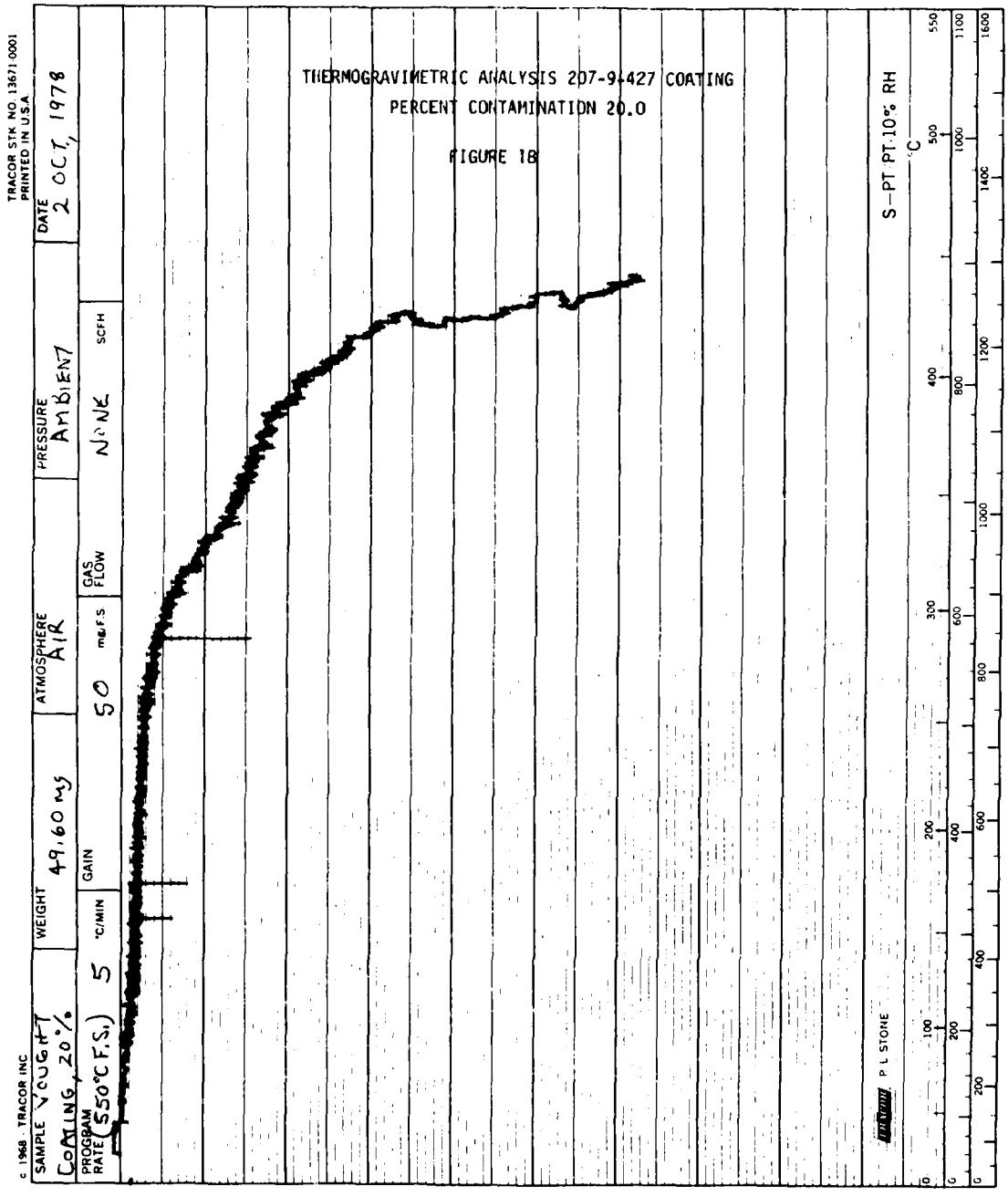
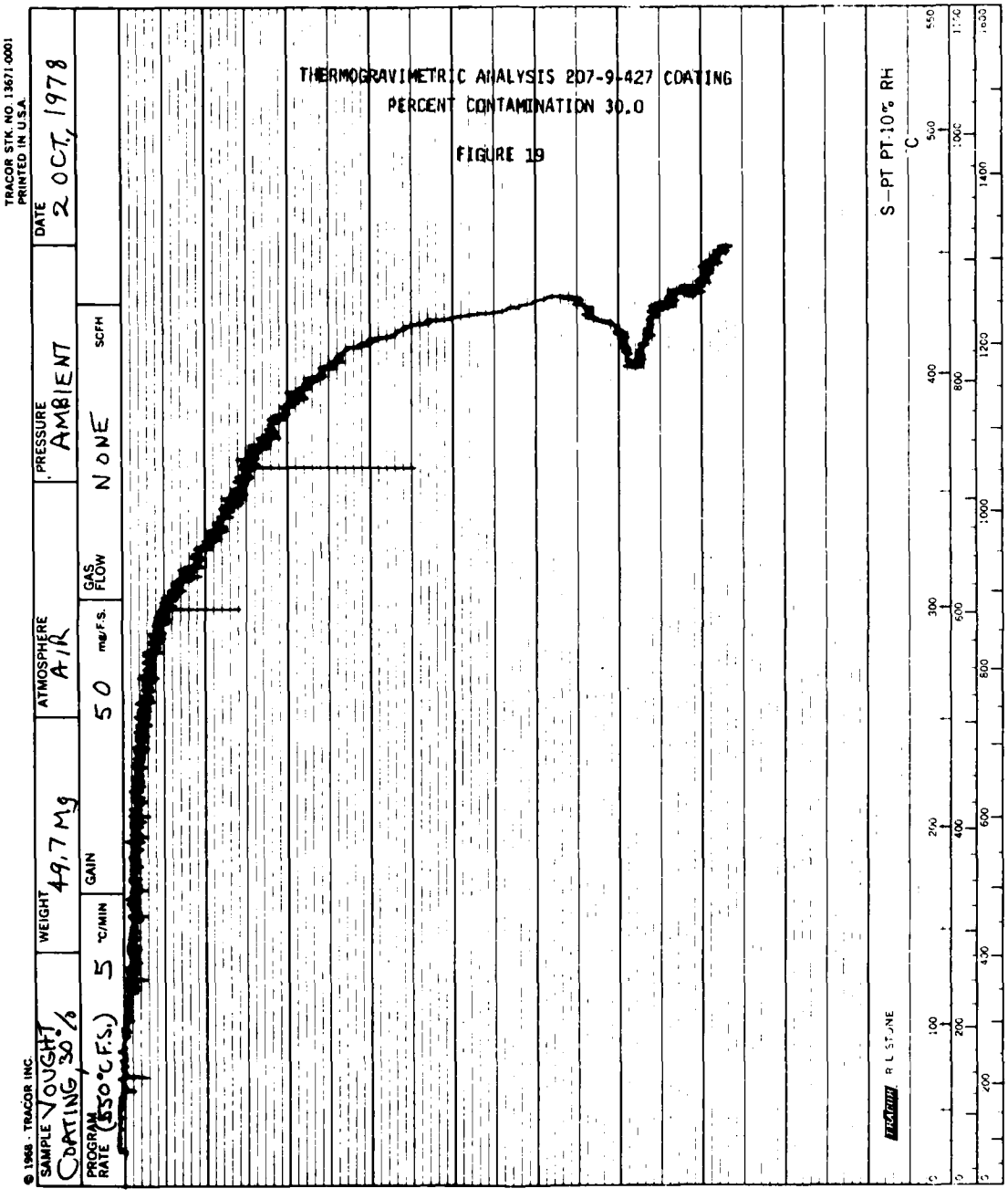


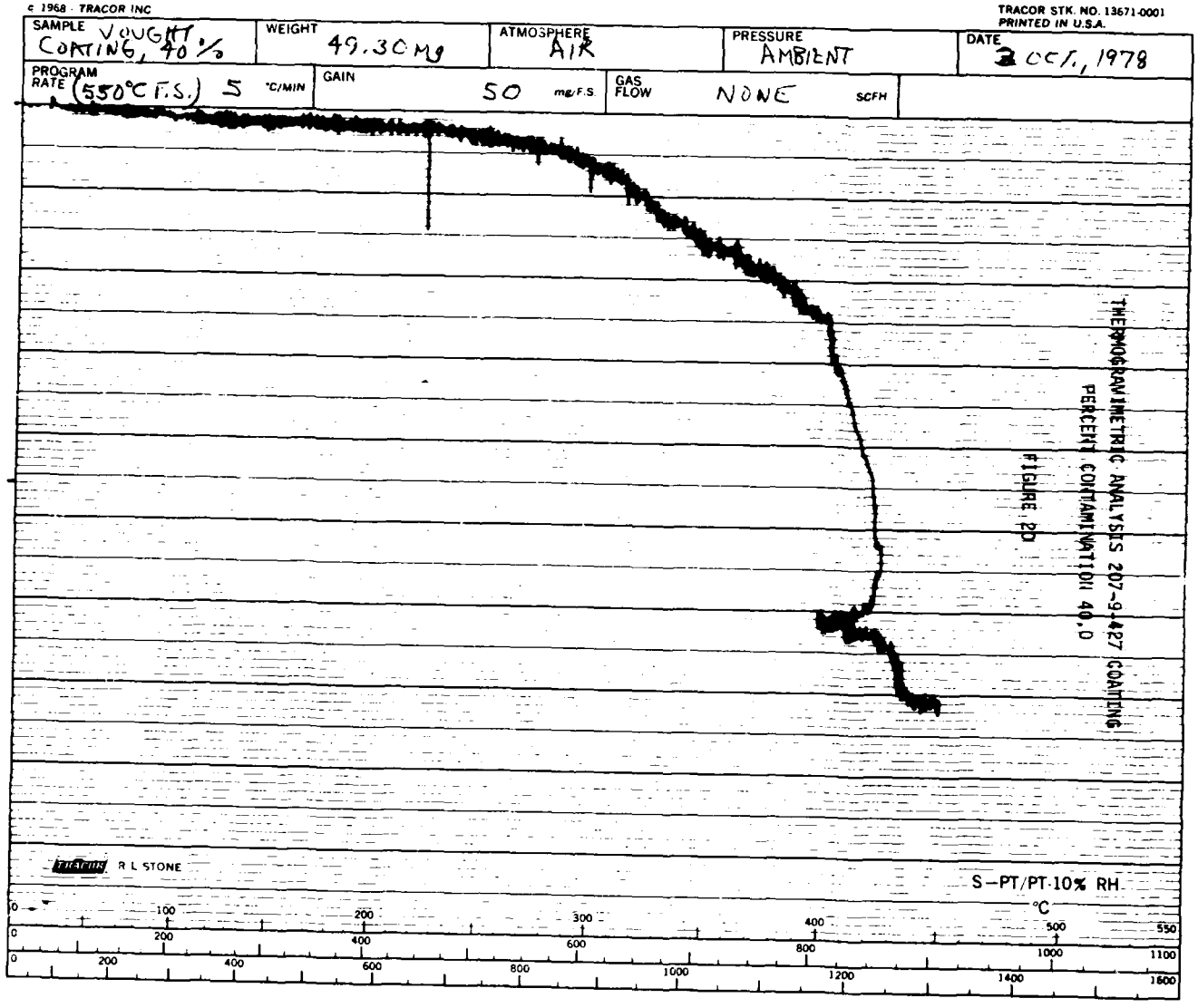
Figure 15. Tensile Modulus at 100% Elongation vs. Percent Contamination — Vought Coating


THERMOGRAVIMETRIC ANALYSIS 207-9-427 COATING
PERCENT CONTAMINATION 0.0
FIGURE 16
© 1968 TRACOR INC
TRACOR STK NO 13671 0001
PRINTED IN U.S.A.
SAMPLE VOUGHT CORTING STD.
WEIGHT 48.40 mg
ATMOSPHERE AIR
PRESSURE AMBIENT
DATE 29 SEPT. 1976
PROGRAM RATE 550°C (F, S) 5 °C/MIN
GAIN
50 m@F.S.
GAS FLOW NONE SCFH
S-PT/PT-10% RH
°C
R L STONE


THERMOGRAVIMETRIC ANALYSIS 207-9-427 COATING
PERCENT CONTAMINATION 10.0
FIGURE 17
© 1968 - TRACOR INC.
TRACOR STK. NO. 13671-0001
PRINTED IN U.S.A.
SAMPLE VOUGHT COATING 10%
WEIGHT 49.50 mg
ATMOSPHERE AIR
PRESSURE AMBIENT
DATE 29 SEPT. 1978
PROGRAM RATE (550°C F.S.) 5 °C/MIN
GAIN 50 mg/F.S.
GAS FLOW NONE SCFH
S-PT PT 10% RH
°C
R L STONE


THERMOGRAVIMETRIC ANALYSIS 207-91427 COATING
PERCENT CONTAMINATION 20.0
FIGURE 18
TRACOR STK NO 13671 0001
PRINTED IN U.S.A.
© 1968 TRACOR INC
SAMPLE VOUGHT COATING, 20%
WEIGHT 49.60 mg
ATMOSPHERE AIR
PRESSURE AMBIENT
DATE 2 OCT, 1978
PROGRAM RATE (550°C F.S.) 5 °C/MIN
GAIN
50 mg F.S
GAS FLOW NONE SCFH
S-PT PT.10% RH
°C
P L STONE


TRACOR STK. NO. 13671-0001
PRINTED IN U.S.A.
© 1968 - TRACOR INC.
SAMPLE VOUGHT COATING, 30%
WEIGHT 49.7 Mg
ATMOSPHERE AIR
PRESSURE AMBIENT
DATE 2 OCT, 1978
PROGRAM RATE 5 °C/MIN (550°C F.S.)
GAIN 50 mg/F.S.
GAS FLOW NONE SCFM
THERMOGRAVIMETRIC ANALYSIS 207-9-427 COATING
PERCENT CONTAMINATION 30.0
FIGURE 19
S-PT PT-10% RH
°C


© 1968 · TRACOR INC
TRACOR STK. NO. 13671-0001
PRINTED IN U.S.A.
SAMPLE VOUGHT COATING, 40 %
WEIGHT 49.30 MG
ATMOSPHERE AIR
PRESSURE AMBIENT
DATE 2 OCT., 1978
PROGRAM RATE (550°C F.S.) 5 °C/MIN
GAIN 50 mg/F.S.
GAS FLOW NONE SCFH
THERMOGRAVIMETRIC ANALYSIS 207-9-427 COATING
PERCENT CONTAMINATION 40.0
FIGURE 2D
R L STONE
S-PT/PT-10% RH
°C
0
100
200
300
400
500
550
0
200
400
600
800
1000
1100
0
200
400
600
800
1000
1200
1400
1600

TRACOR STK. NO. 13671-0001
PRINTED IN U.S.A.

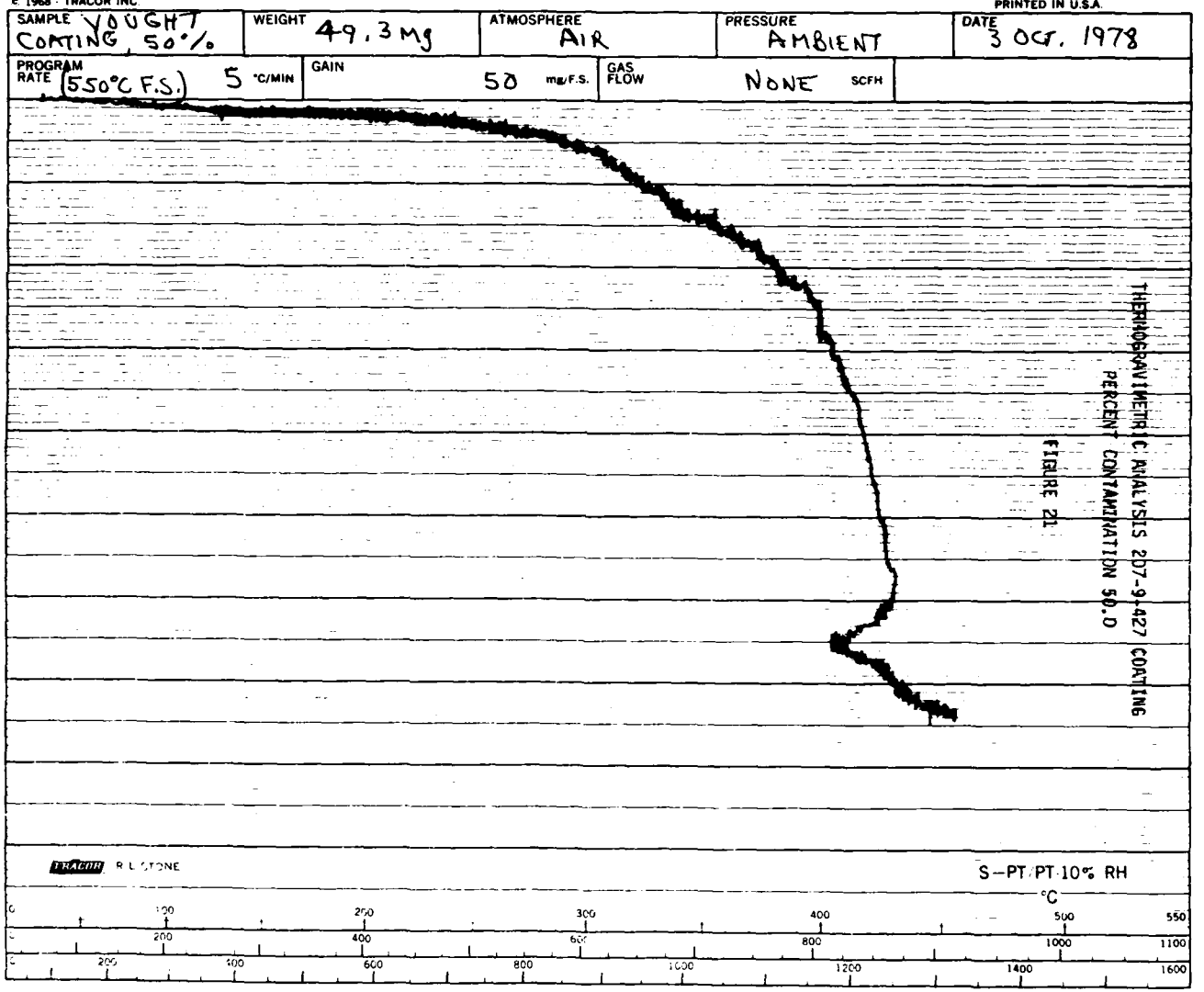


FIGURE 21

CSI STK. NO. 13673-0001
PRINTED IN U.S.A.

SAMPLE VOUGHT COATING, STD.	WEIGHT 0.0026	REF. MATL. NONE WT.	ATMOSPHERE AIR	PRESSURE
PROGRAM RATE 5 °C/MIN	ΔT GAIN 80 μV 500 °C/F.S.	SAMPLE HOLDER SH-11BR Al. Pans	GAS FLOW 0.10 SCFH	10 AUG '78

STONE—PREMCO
Analytical Instruments

DIFFERENTIAL THERMAL ANALYSIS, 207-9-427 COATING
PERCENT CONTAMINATION 0.0
FIGURE 22

P—PLATINEL II

°C

0 50 100 150 200 250 270

0 100 200 300 400 500

0 200 400 600 800 1000 1100

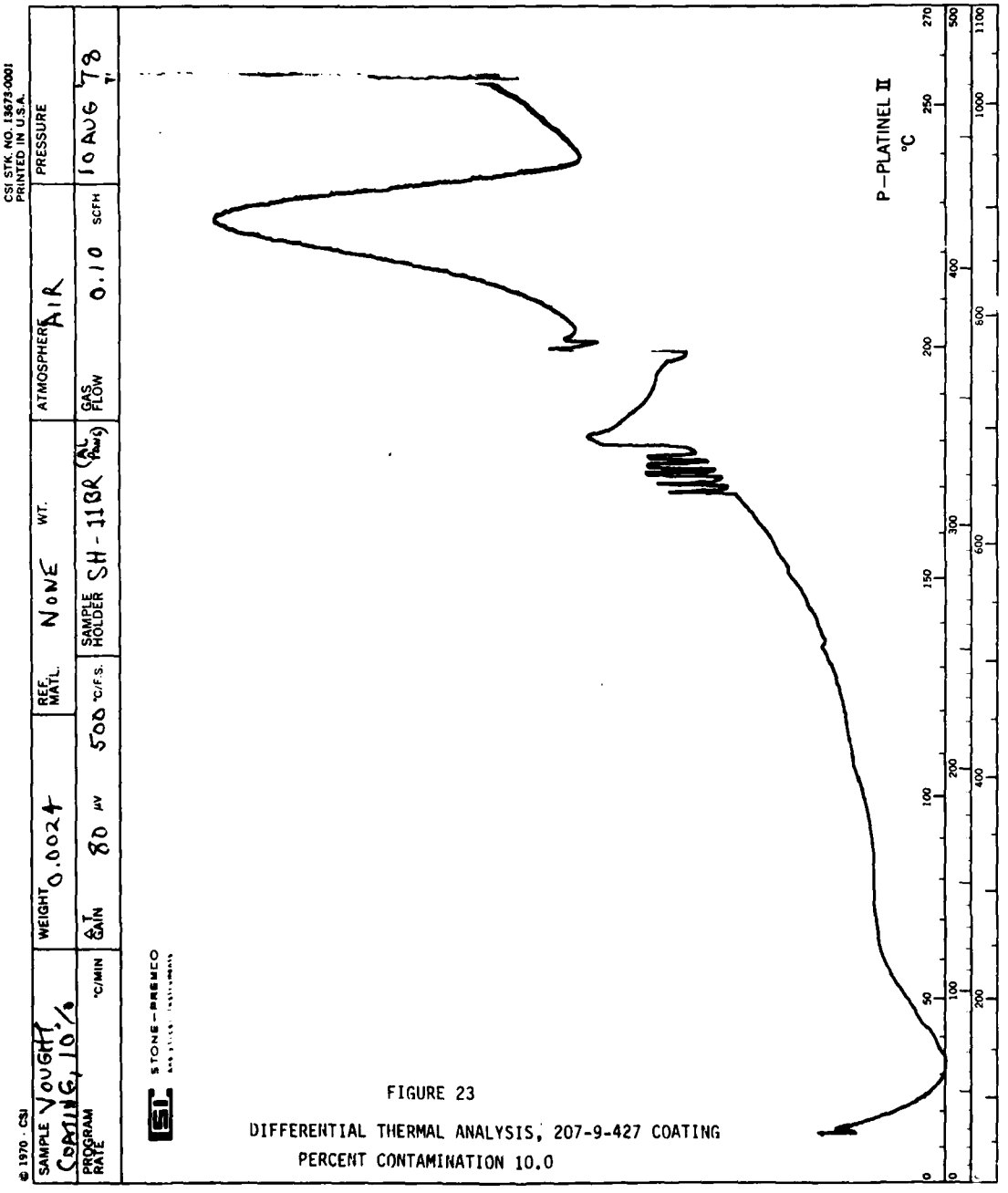


FIGURE 23

DIFFERENTIAL THERMAL ANALYSIS, 207-9-427 COATING
PERCENT CONTAMINATION 10.0

CSI STK. NO. 13673-0001
PRINTED IN U.S.A.

SAMPLE VOUGHT COATING, 20%	WEIGHT 0.0022	REF. MATL. NONE WT.	ATMOSPHERE AIR	PRESSURE
PROGRAM RATE 5 °C/MIN	ΔT GAIN 80 μV 500 °C/F.S.	SAMPLE HOLDER SH-11BR AL PANS	GAS FLOW 0.10 SCFH	9 AUG 78

STONE–PREMCO
Analytical Instruments

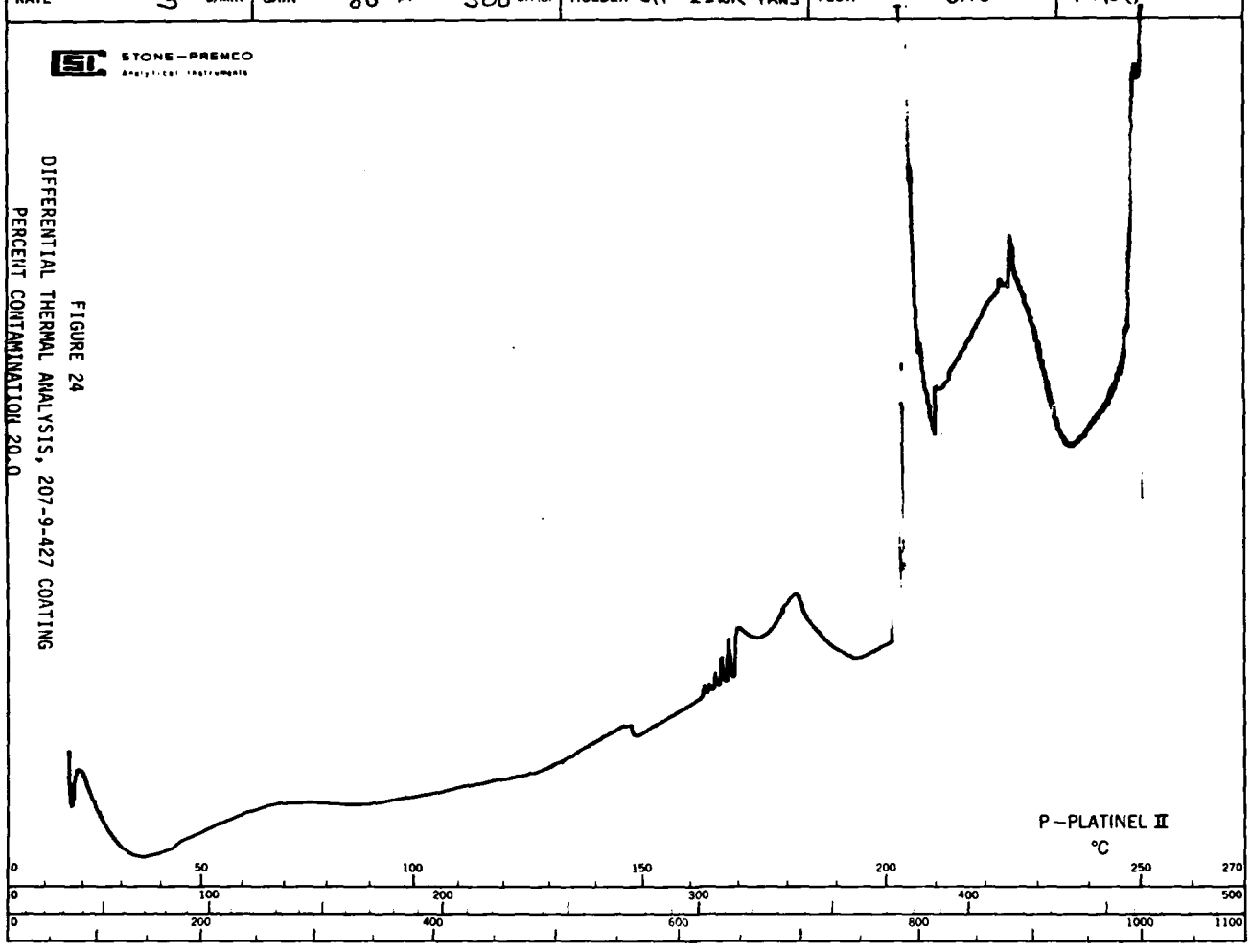
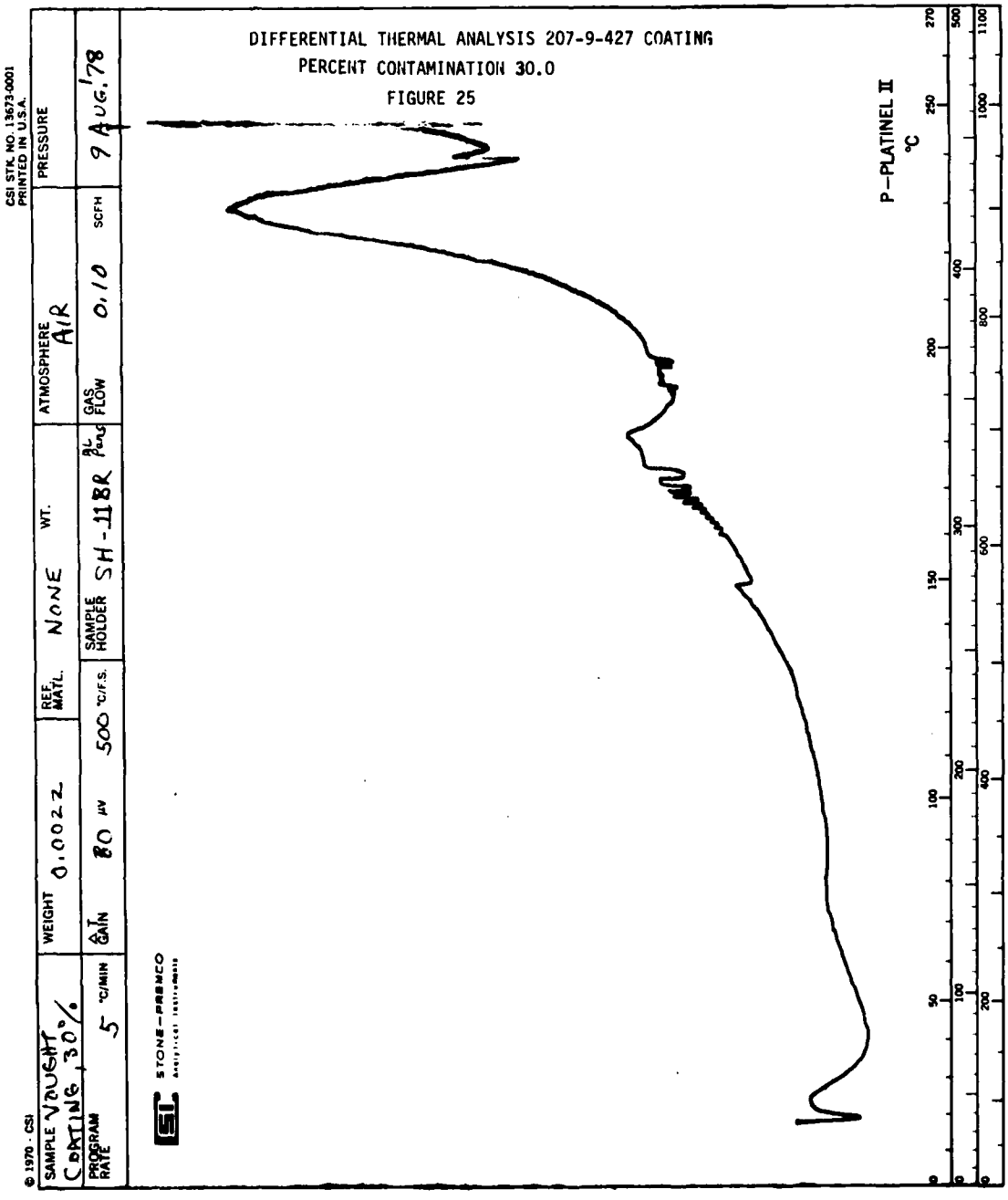


FIGURE 24
DIFFERENTIAL THERMAL ANALYSIS, 207-9-427 COATING
PERCENT CONTAMINATION 20.0


DIFFERENTIAL THERMAL ANALYSIS 207-9-427 COATING
PERCENT CONTAMINATION 30.0
FIGURE 25
SAMPLE VOUGHT COATING, 30%
WEIGHT 0.0022
REF. MATL. NONE
SAMPLE HOLDER SH-11BR Pt
ATMOSPHERE AIR
GAS FLOW 0.10 SCFH
PRESSURE 9 AUG. '78
PROGRAM RATE 5 °C/MIN
ΔT GAIN 80 μV
500 °C/F.S.
STONE-FRENCO
P-PLATINEL II
°C
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CSI STK. NO. 13673-0001
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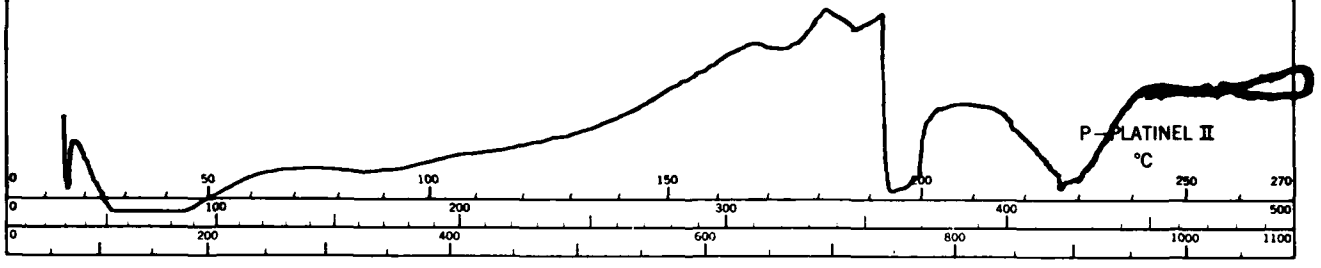
SAMPLE VOUGHT COATING, 40%	WEIGHT 0.0022	REF. MATL. NONE WT.	ATMOSPHERE AIR	PRESSURE
PROGRAM RATE 5 °C/MIN	ΔT GAIN 80 μV 500 °C/F.S.	SAMPLE HOLDER SH-11BR (AL (PAN))	GAS FLOW 0.10 SCFH	9 AUG 78

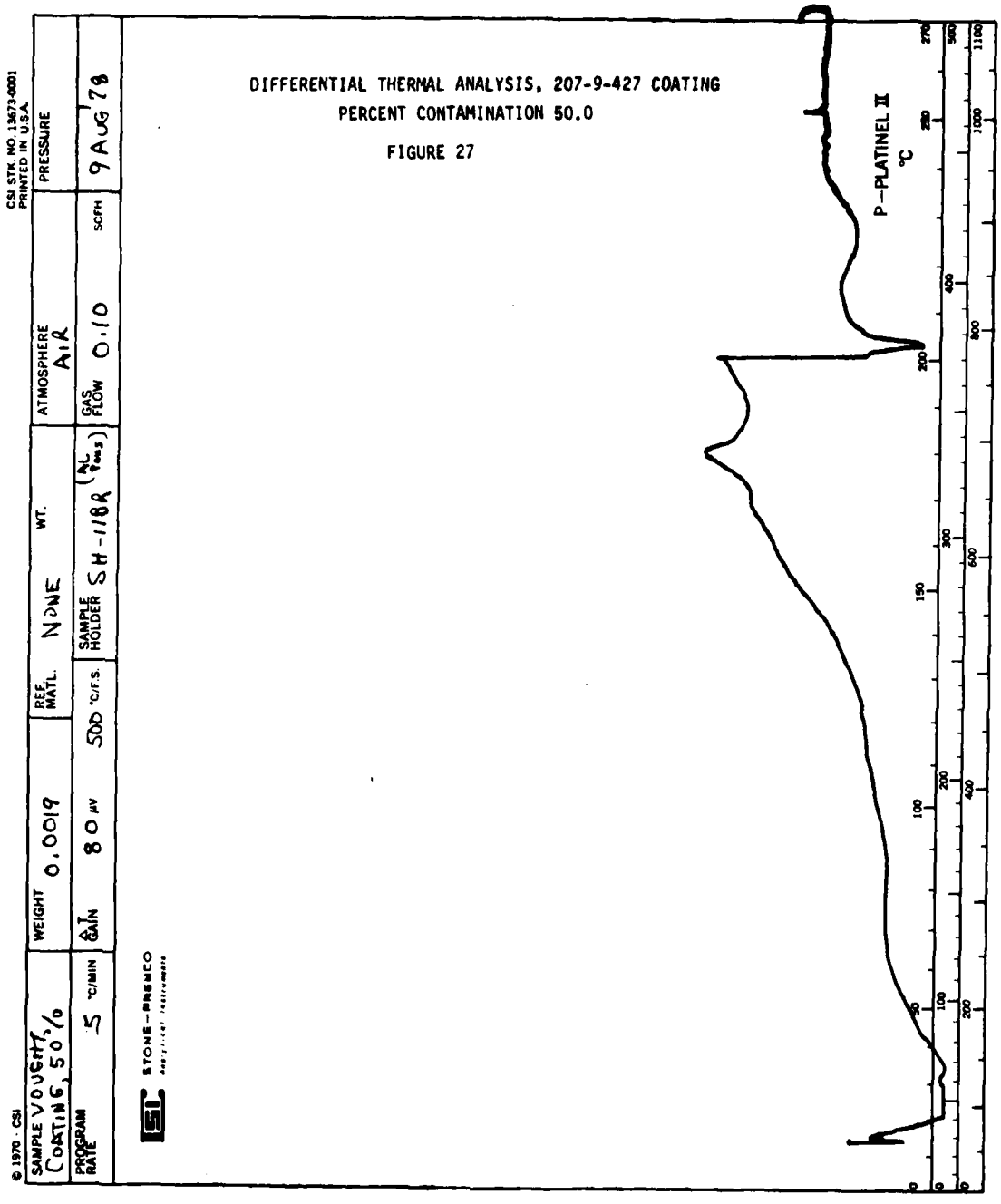
STONS—PRINCO
Analytical Instruments

DIFFERENTIAL THERMAL ANALYSIS, 207-9-427 COATING

PERCENT CONTAMINATION 40.0

FIGURE 26





DIFFERENTIAL THERMAL ANALYSIS, 207-9-427 COATING
PERCENT CONTAMINATION 50.0

FIGURE 27

- o Thermogravimetric analysis and differential analysis are not as definitive for determining the degree of moisture contamination as are the tensile strength and tensile modulus methods.

4.5 RESULTS OF THE SIGNAL TRANSMISSION EFFICIENCY INVESTIGATION

Tests results of the signal transmission efficiency investigation were included in Figure 28 for parallel polarization and Figure 29 for perpendicular polarization. Panel identification for these tests were as follows:

Panel No.	Coating Thickness	Coating
1	12 mils	207-9-427 Coating W/O Primer
2	15 mils	207-9-427 Coating W/MIL-P-23377 Primer
3	15 mils	M413 W/O Primer
4	12 mils	M413 W/MIL-P-8514 Primer
Ref	---	No Coating

Panels 1 and 4 exhibited less transmission efficiency variation at all angles with perpendicular polarization than panels 2 and 3. Panels 1 and 4 showed transmission efficiencies of around 95%. Panel 2 ranged from 97 to 95 percent approximately, and Panel 3 varied from 93 to 95 percent both by perpendicular polarization. Panels 2 and 4 showed less variation by parallel polarization, while Panels 1 and 3 were found to vary more at various angles at parallel polarization. All transmission efficiencies were above 93 percent.

Pertinent observations concerning transmission efficiency tests:

- o Primers did not always reduce the transmission efficiency of the test specimen.
- o Primers used for Panel 2 contained strontium chromate and titanium dioxide pigments. Pigments contained in the primer used on Panel 4 were zinc chromate.
- o The transmission efficiency curves for all panels tested were considerably different for perpendicular polarization and parallel polarization.

4.6 Test results of high-speed rain erosion tests will be made available to recipients of this report when this effort is completed.

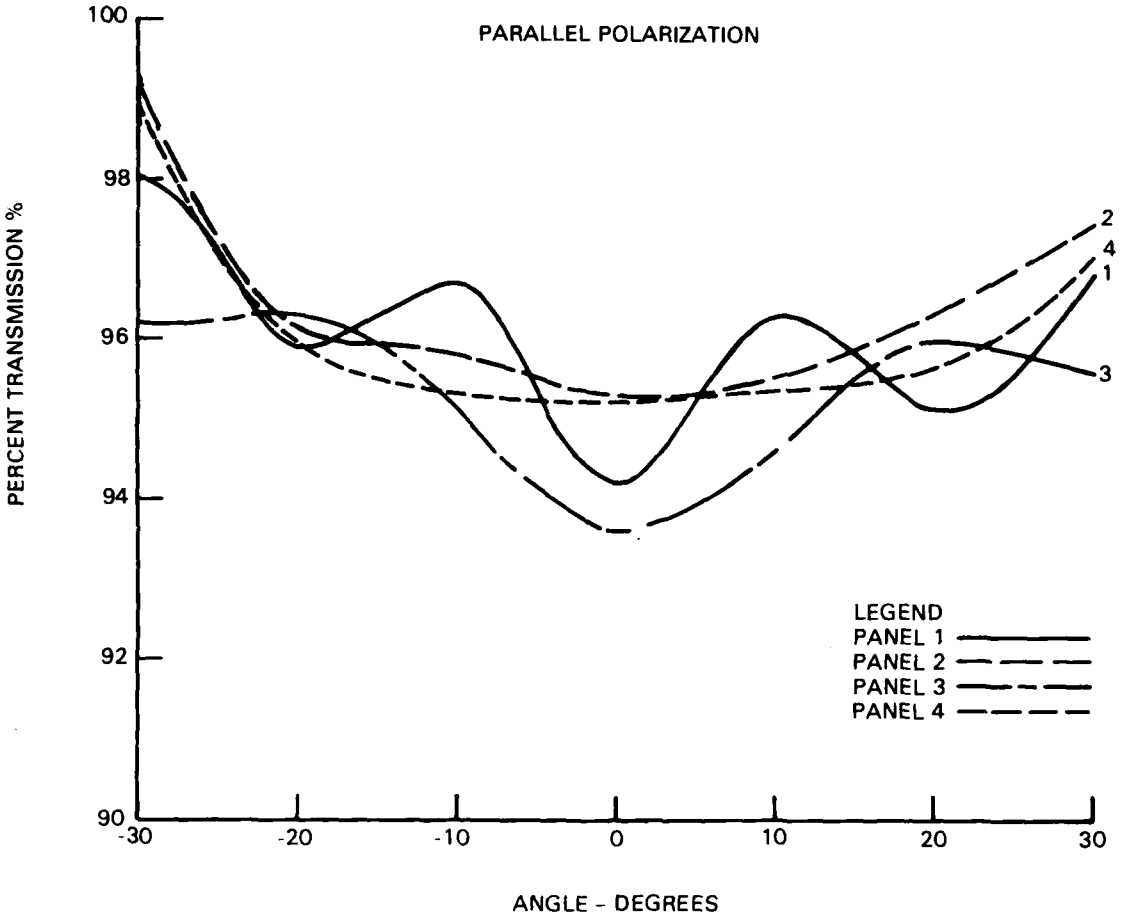


Figure 28. Coating Transmission Efficiency

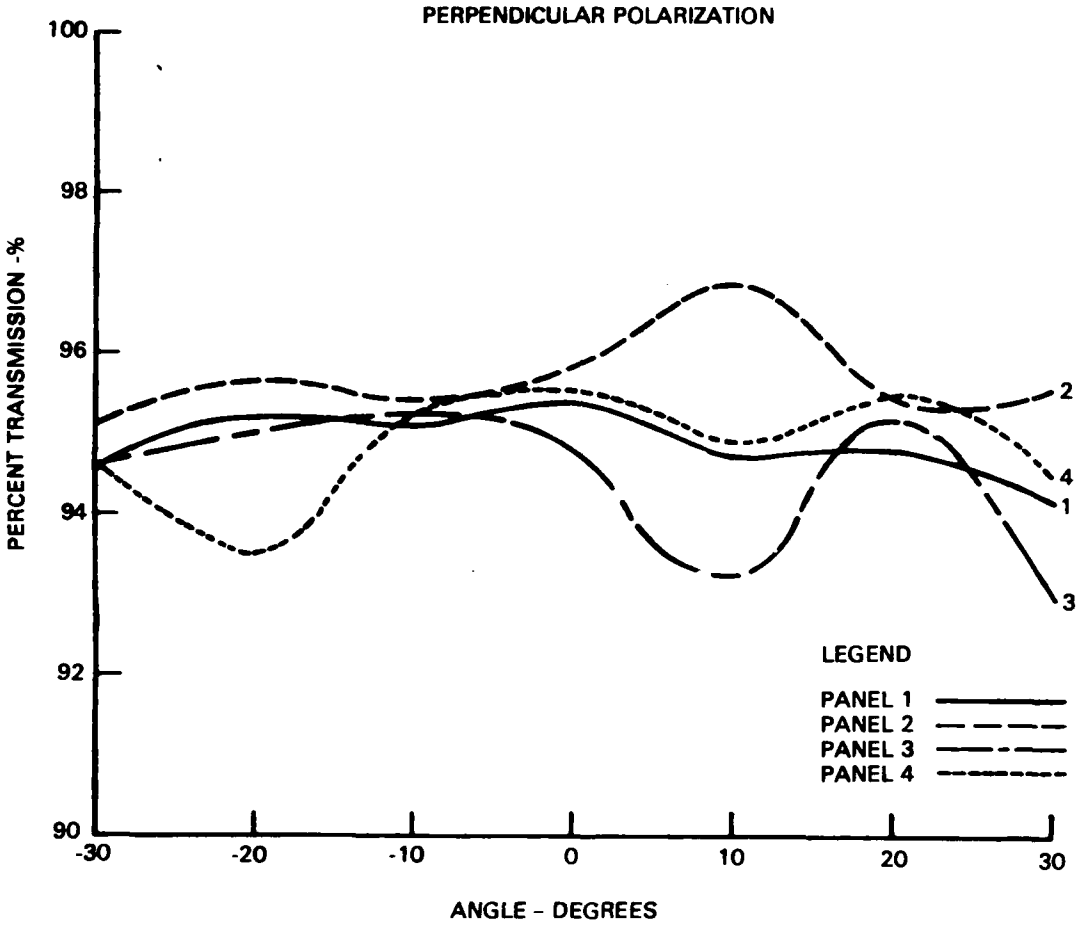


Figure 29. Coating Transmission Efficiency

5.0 TEST SPECIMEN PREPARATION PROCEDURES

5.1 COMPLETION OF THE COATING FAMILIARIZATION STUDY

Samples of each rain erosion coating were prepared according to manufacturers recommendations and the viscosity of each was determined immediately after mixing and at intervals of approximately 15 minutes up to 120 minutes. Coatings were prepared in closed containers on a power shaker and left sealed until the time at which the viscosity was determined. The viscosity of each sample was tested using a #2 Zahn viscometer. Samples of the material were sprayed onto plastic laminates to determine the usable spray life of each coating. Viscosity curves were drawn for use as a guide in setting pot life limits for these materials.

Spray equipment was evaluated for use in spraying the rain erosion coatings, and spray-outs of samples on plastic laminates were made using a JGA 502 suction feed DeVilbiss spray gun with a JGA-402-FX needle and an AV 601-15-FF fluid tip and an MBC-4039-30 air cap. The combination was changed to the larger AV 601-15-EX fluid tip and JGA 402-EX needle to more efficiently handle the higher viscosity rain erosion coatings. The build-up rate per cross coat pass obtained using the spray equipment described, and the cure rate of the samples was determined after spraying.

Additional spray-out tests were completed for the M413 gray material used to coat transmission efficiency test specimens completed the last portion of this program. The same spray equipment and spray techniques were utilized to spray the special 207-9-427 black coating compounded for use in coating leading edge shapes and a trial aircraft.

5.2 PREPARATION OF ADHESION SPECIMENS

Forty-eight 3" x 3" x .25" blister adhesion specimens were cut to size and a .25" pressurization hole was drilled in the center of the 3" x 3" dimension. These 2024-T3 aluminum alloy specimens were vapor degreased and grit blasted lightly with #80 grit Al_2O_3 abrasive. Residual grit was blasted off of the specimens with clean compressed air. The aluminum specimens were then bond cleaned per 208-8-51 process, reference Appendix I. Fiberglass reinforced epoxy and quartz reinforced polybutadiene laminates were layed up and cured with a "rip strip" on each side to provide a clean surface for bonding and coating adhesion. Stripping the rip strip on one side of the laminates prepared these for bonding. The laminates were bonded to the aluminum

backing plates with AF-126 grade 7 adhesive. The adhesive was cured in a vacuum bag, vented to atmosphere, with 35 PSIG autoclave pressure for 1.0 hour at 245±5°F. Parts were cooled to room temperature and the .25 pressurization port was drilled through the laminate to meet the .25" hole drilled in the center of the aluminum backing plates earlier. Stripping of the top "rip strip" prepared the laminates for coating.

Forty-eight adhesive peel specimens were prepared from 6" x 8" x .125" 2024-T3 aluminum alloy and the reinforced composite laminates. Cleaning and bonding were exactly as described for the blister adhesion specimens. Removal of the "rip strip" prepared the laminate surface for coating.

Specimens were divided into six categories: primed, unprimed, epoxy substrate, polybutadiene substrate, M213 coated, and 207-9-427 coated. The M213 material was applied over MIL-C-8514 wash primer and the 207-9-427 was applied over MIL-P-23377 epoxy-polyamide primer. All specimen sets were identified as follows:

- o HFP for M213 rain erosion coating on fiberglass reinforced plastic laminate primed with MIL-C-8514 as a primer.
- o VFP for 207-9-427 rain erosion coating on fiberglass reinforced plastic laminate primed with MIL-P-23377 epoxy polyamide primer.
- o HFU for M213 rain erosion coating on fiberglass reinforced plastic laminate without a prime coat.
- o VFU for 207-9-427 rain erosion coating on fiberglass reinforced plastic laminate without a prime coat.
- o HQP for M213 rain erosion coating on quartz reinforced polybutadiene laminate with MIL-C-8514 as a primer.
- o VQP for 207-9-427 rain erosion coating on quartz reinforced polybutadiene laminate with MIL-P-23377 as a primer.
- o HQU for M213 rain erosion coating on quartz reinforced polybutadiene laminate without a primer coat.
- o VQU for 207-9-427 rain erosion coating on quartz reinforced polybutadiene laminate without a primer coat.

Nominal thickness applied for each coating was as follows:

- o M213 rain erosion coating 14-17 mils dry film thickness.
- o 207-9-427 rain erosion coating 13-16 mils dry film thickness.
- o MIL-C-8514 primer 0.4 to 0.6 mil dry film thickness.
- o MIL-P-23377 epoxy-polyamide primer 0.6 to 0.9 mil dry film thickness.

The MIL-C-8514 primer was applied in accordance with MIL-C-8507. The material was allowed two hours in which to dry before the rain erosion coating was applied.

The MIL-P-23377 primer was applied in accordance with MIL-C-22751 and allowed three hours in which to dry before application of the rain erosion coating.

Any roughness that appeared after the primers dried was removed by light abrasion with a 600 grit wet or dry abrasive paper. Residual sanding debris was removed by clean compressed air and a very light wipe with a tack rag.

Rain erosion coatings were applied twice daily with 4 to 6 hours drying time between coats and an approximate 18 hour overnight cure period was allowed before the next day's coating application. Application rates averaged 4.1 and 3.9 mils per cross coat pass for the M213 and 207-9-427 coatings, respectively.

Spray equipment utilized for application of the primers and rain erosion coatings was a DeVilbiss, suction feed type JGA-502 gun equipped with an AV 601-15-EX fluid tip, a JGA-402-FZ needle and an MBC-4039-30 air cap. Air pressure of 35-45 psig was used during spraying of the coating materials.

During the coating application, air was exhausted from the spray room through a dry type DeVilbiss DE 564 spray booth with a duct sectional area of 11" x 24".

The temperature and relative humidity were controlled within 74-80^{o}F and 45-58%, respectively during coating applications.

After completion of the last rain erosion coating application, the blister adhesion specimens were allowed to dry at room temperature for 7-9 days. The adhesive peel specimens were completed by applying a piece of the 12.1 oz/yd^2 canvas reinforcing strap into the (still wet) last coating layer of the rain erosion material. The canvas was smoothed and brought into intimate contact with the rain erosion material and allowed 4-6 hours to dry. An eighteen hour overnight cure was allowed for excess solvents to escape through the last layers of the coating material and canvas. Two final applications of the rain erosion coating material completed the specimen. These specimens were also cured 7-9 days before exposure to MIL-H-5606 hydraulic fluid.

Specimens were exposed to MIL-H-5606 hydraulic fluid for a period of seven days, and the adhesion degradation was measured by both the blister method and the 180^{o} peel method, as described above in test methods.

5.3 SOLVENT EVAPORATION TEST PROCEDURES

The 207-9-427 coating was used for solvent release studies. A special accelerator component was made that would allow addition of 8% by weight of a test solvent, thus maintaining the exact reaction stoichiometry and generally the same viscosity of the material. Spray-outs were made with the coating diluted with various solvents added in the quantity of 8% by weight based on total weight of the admixed coating. Spray-outs were made on waxed plate glass, and the cured coating films were cut in cross section. Sectioned films were mounted and polished. Photomicrographs were made at 100X and the number of voids per unit area determined.

Spray-outs were made using the M213 coating and the 207-9-427 material. Coatings were applied in 1, 2, 3, 4, and 5 cross coat passes with 15 minutes being allowed between subsequent coats. The cured films were released from the backing plates and cut in cross section. Photomicrographs were made at 100X as described in the previous paragraph and the number of voids per unit area were determined.

5.4 TEST SPECIMEN PREPARATION FOR POLYMERIZATION STUDY

The 207-9-427 coating material was used to make a number of controlled contaminated specimens. Samples of the base resin were weighed out in a container and a predetermined quantity of a 95% acetone - 5% water solution was added to each container. The container was closed five weeks to simulate storage after manufacture, allowing the water sufficient time to react with the isocyanates. These prereacted or blocked materials were then reacted with the standard diamine curative solution to form a rain erosion coating that had from 10% to 50% of the reactive isocyanate sites on the prepolymer molecule prereacted, resulting in an inversely proportionally reduced crosslinking ratio. Tensile strength and tensile modulus tests were performed to illustrate the loss of these mechanical properties as the amount of contamination was increased.

Differential thermal analysis and thermogravimetric analysis were performed to corroborate findings of the tensile property tests.

Differential thermal analysis of the 207-9-427 coating was performed on a Tracor Model DTA-202 Differential Thermal Analysis System. Specimens weighing approximately 2 mg. were heated at a rate of $5^{o}C$/min. in air to an upper temperature of $460^{o}C$. Aluminum oxide was used to provide the inert material in the units reference cell.

Thermogravimetric analyses of the 207-9-427 coatings were performed on a Tracor Model TGA-5B Thermogravimetric Analyzer. Specimens weighing approximately 50 mg. were heated at a rate of $5^{o}C$/min. in air. The weight loss vs. temperature was obtained up to $440^{o}C$.

5.5 PREPARATION OF SIGNAL ATTENUATION TEST PANELS

Five each 24" x 24" x .050" electrical grade laminates were fabricated per MIL-R-7705 as outlined per MIL-C-83231. The laminates were layed up and cured with a "rip strip" over the outer ply. The "rip strip" was removed to prepare the panels for coating. The panels were identified and coated as follows:

Panel No.	Coating Thickness	Coating
1	12 mils	Vought coating w/o primer
2	15 mils	Vought coating w/Mil-P-23377 primer
3	15 mils	Hughson M413 w/o primer
4	12 mils	Hughson M413 w/Mil-C-8514 primer
Ref	---	Uncoated

After 7 - 9 days cure time, test panels were placed in the sample holder, and the signal detection and emitting apparatus was set up as illustrated in Figure 9.

The following check out and test procedure was used:

1. Set up equipment for parallel polarization per Figures 7 and 8.
2. Allow 30 minutes warm up. Monitor Pr and Po for stability.
3. Record Pr and Po
4. Insert panel at -30^{o} angle.
5. Record power reading (P_1).
6. Move panel 0.1 inch further away from the transmitting antenna and record P_2.
7. Repeat step 6 at every 0.1 inch increment over 1 inch linear displacement. Record P_2, P_4, etc.
8. Repeat steps 3-7 at each angle (10^{o} increments).
9. Repeat steps 3-8 for perpendicular polarization.
10. Calculate T^2 for panel for each orientation angle:

$$T^2_{Panel} = \frac{P_{max} + P_{min}}{2Po} \times 100$$

11. Test five panels (one w/o coating; four w/coating)
12. Calculate percent transmission for coating:

$$T^2_{Coating} = \frac{T^2_{Coated\ Panel}}{T^2_{Blank\ panel}} \times 100 = \%\ Tx$$

Data were collected and the percent transmission efficiency calculated for angles of $+30^{o}$ to -30^{o} at points through a range of 1.0 inch by 0.1 inch increment linear movement. Data points were collected as indicated on the following Test Panel Data Sheet.

TABLE 4

TEST PANEL DATA SHEET

PANEL NO. REF PNL DATE 5-4-79

POLARIZATION HOR FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	95.8%	93.5%	92.9%	95.8%	92.5%	93.8%	95.5%
P_2	96.0%	93.2%	92.6%	96.0%	93.3%	94.0%	95.2%
P_3	96.2%	93.5%	92.0%	93.4%	93.7%	94.4%	95.2%
P_4	96.0%	94.1%	91.6%	89.8%	93.2%	94.7%	95.3%
P_5	95.7%	94.2%	91.9%	88.8%	92.5%	94.8%	95.4%
P_6	95.4%	94.1%	92.3%	90.9%	92.1%	94.7%	95.6%
P_7	95.3%	94.0%	92.9%	94.6%	92.3%	94.2%	95.7%
P_8	95.4%	93.5%	92.9%	96.2%	92.9%	93.8%	95.7%
P_9	95.8%	93.0%	92.2%	94.2%	93.5%	94.0%	95.4%
P_{10}	96.0%	93.2%	91.7%	90.3%	93.3%	94.4%	95.1%
P_{11}	96.0%	93.9%	91.5%	88.5%	92.7%	94.7%	95.1%
P_{MAX}	96.2%	94.2%	92.9%	96.2%	93.7%	94.8%	95.7%
P_{MIN}	95.3%	93.0%	91.5%	88.5%	92.1%	93.8%	95.1%
T^2_{PANEL}	95.75	93.6	92.2	92.35	92.9	94.3	95.4

TABLE 5

TEST PANEL DATA SHEET

PANEL NO. _____ DATE 5-4-79

POLARIZATION _____ FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R							
P_0							
P_1							
P_2							
P_3							
P_4							
P_5							
P_6							
P_7							
P_8							
P_9							
P_{10}							
P_{11}							
P_{MAX}							
P_{MIN}							
T^2_{PANEL}							
$T^2_{COATING}$							

All data points taken for each panel were included in Appendix A of this report.

5.6 PREPARATION PROCEDURE FOR HIGH SPEED EROSION TEST SPECIMENS

Leading edge shapes were coated for test on the high speed simulated rain erosion test facility at B. F. Goodrich Company. These specimens were thoroughly abraded with #320 grit wet or dry abrasive paper to completely remove all mold release compounds from the surface of these parts and smooth any surface irregularity, if any, on the exterior of these specimens. The parts were then cleaned of residual sanding debris with clean compressed air. The parts were then vapor degreased in a vapor degreaser using MIL-T-81533 (1,1,1 trichloroethane). Parts were air dried for approximately 30 minutes and inspected for surface voids or pits that show up after cleaning. Pitted specimens were discarded rather than being filled and resanded. The specimens were then covered with a plastic bag to prevent dust contamination and these were allowed to completely dry overnight before coating application was begun. Coating of the leading edge shapes was conducted exactly as described above in paragraph 5.2 under preparation of adhesion specimens. Coating thickness was built up applying two applications per day; the total coating build-up of 12-15 mils required 2 to 2.5 days to complete. Fourteen sets (two specimens per set) were coated for testing under supervision and direction of the NAVAIR program technical monitor at the B. F. Goodrich Company.

In addition to the leading edge shapes coated, 40 additional aluminum alloy high-speed erosion specimens were coated with the M413 gray rain erosion coating and the 207-9-427 materials. Two sets of specimens (20 specimens per set) were made; one a $.955^{+000}_{-005}$ inch diameter disk x .125 inch thick; the other 20 specimen set was a 1.0 x 1.0 x .125 square plate coated with the same materials as the disks. Coating of these specimens was conducted in a manner identical to the procedure used to coat the reinforced plastic leading edge samples.

The aluminum alloy disks and squares were given a MIL-C-5541 chromate conversion coating treatment prior to coating. All specimens were primed before application of the rain erosion coating. MIL-C-8514 was applied to a dry film thickness of 0.5 mil for the M413 gray coating and

the MIL-P-23377 epoxy-polyamide was applied to a dry film thickness of 0.8 mil for the 207-9-427 coating. Two specimens for each coating thickness were coated in the following thickness.

- o M413 gray - 1.4, 6.9, 9.4, 11.8, 15.6 mils dry film
- o 207-9-427 - 2.0, 6.7, 9.0, 13.7, 15.5 mils dry film

Four leading edge shapes were coated with a special 207-9-427 black rain erosion coating for testing at B. F. Goodrich. These specimens were coated exactly as described above for the standard 207-9-427 coating. The special 207-9-427 black material was compounded with 2.5 PPH/wgt. resin carbon black added for extra reinforcement. Thickness of these specimens coated was 12-15 mils dry film.

In addition to coating the leading edge shapes with the black 207-9-427 coating, four-quart kits of this special material were compounded for coating select areas on a test aircraft. This coating was shipped to NAVAIR for use in these coating trials.

Vought production personnel coated four sets of rain erosion leading edge shapes demonstrating differences, if any, between production and laboratory coated specimens. Specimen sets K andL coated by production personnel were identical to sets A and B, except for coating thickness. Sets M and O were coated with the special 207-9-427 BL, black coating.

Photographs of select specimen sets were made to depict the condition of these specimens before test.

Table 6 was prepared to completely characterize each rain erosion specimen set with respect to coating identification and coating thickness.

TABLE 6. COATING SYSTEM IDENTIFICATION OF LEADING EDGE SPECIMENS COATED

Specimen No. Set	Primer - Thickness mils	Rain Erosion Coating - Thickness, mils	Condition, Aberration, Etc.
1 & 2 - A	MIL-P-23377 - 0.7	207-9-427 - 22	Normal
3 & 4 - B	None	207-9-427 - 21	Normal
5 & 6 - C	None	M213 - 12	Normal
7 & 8 - D	MIL-C-8514 - 0.5	M213 - 13	Normal
9 & 10 - E	MIL-C-8514 - 0.5	M213 - 14 - 15	Controlled contamination. Not tested
11 & 12 - F	MIL-P-23377 - 0.8	207-9-427 - 12-14	Controlled contamination. Not tested
13 & 14 - G	MIL-P-23377 - 0.8	207-9-427 -14-16	Overcoated with 0.7 mil MIL-P-23377 and 1.8 mils MIL-C-81773. Not tested.
15 & 16 - H	MIL-P-23377 - 0.8	207-9-427 -14 - 16	Overcoated with 0.7 mil MIL-P-23377 and 1.8 mils MIL-C-81773. Controlled contamination. Not tested.
17 & 18 - I	MIL-C-8514 - 0.5	M213- 12 - 13	Overcoated with 0.7 mil MIL-P-23377 and 1.8 mils MIL-C-81773. Controlled contamination. Not tested.
19 & 20 - J	MIL-C-8514 - 0.5	M213 - 12-13	Overcoated with 0.7 mil MIL-P-23377 and 1.8 mils MIL-C-81773
21 & 22 - K	MIL-P-23377 0.6-0.9	207-9-427-9	Coated by production personnel
23 & 24 - L	MIL-P-23377 0.6-0.9	207-9-427 12-13	Coated by production personnel
25 & 26 -M	MIL-P-23377 - 0.8	207-9-427 BL-15	Normal
27 & 28 - O	None	207-9-427 BL-15	Normal

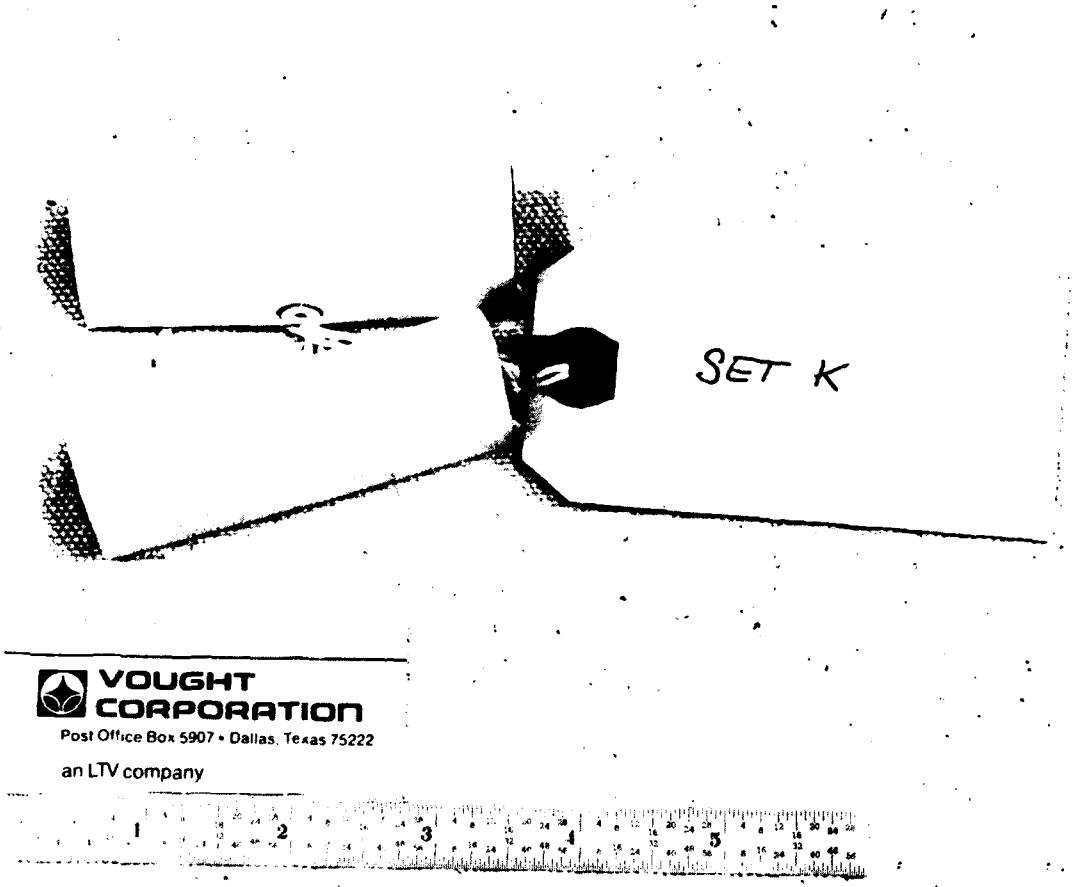


Figure 30. Rain Erosion Set K.

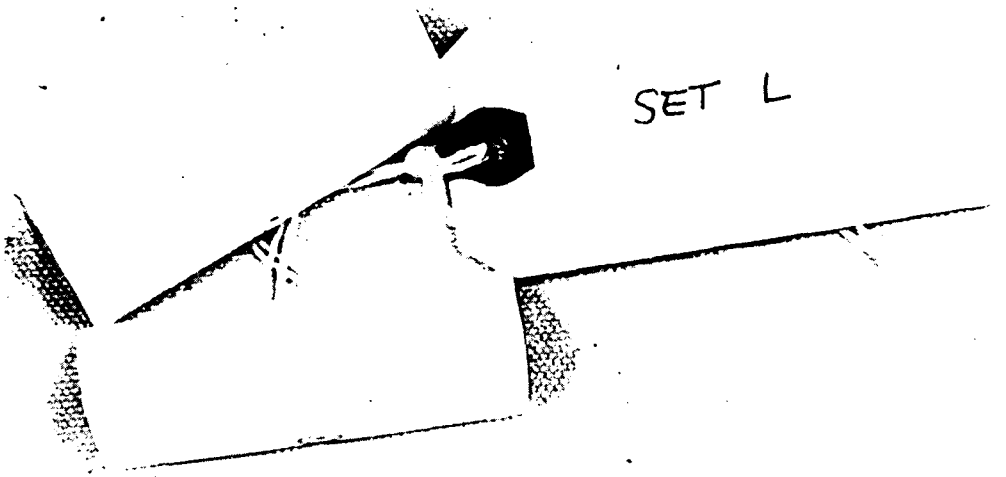


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Figure 31. Rain Erosion Set L.

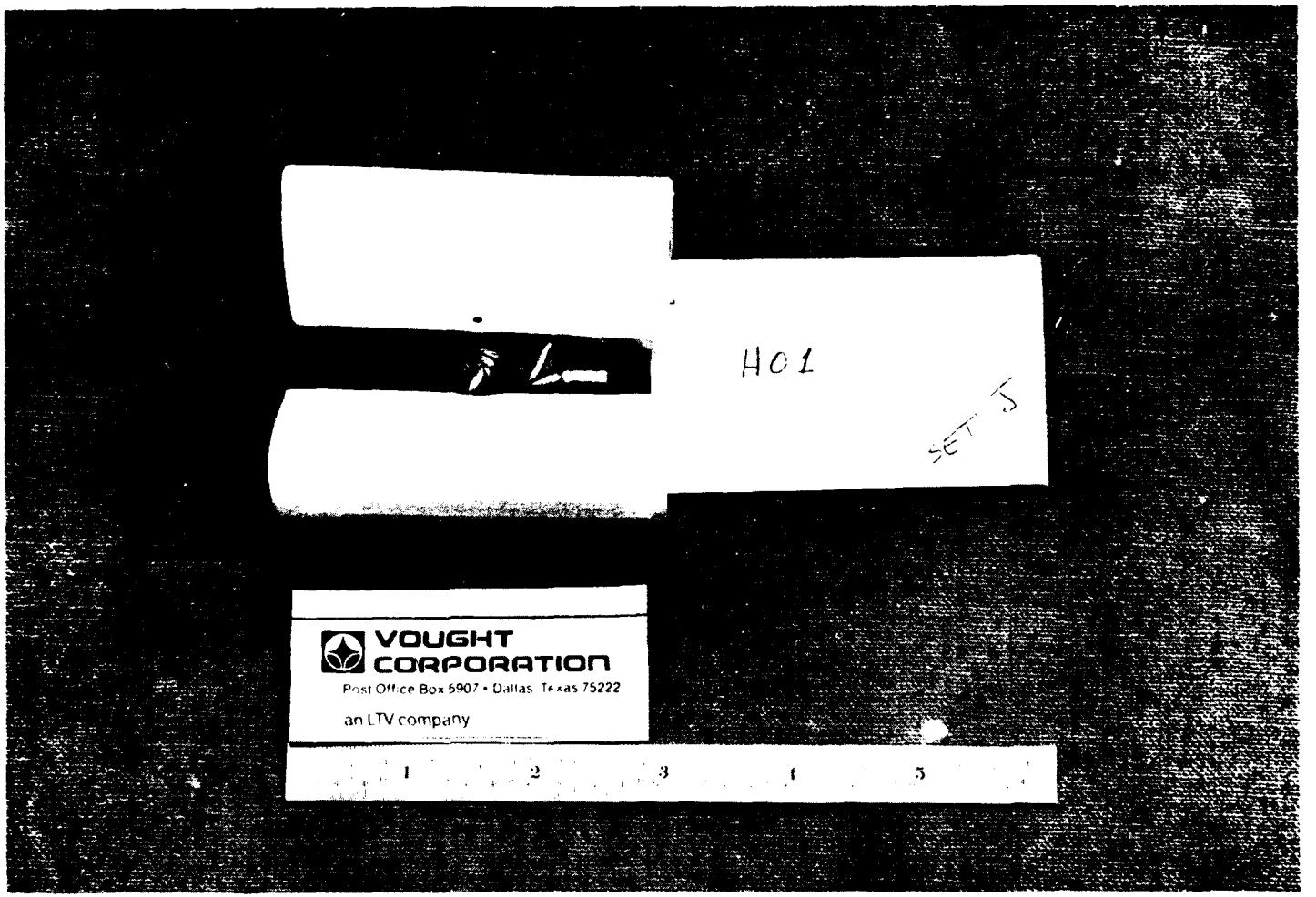

Figure 32. Rain Erosion Set J.

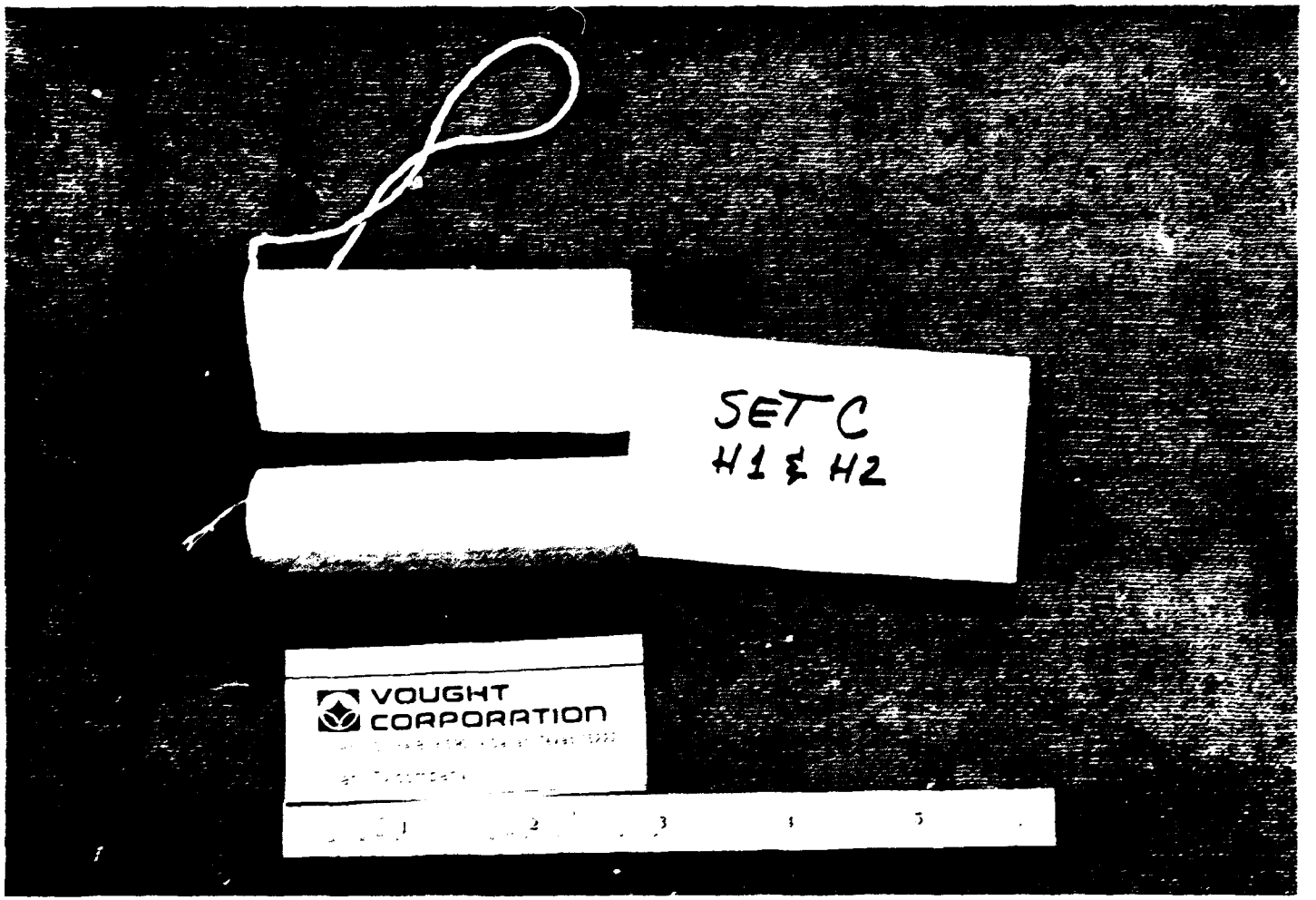

Figure 31. Vane Erosion Set C.

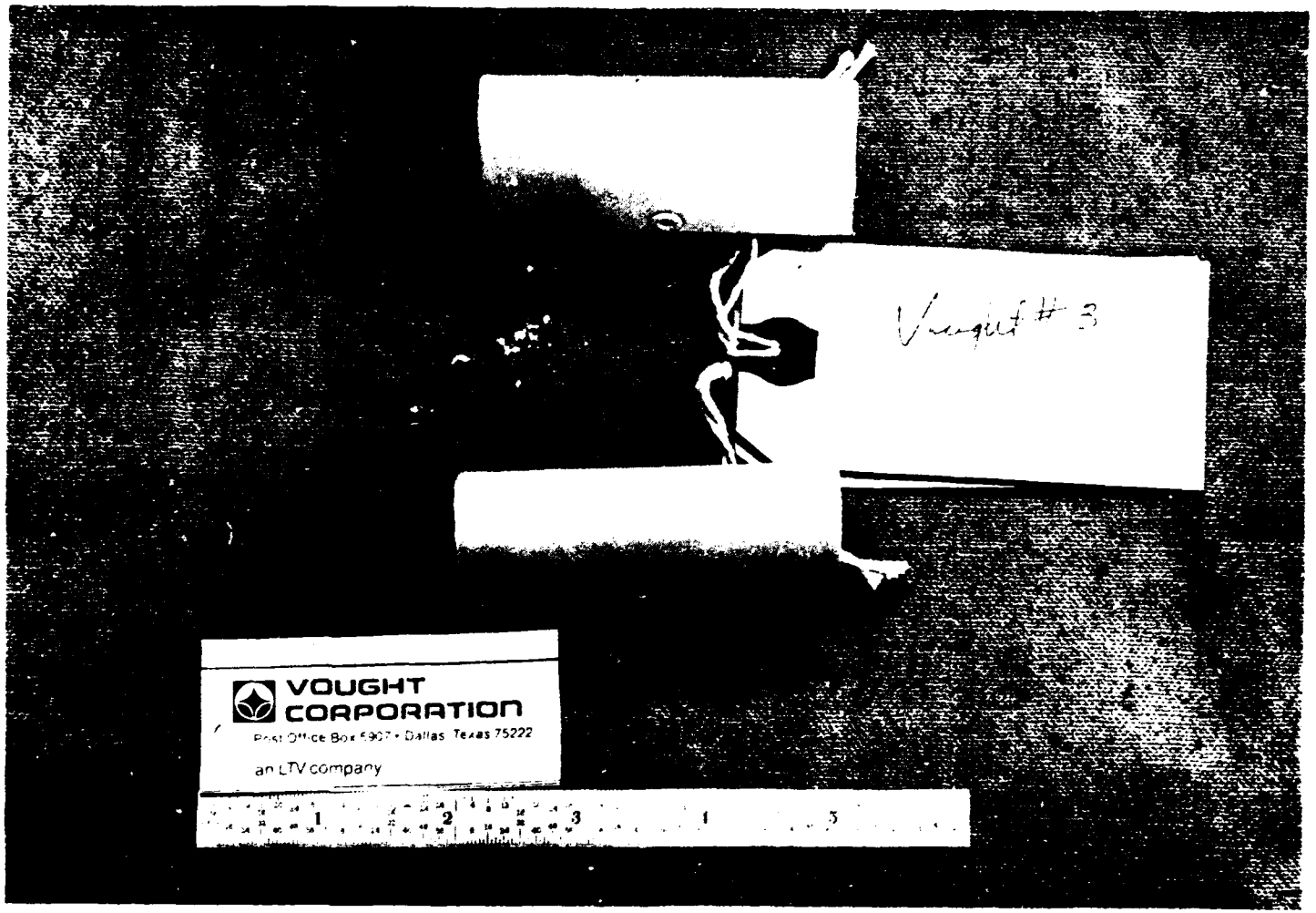

Figure 34. Rain Erosion Set E.

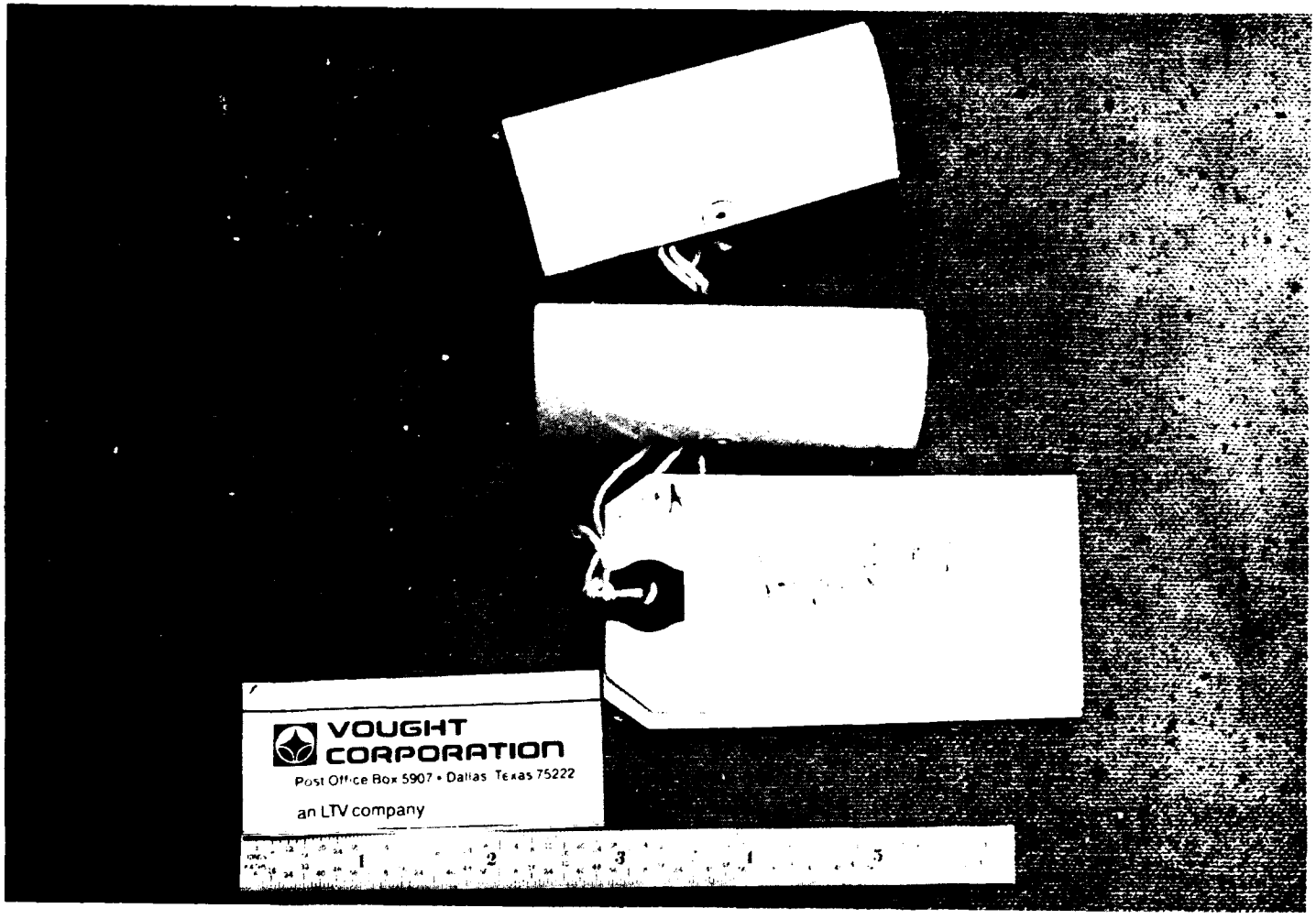

Figure 35. Rain Erosion Set A.

6.0 DISCUSSION OF RESULTS

6.1 COATING FAMILIARIZATION STUDY

No specific anomaly was noted in the test results for the coating familiarization study. Results were obtained using a suction-feed spray gun; naturally, the build rate per pass and the surface smoothness of deposited films would vary, to a small degree, if sprayed with pressure feed spray equipment.

6.2 DISCUSSION OF ADHESION STUDY TEST RESULTS

Results of the adhesion study were variable and a number of reasons for the variables can be expounded upon as follows.

The blister test method is dependent on the tensile strength of the test material. As the blister begins to form, and the pressure increases, the linear transducer begins to record the increase in height of the blister. Blister height increase can be due to a loss of adhesion (in this case the diameter of the blister becomes larger in proportion to the height of the blister). If the tensile strength of the material is low, the height of the blister will increase with little increase in the diameter of the blister. Considering these facts, one should note, also, that there is a significant difference in the modulus of elasticity for the 207-9-427 and the M213 materials. This naturally accounts for some differences between the results obtained for adhesion of the materials to reinforced laminates via the blister test method.

Other variables observed were in the 180^{0} adhesive peel tests. These variations were largely due to the thickness of the peel strip and reinforcement of the elastomer by the canvas peel strap. Variations in the overall thickness of the coating material plus the reinforcement strap also introduce some adhesion data scatter. As the pull strap is doubled back 180^{0} over the peel area, the reinforcement strap, saturated with the cured coating material, becomes resistant to bending or folding at the point of the 180^{0} bend. This reduces the peel angle from 180^{0}, slightly, depending on the thickness and stiffness of the strap. As the peel angle is reduced, the load to effect the peel becomes proportionally smaller than the 180^{0} value.

These variables lead to adhesive peel data that are lower than the actual value for the test condition.

Differences between the blister method and the 180^{0} adhesive peel method serve to illustrate that adhesion of organic coatings is difficult to measure exactly and at best, either of these test methods only provides a relative method which can be used to compare the adhesion of a material before and after exposure to a test environment.

6.3 DISCUSSION OF RESULTS FROM SOLVENT EVAPORATION STUDY

Results indicated that coating films built up at 15 minute intervals between subsequent applications were relatively free of porosity, and there was little difference between all data. The data for both materials indicated fewer areas of porosity in the specimens built up with five spray applications than those composed of one coat. This possibly suggests that the set of specimens of only one layer failed to wet the surface of the substrate as well as the subsequent layers wetted each. Each porosity value was an average of three values taken within an area of the test coating so as to include all coating layers equally within the test area. Considering that the first coating layer on the substrate had the highest frequency of porosity sites, taking an average number of porosity sites for four or five layers of the coating buildup is probably more representative of the actual value, since a one layer rain erosion coating is not likely to be used in an actual service application. The mean/standard deviation for the number of voids per test area was 2.32/1.17 and 4.4/0.70 for the M213 coating and the 207-9-427 coating respectively. The M213 had fewer voids per area with more variation between layers. The 207-9-427 material had slightly more voids per area, but was more consistent from layer to layer than the M213.

6.4 DISCUSSION OF RESULTS OF THE POLYMERIZATION STUDY

The test results clearly illustrate the need for complete dryness of all materials used in the compounding of polyurethane coatings. The tensile property tests provided the best quantitative means of evaluation of the degree of moisture contamination of the polyurethane materials. Thermogravimetric analysis and differential thermal analysis were not as effective in determining the quantitative degree of moisture contamination of the polyurethane as the tensile property tests. The disadvantage

of all methods investigated to determine the degree of dryness of the polyurethane materials was that the material must be mixed and allowed to cure before these test methods can be utilized. This presents a problem on receiving materials of dubious quality, since approximately eight days are required to complete an evaluation of dryness by one of these test methods.

6.5 DISCUSSION OF RESULTS OF SIGNAL TRANSMISSION EFFICIENCY TESTS

Test results of the signal transmission efficiency tests were generally within expected limits. The test panels evaluated for percent transmission efficiency were coated and cured for seven days at room temperature before being tested for transmission efficiency. Values obtained were within the range of 95% specified in MIL-C-83231 for the Type I coating (non-electrically conductive). The lowest value obtained for these tests was slightly above 93% transmission efficiency. Performance of Panel No. 3 was less than expected for a panel having no primer; however, the coating thickness of this panel was 25% thicker than panel No. 4. Panel No. 4 had no primer on it. It should also be noted that the pigment in the primer used on Panel No. 2 was strontium chromate, and the pigment of the primer of Panel No. 3 was zinc chromate. These differences in pigmentation probably accounted for some variation of these data. The pigments of the rain erosion coating materials were also different. The 207-9-427 white material contained only titanium dioxide. The gray M413 apparently contained a small amount of black.

7.0 CONCLUSIONS

7.1 The M213 polyurethane coating material is more difficult to apply than the 207-9-427 material due to pot life limitations. Exposure of the M213 ketamine coating to atmospheric moisture during mixing reduced the pot life considerably. The pot life of the diamine-cured 207-9-427 coating was approximately four times longer than that of the ketamine-cured coating.

7.2 The surface finish of the cured coating was slightly smoother for the M213 coating as compared to the 207-9-427 coating. Both coating materials produced a dry film thickness of 2.5 to 3.0 mils per cross coat pass.

7.3 Conventional spray equipment was successfully used for spraying the rain erosion coatings.

7.4 Adhesion of both coating systems was adequate for satisfactory rain erosion coating performance.

7.5 Adhesion data obtained for identical coating/primer/substrate combinations via the blister method and the 180^{o} adhesive peel method did not correlate.

7.6 The M213 ketamine-cured coating was found to have slightly less porosity when cured than the 207-9-427 diamine-cured coating.

7.7 Ultimate tensile strength and tensile modulus were the best methods evaluated by which to detect moisture contamination of the polyurethane materials.

7.8 The rain erosion coatings tested for percent signal transmission efficiency were generally acceptable to MIL-C-83231. Only approximately three or four data points were below the 95% specified value.

8.0 RECOMMENDATIONS

8.1 Polyurethane rain erosion materials cured with a ketamine curative should be tested to determine their performance after exposure to natural weathering.

8.2 The ketamine-cured polyurethane should be evaluated for use in a Type II electrically conductive application.

8.3 Polyurethane rain erosion coatings cured by diamines should be compounded with suitable reinforcing pigments to upgrade their performance.

8.4 Additional signal transmission efficiency evaluations should be performed for these rain erosion coatings after exposure to natural weathering.

9.0 REFERENCES

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2. Williams, M. L., "The Continuum Interpretation for Fracture and Adhesion," J. Appl. Polymer Science, 13, 29 (1969).

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5. Dannenberg, Hans, "Measurement of Adhesion by a Blister Method," J. Appl. Polymer Science, Vol. V, Issue 14, 125-134 (1961).

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9. Williams, M. L., R. D. Luntz, D. L. Devries, and R. R. Despain, "A Technique for Evaluating Dental Adhesives," Report UTEC DO 70-196. University of Utah (1970).

10. Military Specification MIL-C-83231, "Coatings, Polyurethane, Rain Erosion Resistant for Exterior Aircraft and Missile Plastic Parts."

10.0

Recipients of this report will receive the results of the rain erosion tests when this effort is completed.

APPENDIX I

APPENDIX I

1.0 Cleaning Procedure for Aluminum alloys (excerpt from CVA-8-51 Process Specification, Aluminum Cleaning and Etching for Bonding):

1.1 Acid Cleaning Solution:

1.1.1 Dissolve 5 ± 0.5 ounces (by weight) of sodium dichromate in 8.34 + 0.03 pounds (1 gallon ± 0.5 fluid ounces) of refined water

1.1.2 Add 50 ± 5 ounces (by weight) of 66° Be sulfuric acid.

Caution

Always add acid slowly to the water; never add water to concentrated acid. Chromic acid employed in this process is toxic and bodily contact with the solution or fumes shall be avoided.

1.1.3 Maintain the solution at an acid normality between 3 and 7 and a concentration of hexavalent chromium between 2.5 and 5.0 ounces (by weight) per gallon of solution.

2.0 Cleaning Procedure For Clad Aluminum Alloy Parts:

2.1 Degrease using a suitable vapor degreaser for approximately five minutes.

2.2 Acid clean parts for 8-10 minutes at 150 ± 10°F in the acid cleaning solution prepared per paragraph 1.1 above.

2.3 Remove parts from the acid cleaning solution and examine visually for acid break. If acid break is evident, repeat 2.2 for 3 minute cycles until there is no acid break. Parts not clean after total accumulative time of 30 minutes in the acid tank shall be rejected.

2.4 Rinse parts in refined water spray for 2 minutes minimum.

2.5 Examine parts for evidence of water break. When water break is evident, the parts shall be examined for contamination. Contamination such as oxidation corrosion fingerprints, chromate stains etc., shall be removed by sanding with #320A wet or dry

sandpaper using a circular motion. Parts shall be recleaned per 2.1 through 2.4 to a no water break condition. Parts which have visible contamination over more than 1% of the area after cleaning shall be referred to the Process Control Engineer.

2.6 Dry parts in oven or by infrared lamps at a maximum temperature of 150°F. Handle cleaned parts with clean white cotton gloves.

TEST PANEL DATA SHEET

PANEL NO. 1 DATE 5-4-79

POLARIZATION VERT FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	86.9%	85.4%	86.8%	80.2%	87.1%	86.4%	84.9%
P_2	86.8%	85.8%	86.9%	87.9%	87.6%	86.6%	84.9%
P_3	86.8%	86.4%	86.2%	95.0%	87.2%	86.1%	85.0%
P_4	86.8%	86.3%	85.8%	94.3%	86.2%	86.2%	84.9%
P_5	86.8%	85.5%	85.3%	87.0%	85.7%	86.2%	84.8%
P_6	86.6%	85.1%	85.5%	79.4%	86.3%	85.6%	85.0%
P_7	86.5%	85.4%	86.6%	78.4%	87.0%	85.7%	85.2%
P_8	86.6%	85.5%	87.0%	85.4%	87.4%	86.6%	85.1%
P_9	86.7%	86.0%	86.5%	93.8%	87.3%	86.8%	85.0%
P_{10}	86.9%	86.3%	85.9%	95.3%	86.6%	86.3%	85.0%
P_{11}	87.0%	86.1%	85.5%	87.1%	85.9%	86.4%	85.0%
P_{MAX}	87.0%	86.4%	87.0%	95.3%	87.6%	86.8%	85.2%
P_{MIN}	86.5%	85.1%	85.3%	78.4%	85.7%	85.6%	84.8%
T^2_{PANEL}	86.75	85.75	86.15	86.85	86.65	86.2	85.0
$T^2_{COATING}$	94.5	95.2	95.1	95.4	94.7	94.8	94.2

TEST PANEL DATA SHEET

PANEL NO. 2 DATE 5-4-79

POLARIZATION VERT FREQ 9375

MEASUREMENT	ANGLE						
	30	20	10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	87.4%	85.7%	86.3%	88.8%	88.2%	86.9%	85.9%
P_2	87.3%	85.8%	85.3%	84.8%	86.5%	86.3%	86.2%
P_3	87.3%	86.3%	85.4%	82.5%	86.9%	86.2%	86.3%
P_4	87.5%	86.5%	86.3%	83.9%	88.6%	85.9%	86.3%
P_5	87.6%	86.4%	87.4%	88.3%	90.4%	86.1%	86.4%
P_6	87.5%	86.2%	87.7%	91.9%	90.8%	87.1%	86.2%
P_7	87.6%	86.0%	86.8%	90.8%	88.8%	87.5%	85.8%
P_8	87.6%	85.8%	85.6%	85.9%	86.7%	86.8%	85.8%
P_9	87.2%	85.9%	85.2%	82.7%	86.6%	86.3%	86.1%
P_{10}	87.0%	86.5%	85.9%	83.1%	88.0%	86.3%	86.3%
P_{11}	87.1%	86.7%	87.0%	86.8%	89.9%	86.2%	86.3%
P_{MAX}	87.6%	86.7%	87.7%	91.9%	90.8%	87.5%	86.4%
P_{MIN}	87.0%	85.7%	85.2%	82.5%	86.5%	85.9%	85.8%
τ^2_{PANEL}	87.3	86.2	86.45	87.2	88.65	86.7	86.1
$\tau^2_{COATING}$	95.1	95.7	95.4	85.8	96.9	95.4	95.5

TEST PANEL DATA SHEET

PANEL NO. 1 DATE 5-4-79

POLARIZATION HOR FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	94.0%	90.7%	91.1%	88.0%	92.9%	89.4%	92.5%
P_2	93.8%	90.5%	91.1%	82.0%	90.9%	89.6%	92.7%
P_3	93.5%	90.3%	89.5%	81.2%	87.3%	89.9%	92.9%
P_4	93.3%	89.6%	87.6%	86.0%	86.0%	90.2%	92.7%
P_5	93.3%	88.7%	87.1%	91.8%	87.5%	90.5%	92.3%
P_6	93.4%	89.2%	88.3%	93.7%	90.6%	90.3%	92.0%
P_7	93.7%	90.5%	90.2%	89.6%	92.9%	89.4%	91.8%
P_8	93.9%	90.8%	91.3%	83.1%	92.1%	88.9%	91.7%
P_9	94.3%	90.5%	90.6%	80.2%	88.9%	89.0%	92.1%
P_{10}	94.0%	90.4%	88.6%	83.6%	86.2%	89.4%	92.5%
P_{11}	93.3%	90.0%	87.3%	89.5%	86.3%	89.7%	92.6%
P_{MAX}	94.3%	90.8%	91.3%	93.7%	92.9%	90.5%	92.9%
P_{MIN}	93.3%	88.7%	87.1%	80.2%	86.0%	88.9%	91.7%
T^2_{PANEL}	93.8	89.75	89.2	86.95	89.45	89.7	92.3
$T^2_{COATING}$	98.0	95.9	96.7	94.2	96.3	95.1	96.8

TEST PANEL DATA SHEET

PANEL NO. 3 DATE 5-4-79

POLARIZATION HOR FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	92.6%	90.0%	87.0%	90.3%	87.3%	91.2%	90.9%
P_2	92.4%	89.9%	87.9%	89.8%	87.7%	90.9%	91.1%
P_3	92.2%	90.3%	88.8%	86.8%	88.4%	90.1%	91.3%
P_4	92.1%	90.8%	88.8%	83.8%	88.5%	90.0%	91.5%
P_5	92.0%	90.9%	87.7%	83.2%	88.2%	89.9%	91.6%
P_6	91.8%	90.4%	86.7%	85.7%	87.6%	90.3%	91.4%
P_7	91.7%	89.7%	86.6%	89.0%	87.2%	90.7%	91.1%
P_8	92.0%	89.3%	87.2%	89.7%	87.4%	91.0%	90.9%
P_9	92.2%	89.6%	88.4%	87.1%	88.1%	90.7%	90.8%
P_{10}	92.2%	90.0%	88.9%	83.8%	88.6%	90.2%	90.9%
P_{11}	92.0%	90.5%	88.3%	82.5%	88.5%	89.8%	91.0%
P_{MAX}	92.6%	90.9%	88.9%	90.3%	88.6%	91.2%	91.6%
P_{MIN}	91.7%	89.3%	86.6%	82.5%	87.2%	89.8%	90.8%
T^2_{PANEL}	92.15	90.1	87.75	86.4	87.9	90.5	91.2
$T^2_{COATING}$	96.2	96.3	95.2	93.6	94.6	96.0	95.6

TEST PANEL DATA SHEET

PANEL NO. REF PNL DATE 5-4-79

POLARIZATION VERT FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	92.1%	90.3%	90.8%	95.2%	93.4%	91.3%	90.1%
P_2	92.3%	90.2%	91.2%	95.7%	90.6%	91.0%	90.3%
P_3	92.2%	89.7%	91.2%	93.2%	89.3%	90.7%	90.5%
P_4	91.9%	89.7%	90.5%	88.7%	90.2%	90.5%	90.5%
P_5	91.7%	90.4%	90.0%	86.5%	92.2%	90.5%	90.4%
P_6	91.6%	90.5%	90.0%	88.3%	93.8%	90.9%	90.2%
P_7	91.4%	90.2%	90.5%	92.5%	93.7%	91.3%	90.0%
P_8	91.3%	90.2%	91.0%	95.5%	91.3%	91.1%	89.9%
P_9	91.5%	90.2%	91.0%	93.9%	89.2%	90.7%	90.1%
P_{10}	91.8%	89.8%	90.6%	89.5%	89.6%	90.6%	90.3%
P_{11}	91.7%	89.8%	90.0%	86.4%	91.4%	90.5%	90.3%
P_{MAX}	92.3%	90.5%	91.2%	95.7%	93.8%	91.3%	90.5%
P_{MIN}	91.3%	89.7%	90.0%	86.4%	89.2%	90.5%	89.9%
T^2_{PANEL}	91.8	90.1	90.6	91.05	91.5	90.9	90.2
$T^2_{COATING}$							

TEST PANEL DATA SHEET

PANEL NO. 3 DATE 5-4-79

POLARIZATION VERT FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	86.6%	85.3%	86.7%	85.6%	86.5%	86.6%	83.8%
P_2	86.7%	85.3%	86.9%	84.8%	85.1%	86.7%	83.5%
P_3	86.8%	85.4%	86.7%	85.5%	83.9%	86.6%	83.8%
P_4	86.9%	85.6%	86.1%	87.1%	84.2%	86.4%	84.3%
P_5	87.1%	86.0%	85.7%	88.1%	85.5%	86.4%	84.3%
P_6	87.2%	86.0%	86.0%	87.6%	86.7%	86.4%	84.0%
P_7	87.1%	85.5%	86.6%	86.0%	86.8%	86.4%	83.8%
P_8	86.7%	85.1%	86.8%	84.8%	85.7%	86.5%	83.9%
P_9	86.5%	85.3%	86.7%	85.1%	84.2%	86.7%	83.6%
P_{10}	86.7%	85.5%	86.2%	86.6%	83.8%	86.7%	83.5%
P_{11}	86.9%	85.7%	85.8%	88.0%	84.7%	86.6%	83.8%
P_{MAX}	87.2%	86.0%	86.9%	88.1%	86.8%	86.7%	84.3%
P_{MIN}	86.5%	85.1%	85.7%	84.8%	83.8%	86.4%	83.5%
T^2_{PANEL}	86.85	85.55	86.3	86.45	85.3	86.55	83.9
$T^2_{COATING}$	94.6	95.0	95.3	94.9	93.2	95.2	93.0

TEST PANEL DATA SHEET

PANEL NO. 2 DATE 5-4-79

POLARIZATION HOR FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	95.3%	89.9%	88.0%	87.1%	90.4%	90.9%	92.6%
P_2	95.4%	90.1%	88.0%	87.4%	91.3%	91.5%	92.7%
P_3	95.5%	90.4%	88.3%	88.8%	89.7%	91.3%	93.2%
P_4	95.3%	90.7%	88.6%	89.2%	87.3%	90.9%	93.3%
P_5	94.9%	90.3%	88.5%	87.9%	86.1%	90.5%	92.9%
P_6	94.6%	89.6%	88.3%	86.9%	87.4%	90.2%	92.9%
P_7	94.5%	89.2%	88.1%	87.3%	89.8%	90.4%	93.1%
P_8	94.5%	89.5%	88.2%	87.7%	91.2%	91.1%	93.0%
P_9	94.7%	90.0%	88.4%	88.4%	90.3%	91.4%	92.6%
P_{10}	95.1%	90.4%	88.6%	89.0%	88.1%	91.1%	92.7%
P_{11}	95.3%	90.7%	88.6%	88.2%	86.3%	90.6%	93.1%
P_{MAX}	95.5%	90.7%	88.6%	89.2%	91.3%	91.5%	93.3%
P_{MIN}	94.5%	89.2%	88.0%	86.9%	[illegible]1%	90.2%	92.6%
T^2_{PANEL}	95.0	89.95	88.3	88.05	88.7	90.85	92.95
$T^2_{COATING}$	99.2	96.1	95.8	95.3	95.5	96.3	97.4

TEST PANEL DATA SHEET

PANEL NO. 4 DATE 5-4-79

POLARIZATION VERT FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	86.6%	83.4%	86.0%	91.4%	85.0%	86.5%	85.7%
P_2	86.9%	84.2%	85.6%	89.6%	85.8%	86.9%	85.5%
P_3	86.8%	84.9%	86.0%	85.0%	87.5%	87.2%	84.8%
P_4	86.8%	85.0%	86.8%	82.4%	88.6%	86.7%	85.0%
P_5	87.1%	85.0%	87.1%	83.7%	88.2%	86.4%	85.5%
P_6	87.2%	84.6%	86.9%	88.1%	86.5%	86.7%	85.3%
P_7	86.9%	84.0%	86.5%	91.6%	85.1%	86.7%	84.7%
P_8	86.5%	83.9%	85.7%	90.6%	85.4%	86.7%	85.0%
P_9	86.7%	84.5%	85.6%	86.0%	87.0%	87.1%	85.8%
P_{10}	86.8%	85.0%	86.3%	82.6%	88.5%	87.1%	85.4%
P_{11}	86.8%	85.0%	87.0%	82.6%	88.7%	86.6%	84.6%
P_{MAX}	87.2%	85.0%	87.1%	91.6%	88.7%	87.2%	85.8%
P_{MIN}	86.5%	83.4%	85.6%	82.4%	85.0%	86.4%	84.6%
T^2_{PANEL}	86.85	84.2	86.35	87.0	86.85	86.8	85.2
$T^2_{COATING}$	94.6	93.5	95.3	95.6	94.9	95.5	94.5

TEST PANEL DATA SHEET

PANEL NO. 4 DATE 5-4-79

POLARIZATION HOR FREQ 9375

MEASUREMENT	ANGLE						
	-30	-20	-10	0	10	20	30
P_R	100%	100%	100%	100%	100%	100%	100%
P_0	100%	100%	100%	100%	100%	100%	100%
P_1	95.0%	89.5%	87.9%	90.1%	89.9%	90.3%	92.2%
P_2	95.5%	90.0%	88.0%	90.2%	91.3%	90.6%	92.5%
P_3	95.5%	90.0%	87.9%	88.2%	90.1%	90.8%	93.1%
P_4	95.0%	89.6%	87.9%	86.0%	87.7%	90.4%	93.3%
P_5	94.5%	89.5%	87.9%	85.8%	85.9%	89.6%	92.7%
P_6	94.1%	89.6%	87.9%	87.8%	86.6%	89.5%	92.0%
P_7	94.0%	89.5%	87.7%	89.9%	89.4%	90.1%	91.7%
P_8	94.3%	89.5%	87.7%	90.4%	91.3%	90.5%	91.9%
P_9	94.9%	89.9%	87.8%	88.7%	90.9%	90.6%	92.3%
P_{10}	95.4%	90.0%	87.7%	86.3%	88.6%	90.7%	92.6%
P_{11}	95.5%	89.7%	88.0%	85.5%	86.3%	90.4%	93.2%
P_{MAX}	95.5%	90.0%	88.0%	90.4%	91.3%	90.8%	93.3%
P_{MIN}	94.0%	89.5%	87.7%	85.5%	85.9%	89.5%	91 7%
T^2_{PANEL}	94.75	89.75	87.85	87.95	88.6	90.15	92.5
$T^2_{COATING}$	99.0	95.9	95.3	95.2	95.4	95.6	97.0

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