RAIN EROSION CHARACTERISTICS OF THERMAL PROTECTION SYSTEM MATERIALS AT SUBSONIC VELOCITIES

Norman E. Wahl

Bell Aerospace Company

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NORMAN E. WAHL
TEXTRON'S BELL AEROSPACE COMPANY

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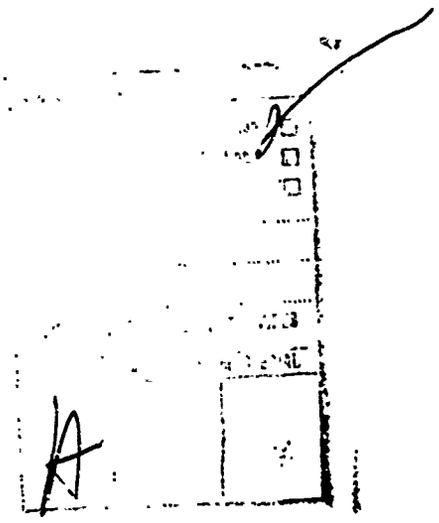

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13 ABSTRACT

The relative rain erosion resistance of low density thermal protection materials for the space shuttle were evaluated at velocities of 200, 350 and 410 miles per hour, angles of attack of 10, 20, 40 and 90 degrees and rainfall intensities of 1/4, 1/2 and 1 inch per hour on the AFML-Bell rotating arm rain erosion test apparatus. The program was sponsored and all materials provided by NASA Manned Spacecraft Center.

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RAIN EROSION CHARACTERISTICS OF THERMAL PROTECTION SYSTEM MATERIALS AT SUBSONIC VELOCITIES

NORMAN E. WAHL

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FOREWORD

This report was prepared by Bell Aerospace Company, Buffalo, New York under contract F33615-71-C-1219. It was initiated under Project No. 7340, "Nonmetallic and Composite Materials," Task No. 734007, "Coatings for Energy Utilization, Control and Protective, Functions". The work was admininstered under the direction of the Air Force Materials Laboratory, Department of the Air Force, Wright-Patterson Air Force Base, Ohio, with George F. Schmitt, Jr. of the Elastomers and Coatings Branch, Nonmetallic Materials Division, acting as project engineer.

This program was sponsored by the Thermal Technology Branch/ NASA Manned Spacecraft Center, with D. J. Tillian acting as technical liaison.

This report covers the work carried out during the period from 3 April 1972 to 30 June 1972 and was submitted for publication in July 1972.

This technical report has been reviewed and is approved.

WARREN P. JOHNSON, Chief
Elastomers and Coatings Branch
Nonmetallic Materials Division

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I. INTRODUCTION

Rain erosion damage of the exterior components of aircraft at subsonic velocities has been observed at velocities as low as 500 miles per hour in rainy environments at high angles of attack.

The purpose of this program was to determine the relative rain erosion resistance and characteristics of low density insulation materials being considered for use as the exterior thermal protection systems on the space shuttle. The tests were conducted at the low velocities, different angles of attack, and various simulated rainfall rates representative of these expected to be encountered during actual space shuttle operations. All of the materials were provided by NASA Manned Spacecraft Center who sponsored the tests.

II. DESCRIPTION OF TEST APPARATUS

Rain erosion tests were conducted in the AFML-Bell rotating arm rain and sand erosion test apparatus. The supersonic erosion test apparatus designed and built by Bell Aerospace Company consists of the following major pieces of equipment: a rotating arm (test blade), drive system and power station, vacuum chamber and vacuum pump, environmental generators (rain and sand) and remote TV monitor and controls.

Figure 1 is a sketch of the general layout of the test apparatus. Figure 2 shows the vacuum chamber with the hatch cover removed. Shown in the right-hand portion of Figure 2 is the 3000 kva, 12,000 to 2,500 volts, 3-phase substation with transformer and primary and secondary switchgear.

The single counter-balanced rotating test blade has a nine-foot radius and is shown in Figure 3. Specimens are attached to the tip of the blade by means of specimen holders.

The operation of the erosion test apparatus is controlled and monitored on a console as shown in Figure 4, in another building located 250 ft from the test chamber. The control room and test apparatus are separated for safety of operating personnel.

The progress of erosion is monitored by means of a T.V. camera. The lens system employed shows a 3X magnification of the test specimen so small pits and eroded areas are easily observed.

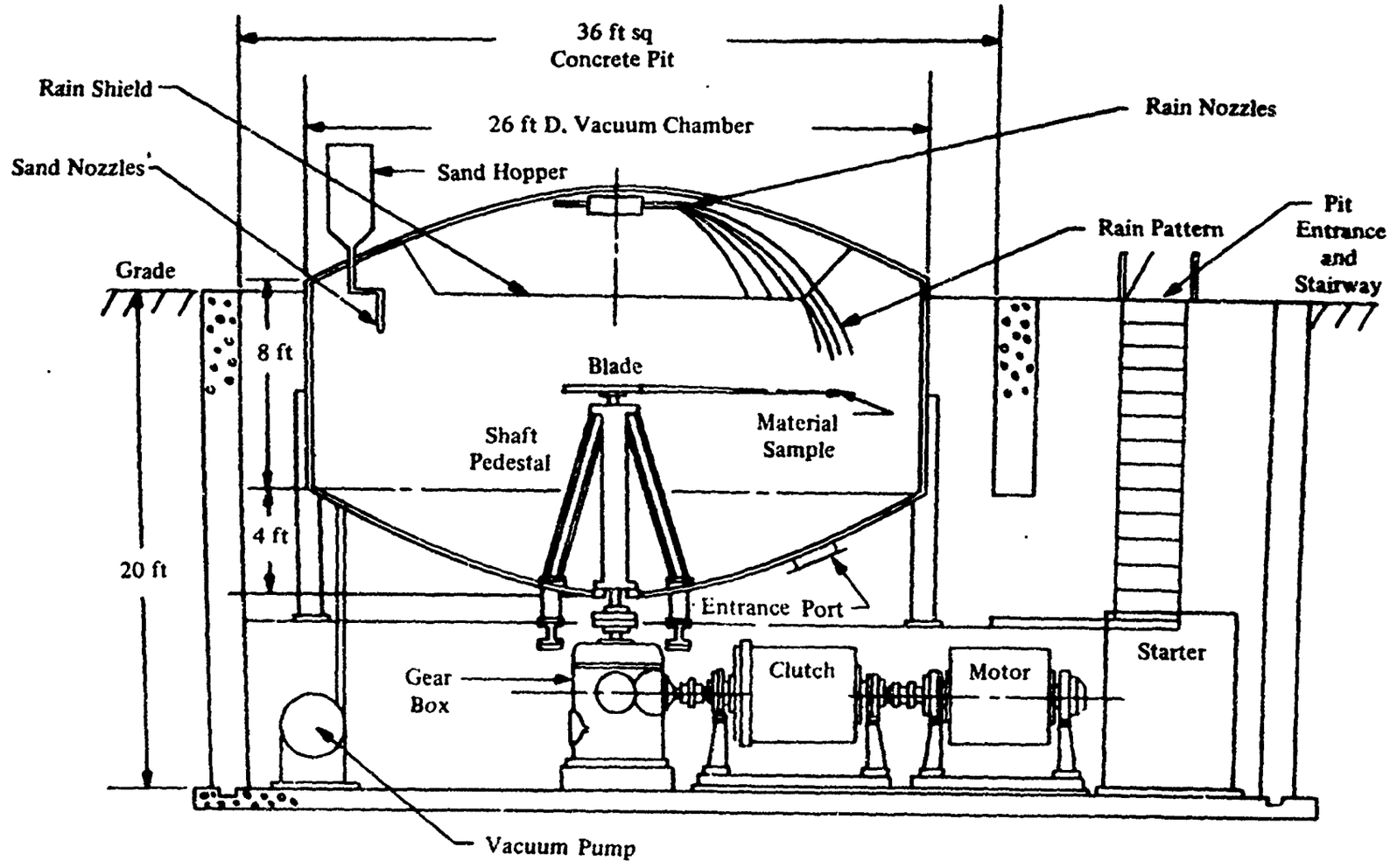


Figure 1. Supersonic Impact Erosion Test Equipment

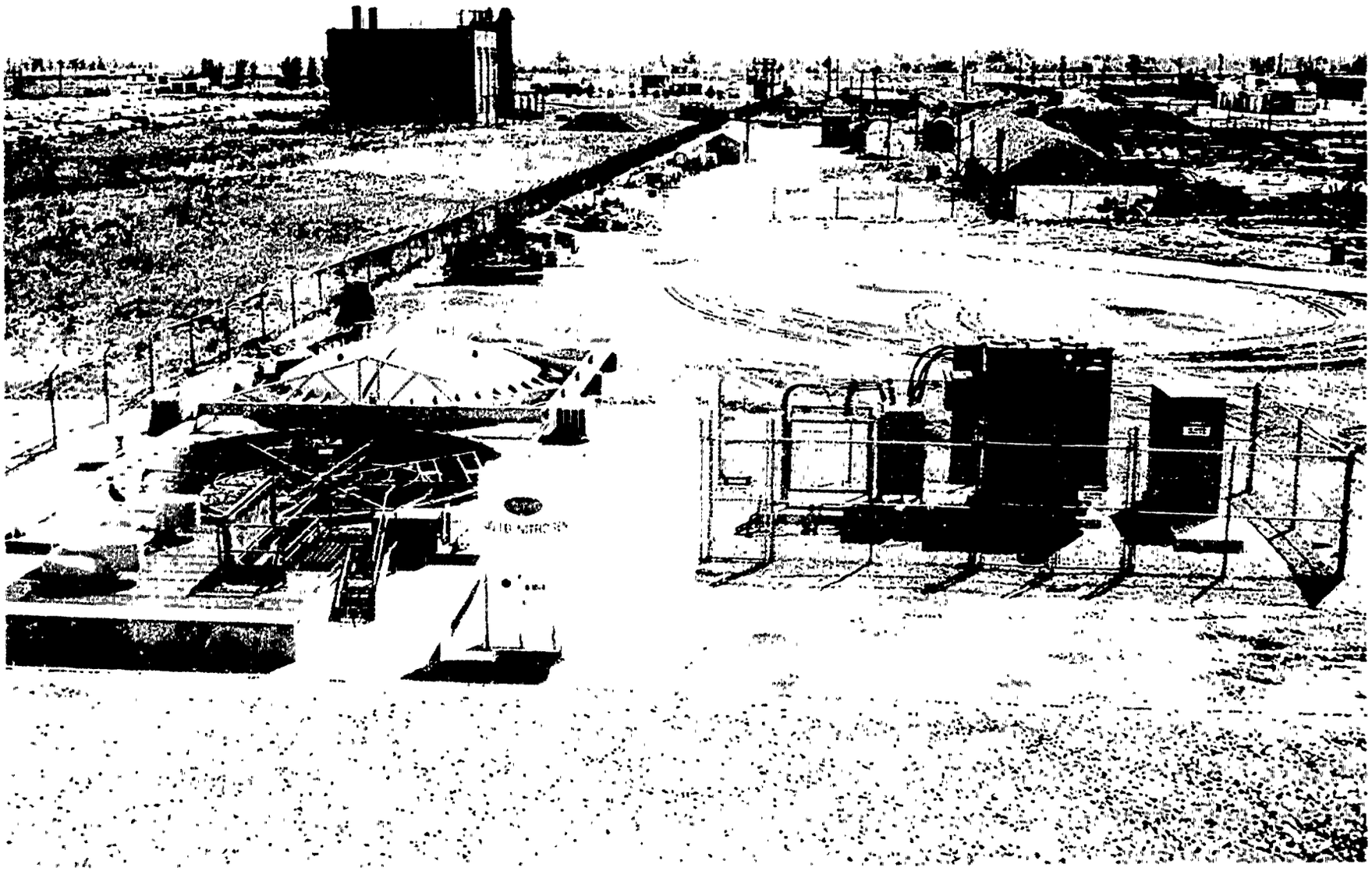


FIGURE 2. TEST FACILITY AND POWER STATION

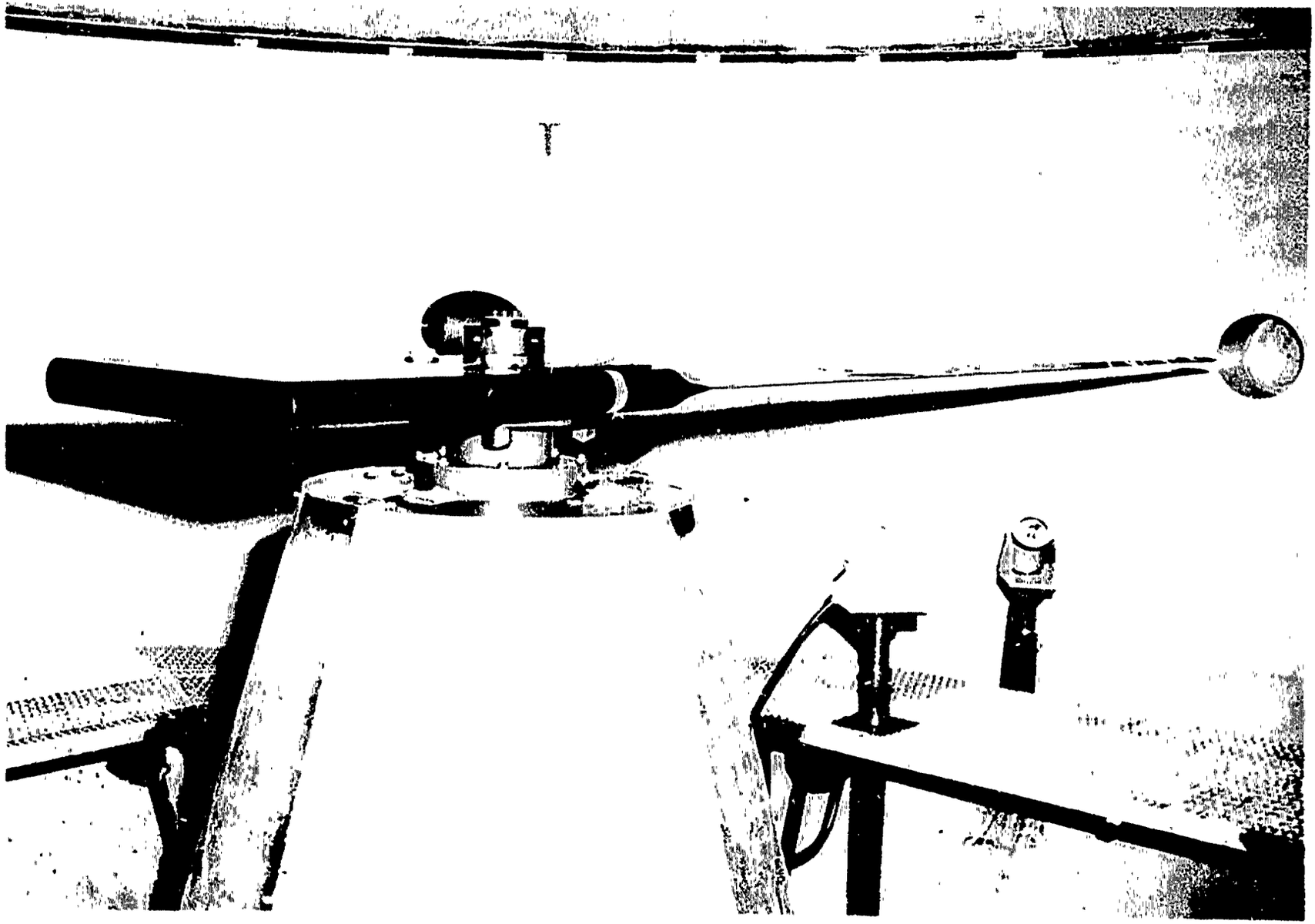


FIGURE 3. COUNTERBALANCED TEST BLADE

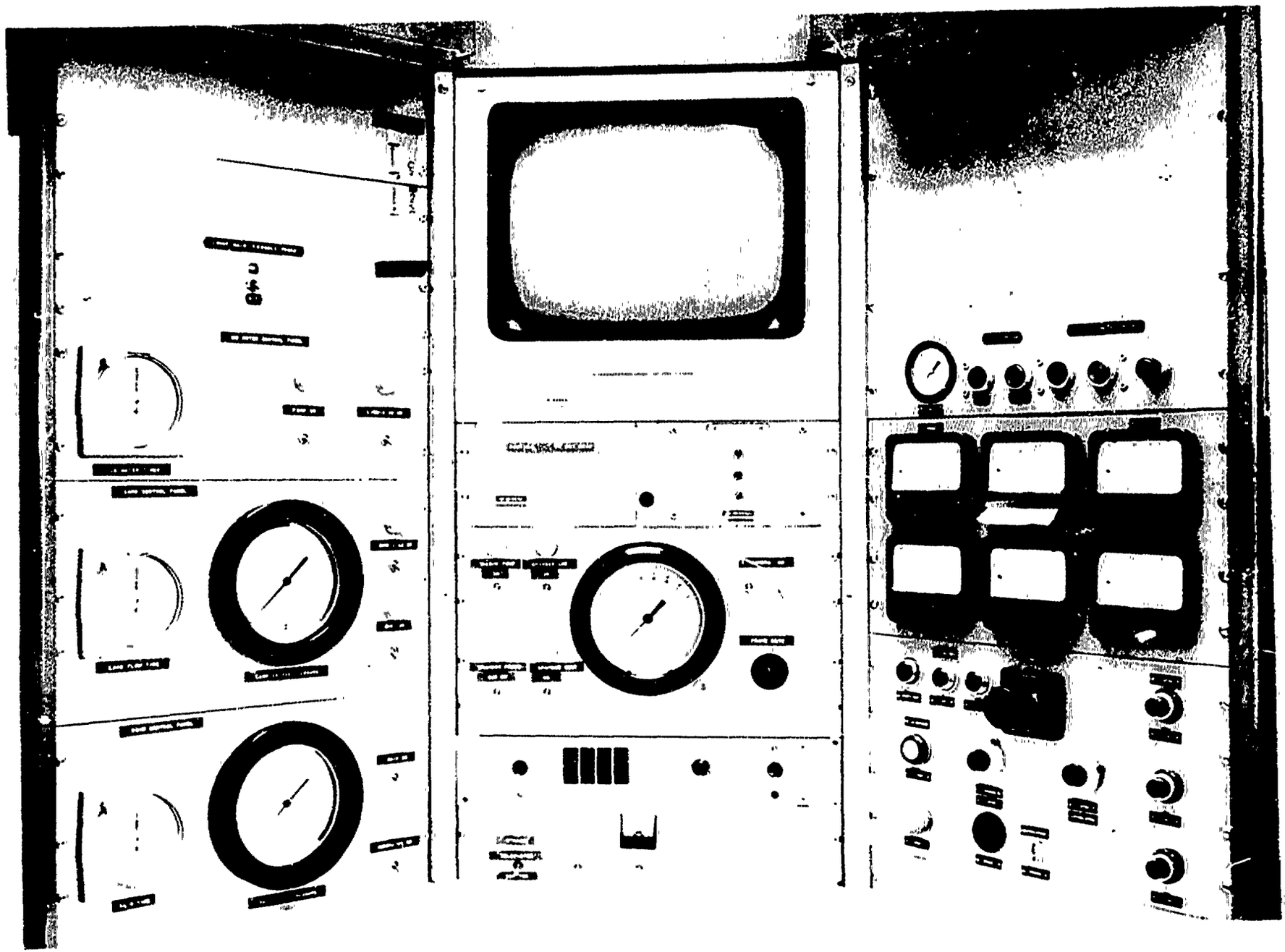


FIGURE 4. CONTROL CONSOLE AND TV MONITOR

III. DESCRIPTION OF SPECIMENS AND HOLDERS

Aluminum alloy (7075-T6) specimen holders were designed and fabricated, one for the ten and twenty degree angle of attack and one for the forty degree angle of attack. The ninety degree angle of attack specimen holder was fabricated from stainless steel (304).

Figure 5 illustrates the angle of impact of rain drops.

Figures 6, 7, and 8 are views of the ten and twenty degree, forty and ninety degree specimen holders with specimens mounted in them.

Figure 9 gives the dimensions of the test specimens for the ten - twenty - forty degree tests.

Figure 10 outlines the dimensions required for ninety degree specimens.

A brief description of the materials which were evaluated during the test program is included in Appendix A.

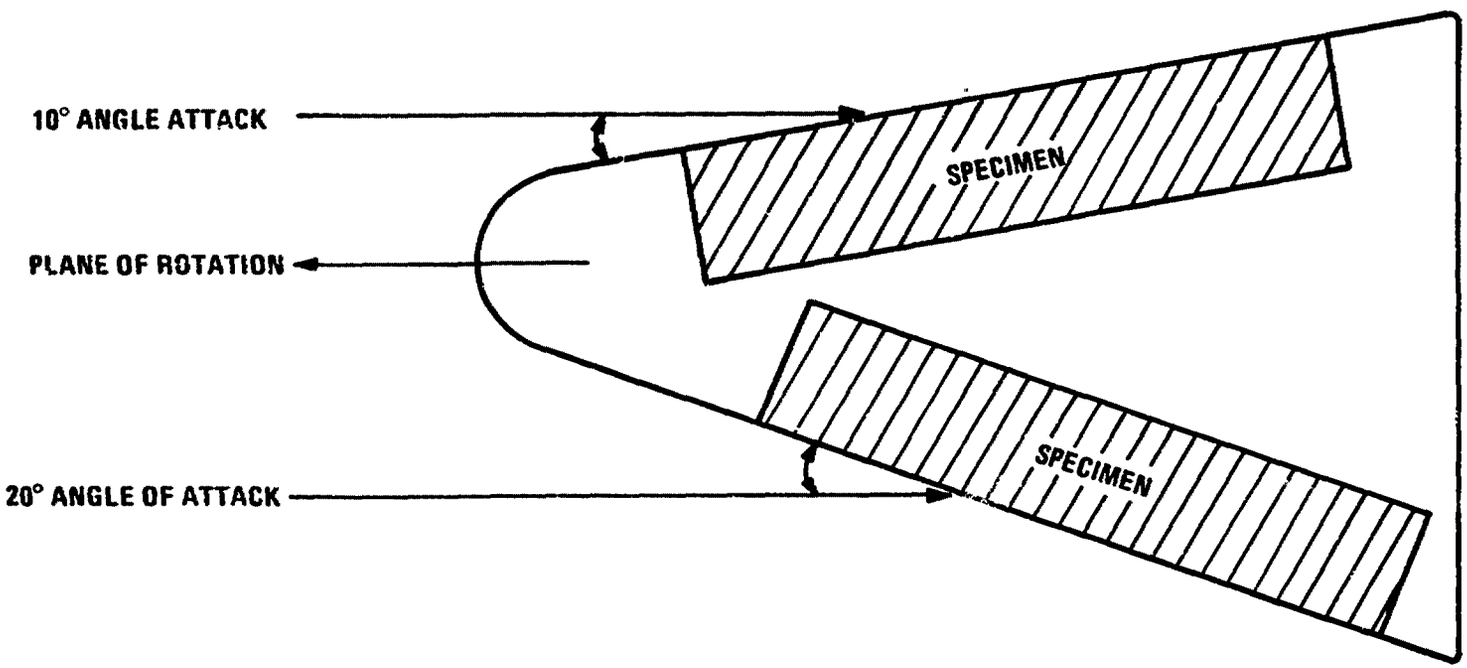
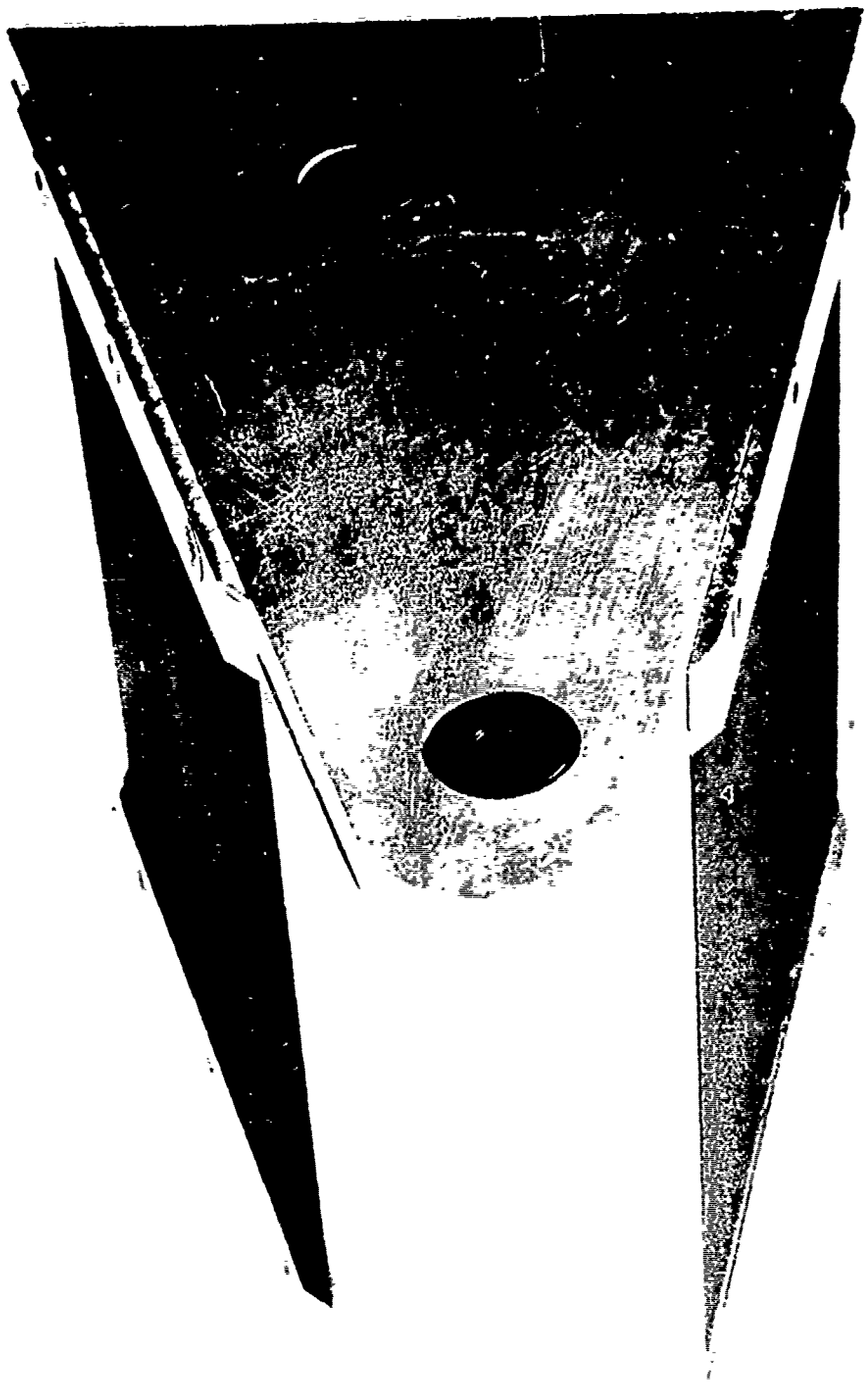


FIGURE 5 - SPECIMEN POSITION FOR 10° AND 20° ANGLE OF ATTACK



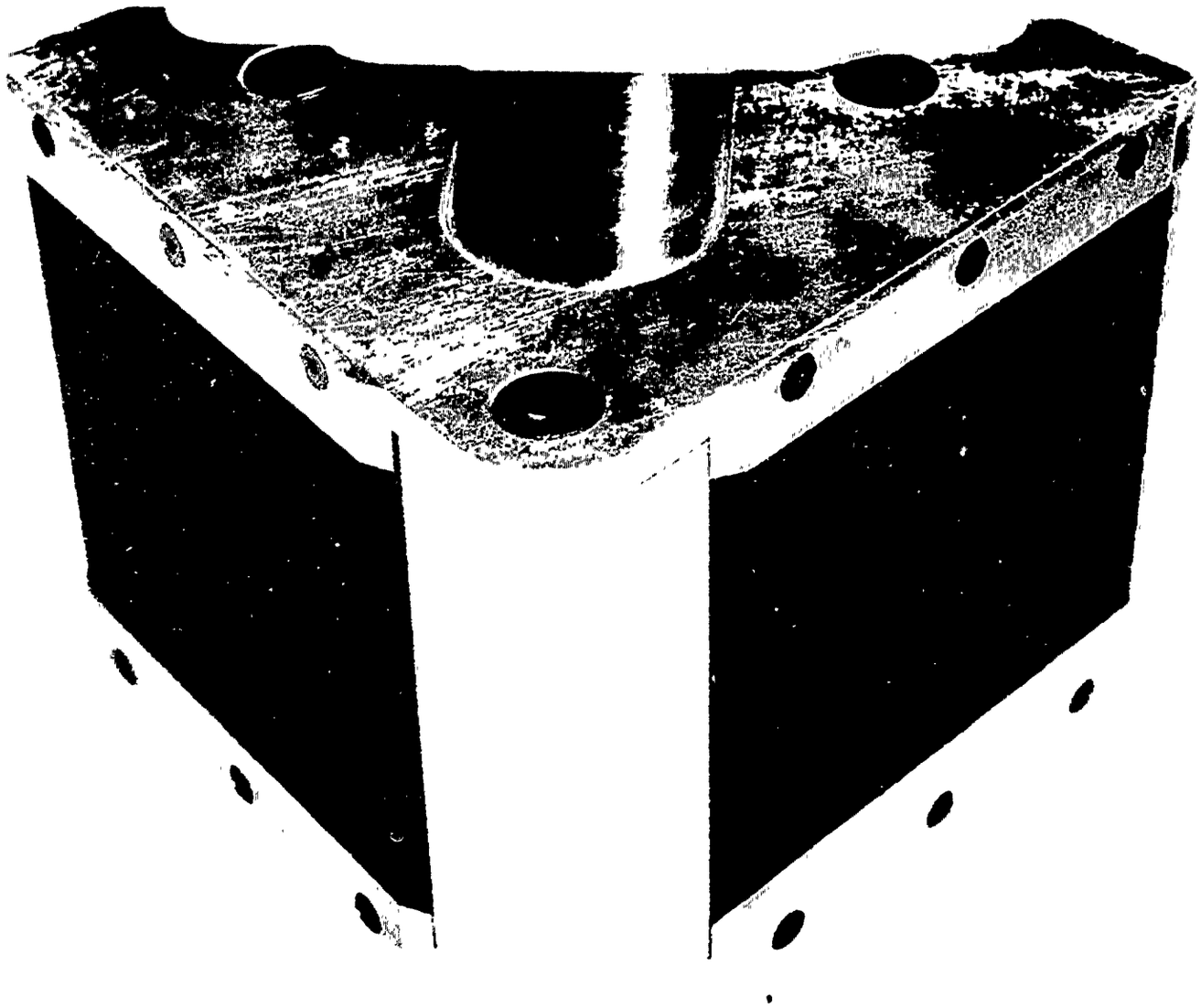
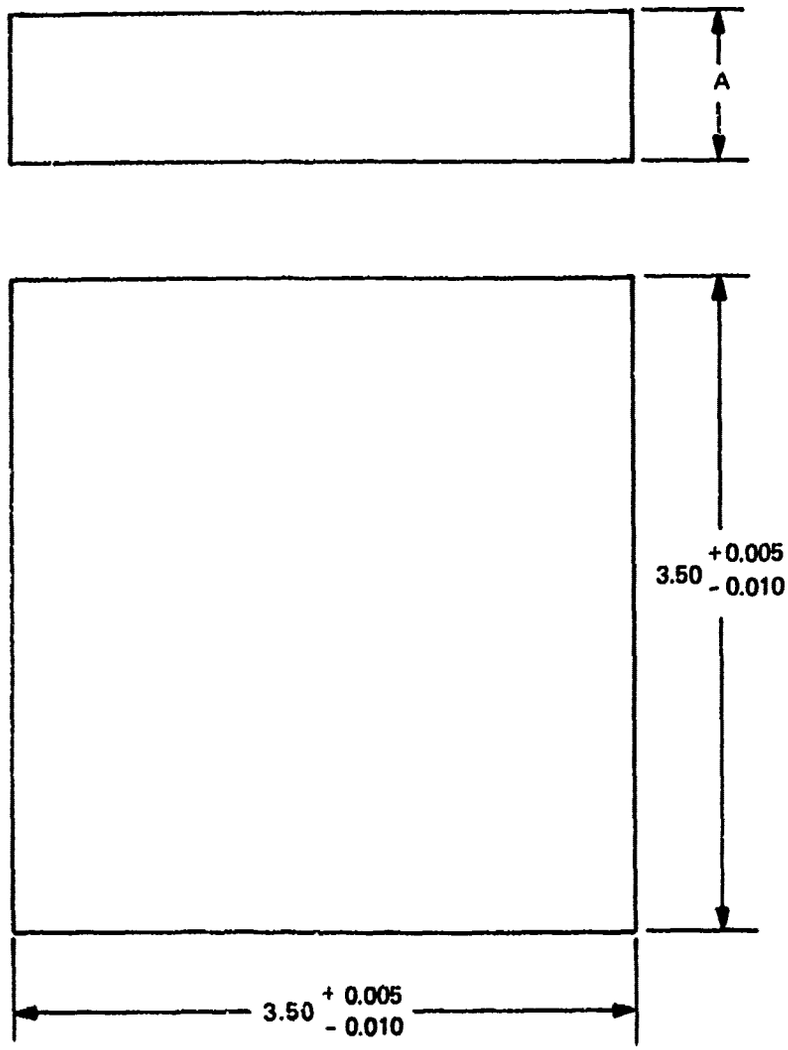


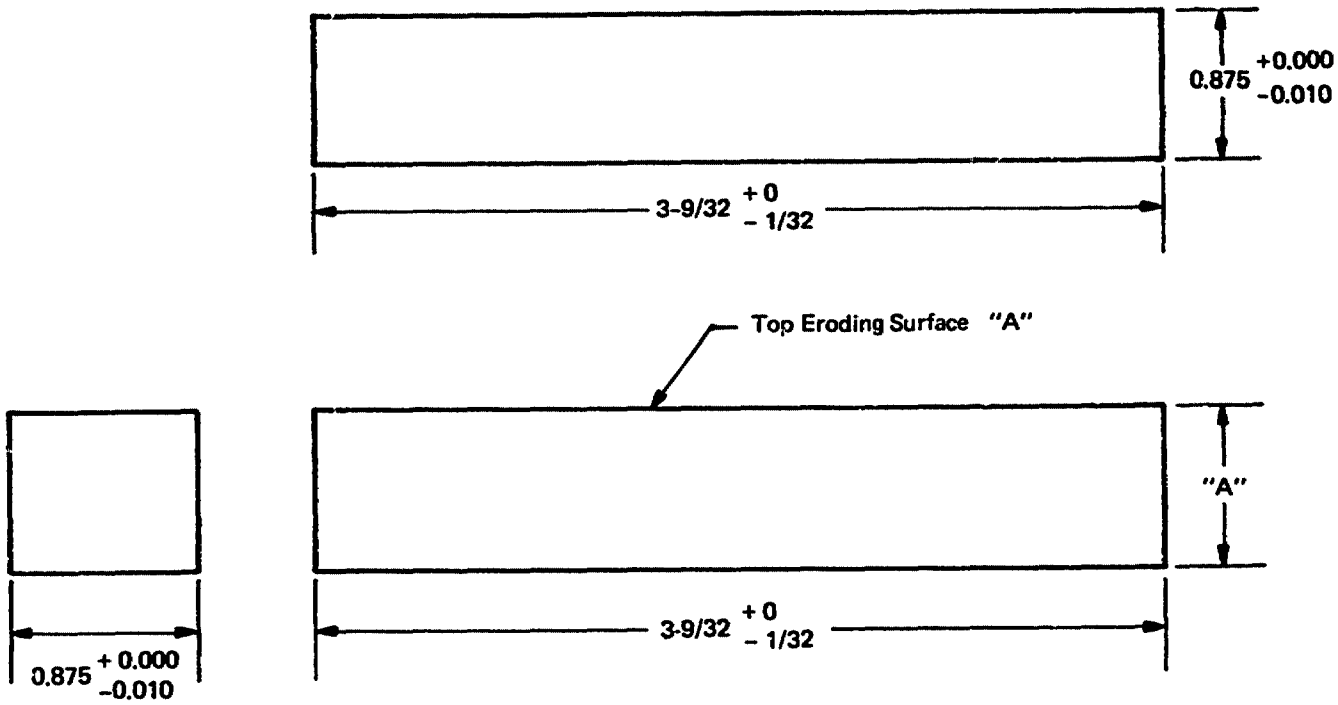
FIGURE 7. 40° SPECIMEN HOLDER

FIGURE 8. 90° SPECIMEN HOLDER



Dimension "A" 0.500, 0.563, 0.625, 0.688, 0.750 $^{+0.005}_{-0.010}$
Thickness as Desired

FIGURE 9 - 10° - 20° - 40° EROSION TEST SPECIMENS



DIMENSION "A" 1/4 IN. - 1/2 IN. - 3/4 IN. AS DESIRED

FIGURE 10 - 90° EROSION TEST SPECIMEN

IV. RESULTS OF RAIN EROSION TESTS

The planned erosion test matrix is outlined in Table 1. However, minor changes were made in the amount of time the specimens were exposed to the rain environment because the specimens eroded severely in many cases.

All the specimens except the polymethymethacrylate standards were dried for 8 hours in an air circulating oven at 250°F and weighed on an analytical balance. The weights were rounded off to the nearest milligram. The nominal dimensions were recorded.

After testing, most of the specimens had adsorbed moisture so they were all dried for 8 hours in an oven at 250°F and reweighed.

The test log for all specimens are included in Appendix B.

The General Electric elastomeric ablator specimens (GE 1004) possessed such low compressive and tear strength they could not be tested at the planned 350 mph. At approximately 235 - 240 mph the specimens were compressed due to centrifugal force and the foamed rubber tore and the specimen flew out of the holders. For this reason the specimens were tested at 200 mph after they were bonded to a .020" thick aluminum plate with rubber adhesive.

Table 2 outlines the test conditions for the GE 1004 test specimens.

TABLE 1

NASA - TPS MATERIALS
RAIN EROSION TEST MATRIX

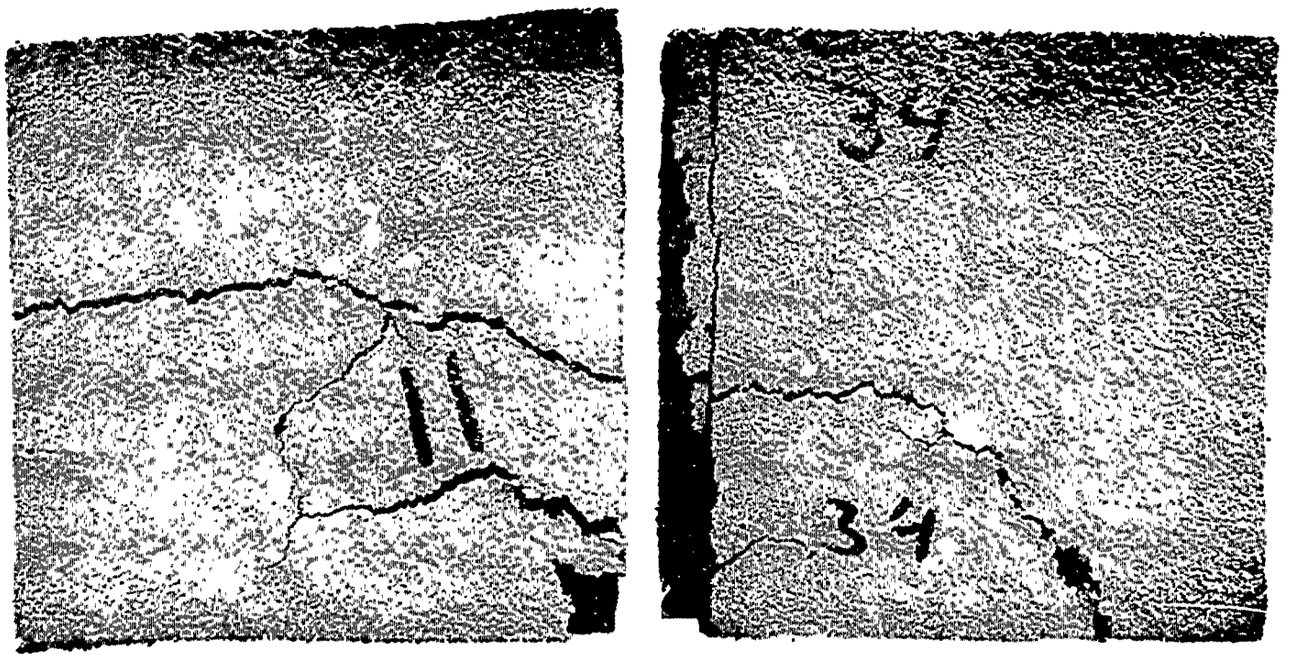
ANGLE OF ATTACK DEGREES	VELOCITY MPH	PLANNED DURATION	RAIN INTENSITY IN./HR	LOCKHEED LI-1500	MDAC HCF	GE REI	LTV CARBON/ CARBON	GE 1004	AVCO 480-1	MARTIN SLA-561	CHARRED GE 1004 MATERIAL	PMMA STD
10	350	5 MIN	0.5	X	X	X						
20	350	5 MIN	0.5	X	X	X						
40	350	5 MIN	0.5				X					
90	350	5 MIN	0.5				X					
10	350	1 HR	0.5	X	X	X						
20	350	1 HR	0.5	X	X	X		X				
40	350	1 HR	0.5					X	X		X	
90	350	1 HR	0.5				X	X	X			
10	350	5 MIN	1.0	X	X	X						X
20	350	5 MIN	1.0	X	X	X		X				X
40	350	5 MIN	1.0				X	X	X	X		X
90	350	5 MIN	1.0				X	X	X	X		
20	410	1 HR	0.25	X	X	X						
20	350	1 HR	0.25	X	X	X						
20	200	1 HR	1.0	X	X	X						
40	350	5 MIN	0.25	X	X	X						
90	350	1 HR	1.0									X

TABLE 2

20°, 40° AND 90° ANGLE OF ATTACK
200 MPH

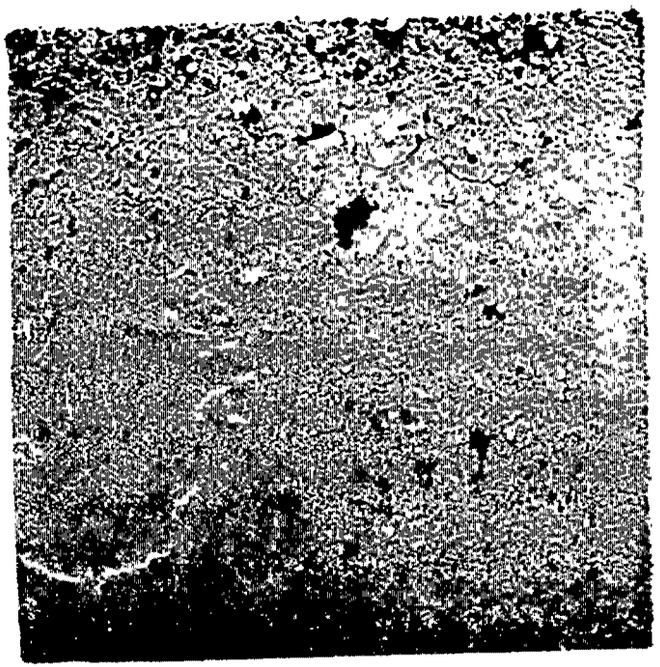
SPECIMEN	MATERIAL	DURATION OF TEST MIN.	RAINFALL
TM-11	GE-1004	0	1"
TM-34	GE-1004	0	1/2"
TM-13	GE-1004	1.5	1"
TM-35	GE-1004	4.0	1/2"
TM-37	GE-1004 Charred	4.0	1/2"
TM-39	GE-1004	1	1/2"

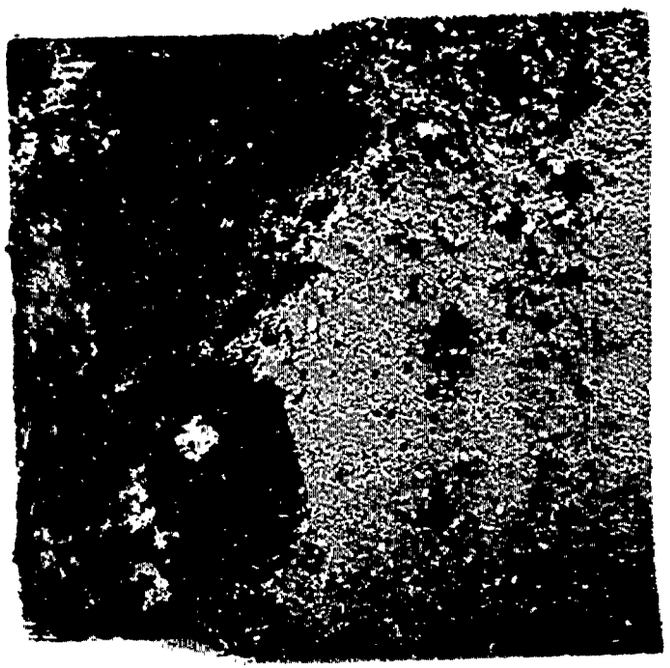
20° ANGLE OF ATTACK



40° ANGLE OF ATTACK

200 MPH





[illegible]	TM-13	TM-35
RAINFALL INTENSITY	1"/HR	0.5"/HR
TIME OF EXPOSURE	1.5 MIN	4.0
WEIGHT LOSS MILLIGRAMS	115	LOST PART OF SPECIMEN

FIGURE 12. G.E.-1004 SPECIMENS TESTED AT 200 MPH

40° ANGLE OF ATTACK

200 MPH - 0.5"/HR. RAINFALL

SPECIMEN NO.	TM-37
TIME OF EXPOSURE	4 MIN
WEIGHT LOSS GRAMS	5.334

FIGURE 13. CHARRED T.E.-1004 SPECIMEN TESTED AT 200 MPH

TABLE 3

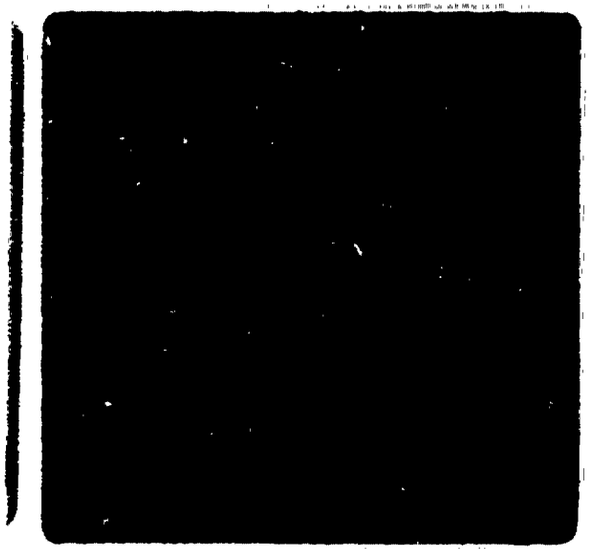
10° ANGLE OF ATTACK

350 MPH

SPECIMEN	MATERIAL	DURATION OF TEST MIN.	RAINFALL
TM-5	Lockheed LI-1500	5	1"
TM-7	MDAC-HCF	5	1"
TM-9	GE-REI	5	1"
TM-20	Lockheed LI-1500	5	1/2"
TM-22	MADC-HCF	5	1/2"
TM-24	GE-REI	5	1/2"
TM-28	Lockheed LI-1500	60	1/2"
TM-30	MADC-HCF	30	1/2"
TM-32	GE-REI	30	1/2"

10° ANGLE OF ATTACK

350 MPH - 1"/HR. RAINFALL



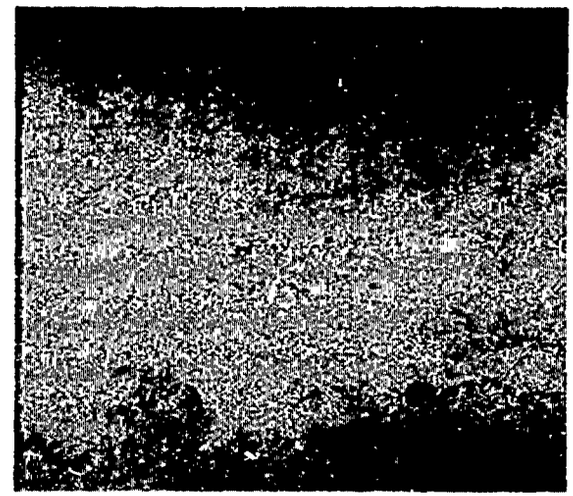
TM-9

	TM-7	TM-8
	5 MIN	5 MIN
	NO EROSION	NO EROSION

FIGURE 14. COATED RSI MATERIALS TESTED AT 350 MPH - 1"/HR.

10° ANGLE OF ATTACK

350 MPH - 0.5"/HR. RAINFALL

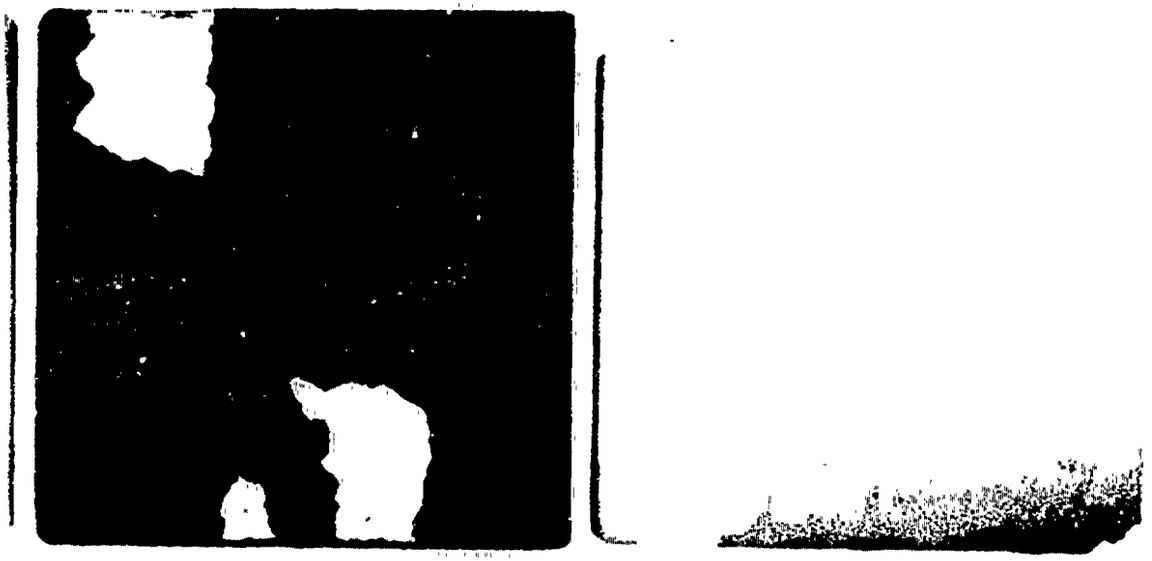


TM-[illegible]	TM-22	TM-24
[illegible] MIN	5 MIN	5 MIN
NO EROSION	NO EROSION	NO EROSION

FIGURE 15. COATED RSI MATERIALS TESTED AT 350 MPH - 1/2"/HR.

10° ANGLE OF ATTACK

350 MPH - 0.5"/HR. RAINFALL



TM-[illegible]	TM-3	TM-32
[illegible] MIN	30 MIN	30 MIN
NO EROSION	1.347 GR.	1.361 GR.

FIGURE 16. COATED RSI MATERIALS TESTED AT 350 MPH - 1/2"/HR.

Figure 11 and 12 show the GE 1004 elastomer after testing. Figure 13 shows the GE 1004 specimen that had been charred prior to rain erosion testing. The surface is cracked and pitted badly.

The conditions and duration of test for the coated, reusable surface insulation (RSI) ceramic specimens: Lockheed LI-1500, MDAC-HCF, and GE-REI tested at 10 degree angle of attack are noted in Table 3.

As shown in Figures 14 and 15, these three ceramic insulation materials exhibited no erosion after exposure to 1/2" and 1"/hr. rainfall at 350 mph for five minutes.

Figure 16 shows the specimens tested at 10 degrees in 1/2"/hr. rainfall at 350 mph. The Lockheed LI-1500 showed no erosion after sixty minutes of exposure while the MDAC-HCF and GE-REI specimens showed similar amounts of erosion after 30 minutes.

The conditions for testing the coated, RSI ceramics at 20 degree angle of attack at 200, 350 and 410 mph are outlined in Table 4.

As shown in Figure 17 the three RSI specimens tested at 200 mph and 1"/hr. rainfall exhibited no erosion after one hour exposure.

Figures 18, 19, 20 and 21 show the erosion experienced by the RSI specimens at 350 mph and 1/4", 1/2" and 1"/hr. rainfall.

The RSI specimens tested at 20 degree angle of attack at 410 mph and 1/4" rainfall all showed severe erosion in

TABLE 4

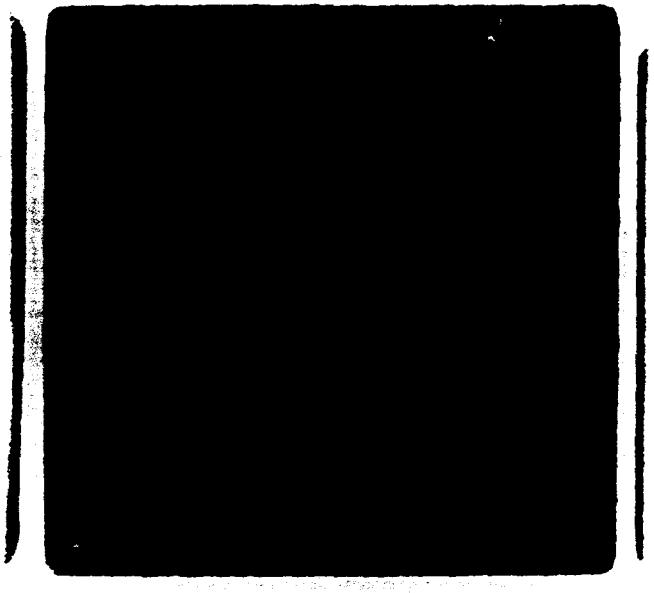
20° ANGLE OF ATTACK

200 MPH

SPECIMEN	MATERIAL	DURATION OF TEST MIN.	RAINFALL
TM-2	Lockheed LI-1500	60	1"
TM-3	MDAC-HCF	60	1"
TN-4	GE-REI	60	1"
	350 MPH		
TM-6	Lockheed LI-1500	5	1"
TM-8	MDAC-HCF	2.5	1"
TM-10	GE-REI	2	1"
TM-21	Lockheed LI-1500	2.5	1/2"
TM-23	MDAC-HCF	3	1/2"
TM-25	GE-REI	2.5	1/2"
TM-29	Lockheed LI-1500	30	1/2"
TM-31	MDAC-HCF	4	1/2"
TM-33	GE-REI	4.5	1/2"
TM-44	Lockheed LI-1500	14	1/4"
TM-45	MDAC-HCF	5	1/4"
TM-46	GE-REI	7.5	1/4"
	410 MPH		
TM-41	Lockheed LI-1500	1	1/4"
TM-42	MDAC-HCF	1	1/4"
TM-43	GE-REI	5	1/4"

20° ANGLE OF ATTACK

200 MPH - 1"/HR. RAINFALL



TM-4

TM-3

60 MIN

NO EROSION

TM-4

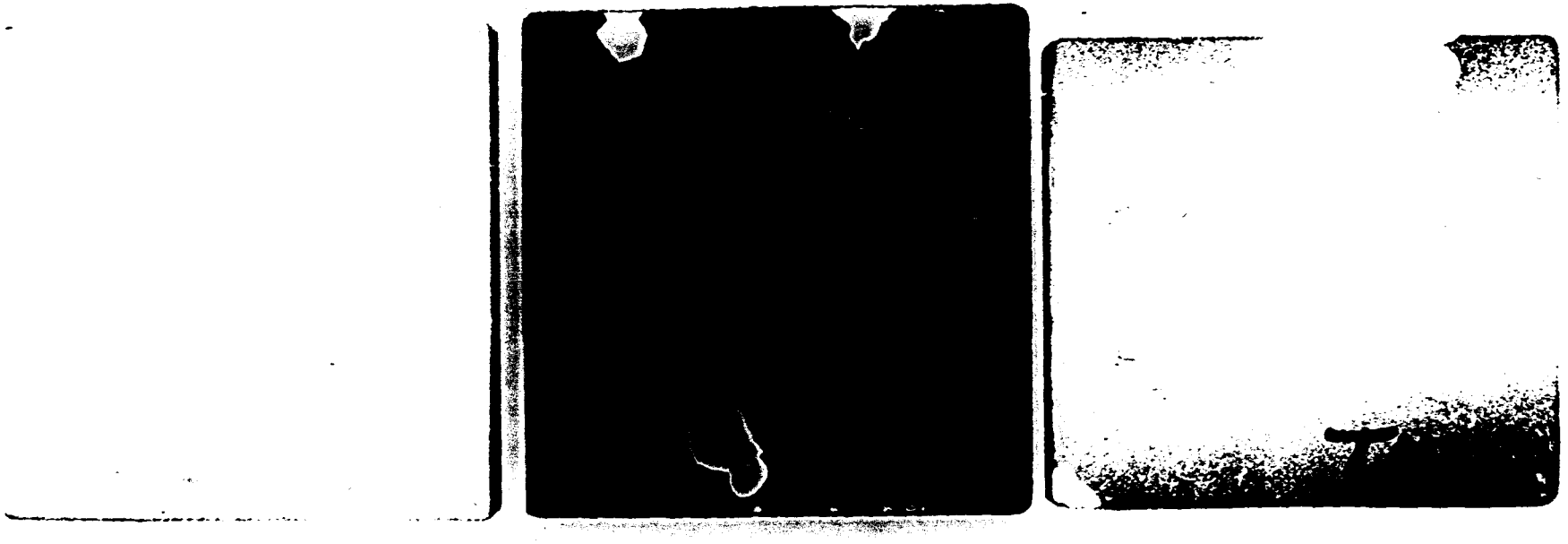
60 MIN

NO EROSION

FIGURE 17. COATED RSI SPECIMENS TESTED AT 20° - 200 MPH AND 1"/HR. RAINFALL

20° ANGLE OF ATTACK

350 MPH - 1"/HR. RAINFALL



TM-7

5 MIN

55 MILLIGRAMS

TM-8

2.5 MIN

530 MILLIGRAMS

TM-10

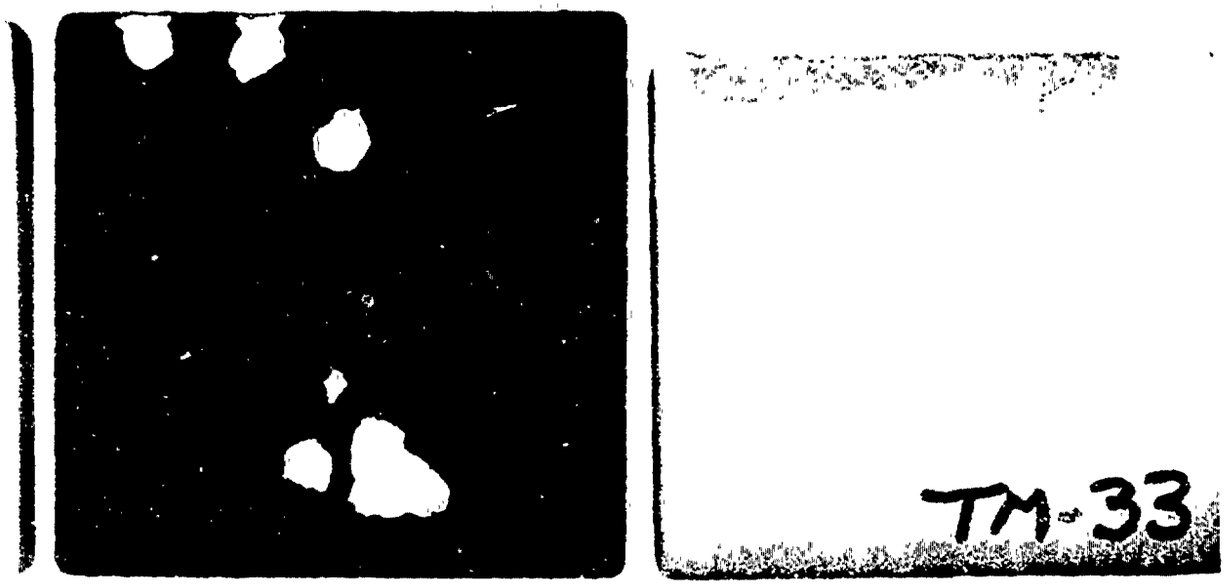
2 MIN

1695 MILLIGRAMS

FIGURE 18. COATED RSI SPECIMENS TESTED AT 20° - 350 MPH AND 1"/HR. RAINFALL

20° ANGLE OF ATTACK

350 MPH - 0.5"/HR. RAINFALL

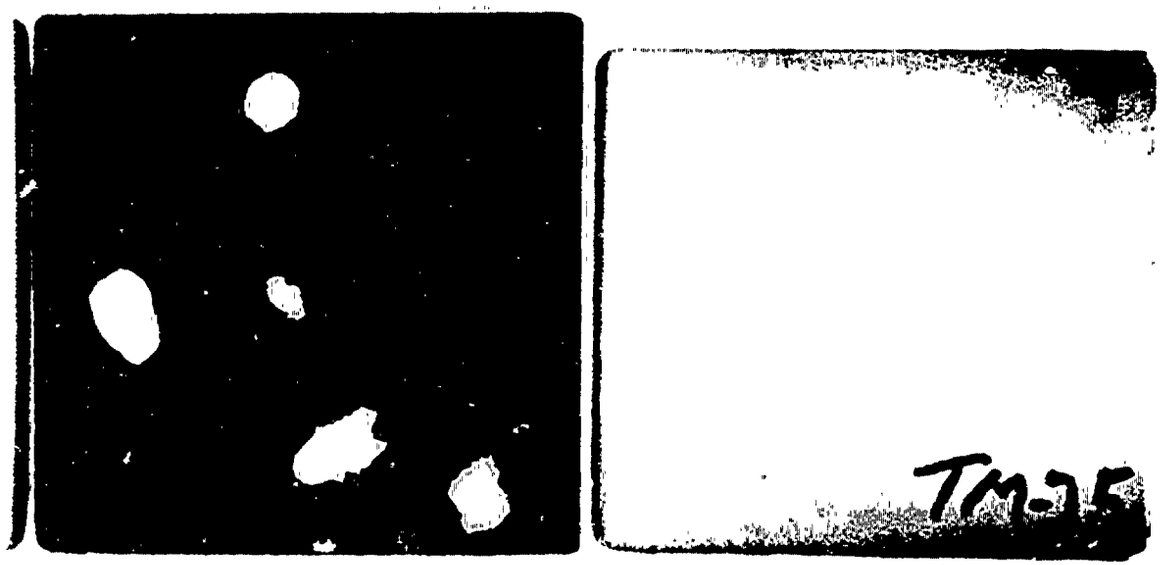


TM-2[illegible]	TM-31	TM-33
[illegible] MIN	4 MIN	4.5 MIN
412 MILLIGRAMS	621 MILLIGRAMS	1744 MILLIGRAMS

FIGURE 19. COATED RSI SPECIMEN TESTED AT 20° - 350 MPH AND 1/2"/HR. RAINFALL

20° ANGLE OF ATTACK

350 MPH - 0.5"/HR. RAINFALL

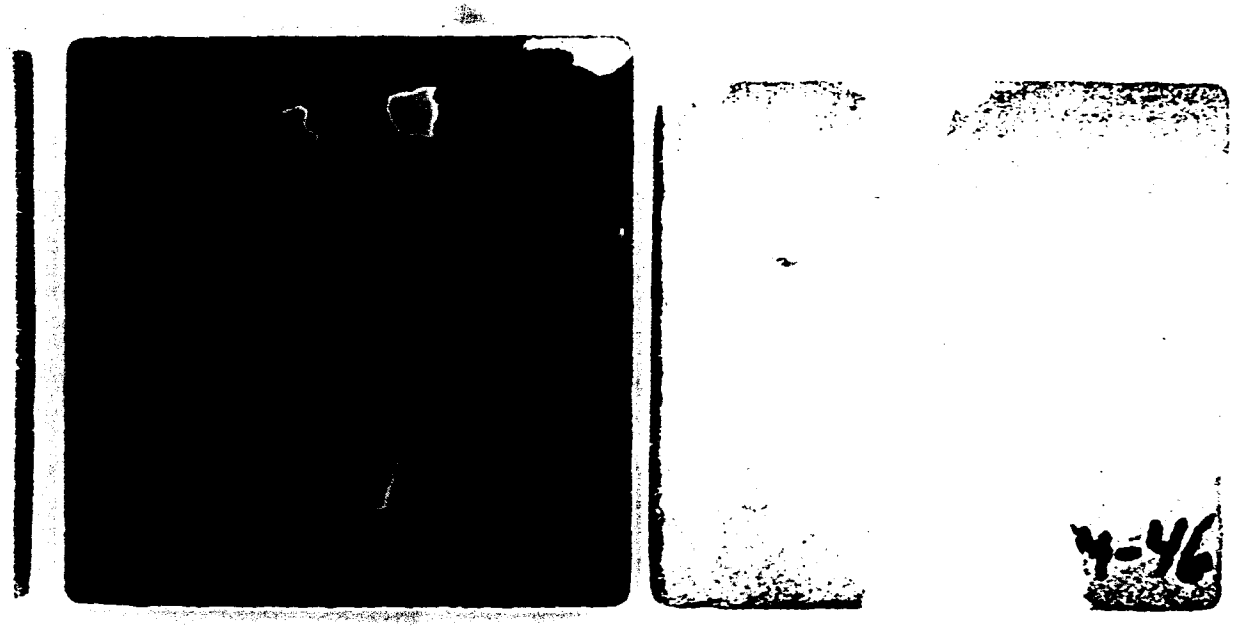


TM-21	TM-23	TM-25
2.5 MIN	3 MIN	2.5 MIN
60 MILLIGRAMS	571 MILLIGRAMS	408 MILLIGRAMS

FIGURE 20. COATED RSI SPECIMENS TESTED AT 20° - 350 MPH AND 1/2"/HR. RAINFALL

20° ANGLE OF ATTACK

350 MPH - 0.25"/HR. RAINFALL

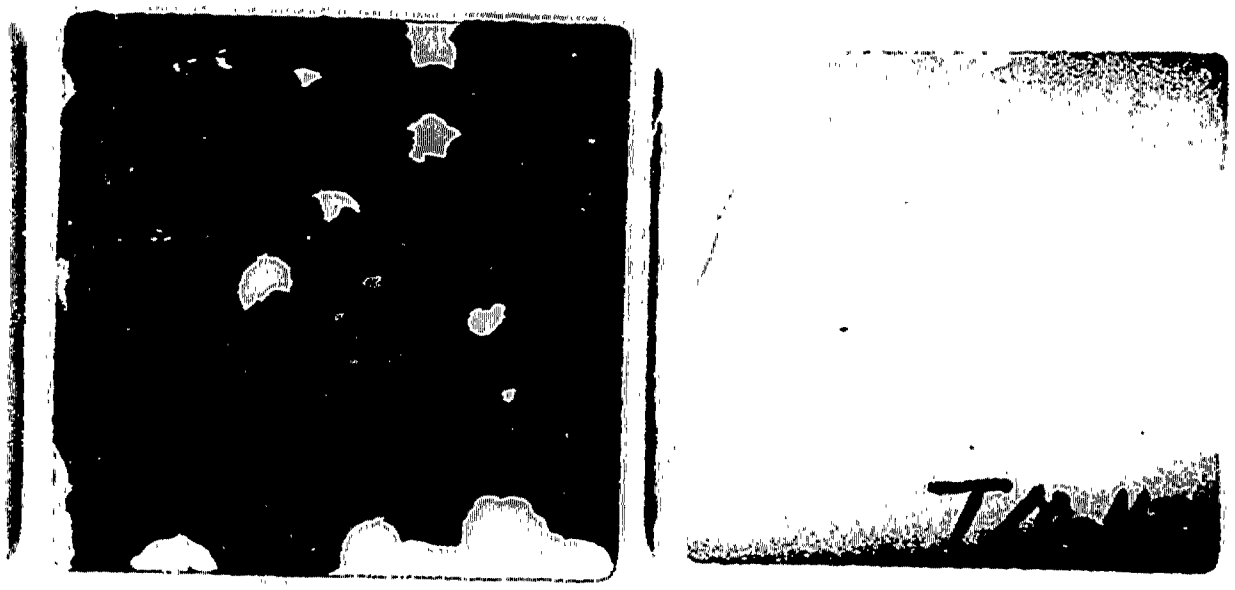


[illegible] MIN	5 MIN	7.5 MIN
[illegible] MILLIGRAMS	506 MILLIGRAMS	2195 MILLIGRAMS

FIGURE 21. COATED RSI SPECIMENS TESTED AT 20° - 350 MPH AND 1/4"/HR. RAINFALL

20° ANGLE OF ATTACK

410 MPH - 0.25"/HR. RAINFALL



TM-41

1 MIN

1165 MILLIGRAMS

TM-42

1 MIN

1165 MILLIGRAMS

TM-43

5 MIN

1105 MILLIGRAMS

FIGURE 22. COATED RSI SPECIMENS TESTED AT 20° - 410 MPH AND 1/4"/HR. RAINFALL

1-5 minutes as illustrated in Figure 22. These specimens demonstrate how a slight increase in velocity from 350 to 410 mph drastically increases the erosion rate.

Table 5 outlines the testing conditions for RSI and other types of ablation materials at 40 degree angle of attack at 350 mph and 1/4", 1/2" and 1"/hr. rainfall.

The weight lost and nature of erosion for the RSI specimens at 350 mph and 1/4" rainfall is shown in Figure 23.

The coated carbon/carbon specimens from LTV showed a trace of erosion and pitting when tested at 350 mph and 1/2" and 1"/hr. rainfall. The specimens are illustrated in Figure 24.

A specimen of Martin SLA-561 ablation material with phenolic honeycomb was tested at 40 degree angle of attack at 350 mph and 1"/hr. rainfall and showed severe erosion after one minute exposure as shown in Figure 25.

Two specimens of Avco's 480-1 ablation material tested at 40 degree angle of attack at 350 mph and 1/2" and 1"/hr. rainfall showed severe erosion in 30 seconds, see Figure 26.

The conditions for the 90 degree tests on polymethyl-methacrylate specimens used as standards, the LTV Carbon/Carbon, AVCO 480-1, GE 1004 and Martin SLA-561 are given in Table 6.

TABLE 5

40° ANGLE OF ATTACK

350 MPH

SPECIMEN	MATERIAL	DURATION OF TEST MIN.	RAINFALL
TM-14	AVCO-480-1	1	1"
TM-36	AVCO-480-1	0.5	1/2"
TM-15	Martin SLA-561	1	1"
TM-12	LTV C/C	5	1"
TM-23	LTV C/C	5	1/2"
TM-47	Lockheed LI-1500	0.5	1/4"
TM-48	MDAC-HCF	0.5	1/4"
TM-49	GE-REI	0.5	1/4"

40° ANGLE OF ATTACK

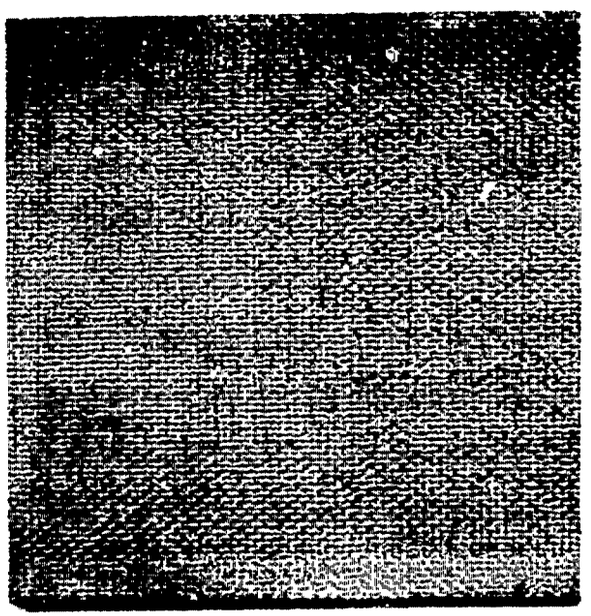
350 MPH - 1/4"/HR. RAINFALL

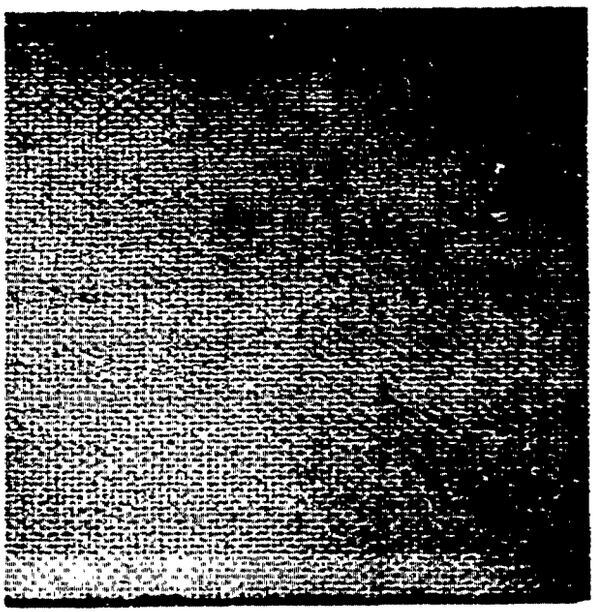
TI-47	TI-48	TI-4[illegible]
30 SEC	30 SEC	30 SEC
1105 MILLIGRAMS	2297 MILLIGRAMS	4239 MILLIGRAMS

FIGURE 23. COATED RGJ SPECIMENS TESTED AT 40° - 350 MPH AND 1/4"/HR. RAINFALL

40° ANGLE OF ATTACK

350 MPH



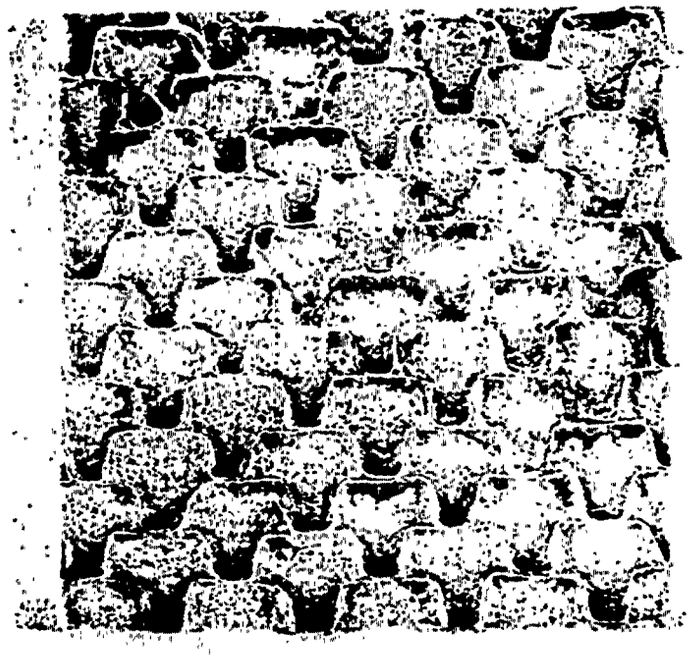


SPECIMEN NO.	TM-12	TM-26
RAINFALL INTENSITY	1"	1/2"
TIME OF EXPOSURE	5 MIN	5 MIN
WEIGHT LOSS MILLIGRAMS	562	465

FIGURE 24. COATED CARBON/CARBON SPECIMENS TESTED AT 40° - 350 MPH - 1/2" AND 1"/HR. RAINFALL

40° ANGLE OF ATTACK

350 MPH - 1"/HR. RAINFALL

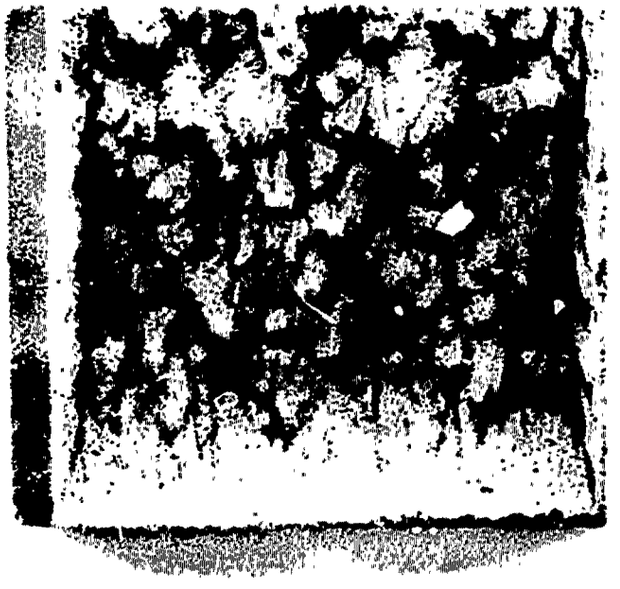


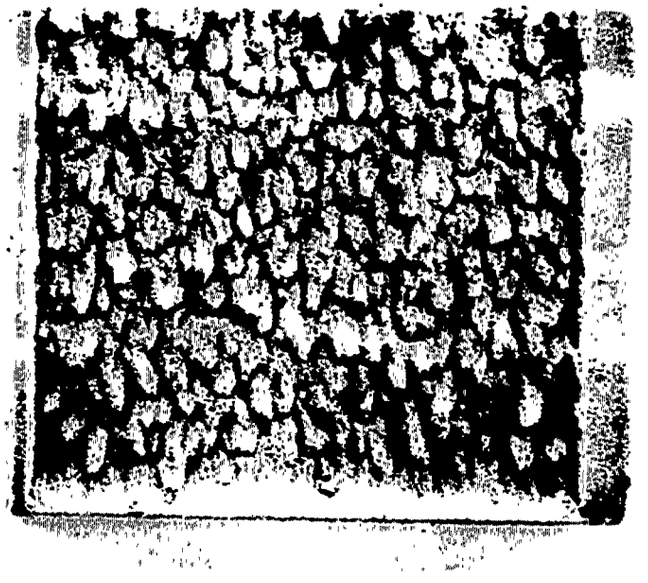
SPECIMEN NO.	TM-15
TIME OF EXPOSURE	1 MIN
WEIGHT LOSS GRAMS	5.790

FIGURE 25. MARTIN ABLATOR SPECIMEN TESTED AT 40° - 350 MPH - 1"/HR. RAINFALL

40° ANGLE OF ATTACK

350 MPH





SPECIMEN NO.	TM-14	TM-36
RAINFALL INTENSITY	1"/HR	0.5"/HR
TIME OF EXPOSURE	1 MIN	30 SEC
WEIGHT LOSS GRAMS	14.049	4.034

FIGURE 26. AVCO ABLATOR SPECIMENS TESTED AT 40° - 350 MPH - 1/2" AND 1"/HR. RAINFALL

TABLE 6

90° ANGLE OF ATTACK

350 MPH

SPECIMEN	MATERIAL	DURATION OF TEST MIN.	RAINFALL
TM-1	PMMA	5	1"
TM-19	SLA-561 Martin	0.25	1"
TM-18	AVCO-480-1	0.25	1"
TM-17	GE-1004	0	1"
TM-16	LTV-Carbon	2	1"
STD-1	PMMA	60	No Rain
STD-2	PMMA	10	1"
STD-3	PMMA	15	1"
TM-40	AVCO 480-1	0.25	1/2"
TM-38	LTV Carbon	6	1/2"
TM-27	LTV Carbon	5	1/2"

Four polymethylmethacrylate (Plexiglas) specimens were tested at 350 mph. One specimen was tested for 60 minutes with no rain to illustrate that no erosion occurs without an impacting particle.

Three specimens were tested for 5, 10 and 15 minutes at 350 mph and 1"/hr. rainfall at 90 degree angle of attack.

The progression of erosion is shown in Figure 27.

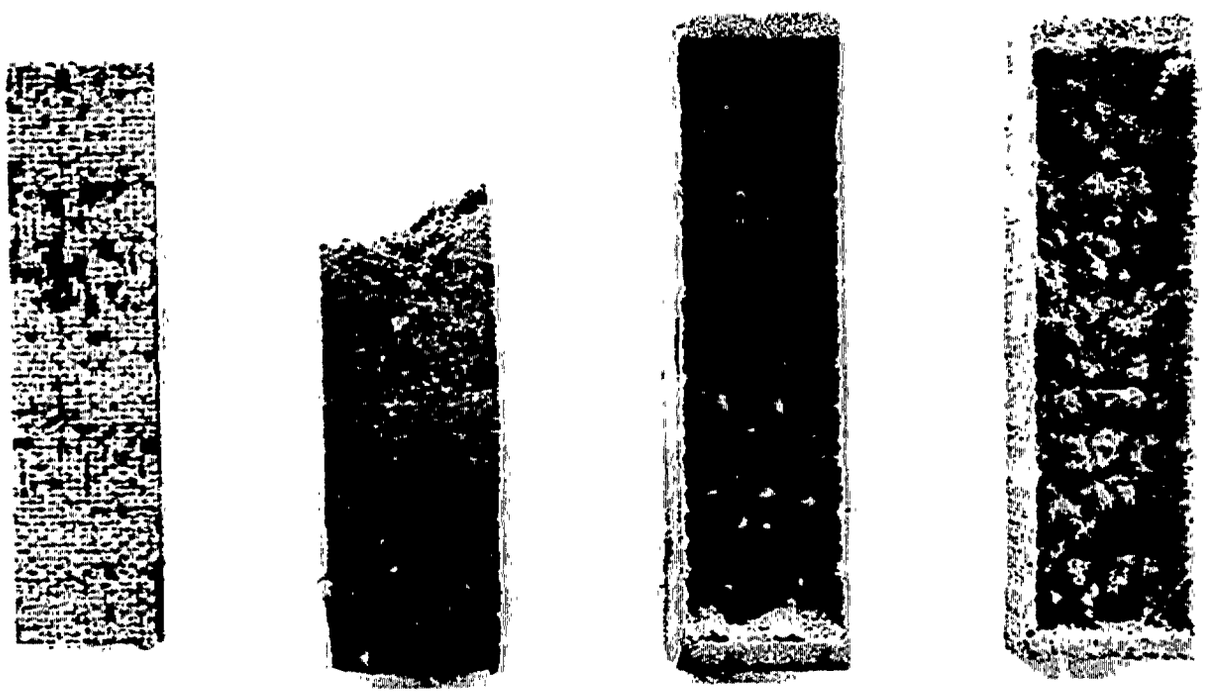
The remaining tests at 90 degree angle of attack were carried out at 350 mph and 1/2" and 1"/hr. rainfall. Figures 28 and 29 illustrate the severe erosion experienced by these insulation materials. These results illustrate the fact that erosion increases rapidly from 40 to 90 degree angles of attack at 350 mph.

Table 7 is a brief summary of all the rain erosion tests carried out in the current program.

FIGURE 27. TESTS ON PMMA STANDARD AT 350 MPH

90° ANGLE OF ATTACK

350 MPH - 1"/HR. RAINFALL

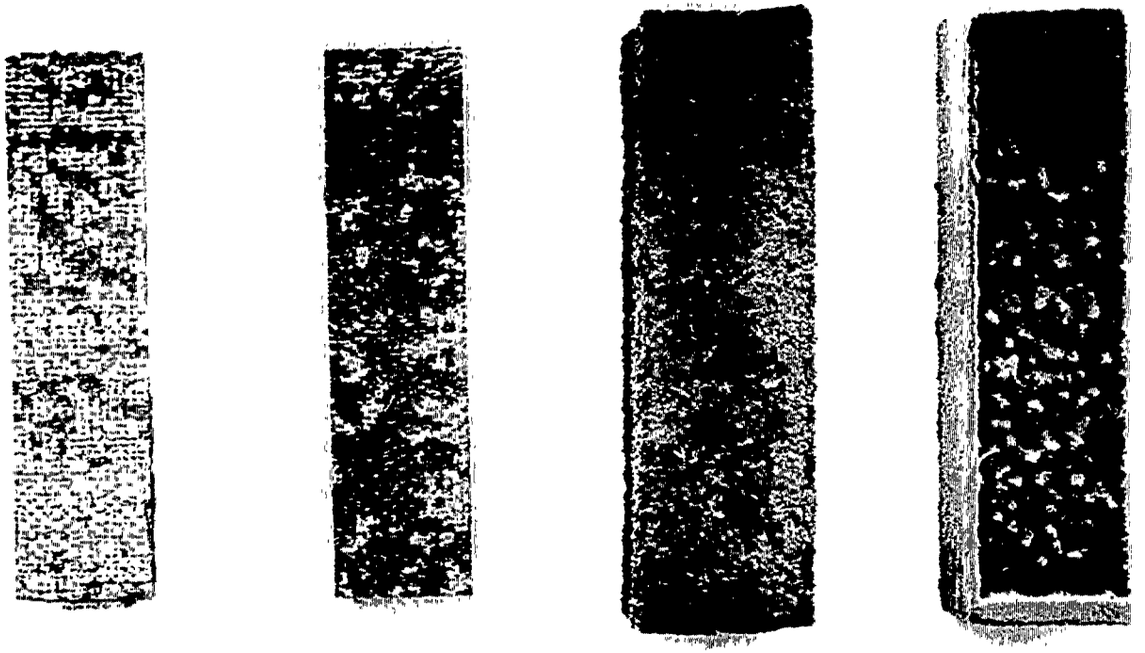


SPECIMEN NO.	TM-16	TM-17	TM-18	TM-19
TIME OF EXPOSURE	120 SEC	FLEW OFF	15 SEC	15 SEC
WEIGHT LOSS MILLIGRAMS	1000		2188	2328

FIGURE 28. TESTS ON VARIOUS ABLATOR MATERIALS AT 90° - 350 MPH AND 1"/HR. RAINFALL

90° ANGLE OF ATTACK

0.5"/ HR. RAINFALL



SPECIMEN NO.	TM-27	TM-38	TM-39	TM-40
VELOCITY MPH	350	350	200	350
TIME OF EXPOSURE	5 MIN	6 MIN	1 MIN	15 SEC
WEIGHT LOSS MILLIGRAMS	1202	2419	51	1288

FIGURE 29. TESTS ON VARIOUS ABLATOR MATERIALS AT 90° - 350 MPH AND 1/2"/HR. RAINFALL

TABLE 7

SUMMARY OF

RAIN EROSION TESTS

NASA - TPS MATERIALS

Bell Specimen No.	Material	Angle of Attack Degrees	Duration Test Min.	Results
		350 mph - 1"/Hr. Rainfall		
TM-1	Bell PMMA	90	5	Slight Pitting
		200 mph - 1"/Hr. Rainfall		
TM-2	Lockheed LI-1500	20	60	No Erosion
TM-3	MDAC HCF	20	60	No Erosion
TM-4	GE REI	20	60	No Erosion
		350 mph - 1"/Hr. Rainfall		
TM-5	Lockheed LI-1500	10	5	No Erosion
TM-6	Lockheed LI-1500	20	5	One Spot Eroded
TM-7	MDAC HCF	10	5	No Erosion
TM-8	MDAC HCF	20	2.5	Slight Erosion
TM-9	GE REI	10	5	No Erosion
TM-10	GE REI	20	2	Slight Erosion
TM-11	GE 1004	20	0	Specimen Tore
TM-12	LTV C/C	40	5	Trace Pitting
TM-13	GE 1004	40	1.5	Run at 200 mph
TM-14	AVCO 480-1	40	1	Severe Erosion
TM-15	Martin SLA-561	40	1	Severe Erosion
TM-16	LTV C/C	90	2	Coating Slightly Eroded
TM-17	GE 1004	90	0	Flew Off
TM-18	AVCO 480-1	90	0.25	Severe Erosion
TM-19	Martin SLA-561	90	0.25	Severe Erosion

Table 7

Bell Specimen No	Material	Angle of Attack Degrees	Duration Test Min.	Results
		350 mph - 0.5"/Hr. Rainfall		
TM-20	Lockheed LI-1500	10	5	No Erosion
TM-21	Lockheed LI-1500	20	2.5	Slight Erosion
TM-22	MDAC HCF	10	5	No Erosion
TM-23	MDAC HCF	20	3	Slight Erosion
TM-24	G.E. REI	10	5	No Erosion
TM-25	GE. REI	20	2.5	Slight Erosion
TM-26	LTV C/C	40	5	Trace of Pitting
TM-27	LTV C/C	90	5	Coating & Specimen Pitted
		350 mph - 0.5"/Hr. Rainfall		
TM-28	Lockheed LI-1500	10	60	No Erosion
TM-29	Lockheed LI-1500	20	30	Slight Erosion
TM-30	MDAC HCF	10	30	Severe Erosion
TM-31	MDAC HCF	20	4	Slight Erosion
TM-32	GE REI	10	30	Severe Erosion
TM-33	GE REI	20	4.5	Severe Erosion
TM-34	GE 1004	20	0	Specimen Tore
TM-35	GE 1004	40	4	Run at 200 MPH
TM-36	AVCO 480-1	40	0.5	Severe Erosion
TM-37	GE 1004-CH	40	4	Pitting & Cracking
TM-38	LTV C/C	90	[illegible]	Coating Eroded Away
TM-39	GE 1004	90	1	Run at 200 MPH
TM-40	AVCO 480-1	90	0.25	Severe Erosion

Table 7

Bell Specimen No.	Material	Angle of Attack Degrees	Duration Test Min.	Results
		410 mph - 1/4"/Hr. Rainfall		
TM-41	Lockheed LI-1500	20	1	Severe Erosion
TM-42	MDAC HCF	20	1	Severe Erosion
TM-43	GE REI	20	5	
		350 mph - 1/4"/Hr. Rainfall		
TM-44	Lockheed LI-1500	20	14	Slight Erosion
TM-45	MDAC HCF	20	5	Slight Erosion
TM-46	GE REI	20	7.5	Severe Erosion
TM-47	Lockheed LI-1500	40	0.5	Severe Erosion
TM-48	MDAC HCF	40	0.5	Severe Erosion
TM-49	GE REI	40	0.5	Severe Erosion
		350 mph - 1"/Hr. Rainfall		
STD-1	Bell PMMA	90	60	No Rain-No Erosion
STD-2	Bell PMMA	90	10	Surface Pitted
STD-3	Bell PMMA	90	15	Surface Badly Pitted
STD-4	Bell PMMA	20	60	No Erosion
STD-5	Bell PMMA	10	60	No Erosion
STD-6	Bell PMMA	40	60	Trace Initial Pitting
STD-7	Bell PMMA	40	60	Trace Initial Pitting

V. SUMMARY OF RESULTS

The following is a summary of the results of rain erosion tests on coated RSI and other TPS materials.

At 20 degree angles of attack - 200 miles per hour and 1 inch per hour rainfall no erosion occurs at 1 hour exposure.

At 10 degree angle of attack - 350 miles per hour and 1/2 and 1 inch per hour rainfall no erosion occurs after 5 minutes exposure.

At 20 degree angle of attack - 350 miles per hour and 1/4, 1/2 and 1 inch per hour rainfall erosion occurs after 2 - 14 minutes exposure.

At 20 degree angle of attack - 410 miles per hour and 1/4 inch per hour rainfall erosion occurs in less than 1 minute.

At 40 degree angle of attack - 350 miles per hour and 1/4 inch per hour rainfall erosion occurs in less than 30 seconds.

Carbon/carbon materials show only trace of erosion after 5 minutes exposure at 40 degree angle of attack - 350 miles per hour and 1/2 and 1 inch per hour rainfall.

Other materials erode badly at 40 degree angle of attack at 200 and 350 miles per hour and 1/2 and 1 inch per hour rainfall.

At 90 degree angle of attack carbon/carbon material showed increasing amounts of erosion at 350 mph and 1/2 and 1 inch per hour rainfall as time of exposure increased from 2 to 6 minutes. Other materials eroded badly in 15 seconds.

VI. RECOMMENDATIONS

Upgrade current foamed ceramic insulation for rain erosion resistance by improving coating or increasing thickness.

Determine optimum thickness of coating to prevent erosion of insulation materials at 350 miles per hour - 1 inch per hour rainfall at 40 and 90 degree angles of attack after 60 minutes exposure.

Test TPS materials at higher velocities in 1/4 inch per hour rainfall tc determine threshold velocity for damage at low angles of attack (10 and 20 degrees).

Examine feasibility of using an elastomeric coating on foamed ceramic that would tumefy and char.

Determine tendency of selected TPS materials to erode at junction of structure and insulation tile. Evaluate discontinuities, i.e., gaps, joints, steps on rain erosion performance of TPS materials.

VII. SUGGESTED QUALIFICATION TESTS

In order to satisfy the requirements for service conditions and determine the flight worthiness of TPS materials the following qualification tests are suggested.

1. Test three specimens of each finally selected TPS material at 40 and 90 degree angles of attack at cruise velocity and 1 inch per hour rainfall.

2. Determine average erosion rate of each material up to 5 percent weight loss under flight conditions.

3. Determine tendency of selected TPS material to erode at juncture of structure and insulation tile.

APPENDIX A

DESCRIPTION OF MATERIALS

Materials selected for the rotating arm rain erosion test program at Bell Aerospace were selected from candidate materials currently under evaluation for the shuttle thermal protection system application. The materials selected and supplied by the Thermal Technology Branch, NASA Manned Spacecraft Center for this test program were as follows:

a. Reuseable Surface Insulation (RSI) Materials

1. Mullite HCF*	McDonnell-Douglas Astronautics Company
2. Mullite REI*	General Electric Company
3. Silica LI-1500*	Lockheed Missiles and Space Company

These materials ranging in density from 12 to 15 lb/ft^3 can be categorized as rigidized ceramic fiber concepts. The RSI materials basically consit of fibers, mullite or silica bonded with binders and covered by a high emittance water proof coating. The coatings consist of variations of borosilicate glasses with pigments of metallic oxides and carbides. These materials are being developed under contract to NASA for application to major areas, i.e. fuselage, and wing areas of the shuttle orbiter.

b. Carbon-Carbon Materials

The material is being developed under contract to NASA by the Vought Missiles and Snace Company. The basic material consists of a carbon cloth laminate bonded with a polymeric resin which has been converted to carbon by pyrolization. Surfaces of the laminate are converted to a silicon

*Company designations for RSI and ablator materials

carbide coating by means of a pack cementation process. This material is under development for application to the leading edge regions of the shuttle orbiter. The density of this material is 88 lb/ft^3.

c. Ablators

1. 1004*	General Electric Company
2. 480-1*	Avco Corporation
3. SLA-561*	Martin-Marietta Company

These materials were all low density ablators with nominal densities from 14 - 16 lb/ft^3. The General Electric material consists of a foamed RTV560 elastomer reinforced with inorganic binders. The Avco material consists of a composite of ceramic fibers, silicone resin and ceramic microballoons. The Martin-Marietta material consists of a composite composed of a silicone resin with cork, phenolic microballoons, silica microballoons, and refractory fiber fillers.

*Company designations for RSI and ablator materials

APPENDIX B

RAIN EROSION TEST LOG

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-1
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack -- Degrees	90
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32 x 7/8 x 1/4"
Initial Weight - Grams	13.060
Final Weight - Grams	13.053
Loss in Weight - Grams	.007

Remarks:

Slight pitting of surface of PMMA.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-2
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	20
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	46.494
Final Weight - Grams	46.491
Loss in Weight - Grams	.003

Remarks:

No erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-3
Source and Identification:	MDAC HCF
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	20
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	50.416
Final Weight - Grams	50.409
Loss in Weight - Grams	.007

Remarks:

No erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-4
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	20
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/32" x 3 13/32 x 23/32"
Initial Weight - Grams	39.778
Final Weight - Grams	39.772
Loss in Weight - Grams	.006

Remarks:

No erosion

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-5
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	46.796
Final Weight - Grams	46.791
Loss in Weight - Grams	.005

Remarks:

No erosion.
Small chip on corner due to specimen holder clamp.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-6
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 15/32" x 23/32"
Initial Weight - Grams	47.918
Final Weight - Grams	47.863
Loss in Weight - Grams	.055

Remarks:

Small pit upper center after 1 min. 45 sec.
No further damage after 5 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-7
Source and Identification:	MDAC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	50.529
Final Weight - Grams	50.529
Loss in Weight - Grams	.000

Remarks:

No Erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-8
Source and Identification:	MDAC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	2.5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	48.827
Final Weight - Grams	48.297
Loss in Weight - Grams	.530

Remarks:

First pit 80 seconds.
Enlarge first pit
Second pit 110 seconds.
Third pit 135 seconds.
Shutdown 2.5 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-9
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/16 x 3 7/32 x 23/32"
Initial Weight - Grams	39.983
Final Weight - Grams	39.981
Loss in Weight - Grams	.002

Remarks:

No erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-10
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	2
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/32" x 23/32"
Initial Weight - Grams	38.719
Final Weight - Grams	37.024
Loss in Weight - Grams	1.695

Remarks:

Large pit in 80 second - large chunk at 2 minutes - shutdown.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-11
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	C
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2 x 3 17/32 x 15/16
Initial Weight - Grams	48.902
Final Weight - Grams	48.808
Loss in Weight - Grams	.094

Remarks:

Specimen compressed due to centrifugal force, flew out of clamps on holder at approximately 235 mph.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-12
Source and Identification:	LTV C/C
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2 x 3 1/2 x 5/32
Initial Weight - Grams	52.678
Final Weight - Grams	52.116
Loss in Weight - Grams	.562

Remarks:

Initial [illegible]s in coating after 2 min. 10 seconds.
Shutdown after five minutes surface of coating pitted.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-13
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	40
Exposure Time - Minutes	1.5
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 15/32" x 3 17/32" x 15/16"
Initial Weight - Grams	60.090
Final Weight - Grams	59.975
Loss in Weight - Grams	.115

Remarks:

Bonded to aluminum plate.
Initial pits in 45 seconds.
Shutdown after 90 seconds due to tearing.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-14
Source and Identification:	AVCO 480-1
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	1
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 x 3 1/2 x 3/4"
Initial Weight - Grams	31.749
Final Weight - Grams	17.700
Loss in Weight - Grams	14.049

Remarks:

First signs of erosion 20 seconds.
Shutdown after 60 seconds.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-15
Source and Identification:	Martin SLA-561
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	1
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 3 15/32" x 3/4"
Initial Weight - Grams	38.465
Final Weight - Grams	32.465
Loss in Weight - Grams	5.790

Remarks:

First signs of surface damage in 28 seconds.
Shutdown after 60 seconds.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-16
Source and Identification:	LTV C/C
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	2
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3" x 3/4" x 5/32"
Initial Weight - Grams	9.664
Final Weight - Grams	8.664
Loss in Weight - Grams	1.000

Remarks:

Initial pitting of surface coating in 40 seconds increasing in number and depth to 120 seconds.

Shutdown at 2 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-17
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	Flew Off
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 7/8 " x 15/16"
Initial Weight - Grams	11.1320
Final Weight - Grams	7.4584*
Loss in Weight - Grams	

Remarks:

*Specimen flew off at 225 mph

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-18
Source and Identification:	AVCO 480-1
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	15 sec.
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32 x 27/32 x 7/8
Initial Weight - Grams	10.439
Final Weight - Grams	8.251
Loss in Weight - Grams	2.188

Remarks:

Initial pitting in 5 seconds.
1/4 deep erosion - 15 seconds.
Shutdown 15 seconds.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-19
Source and Identification:	Martin SLA-561
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	15 seconds
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 7/32" x 3 15/32" x 3/4"
Initial Weight - Grams	7.082
Final Weight - Grams	4.754
Loss in Weight - Grams	2.328

Remarks:

First signs of erosion 6 seconds.
Shutdown at 15 seconds.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-20
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	46.342
Final Weight - Grams	46.319
Loss in Weight - Grams	.023

Remarks:

No erosion.
Small chip on corner due to specimen clamp.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-21
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	2.5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 15/32" x 3 15/32" x 23/32"
Initial Weight - Grams	46.739
Final Weight - Grams	46.670
Loss in Weight - Grams	.069

Remarks:

Small pit in center surface observed at 90 seconds running. Three more pits formed at 120 seconds. Initial pit larger - shutdown at 2 1/2 minutes (150 seconds).

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-22
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	48.749
Initial Weight - Grams	48.740
Final Weight - Grams	.009
Loss in Weight - Grams	

Remarks:

No erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-23
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	3
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	48.686
Final Weight - Grams	48.115
Loss in Weight - Grams	.571

Remarks:

First pit 1/16" diameter 35 seconds.
First pit enlarging
Second pit 80 seconds
Third pit 95 seconds
Fourth pit 100 seconds
Fifth pit 125 seconds
All pits enlarged to 1/8" and 1/4" at 2.5 minutes
Shutdown at 3 minutes

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-24
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/32" x 23/32"
Initial Weight - Grams	40.339
Final Weight - Grams	40.338
Loss in Weight - Grams	.001

Remarks:

No erosion.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-25
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	2.5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/32" x 23/24"
Initial Weight - Grams	39.327
Final Weight - Grams	38.919
Loss in Weight - Grams	.408

Remarks:

Small pit 100 seconds - enlarged and became deeper at 150 seconds - 2 1/2 minutes shutdown.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-26
Source and Identification:	LTV C/C
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 15/32" x 3 15/32" x 5/32"
Initial Weight - Grams	52.578
Final Weight - Grams	52.113
Loss in Weight - Grams	.465

Remarks:

First pits in coating after 3 1/2 minutes.
Shutdown after 5 minutes.
Coating surface slight pitted - specimen in good shape.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-27
Source and Identification:	LTV C/C
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3" x 23/32" x 5/32"
Initial Weight - Grams	9.583
Final Weight - Grams	8.381
Loss in Weight - Grams	1.202

Remarks:

First pit observed in coating after 50 seconds - increasing in number and depth up to 5 minutes shutdown 5 minutes.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-28
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	47.007
Final Weight - Grams	46.959
Loss in Weight - Grams	.048

Remarks:

Chip on corner due to clamp on edge of specimen holder - no erosion.

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NASA - TPS MATERIALS

RAIN EROSION TEST LOG

Bell Specimen No.:	TM-29
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	30
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 15/32" x 3 15/32" x 23/32
Initial Weight - Grams	47.827
Final Weight - Grams	47.415
Loss in Weight - Grams	.412

Remarks:

Two small pits 5 min. Grew larger and deeper at 15 minutes. Three more pits at 20 minutes. Grew larger and deeper at 30 minutes. Shutdown

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-30
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	30
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	48.970
Final Weight - Grams	47.623
Loss in Weight - Grams	1.347

Remarks:

First pit occurred at 17 min. 20 seconds
Second pit observed at 19 min. 50 seconds
Pits enlarged up to 25 minutes
Third pit 25 min. 20 seconds
Shutdown after 30 minutes

NASA TMS MATERIALS

RAIN EROSION TEST LOG

Bell Specimen No.:	TM-31
Source and Identification:	MALC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	4
Rainfall intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	49.587
Final Weight - Grams	48.966
Loss in Weight - Grams	.621

Remarks:

First 1/16" diameter pit - 75 sec.
Second pit 105 seconds
Third pit 125 seconds
Pits growing
Fourth pit 230 seconds
Shutdown 4 minutes

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-32
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	30
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 13/32" x 3 7/16" x 23/32"
Initial Weight - Grams	38.221
Final Weight - Grams	36.860
Loss in Weight - Grams	1.361

Remarks:

First pit at juncture of specimen and holder after 18 min. - 25 sec.
Enlarged up to 23 min.
Second pit 23 min. 45 sec.
Shutdown after 30 minutes.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-33
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	4.5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 13/32" x 3 7/32" x 11/16"
Initial Weight - Grams	35.130
Final Weight - Grams	33.386
Loss in Weight - Grams	1.744

Remarks:

First pit observed at 3 min. 40 sec.
Second pit 4 min. 10 sec.
Large chunk from each pit 4 min. 20 sec.
Shutdown at 4.5 min.

NASA - :PS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-34
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	0
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 17/32" x 15/16"
Initial Weight - Grams	55.706
Final Weight - Grams	55.112
Loss in Weight - Grams	.594

Remarks:

Specimen bonded to aluminum plate.
Specimen tore at 240 mph due to centrifugal force.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-35
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	40
Exposure Time - Minutes	4
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 17/32" x 15/16"
Initial Weight - Grams	57.906
Final Weight - Grams	41.572
Loss in Weight - Grams	16.334

Remarks:

Bonded to aluminum plate surface began to pit after 50 seconds. Continued to erode - lost half of specimen after 3 minutes 55 seconds. Shutdown in 4 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-36
Source and Identification:	AVCO 480-1
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	0.5
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 2 15/16" x 3/4"
Initial Weight - Grams	29.710
Final Weight - Grams	25.676
Loss in Weight - Grams	4.034

Remarks:

First pits in surface in 10 seconds, test for 30 seconds surface eroded 1/8" deep uniformly.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-37
Source and Identification:	GE 1004-CH
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	40
Exposure Time - Minutes	4
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3" x 3 17/32" x 29/32"
Initial Weight - Grams	77.789
Final Weight - Grams	72.455
Loss in Weight - Grams	5.334

Remarks:

Initial pitting 2 min. 20 seconds.
Shutdown after 4 minutes
Specimen cracked and pitted.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-38
Source and Identification:	LTV C/C
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	6
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3" x 3/4" x 5/32"
Initial Weight - Grams	9.619
Final Weight - Grams	7.200
Loss in Weight - Grams	2.419

Remarks:

First pitting of surface observed after 45 seconds.
Pitting area enlarged up to 5 minutes.
Shutdown 6 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-39
Source and Identification:	GE 1004
Test Parameters:	
Velocity - mph	200
Angle of Attack - Degrees	90
Exposure Time - Minutes	1
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 5/16" x 7/8" x 15/16"
Initial Weight - Grams	11.284
Final Weight - Grams	11.233
Loss in Weight - Grams	.051

Remarks:

Sample compresses in holder at 350 mph had to reduce speed to 200 mph to be able to conduct test - pits began to form in 30-45 seconds, badly pitted at 1 minute shutdown.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-40
Source and Identification:	AVCO 480-1
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	15 sec.
Rainfall Intensity - in./hr	0.5
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 7/8" x 27/32"
Initial Weight - Grams	10.523
Final Weight - Grams	9.235
Loss in Weight - Grams	1.288

Remarks:

Initial pitting 8 seconds.
1/8 deep pitting in 15 seconds - shutdown.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-41
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	410
Angle of Attack - Degrees	20
Exposure Time - Minutes	1
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	44.895
Final Weight - Grams	44.292
Loss in Weight - Grams	.603

Remarks:

First 1/16 diameter pit observed at 28 seconds.
Second and third pits in 32 seconds.
Pits enlarged - shutdown after 1 minute.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-42
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	410
Angle of Attack - Degrees	20
Exposure Time - Minutes	1
Rainfall Intensity - in /hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	50.162
Final Weight - Grams	48.997
Loss in Weight - Grams	1.165

Remarks:

Pit occurred at juncture of specimen and metal holder in 20 seconds.
This area enlarged and pits formed over entire surface in 35 seconds.
Shutdown after one minute.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-43
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	410
Angle of Attack - Degrees	20
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 13/32" x 3 7/32" x 23/32"
Initial Weight - Grams	38.398
Final Weight - Grams	37.293
Loss in Weight - Grams	1.105

Remarks:

First pit in upper corner at juncture holder and specimen 2 min. 10 seconds.
Second pit in center after 3 min. 40 seconds.
Pitting on edge 4 min. 5 seconds.
Shutdown after 5 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-44
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	14
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 15/32" x 23/32"
Initial Weight - Grams	47.429
Final Weight - Grams	47.293
Loss in Weight - Grams	.136

Remarks:

Initial pit in upper surface 9 min. 35 seconds.
Second pit 10 min. 25 seconds.
Third pit 13 min. 8 seconds.
Fourth pit 13 min. 20 seconds.
Shutdown in 14 minutes.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-45
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 1/2" x 3/4"
Initial Weight - Grams	49.812
Final Weight - Grams	49.306
Loss in Weight - Grams	.506

Remarks:

First pit 1 min. 10 seconds.
Second pit 2 min. 40 seconds.
Third pit 30 min. 5 seconds.
Fourth pit thru seventh pit 4 min. 20 seconds.
Shutdown 5 minutes.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-46
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	7.5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 13/32" x 3 3/16" x 3/16"
Initial Weight - Grams	37.638
Final Weight - Grams	35.443
Loss in Weight - Grams	2.195

Remarks:

Initial pit at top edge 3 min. 15 seconds.
Second pit 4 min. 10 seconds.
Pits enlarged and third pit 6 min. 50 seconds.
Shutdown at 7.5 minutes.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-47
Source and Identification:	Lockheed LI-1500
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	0.5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 7/16" x 23/32"
Initial Weight - Grams	44.202
Final Weight - Grams	43.197
Loss in Weight - Grams	1.105

Remarks:

Initial pitting in center section of specimen -
3 pits in 12 seconds.
Tested for 30 seconds.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-48
Source and Identification:	MADC HCF
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	0.5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	
Initial Weight - Grams	45.645
Final Weight - Grams	43.348
Loss in Weight - Grams	2.297

Remarks:

Initial pitting at lower juncture of holder and specimen after 1? seconds.
Shutdown after 30 seconds.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	TM-49
Source and Identification:	GE REI
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	0.5
Rainfall Intensity - in./hr	1/4
Specimen Data:	
Specimen Dimension - Nominal	3 7/16" x 3 3/16" x 23/32"
Initial Weight - Grams	38.716
Final Weight - Grams	34.477
Loss in Weight - Grams	4.239

Remarks:

Initial pitting at juncture of specimen and holder in 14 seconds.
Shutdown after 30 seconds.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-1
Source and Identification:	BELL PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	No Rain
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 7/8" x 1/4"
Initial Weight - Grams	13.081
Final Weight - Grams	13.081
Loss in Weight - Grams	0

Remarks:

Run to demonstrate no pitting without rain.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-2
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	10
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 7/8" x 1/4"
Initial Weight - Grams	13.115
Final Weight - Grams	13.085
Loss in Weight - Grams	.030

Remarks:

Run as standard material for erosion resistance.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-3
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	90
Exposure Time - Minutes	15
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 9/32" x 7/8" x 1/4"
Initial Weight - Grams	13.165
Final Weight - Grams	13.108
Loss in Weight - Grams	.057

Remarks:

Run as standard material for erosion resistance.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-4
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	20
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 1/2" x 1/4"
Initial Weight - Grams	57.202
Final Weight - Grams	57.198
Loss in Weight - Grams	.004

Remarks:

No erosion.

NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-5
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	10
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 1/2" x 1/4"
Initial Weight - Grams	56.760
Final Weight - Grams	56.757
Loss in Weight - Grams	.003

Remarks:

No erosion.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-6
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 1/2" x 1/4"
Initial Weight - Grams	55.494
Final Weight - Grams	55.465
Loss in Weight - Grams	.029

Remarks:

Trace initial pitting.

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NASA - TPS MATERIALS
RAIN EROSION TEST LOG

Bell Specimen No.:	STD-7
Source and Identification:	Bell PMMA
Test Parameters:	
Velocity - mph	350
Angle of Attack - Degrees	40
Exposure Time - Minutes	60
Rainfall Intensity - in./hr	1
Specimen Data:	
Specimen Dimension - Nominal	3 1/2" x 3 1/2" x 1/4"
Initial Weight - Grams	54.482
Final Weight - Grams	54.450
Loss in Weight - Grams	.032

Remarks:

Trace of initial pitting.