12

AFWAL-TR-87-2004

EFFECTS OF AIRCRAFT ENGINE BLEED AIR DUCT FAILURES ON SURROUNDING AIRCRAFT STRUCTURE

A. M. Johnson
BOEING MILITARY AIRPLANE COMPANY
Propulsion Technology
P.O. Box 3707
Seattle, WA 98124-2207

April 1987
INTERIM for period March 1986 to May 1986

Approved for public release; distribution unlimited

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6563

NOTICE

This technical report has been reviewed and is approved for publication.

R. G. Clodfelter

R. G. Clodfelter, Chief
Fire Protection Branch
Fuels and Lubrication Division
Aero Propulsion Laboratory

FOR THE COMMANDER

R. D. Sherrill

R. D. Sherrill, Chief
Fuels and Lubrication Division
Aero Propulsion Laboratory

If your address has changed, if you wish to be removed from our mailing list or if the addressee is no longer employed by your organization, please notify AFWAL/POSH, Wright-Patterson, OH 45433-6563 to help us maintain a current mailing list.

Copies of this report should not be returned unless is required by security considerations, contractual obligations or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

A181071

(12)

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) D180-29965-1	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFWAL-TR-87-2004
6a. NAME OF PERFORMING ORGANIZATION Boeing Military Airplane Company 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Aero Propulsion Laboratory (AFWAL/POSH)
6c. ADDRESS (City, State and ZIP Code) P.O. Box 3707, M/S 33-14 Seattle WA 98124-2207	7b. ADDRESS (City, State and ZIP Code) Air Force Wright Aeronautical Labs Wright-Patterson AFB, OH 45433-6563
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Aero Propulsion Laboratory 8b. OFFICE SYMBOL (If applicable) AFWAL/POSH	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-84-C-2431
8c. ADDRESS (City, State and ZIP Code) Air Force Wright Aeronautical Labs. Wright-Patterson AFB, OH 45433-6563	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO.: 62203F; PROJECT NO.: 3048; TASK NO.: 07; WORK UNIT NO.: 94
11. TITLE (Include Security Classification) see Block 19.	
12. PERSONAL AUTHOR(S) A. M. Johnson	
13a. TYPE OF REPORT: INTERIM 13b. TIME COVERED: FROM 3/86 TO 5/86	14. DATE OF REPORT (Yr., Mo., Day): April 1987 15. PAGE COUNT: x + 110
16. SUPPLEMENTARY NOTATION	

17. COSATI CODES

FIELD	GROUP	SUB. GR.
01	03	
21	04,05	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
bleed air, bleed duct, electrical conductivity, engine nacelle, AENFTS

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

11. TITLE
EFFECTS OF AIRCRAFT ENGINE BLEED AIR DUCT FAILURES ON SURROUNDING AIRCRAFT STRUCTURE

19. ABSTRACT

Simulated bleed air impingement tests were conducted to explore the possibility that an engine bleed air leak contributed to the loss of an F-16 aircraft. A data base of the results of hot engine bleed air impinging on engine compartment walls was established for selected aircraft aluminum materials. Testing indicated the specific F-16 conditions could not have caused panel burnthrough; however, substituting other conditions did result in panel burnthrough. The results provide information which will assist in future mishap investigations. Keywords: electrical conductivity

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☑ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Robert G. Clodfelter	22b. TELEPHONE NUMBER (Include Area Code): (513)255-4208 22c. OFFICE SYMBOL: AFWAL/POSH

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

SUMMARY

The probability that high temperature, high pressure, engine bleed air leakage could perforate surrounding aircraft structure was investigated in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS) at Wright-Patterson Air Force Base. Of particular interest was the possibility of bleed air perforation of engine compartment walls which also form fuel tank walls.

The testing included consideration of four types of commonly used aircraft aluminum panels, panels treated with thermally insulative coatings and measurement of electrical conductivity changes due to heating of the materials.

Significant conclusions for the test program were that:

1. High pressure, high temperature bleed air can, in fact, structurally degrade and perforate aircraft aluminum.

2. The accidental aircraft loss which prompted this study could not have been caused by penetration of the adjacent fuel tank wall by engine bleed air, as demonstrated by simulation of the aircraft geometry and environment.

3. At a flowrate of 1 lb/sec, bleed air of 1000°F must be directed to a panel, at a distance of four-inches or less to cause failure. The bleed air temperature and distance from the panel required to cause failure are related to panel thickness.

4. Insulating materials have little effect on the tendency of panels to fail.

5. Changes in the electrical conductivity of panel matierlas do occur as the result of heating and may be used to reach some general conclusions about the temperatures to which the panels were exposed.

PREFACE

This is a technical operating report of work conducted under F33615-84-C-2431 by the Boeing Military Airplane Company, Seattle, Washington for the period 21 March 1986 through 1 May 1986. Program sponsorship and guidance were provided by the Fire Protection Branch of the Aero Propulsion Laboratory (AFWAL/POSH), Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Under Project 3048, Task 07, and Work Unit 94. Robert G. Clodfelter was the project engineer.

The work partially satisfies the requirements of Task III of the contract, AEN (Aircraft Engine Nacelle) Test Requirements, that requires utilization of the AEN fire test simulator to establish the fire initiation, propagation, and damage effects exhibited by aircraft combustible fluids under representative dynamic operational environmental conditions, followed by the evaluation and development of protection measures.

The test program was performed to determine whether high temperature, high pressure engine bleed air could, in fact, structurally degrade and penetrate engine compartment wall panels. It is important to mention that this was not a comprehensive test program; the results serve, however, to establish a preliminary data base in a previously unexplored research area.

Boeing wishes to acknowledge with appreciation the contributions of the following to this program: Mr. Robert G. Clodfelter, the Air Force Project Engineer, who provided overall program direction, Mr. Harold Zoller and Mr. Fred Meyer of the AFWAL Materials Laboratory Staff at WPAFB who provided the eddy current conductivity meter and training concerning its use, Mr. Harold Kamm of United Technology Corporation who provided assistance in interpreting the eddy current conductivity data, Mr. Robert E. Esch and Mr. David C. Clarkston of STS (SelectTech Services Inc.), test technicians, and Mr. Albert J. Meyer, also of STS, the test instrumentation engineer.

Key Boeing contributors to the program were: Alan M. Johnson, test supervision, Norton H. Goldstein of the Boeing Commercial Aircraft Company Power Pack and Strut Organization, who provided technical assistance and coordinated the acquisition of the various panel insulation materials and also provided assistance in the preparation of this report, Ed Seivert of the Boeing Military Airplane Company Manufacturing Organization in Wichita who arranged to coat the test panels with insulation material, and Lynn Desmarais who also assisted in report preparation.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AENFTS	Aircraft Engine Nacelle Fire Test Simulator
CRES	Corrosion Resistant Stainless
PSIA	Pounds Per Square Inch
SIB	Safety Investigation Board
WPAFB	Wright-Patterson Air Force Base

1.0 INTRODUCTION

The probability that F-16 engine high-temperature high-pressure, bleed air leakage could perforate engine compartment wall panels, particularly those forming fuel tanks, was investigated in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS) at Wright-Patterson Air Force Base.

1.1 Background

Aircraft jet engine bleed air ducts and duct clamps exhibit a long failure history; these failures often caused major mishaps. During the first six years of Air Force experience with the F-111 airplane, 11 out of a total of 33 total fire and overheat incidents were the result of bleed air duct or duct clamp failures (Reference 1). While these failures often led to major nacelle damage, they did not result in fires.

The outer surface of an engine compartment may form the wall of a fuel tank. This may be a single panel of aluminum. The bleed air exits the engine at temperatures as high as 1300^{o}F and pressure up to 420 psig. These conditions may be even more severe in future aircraft. Any failure of the bleed air ducts could result in a jet of bleed air impinging on the surrounding walls. The F-16 aft fuel tank, a 0.050-inch 2024-T81 aluminum structure, is only six inches from the bleed air line.

An even more severe hazard exists in a combat scenario. A projectile perforating the bleed duct might create a hole in the bleed line directing a much higher pressure jet onto a fuel tank wall or, similarly, a projectile may penetrate the engine case itself.

1.2 Objective and Approach

The objectives of this study were:

- o to investigate the likelihood that a bleed duct failure had caused the recent loss of an F-16 aircraft
- o to provide aircraft designers with additional information on the risks associated with bleed air leakage in the vicinity of thin aluminum panels, particularly fuel tanks

- o to provide information to future accident investigation teams concerning the identification of this type of damage

With these objectives in mind, a fixture that would allow the impingement of a jet of simulated hot bleed air on one-foot square panels of representative aircraft materials was constructed and installed adjacent to the AEN test section. Experiments were conducted to examine the temperatures, pressures and spacing necessary to perforate panels similar to those used inthe F-16 airplane.

Similar tests were run with a variety of other common aircraft materials; several thicknesses of one alloy were tried. Panels with common aircraft engine compartment insulative coatings were also tested.

Some of the tests were repeated with a representative set of panels and electrical conductivity measurements were made at various locations on the panels. These data were examined to see if such measurements could be employed by accident investigators to better understand aircraft incidents by measuring the electrical conductivity of damaged components.

1.3 Summary

Testing was initiated in response to a request from an Air Force Safety Investigation Board (SIB). The SIB was concerned that leaking bleed air impinging on an empty F-16 aft fuel tank may have contributed to the loss of the aircraft. As the test plan was being implemented, the SIB determined bleed air burnthrough was not a factor. However, testing was continued since this type of threat had not previously been adequately investigated or documented.

Testing was organized into four phases:

- o Phase I: 2024-T81 panels, 0.050-inch thick, simulating the F-16 aft fuel tank adjacent to engine air bleed ducts
- o Phase II: aluminum panels common to other aircraft types, including 2024-T3 in three different thicknesses (0.045, 0.050 and 0.071 inch thick), 0.050 inch thick 6061-T6 and 7075-T6
- o Phase III: 2024-T81 panels, 0.050-inch thick, coated with several common aircraft engine compartment insulating materials

- Phase IV: measurement of the electrical conductivity of a series of 0.050-inch thick 2024-T81 panels after they were exposed to 900 and 1100 degree F jets at distances of two and four inches from the jet exit

A structure was fabricated from Unistrut channels and attached to the side of the AEN. This structure supported a short length of 1.5-inch Corrosion Resistant Steel (CRES) tubing and the 12-inch square of the panel material being tested. The structure also supported six thermocouples which were held against the back side of the test panel. One end of the CRES tubing was connected to the AEN bleed air heater supply line, and the other to a butterfly throttling valve connected to tubing that entered the AEN test section. A 0.6875-inch diameter hole was drilled in the CRES tubing so that a jet of the simulated engine bleed air would impinge on the center of the test panel.

Test conditions included jet temperatures up to 1000^{o}F and jet temperatures up to 220 psia, to which the AENFTS facility is limited, but which are representative of fighter engine bleed duct conditons. During the initial tests with the 0.050-inch thick 2024-T81 panels which simulated the F-16 aft tank wall, little damage was done to the panels when they were placed six inches from the jet exit plane. The center of the panel was dented, but no perforation had occurred after ten minutes of exposure to the jet (Figure 1). Panel perforation did not occur until the panel was located two inches from the jet exit plane. At that point, perforation occurred within the first six seconds of jet impingement (Figure 2).

It is important to note the failure mode of the panels due to perforation by the hot, high pressure air. It might be assumed that a failure of this kind would be melting with smooth deformation. In fact, the failure has the appearance of being "punched out," with smooth deformation followed by shearing of the weakened material (Figures 3 and 4).

The 0.050-inch panels of 2024-T3 and 7075-T6 had about the same resistance to perforation as the 2024-T81 panels. The thinner, 0.032-inch, 2024-T3 panels were perforated somewhat more quickly at two inches distance and were perforated in about eight minutes at the four inches spacing. The thicker, 0.071-inch, 2024-T3 panels took about twice as long to perforate at two inches distance from the jet exit plane as the 0.050-inch thick panels.

Figure 1. Simulated F-16 Panel Tested Six Inches From Jet Exit Plane

Figure 2. Simulated F-16 Panel Tested One Inch from Jet Exit Plane

Figure 3. Closeup of Failed Panel (0.032" thick 2024-T3)

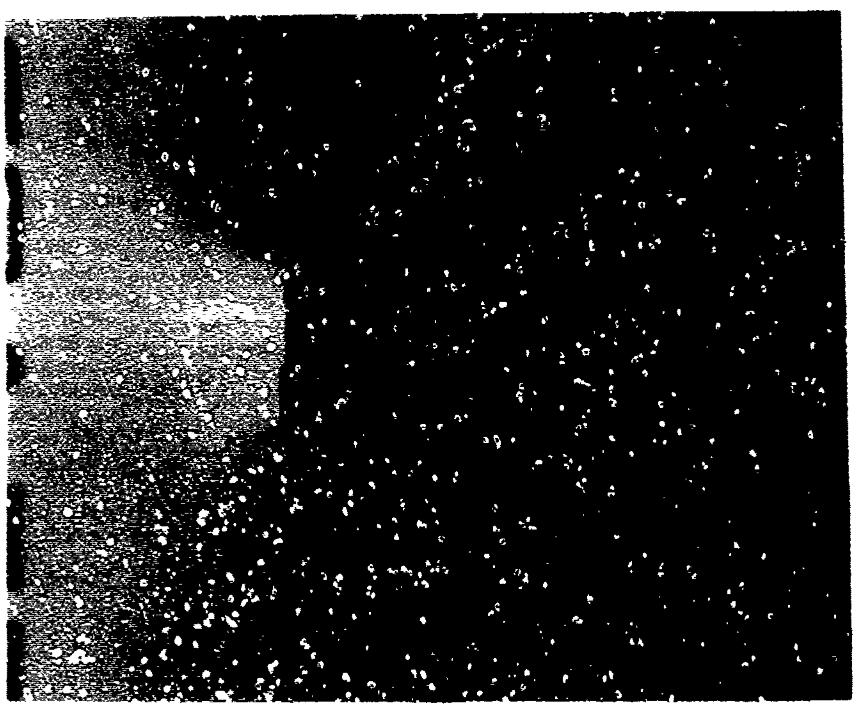


Figure 4. Closeup of Failed Panel (0.050" Thick 7075-T6)

The 6061-T6 panels were not perforated at any distance from the jet exit plane. even at 1100°F and 220 psia. However, large deformations were quickly formed where the jet impinged on the panel.

The insulating materials, Martin Marietta MA-25S and Crown Metro 64-1-2, were applied to 0.050-inch thick 2024-T81 panels similar to what is done at an engine compartment installation to provide protection against fire/heat damage. Tests revealed that these materials provided little extra protection. At distances of four inches and less, the Kevlar top coat protection on the coatings burned through within the first few seconds of jet impingement. The silicon insulation was then eroded until bare metal was visible at the center of the panel. The entire process usually occurred within about 20 seconds. At that time, the panels were perforated at the same distances and in about the same time as they were without the coating. In summary, the effect of the coatings was limited to about 20 seconds of extra time while the coating was being eroded.

The sponsoring organization specifically requested that electrical conductivity measurement be included in this test program. These measurements are commonly employed to decide whether aircraft aluminum panels exposed to heat have retained their original strength and hardness or have been damaged extensively enough to require replacement. Therefore, electrical conductivity changes were measured in panels subjected to jets of simulated hot bleed air as a potential aid to teams attempting to establish the cause of aircraft fire and overheat incidents.

Electrical conductivity measurements were made with a Verimet model M 4990 A eddy-current CU (Conductivity) meter at various locations on a set of six 0.050-inch thick 2021-T81 panels, five of which were exposed to hot jets and the sixth used as a baseline. The measurements were repeated at intervals during the eight days following testing. The expected change in conductivity readings with time was not observed.

Some observations of potential value to aircraft accident investigators were made. Exposure to hot jets, where the panel temperature is below about 800 degrees F (the process temperature for the T81 heat treating), has the effect of permanently reducing the electrical conductivity of the panel. Exposures above that temperature increase the conductivity. The initial effect of temperatures above the process temperature is similar to additional heat treating and the eventual effect is similar to annealing.

2.0 TEST FACILITIES

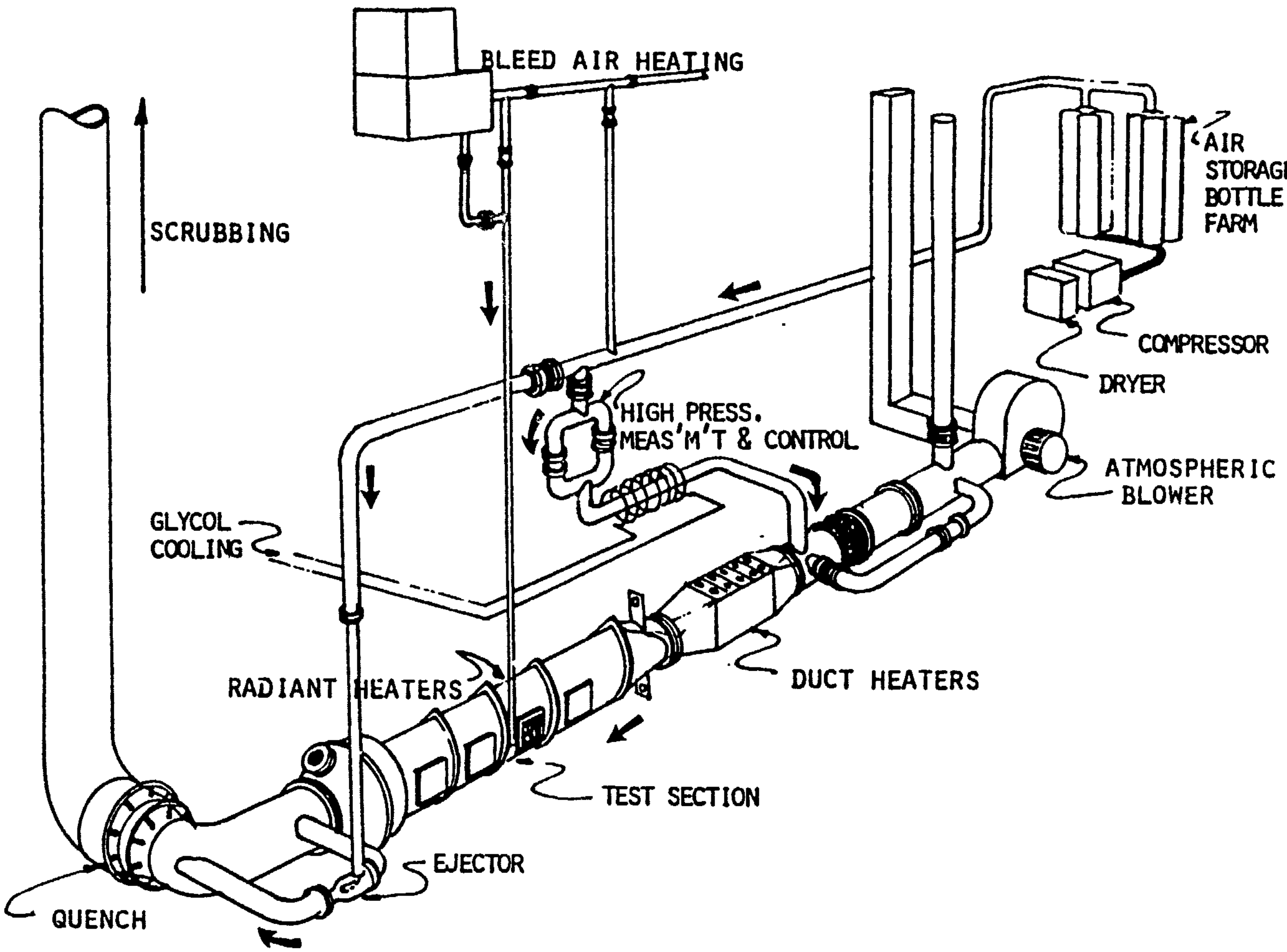
2.1 AENFTS Facility

The Aircraft Engine Nacelle Fire Test Simulator (AENFTS) is a ground test facility designed to simulate potential fire hazards in the annular compartment around an aircraft engine. The simulator is installed in I-Bay of Building 71-B in Area B of Wright-Patterson Air Force Base in Ohio. The facility includes air delivery and conditioning equipment to simulate engine compartment ventilation and bleed airflow. The test section is used for safe, dynamic fire testing. This test section is connected to an exhaust system that includes equipment to cool and scrub combustion gases prior to releasing them into the atmosphere (Figure 5).

Simulation of the hazards associated with high temperature engine bleed air leaks from either damaged ducts or the engine case is provided by the AEN bleed air heating system. A natural gas fired heater, mounted on a platform above the AEN test cell, heats the incoming high-pressure air. This air supply is a 2000 psig air storage bottle farm equipped with automatic flowrate and temperature control. Testing is possible at flowrates up to 1 pound per second with the temperature up to 1500°F and pressures up to 220 psia.

The bottle farm high-pressure air is conserved by the use of shop air during the start-up and preheating of this system and between test conditions. Up to 20 minutes is required to preheat the system and the piping which delivered the hot bleed air to the test panel when the highest bleed air temperature, 1100°F is required.

In normal AEN operation, an insulated flex duct delivers the heated, simulated engine bleed air to the test section. During AEN tests employing simulated engine bleed airflow, air is routed directly into the AEN test section. For the panel bleed air impingement testing, a simulated bleed duct was installed outside the AEN test section, connected between the insulated flex duct and the fitting where the bleed airflow normally entered the test section. Configuration of the test article relative to the existing nacelle simulator is discussed further in Section 3.0.



(ARROWS INDICATE AIRFLOW DIRECTION)

Figure 5. Components of the AEN

The AEN bleed air heating system is shown schematically (Figure 6). A detailed discussion of the design, arrangement and operation of this system and of other parts of the AEN is included in the AEN Operation Manual (Reference 2).

2.2 Instrumentation

2.2.1 Basic Test Instrumentation

The basic test instrumentation consisted of the sensors for measurement of the simulated engine bleed airflow temperature, pressure and flowrate and the temperatures on the backside of the test panels. Additional equipment was employed to acquire video records of the testing.

Pressure data were obtained using four standard commercial transducers manufactured by Sensotec and Setra. They were precalibrated by their manufacturers with standards traceable to the NBS and periodically checked using a dead weight tester. Details of the transducer ranges, sensitivities and accuracies are included in Table 1.

Type K thermocouples were used to measure the simulated bleed airflow temperature at the flowmeter, the jet temperature and the temperatures on the backside of the test panels. Table 2 describes the nomenclature, channel assignment, accuracy and measurement location of all these thermocouples.

A Honeywell Visicorder, model 1858, high-speed oscillograph was also used to record temperature versus time data for the panel thermocouples and the bleed air temperature. These data provided a "quick look" at the temperature measurements as well as providing backup information.

2.2.2 AEN Video Instrumentation

A closed circuit television camera equipped with a F 2.8, 15- to 150-mm zoom lens was mounted on a pan and tilt platform. During these tests, the camera was focused on the point where the simulated bleed air jet impinged on the test panel. The output signal could be monitored on a video monitor on the AEN control panel to allow the test operator to observe the jet impingement effects on the test panel and the exact time at which the panel failed in those cases where perforation occurred.

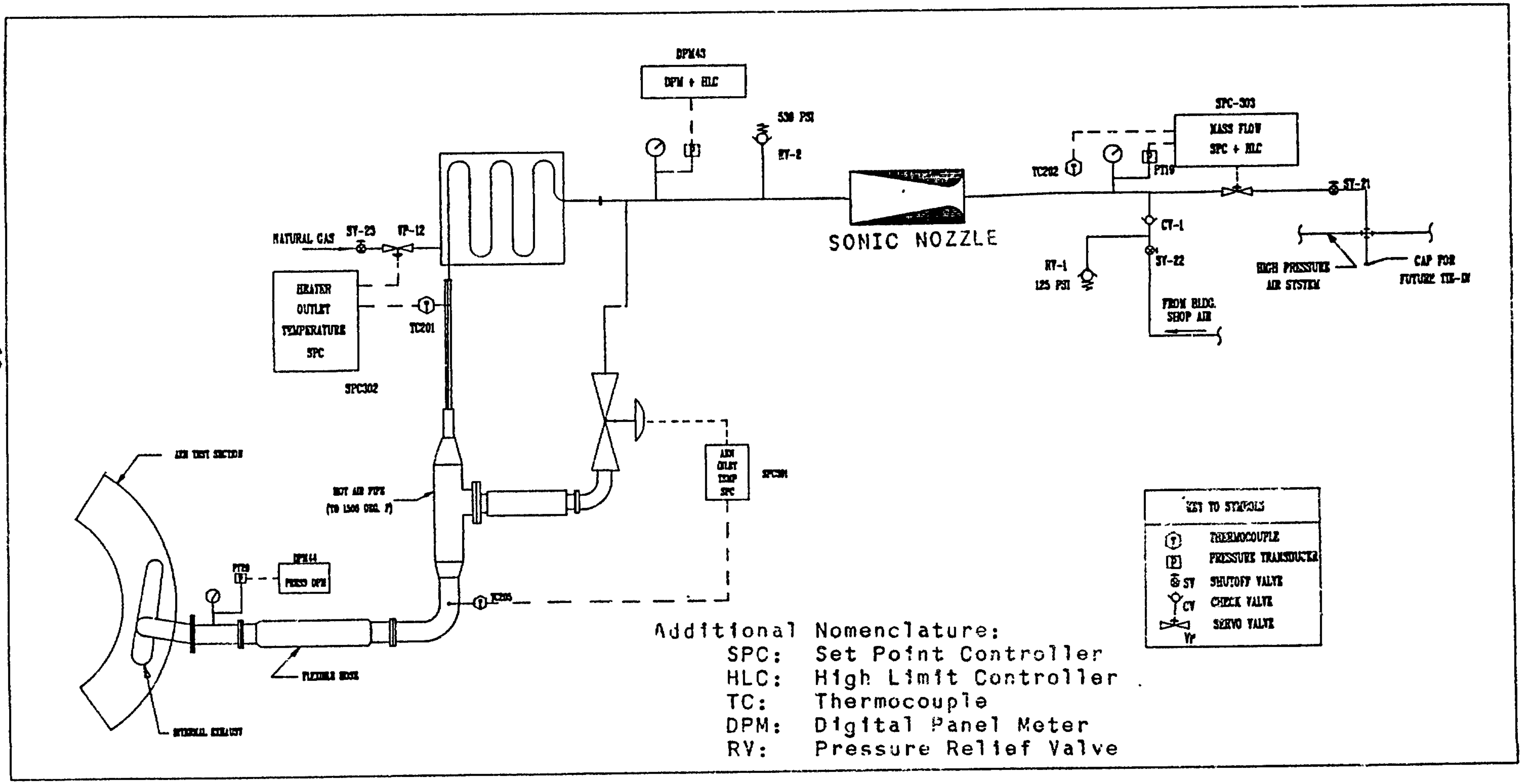


Figure 6. AEN Bleed Air Heater System

Table 1. Details of AEN Pressure Instrumentation Employed in Panel Penetration Testing

ITEM	SYMBOL	DESCRIPTION	MFG&S/N	RANGE	ACCURACY*
1	PBAROM	Barometric press	S-40737	26-32 in.Hg	0.25
2	PBHNAI	Bleed heater inlet pressure	ST-67774	0-500 psia	0.25
3	PBH-IN	Bleed air press @ nacelle inlet	ST-67773	0-500 psia	0.25
4	PBHNOI	Bleed Heater Nozzle Inlet Pressure	ST-67772	0-1000 psia	0.25

Manufacturers: S: Sensotec
ST: Setra

*Percent of full scale reading

Table 2. Details of AEN Temperature Measurement

THERMOCOUPLE NUMBER	MODCOMP CHANNEL	SOFTWARE SYMBOL	ITEM DESCRIPTION
TC-40	105	TPAN-1	Test Panel Backside Temp. #1
TC-41	106	TPAN-2	Test Panel Backside Temp. #2
TC-42	107	TPAN-3	Test Panel Backside Temp. #3 (Runs 60 and 61 only)
TC-42	107	T-JET	Bleed air temp. adjacent to in duct (Run 62 and on)
TC-43	108	TPAN-4	Test Panel Backside Temp. #4
TC-44	109	TPAN-5	Test Panel Backside Temp. #5
TC-45	110	TPAN-6	Test Panel Backside Temp. #6
TC-201	97	TBHOUT	Bleed Heater Outlet Temp.
TC-202	99	TBHNAI	Bleed air temp. at nacelle inlet
TC-205	98	TBHNOI	Bleed air nozzle inlet temp

All TC's are type K and are accurate to approximately ± 4 deg. F.

A date/time generator providing date and time information to the nearest second was displayed at the top of the screen on the control room video monitor. A Umatic format video tape recorder also received signals from the video camera in the test cell and from the date/time generator. Video tapes were made of all panel tests using this equipment.

During actual testing, the date/time code could not be exactly correlated with the operation of the sliding gate that uncovered the jet or with the control system that increased the bleed airflow from its preheat level to the intended test condition. Examination of these tapes after testing, however, allowed relatively precise definition of these events. A change in the pattern of light reflection caused by panel deflection identified the time at which the jet was fully impinging on the panel. Because 60 video fields were acquired per second, the actual timing resolution available replaying the tapes was about 1/60 the second. Hence, the time code on the tape allowed the failure time to be checked by replaying the tape after each test where a failure had occurred.

The AEN video equipment used during this test is identified in greater detail in Figure 7.

2.2.3 Electrical Conductivity Meter

A Verimet conductivity meter, model M 4900A, on loan from the Materials Laboratory of AFWAL at WPAFB and was used to determine changes in the electrical conductivity of the panels exposed to the high temperature jet. This unit generates an eddy current and measures the resistance to current passage through the tip of the unit in contact with the panel. The unit was calibrated prior to the acquisition of conductivity data using strips of metal supplied with the unit by the Materials Lab.

The output reading is the ratio of the panel conductivity to that of a standard annealed copper panel, hence % IACS (International Annealed Copper Standard) is the normal conductivity measurement parameter.

2.3 Data Acquisition and Reduction

The panel penetration test data consisted of temperature, pressure, flowrate and time data, along with test run and condition number and test title information. This information was measured by sensors in the test cell and sampled,

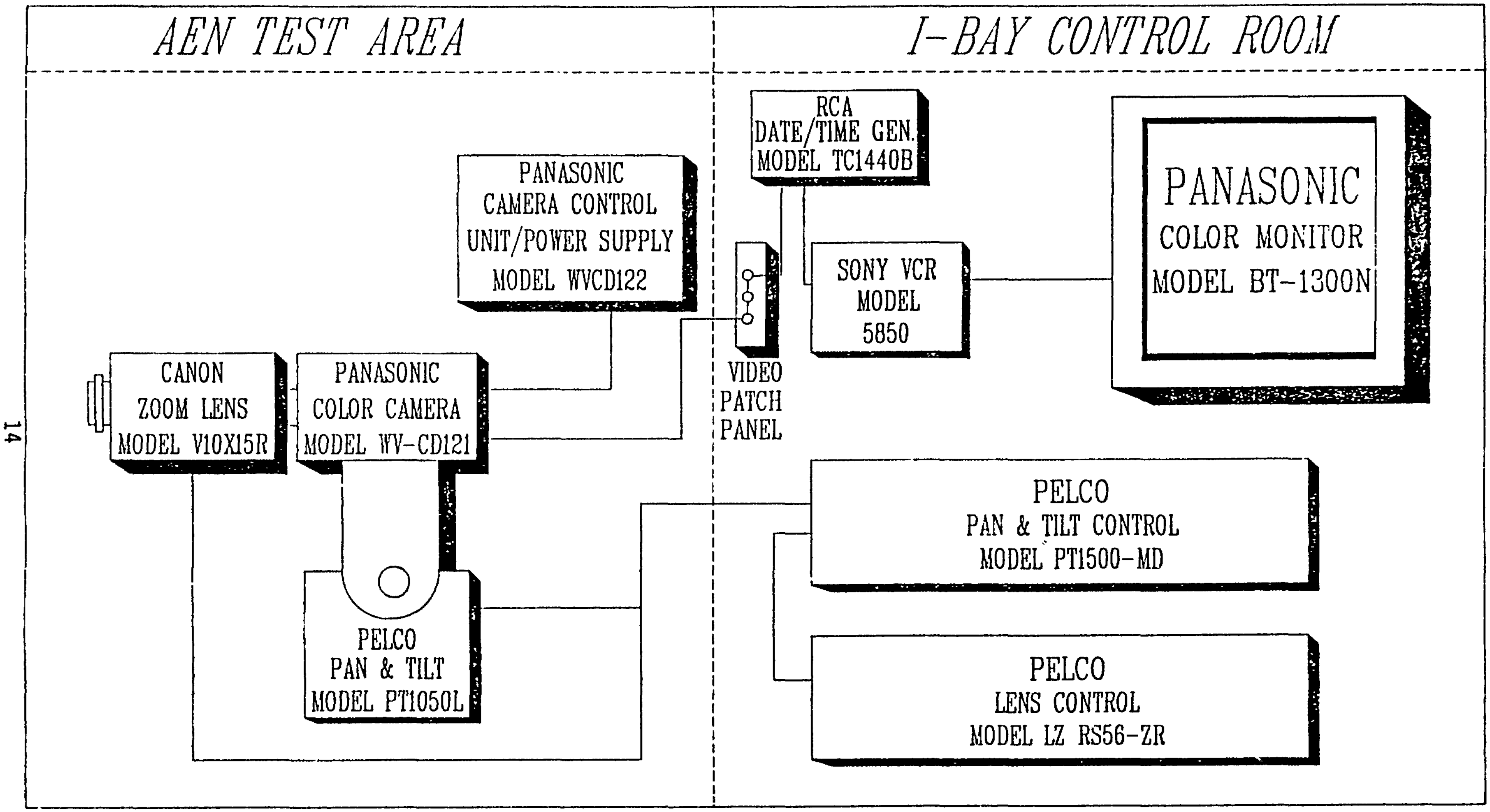


Figure 7. AEN Video Equipment

digitized, averaged, and calibrated by the facility computer system. In addition, video tape records were made of the tests.

2.3.1 Basic Data

The AEN facility computer is a 16-bit, general purpose, digital computer for real time multi-programming applications with 64 K RAM memory manufactured by Modular Computer (ModComp) Systems, Inc. (Figure 8).

Data were acquired by the AENFTS computer at the rate of one sample every 4 seconds. These data were then reduced to appropriate pressure and temperature engineering units using previously acquired calibration data. Once the ModComp computer had calculated engineering unit data for the thermocouples and pressure transducers and the bleed air system flow meter, these data were displayed on the control console monitor and output to the line printer and ModComp data disk for storage. The actual data reduction equations employed are included in Appendix B. The data displayed on the AEN console were updated approximately once every 10 seconds.

A video tape record was made of all tests to allow reexamination of test events after their occurrence, determination of panel penetration times and allow direct comparison of tests run at different times. Cassette identification and the location of a particular test run on that casette was recorded on the test log sheets.

2.3.2 Panel Conductivity Data

To minimize measurement variation, a paper template was prepared to locate the meter in the same locations (Figure 9) on each of the seven panels for each series of readings and the same technician was employed to make the measurements. In addition, the conductivity of a seventh panel, which had not been exposed to high temperatures, was measured at the same locations over a similar period of time to ensure that the meter calibration had not changed and to examine the data scatter experienced when no change in panel conductivity was anticipated.

2.3.3 Disposition of Test Data

All test data, including run logs, magnetic tapes of ModComp data, oscillograph charts, "floppy" disks containing Lotus 1-2-3 worksheets and plot files and

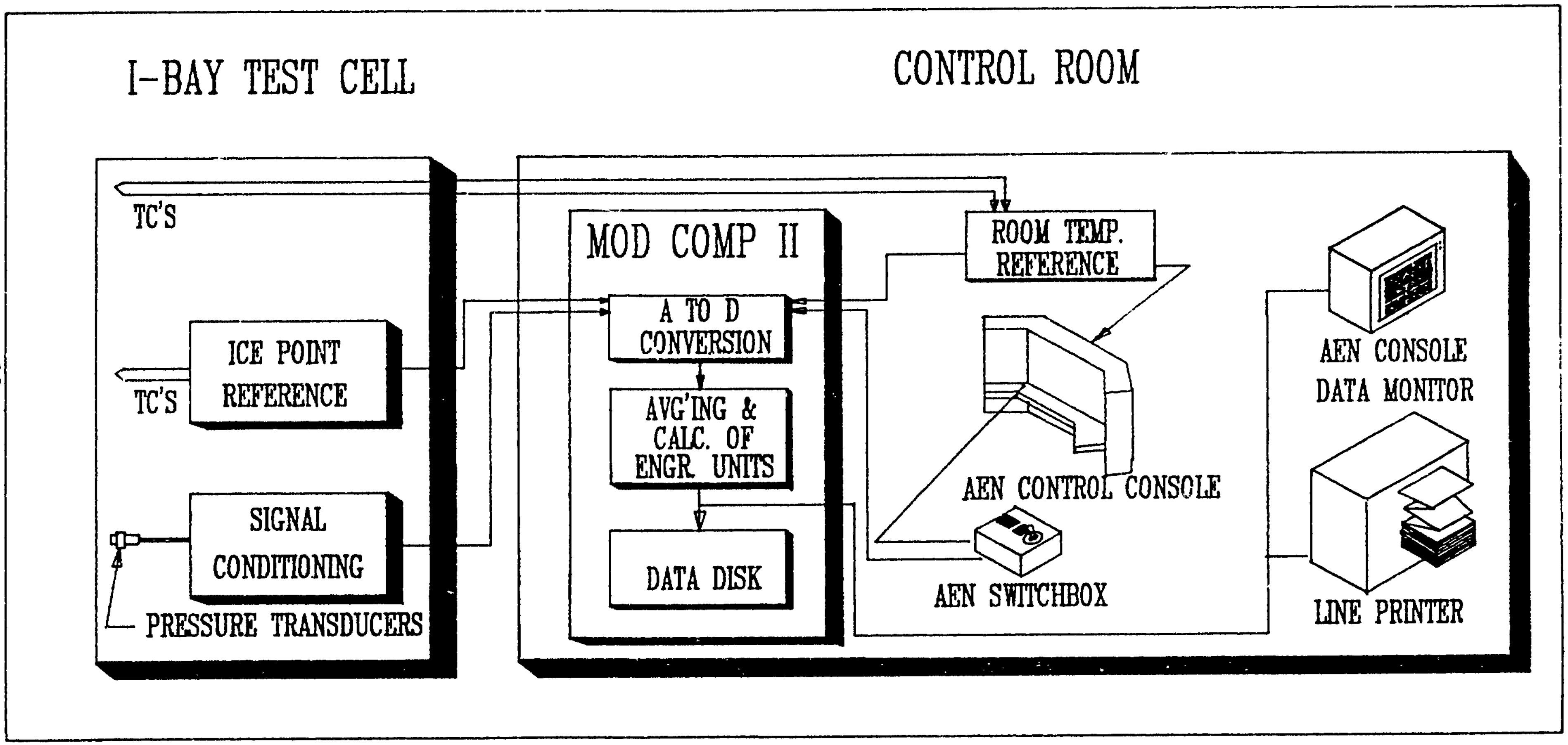
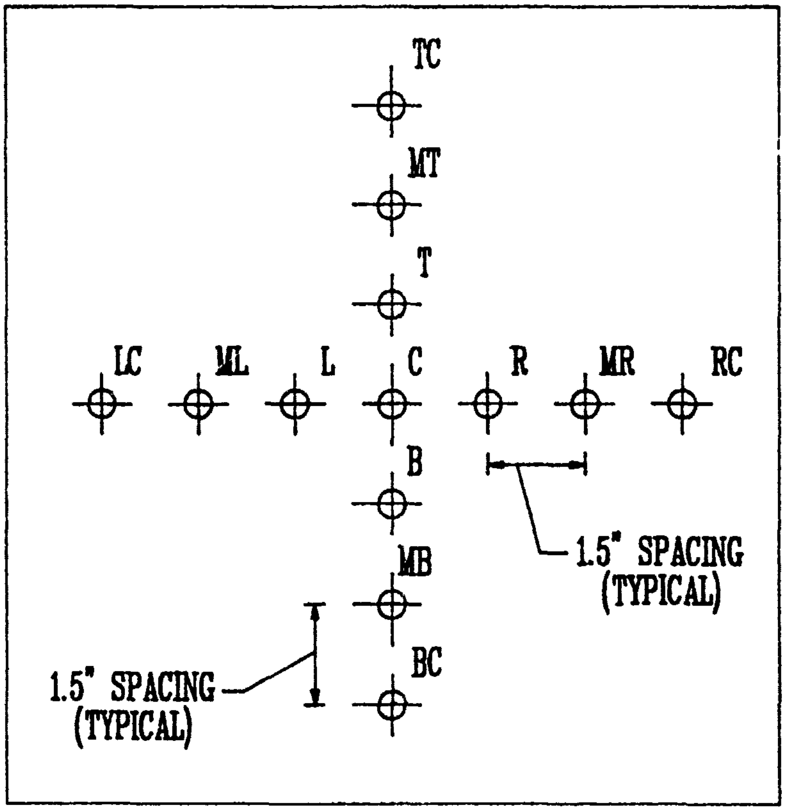


Figure 8. Schematic Diagram of AEN Data Acquisition and Reduction System



12 INCH SQUARE 2024-T81
PANELS, 0.050 INCH THICK

Figure 9. Locations for Conductivity Readings

video tapes acquired during testing are on file in the BMAC test office in I-Bay of Bldg. 71B at WPAFB.

2.4 Test Procedure

The first two test runs (60 and 61) consisted of seven test conditions, run at various jet pressures and temperatures. The 0.050-inch thick 2024-T81 panels were positioned six inches from the simulated bleed duct. The test configuration closely simulated the environment in the F-16 engine compartment. While little damage was observed with the panels at this distance from the jet, a procedure was developed during these tests that was followed throughout the remainder of the panel testing.

2.4.1 Bleed Air Impingement Tests

The bleed duct bypass valve was opened and the sliding gate over the jet was closed during the preheat operation so that most of the simulated hot bleed air was exhausted back into the AEN test section. The bleed air heater system was run in the preheat mode for about half an hour prior to testing with the heater output set point adjusted several hundred degrees higher than the jet temperature to be tested. The bleed airflow was then increased to its maximum, one lb/second, until the air temperature just upstream of the jet, (T-JET) reached the desired jet temperature.

The test was initiated by the manual closing the bleed duct bypass valve as the test operator in the control room started the VCR, oscillograph and data acquisition. Just prior to leaving the test cell, the technician would move the sliding gate to uncover the jet. Once he was out of the test cell, the test operator selected the desired test airflow and observed the TV monitor so that he could start a stopwatch at the moment that the jet was impinging fully on the panel. As mentioned above, this event was determined within a fraction of a second, because the light reflection patterns on the panel changed as the jet impingement began.

The data, displayed on the control console monitor and stored on the ModComp. were acquired once each ten seconds. Observation of the digital panel meters (DPM's) and review of the oscillograph charts indicated the jet airflow, pressure and temperatures stablized within the first several seconds after the test mode was selected on the heater control.

The test cell ambient temperature was not recorded during these tests, but was observed on the console monitor, this temperature varied between about 90° and 100°F.

The temperatures on the panel backside increased to a relatively constant maximum value during the first minute that the jet was impinging on the panel and then remained fairly constant. Generally, panel failure, when it occurred, happened within the first 12 seconds of the test. If there was no failure, the test was continued for ten minutes before concluding that the panel would not be penetrated.

Following ten minutes of testing (or failure), the sliding gate was closed and the bleed duct bypass valve was opened. If the panel failed, the time until failure was entered in the test log along with other observations. The panel was then replaced with the next test specimen.

2.4.2 Eddy Current Conductivity Tests

Eddy current electrical conductivity tests were also made on the panels in support of the F-16 incident investigation, because previous studies had shown that exposure to high temperatures alters the electrical conductivity of aluminum panels. The objectives were to determine the change in conductivity and if the change was permanent.

AFWAL Materials Labaratory personnel suggested that the conductivity could change by the hour immediately following exposure to the hot jets and by the day for some time after that. Hence, following completion of the panel penetration testing another set of five 0.050-inch thick 2024-T81 panels was exposed to temperatures of 900 and 1100°F for time periods from 6 seconds to 10 minutes. A sixth panel which was not exposed to the hot jets was included in this set as a baseline.

A template had been prepared defining the locations for conductivity measurements on the panel front surface (Figure 9). Care was taken to assure that measuring points were duplicated as closely as possible from test to test. Measurements were repeated on some of the panels following exposure to the hot jets at intervals of 10 minutes, 1, 2, 24, 48, 72, 96 and 192 hours. Panels with little or no change in conductivity after the first 24 hours were tested less frequently.

3.0 TEST ARTICLE

While the AEN bleed air heater system was designed and constructed so that its airflow would be routed through the side of the AEN test section into an actual engine bleed duct in the normal AEN test article, the flow was rerouted for the panel penetration testing.

An engine bleed duct simulator (Figure 10) made from a 16-inch length of 1.5-inch diameter 0.032 wall CRES tubing was attached to a framework of Unistrut channels at the outside of the test section. This tubing, a throttling valve and appropriate elbows and fittings were installed between the insulated flex duct which delivered the simulated bleed airflow and the fitting where the airflow normally entered the AEN test section (Figure 11).

In order to maximize the pressure of the simulated bleed airflow, a 0.6875-inch diameter hole was drilled in the side of the duct simulator and located to direct the air jet at the center of the test panel. A short section of two-inch diameter CRES tubing was installed over the simulated bleed duct to prevent heated air from impinging upon the panel during preheat operation or when panels were being changed; the outer tubing formed a sliding gate (Figure 12).

The panels were bolted to the Unistrut structure which supported the simulated bleed duct. The outer 3/4-inch of the edge of each panel was bolted to and supported by the Unistrut channel (Figure 13); the center of the panels was unsupported. Thermocouples were located behind the panel to measure the backside temperature, and were held in place by coil springs (Figure 14). The springs were used so that the thermocouples would not provide any additional support to the center of the panels. The thermocouple positions on the back side of the panel are identified in Figure 10.

The test panels were all 12-inch squares of common aircraft aluminum alloys, including 2024 (T3 and T81), 6061-T6 and 7075-T6. Most were 0.050-inch thick, although 0.032- and 0.071-inch thick panels of 2024-T3 were also tested. In addition, 2024-T81 panels, 0.050-inch thick, were tested with insulative panel coatings. These included Crown Metro 64-1-2 and Martin Marietta MA-25S, 0.090 and 0.25-inches thick. Table 3 identifies all the test panels in terms of their alloy, heat treating, thickness and coating (when applicable).

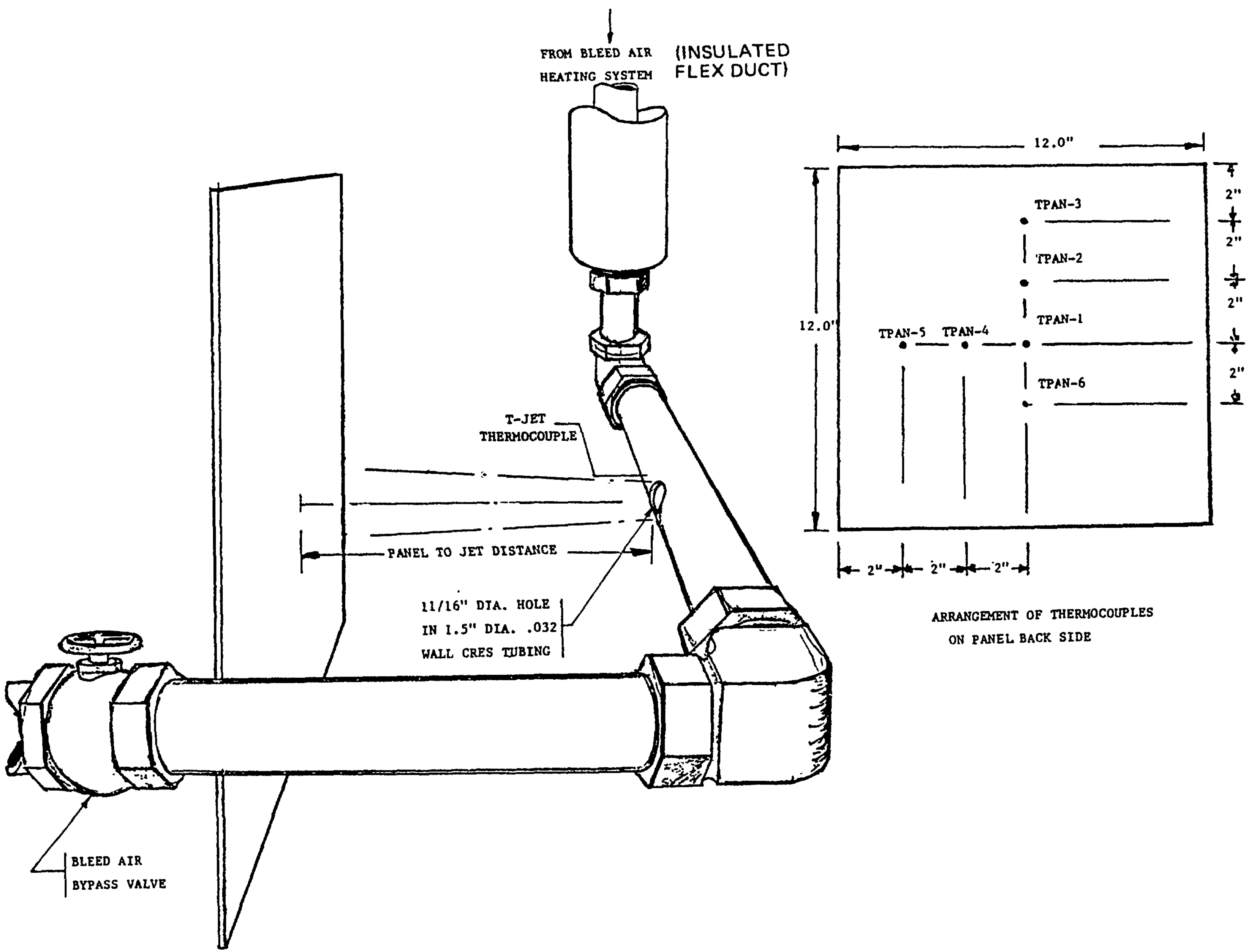


Figure 10. Test Article for F-16 Panel Penetration Testing

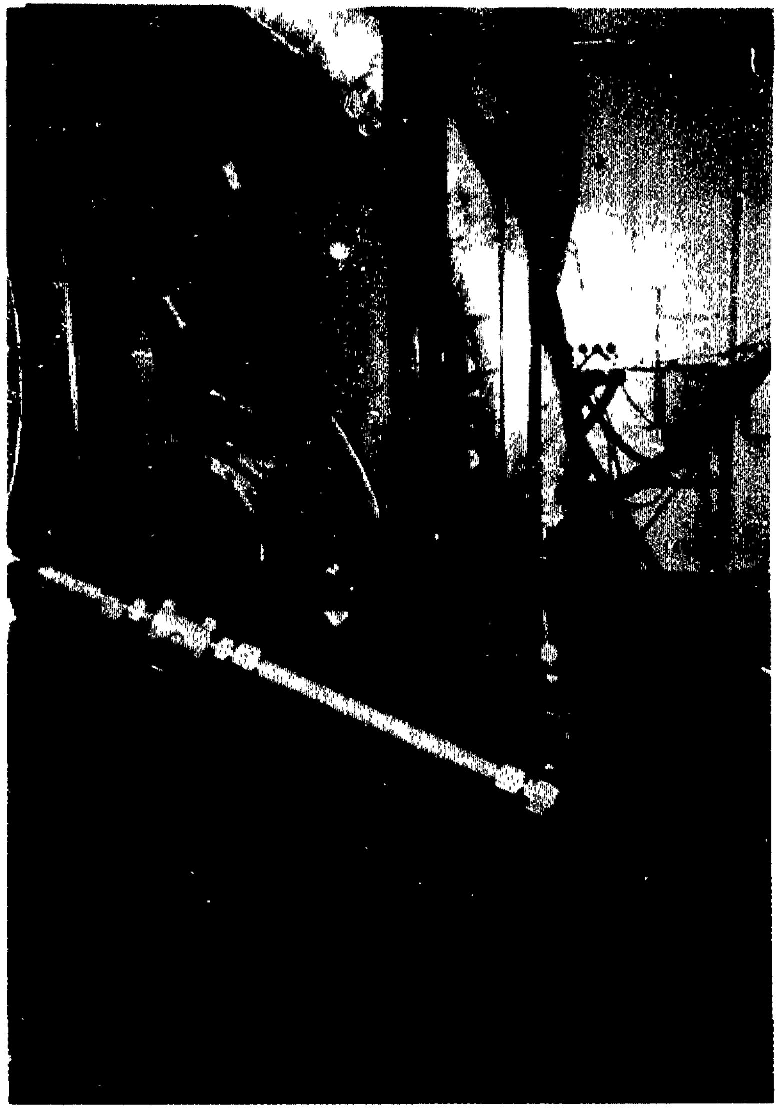


Figure 11. *Test Article Viewed From Side*

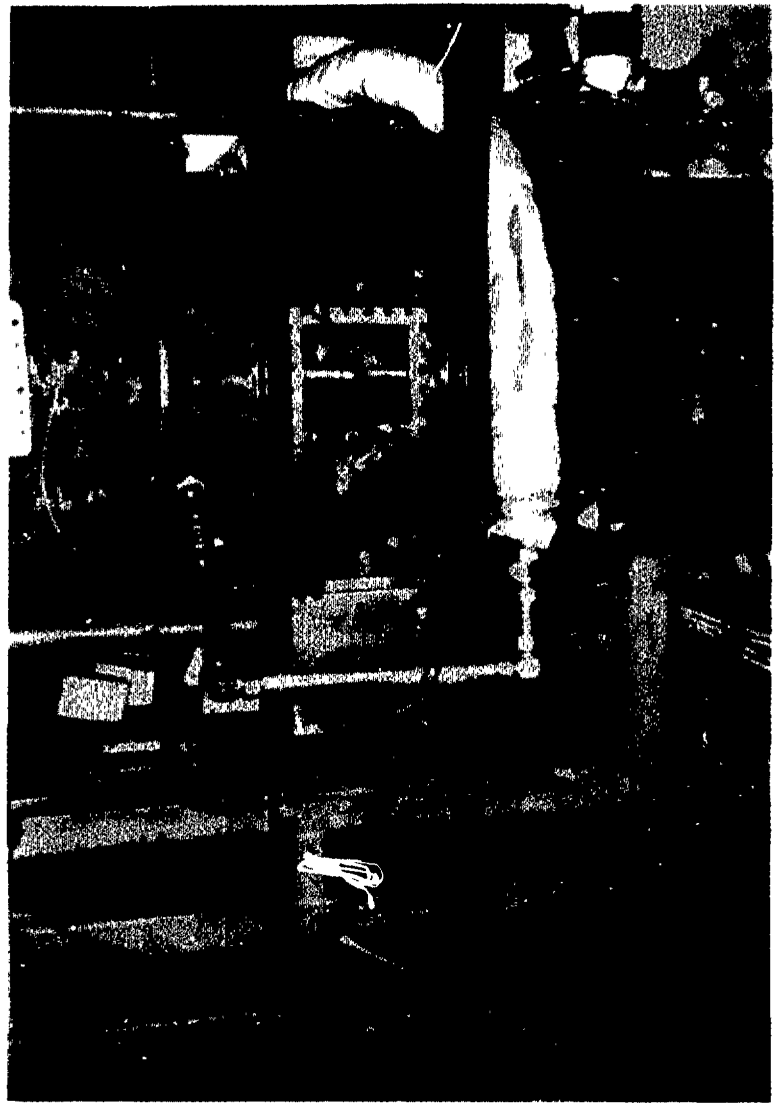


Figure 12. *Test Article with Test Panel Installed Showing Sliding Gate*

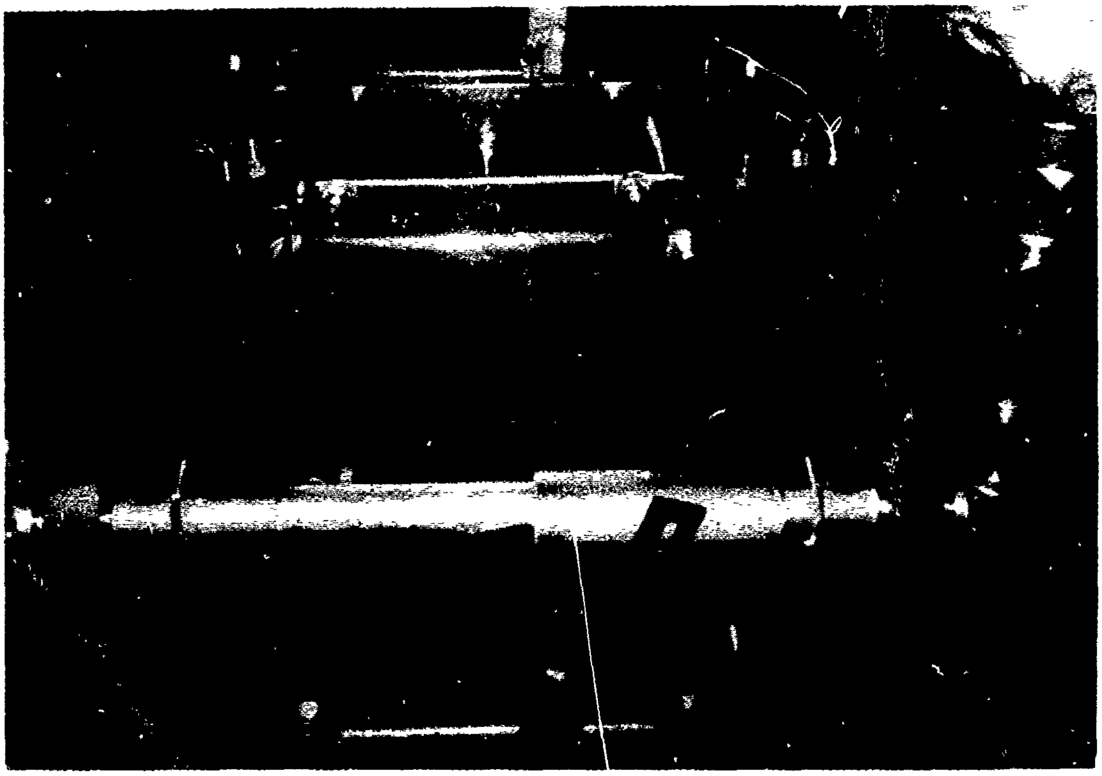


Figure 13. Close-Up of Test Article with Test Panel Installed

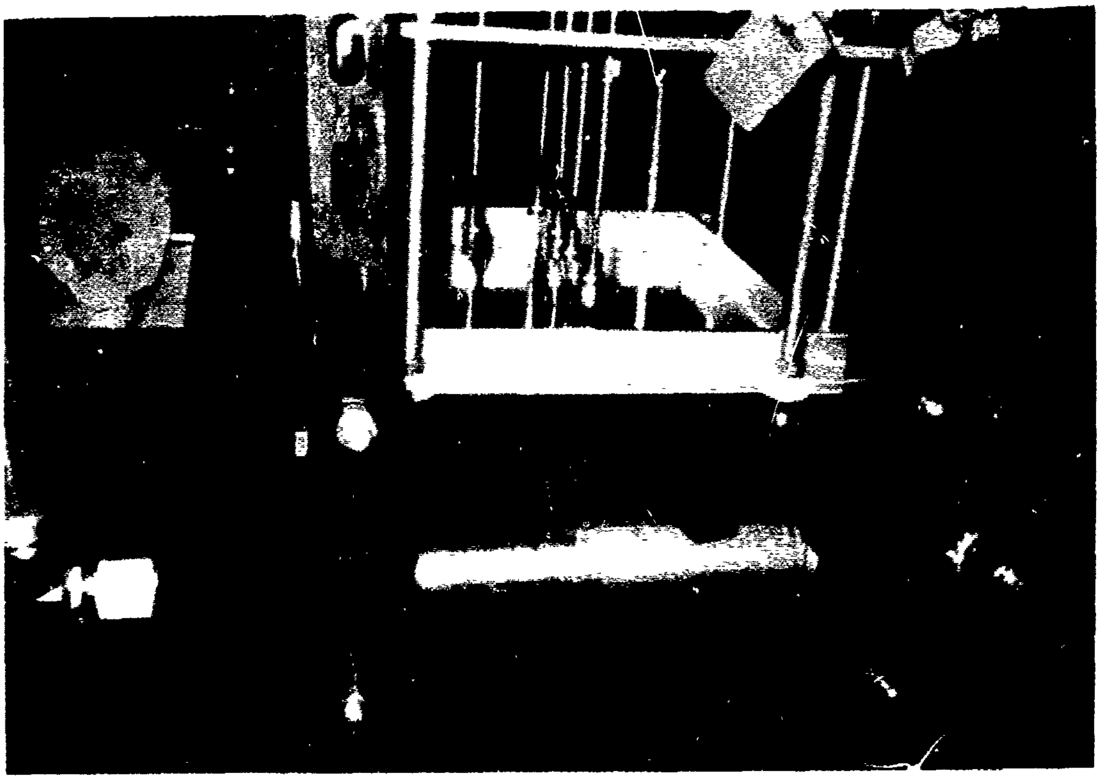


Figure 14. Test Article Viewed from Above Showing Backside Thermocouples Held in Contact with Panel

4.0 TEST RESULTS

Test results are summarized in Table 3. Photographs of all the panels tested showing the extent of the damage sustained are included in Appendix C, and plots showing the variation in jet and panel backside temperature during the tests are included in Appendix D. Test results are explained in detail below and analysis of results is provided in Section 3.0.

4.1 Phase I: 2024-T81 Panels

Initial tests involved 0.050-inch thick 2024-T81 panels located six inches from the hot bleed duct because the original purpose of the test was to explore the possibility that a bleed leak impinging on the aft fuel tank wall had been the cause of the loss of an F-16. Tests were conducted with jet temperatures of 900, 1000 and 1100 degrees F as jet airflow and pressure were increased from 0.33 lbs/second at 66 PSIA to 1.03 lbs/second at 220 PSIA. None of the panels failed. At the highest pressure and temperature, minimal deformation took place after ten minutes of jet impingement. At the maximum, a "dimple" was formed about 0.130-inches deep, over an area about four-inches by two-inches.

When a 0.050-inch thick 2024-T81 panel was placed within one inch of an 1100^{o}F jet, an area about one square inch in the center of the panel blew out within six seconds; results for a panel located two inches from the jet were nearly identical. When failure of panel materials occurred, its appearance was that of weakening of the metal from high temperature accompanied by deformation due to the high pressure, followed by failure in shear (Figures 3 and 4). No melting or burning in the region of the failure was observed.

With the panel at four inches from the exit plane of an 1100^{o}F jet, the backside temperatures increased monotonically during the entire ten minute test, reaching a maximum of about 750^{o}F (Figure 15). Since the temperature at the center of the panel was still increasing at ten minutes, the panel probably would have failed at some point beyond ten minutes. When the test was terminated, a cavity about 0.33-inches deep had formed.

With the panel within one-inch of the jet and the jet temperature at 1000^{o}F, panel backside temperatures increased to about 700^{o}F within 30 seconds but remained essentially constant for the remainder of the ten minute test, and the panel was not perforated. A larger cavity (about 0.5-inches deep) compared with

Table 3. Summary of Panels Tested and Test Results

PANEL NUMBER	MATERIAL	COATING & THICKNESS (SEE NOTE)	THICKNESS (INCHES)	RUN NUMBER	CONDITION NUMBER	DATE	DISTANCE FROM JET (INCHES)	JET PRESSURE (PSIA)	JET TEMP. (DEG. F.)	JET AIRFLOW (LBS/SEC)	BURN-THRU YES/NO & TIME (SECONDS)
1	2024-T81	NONE	0.050	60	1	4/1/86	6	66	996	0.33	NO
2	2024-T81	NONE	0.050	60	2	4/1/86	6	68	996	0.33	NO
3	2024-T81	NONE	0.050	60	3	4/1/86	6	145	995	0.68	NO
4	2024-T81	NONE	0.050	60	4	4/1/86	6	215	995	1.03	NO
5	2024-T81	NONE	0.050	61	1	4/2/86	6	48	997	0.33	NO
6	2024-T81	NONE	0.050	61	2	4/2/86	6	156	996	0.68	NO
7	2024-T81	NONE	0.050	61	3	4/2/86	6	157	1097	0.68	NO
8	2024-T81	NONE	0.050	62	1	4/3/86	6	220	1108	1.02	NO
9	2024-T81	NONE	0.050	62	2	4/3/86	1	220	1091	1.02	YES/ 6
10	2024-T81	NONE	0.050	62	3	4/3/86	2	220	1050	1.02	YES/ 6
11	2024-T81	NONE	0.050	62	4	4/3/86	4	220	1114	1.02	NO
12	2024-T81	NONE	0.050	63	1	4/4/86	1	222	1011	1.01	NO
13	2024-T81	NONE	0.050	63	2	4/4/86	1	220	1100	1.01	YES/ 6
14	2024-T81	NONE	0.050	63	3	4/4/86	2	220	1100	1.01	YES/ 6
15	2024-T3	NONE	0.032	64	1	4/8/86	1	217	1008	1.02	YES/583
16	2024-T3	NONE	0.032	64	2	4/8/86	2	217	1008	1.02	YES/489
17	2024-T3	NONE	0.032	64	3	4/8/86	2	216	1090	1.03	YES/2
18	2024-T3	NONE	0.032	64	4	4/8/86	4	216	1099	1.03	YES/496
19	2024-T3	NONE	0.071	65	1	4/11/86	1	220	1100	1.03	YES/20
20	2024-T3	NONE	0.071	65	2	4/11/86	2	220	1007	1.03	NO
21	2024-T3	NONE	0.071	65	3	4/11/86	2	220	1101	1.03	YES/12
22	2024-T3	NONE	0.071	65	4	4/11/86	1	216	1008	1.03	NO
23	2024-T3	NONE	0.071	65	5	4/11/86	4	220	1102	1.03	NO
24	7075-T6	NONE	0.050	66	1	4/11/86	1	212	1000	1.03	NO
25	7075-T6	NONE	0.050	67	1	4/14/86	1	213	1105	1.02	YES/9
26	7075-T6	NONE	0.050	67	2	4/14/86	2	210	1112	1.00	YES/9
27	7075-T6	NONE	0.050	67	3	4/14/86	4	218	1112	1.03	NO
28	2024-T3	NONE	0.050	68	1	4/15/86	1	214	1009	1.03	NO
29	2024-T3	NONE	0.050	68	2	4/15/86	2	214	1100	1.03	YES/5
30	2024-T3	NONE	0.050	68	3	4/15/86	4	219	1100	1.03	NO
31	6061-T6	NONE	0.050	69	1	4/15/86	1	210	1022	1.03	NO
32	6061-T6	NONE	0.050	69	2	4/15/86	2	215	1106	1.03	NO
33	6061-T6	NONE	0.050	69	3	4/15/86	1	215	1110	1.03	NO
34	2024-T81	NONE	0.050	70	1	4/15/86	1	215	1100	1.02	YES/5
35	2024-T81	M/M @ .090"	0.050	71	1	4/28/86	1	215	1100	1.02	YES/35
36	2024-T81	M/M @ .090"	0.050	71	2	4/28/86	2	215	1100	1.02	YES/18
37	2024-T81	M/M @ .090"	0.050	71	3	4/28/86	4	216	1105	1.02	NO
38	2024-T81	M/M @ .090"	0.050	71	4	4/28/86	2	202	910	1.02	NO
39	2024-T81	M/M @ .250"	0.050	72	1	5/8/86	4	220	1120	1.02	NO
40	2024-T81	M/M @ .250"	0.050	72	2	5/8/86	2	220	1110	1.02	YES/30
41	2024-T81	C/M @ .090"	0.050	72	3	5/8/86	2	215	1110	1.02	YES/21
42	2024-T81	C/M @ .090"	0.050	72	4	5/8/86	4	214	1105	1.02	NO
43	2024-T81	C/M @ .090"	0.050	72	5	5/8/86	2	200	905	1.02	NO
44	2024-T81	C/M @ .250"	0.050	73	1	5/12/86	4	210	904	1.02	NO
45	2024-T81	M/M @ .250"	0.050	73	2	5/12/86	4	208	900	1.02	NO
46	2024-T81	M/M @ .250"	0.050	73	3	5/12/86	4	206	905	1.02	NO
47	2024-T81	NONE	0.050	73	4	5/12/86	4	204	905	1.02	NO
48	2024-T81	NONE	0.050	73	5	5/12/86	2	202	910	1.02	NO
49	2024-T81	NONE	0.050	73	6	5/12/86	4	220	1102	1.02	NO
50	2024-T81	NONE	0.050	73	7	5/12/86	4	218	1102	1.02	NO
51	2024-T81	NONE	0.050	73	8	5/12/86	2	218	1100	1.02	YES/6

NOTE ON COATINGS:
M/M INDICATES MARTIN MARIETTA MA-25S MATERIAL
C/M INDICATES CROWN METRO 64-1-2 MATERIAL

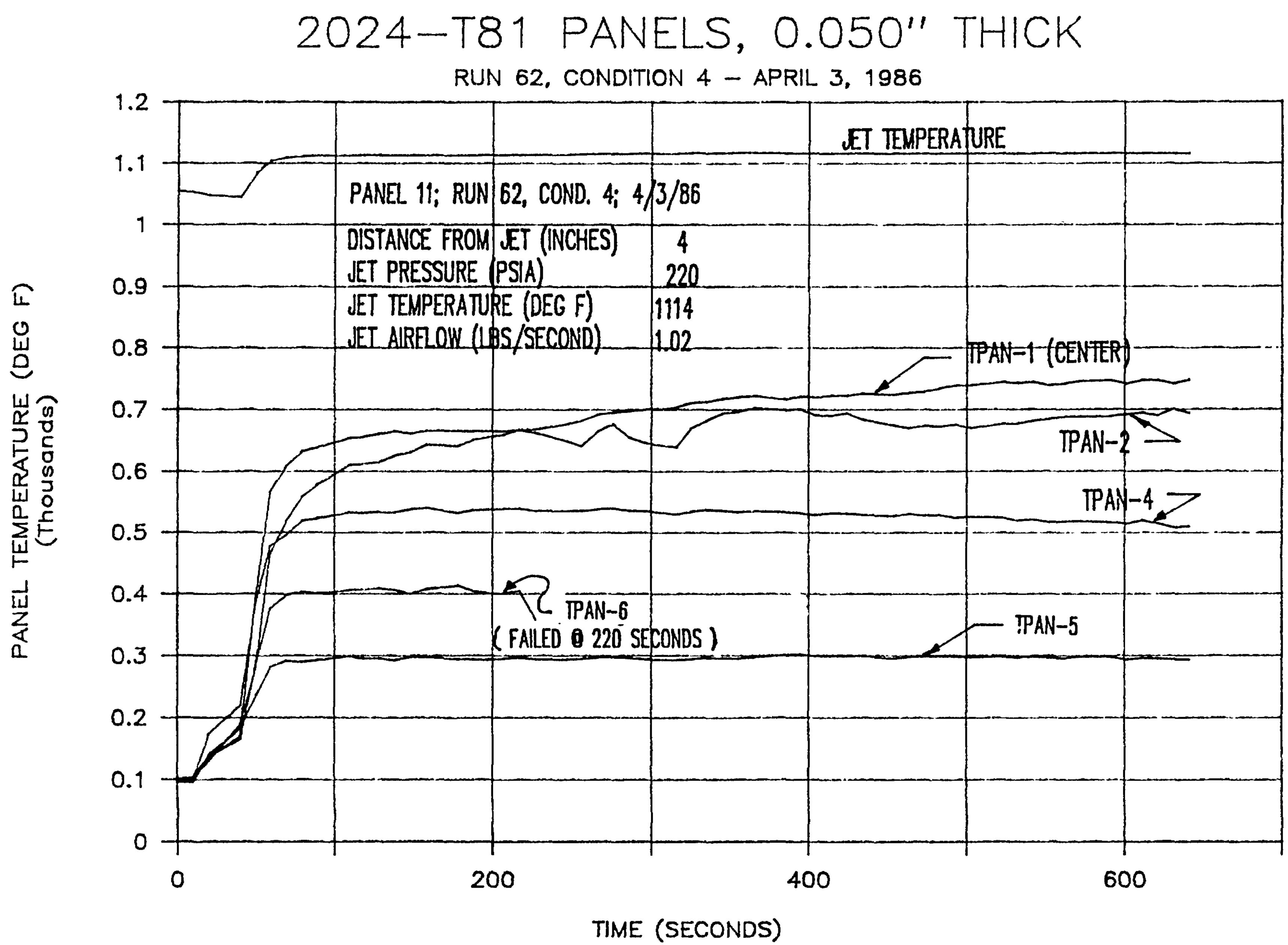


Figure 15. Panel Backside Temperature Variation During Ten Minute Test

tests at six inches away from the jet. The tests at 1100°F were repeated and the results were similar; panels failed within six seconds at both one and two inches from the jet.

The pressure and temperature in fighter aircraft engine bleed ducts can be as high as 420 psia and 1300°F, respectively. It was not within the scope of this testing or capability of the test facility to investigate effects at these conditions. Indications are, however, that failure of the 0.050-inch panels may well have occurred at the higher temperature and pressure conditions at the six-inch spacing. The effect would not necessarily be more severe in terms of damage to the panel, but failure is quite likely to occur faster. A more comprehensive investigation of bleed air conditions and their effect on the probability of failure is appropriate for future work.

4.2 Phase II: Other Aircraft Panel Types

4.2.1 2024-T3 Panels

Three thickness (0.50-, 0.032- and 0.071-inch) panels made from 2024-T3 aluminum were tested. The results from the 0.050-thickness panels were similar to those from tests on the 0.050-inch thick 2024-T81 alloy panels. No failures were observed with a jet exit plane temperature of 1000°F even at the minimum one-inch spacing between the jet and test panel. The backside temperatures reached a maximum of about 500°F within the first minute of testing and remained constant thereafter. When the jet temperature was increased to 1100°F, panel failure occurred within five seconds at a spacing of two-inches, but no failures at a spacing of four-inches were observed.

With 0.032-inch thick panels failure occurred more rapidly and at greater distances from the jet exit plane. The 1100°F jet caused the panel to fail within two seconds at two inches from the jet and after about eight minutes at four-inches. The 1000°F jet caused the panel to fail within about eight minutes at two inches from the jet.

The results with 0.071-inch thick panels were similar to those with the 0.050-inch thick panels except that penetration took somewhat longer. With the jet temperature at 1100°F, 20 seconds were required for failure at a panel distance of one inch from the jet and similarly, 12 seconds at two-inches. While the order of these two occurrences might seem to be reversed, subsequent examination of the test data indicated that the jet temperature was five to ten degrees higher for the two-inch test. The results obtained earlier with the 2024-T81 panels also had indicated that the difference between being one inch or two inches from the jet exit plane was minimal.

4.2.2 7075-T6 Panels

Results from testing 0.050-inch thick 7075-T6 aluminum panels were similar to those for the 2024-T3 and 2024-T81 panels. With a jet temperature of 1100 degrees F, penetration occurred in nine seconds at both one and two inches from the jet, but no penetrations were observed at four inches from the jet. When the jet temperature was reduced to 1000°F, no failures were observed even at a one-inch jet to panel spacing.

4.2.3 6061-T6 Panels

No failures were observed on tests of 6061-T6 aluminum along panels, even at 1100°F and at one inch from the jet exit plane. The size of the depressions which resulted was considerably greater than with other alloys (up to 0.625 inch deep). The panel backside temperatures took somewhat longer to reach their maximum values, e.g., about three minutes with the panel at two inches from the exit plane of the 1100°F jet. Maximum backside temperatures did not exceed 800°F.

4.3 Phase III: Coated 2024-T81 Panels

4.3.1 Martin Marietta MA-25S Coating

Coating the 2024-T81 panels with a 0.090 layer of Martin Marietta MA-25S insulating material (a material suitable for a non-firewall area of an engine compartment) did not change resistance to penetration significantly. This coating consists of a porous silicon insulating material with a top coating made from nonwoven Kevlar mat. Tests run with the panel at one, two and four inches from the exit plane of an 1100°F revealed that the top coating was consistently burned away within the first few seconds of exposure. Erosion began as the preheat flow reached the panel after opening the sliding gate. The preheat flow rate was about 0.15 pounds per second.

Once the top coating was removed, the silicon material was eroded by the jet in times varying from 20 to 90 seconds (at one and four inches, respectively) leaving an area of bare metal. When the bare metal was exposed, it failed in the same time as without the coating (about six seconds). At four inches from the jet, the panel did not fail in the full ten minutes of exposure to the jet, consistent with the results obtained without the coating.

With the jet temperature reduced to 900^{o}F and the coated panel placed within two inches of the jet exit plane, the top coat again eroded within a few seconds. At this temperature, it took much longer for the silicon material to erode, although a clear patch of bare metal was visible within two minutes. No panel penetration occurred during this test, again consistent with the results obtained with the uncoated panels.

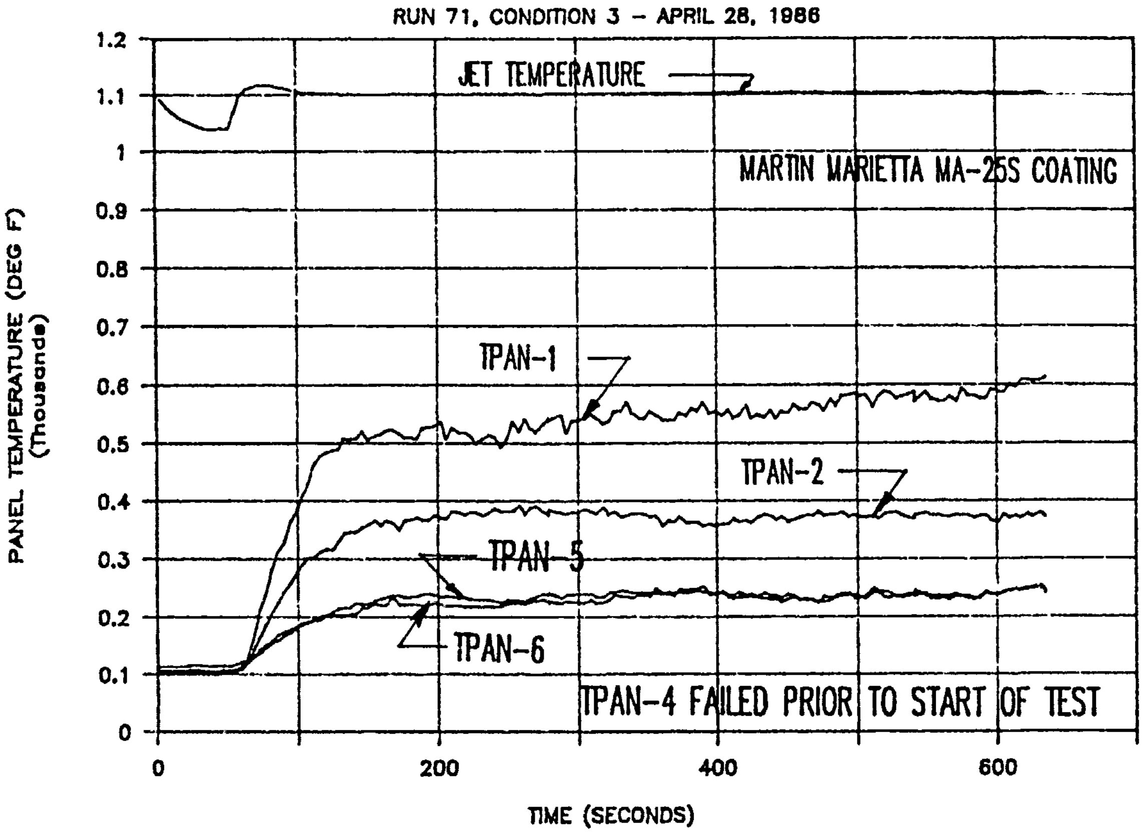
When the MA-25S coating thickness was increased to 0.25 inches, as it would be for an engine compartment firewall, the results did not change. Again, the top coat burned away in the first few seconds. The thicker silicon material eroded from the center of the panel within the first several minutes, and the result of impingement of the jet on the bare panel was then the same as without the coating.

4.3.2 Crown Metro 64-1-2 Coating

The results obtained with the Crown Metro coating were about the same as those obtained with the Martin Marietta coating in the tendency of the panel to be damaged by the jet of hot air.

4.3.3 Comparison of Insulation Provided by Coatings

The backside temperatures experienced with 0.090-inch thick coatings of the two materials for ten minutes of exposure to an 1100^{o}F jet at a distance of four-inches are compared in Figure 16. The backside temperatures experienced with the MA-25S are shown in the top half of the figure while the backside temperatures experienced with the Crown Metro material are shown in the lower half. The thermocouple in the panel center, TPAN-1, reads a 50 to 80 degrees lower temperature with the MA-25S material during the first half of the run but reaches about the same level as with the Crown Metro during the remainder, although the video tape suggests the insulation had been eroded away from the panel center in about the first 30 seconds. TPAN-2, which is two inches above



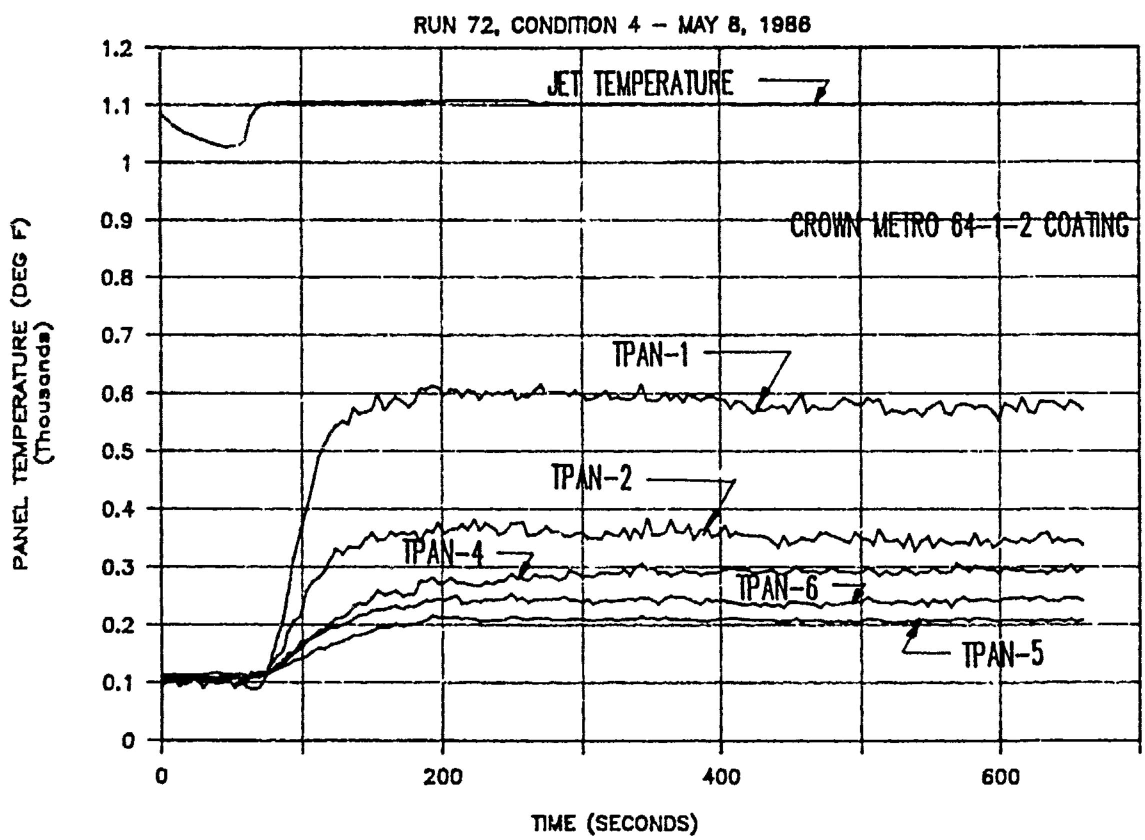


Figure 16. Comparison of Insulating Capabilities with 1100 deg F Jet at 4 Inches

the center, and TPAN-6 which is two inches below the panel center, appear about the same with either material. TPAN-5, which is four inches to the left (upstream) of the panel center, appears to have been 20 to 30 degrees cooler with the Crown Metro material.

A similar comparison was made for a 900°F jet at a distance of two inches from the jet exit plane (Figure 17). In this case TPAN-4 and TPAN-5 still read about the same with either material, but TPAN-1 is 50 to 100 degrees cooler and TPAN-2 is 30 to 60 degrees cooler with the MA-25S. Hence it appears, despite inconsistent results, the MA-25S provides somewhat more insulation than the Crown Metro coating.

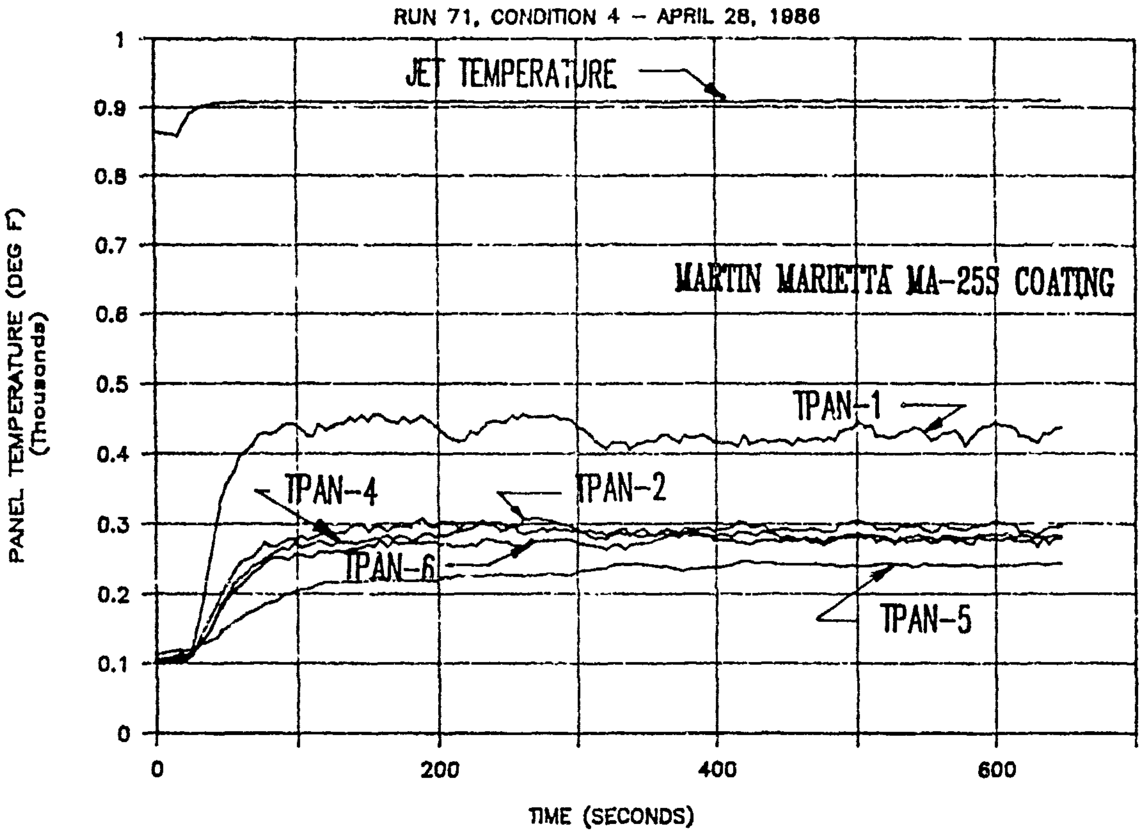
4.4 Phase IV: Panel Electrical Conductivity

The baseline panel, number 52, was not exposed to high temperature during the 8 days that the electrical conductivity measurements were made. Measurements of the baseline panel's conductivity was 36.9± 0.2% of the International Annealed Copper Standard (IACS) at all locations and all times during those eight days. The meaurements were more than 1% below the 38 to 42% range considered appropriate for this alloy in the Reference 5 specification. (Conductivity readings in this report are all based on the IACS standard). Measurements made near the edges of the panels subjected to high temperatures were similar to those made on panel 52.

It was concluded that all of the 2024-T81 panels, which had been specially purchased in 2024-T3 condition and heat treated to T81 condition for this test, had received excessive heat treatment, but that the changes in conductivity would be representative and diagnostic information obtained in this test would still be usable.

The AFWAL Materials Laboratory indicated that it was essential that the base of the CU meter be held normally against a smooth surface or the conductivity readings would be erratic. They also indicated that the conductivity readings would change with time.

The variation in conductivity readings taken on the panel surface 1.5-inches above the panel centers over the first eight days after exposure to the hot jets was plotted (Figure 18). The erratic nature of the data for panel 51 is probably due to the surface roughness caused by exposure to the hot jet at the



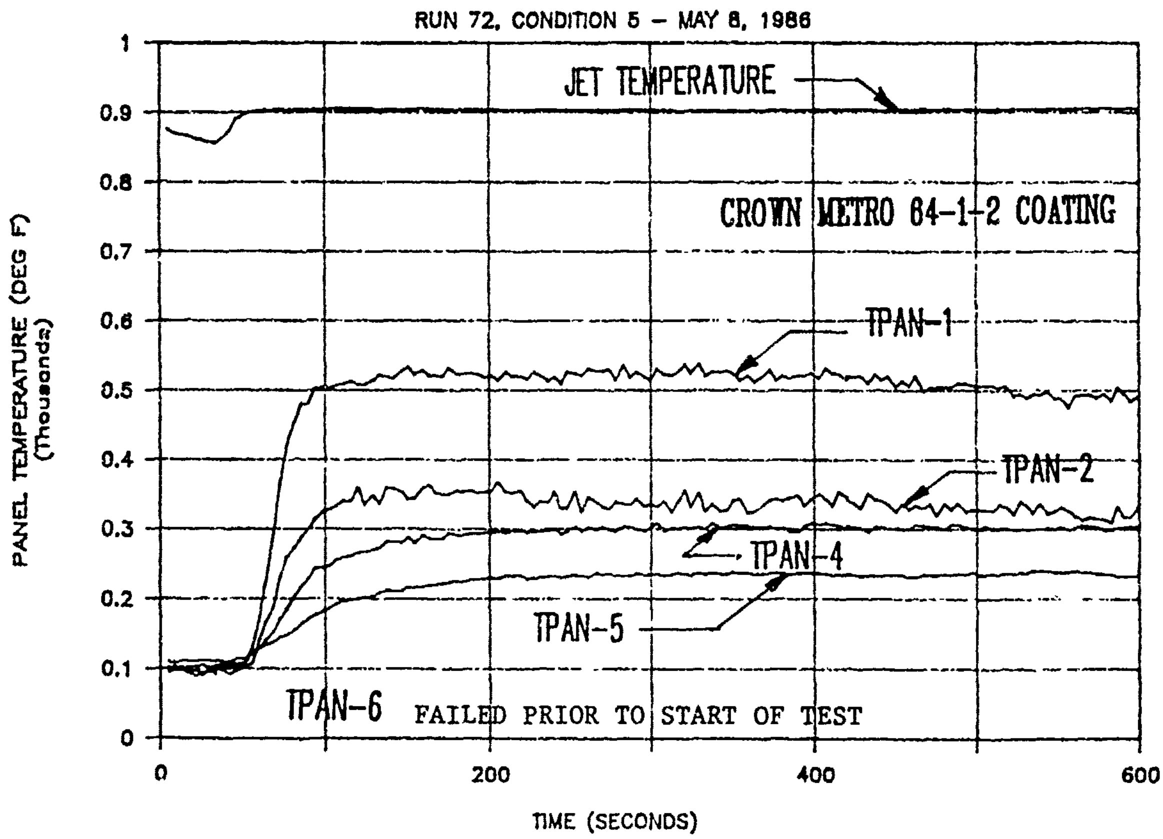


Figure 17. Comparison of Insulating Capabilities with 900 deg F Jet @ 2"

location where the readings were taken, just above the hole where the jet penetrated the panel. The conductivity of panels 48 and 50 decreased about 1% in this location during the first 24 hours and then remained relatively constant during the next week while the conductivity of panel 49 decreased about 2% and then increased again to remain fairly constant at about 1% below the original level.

The conductivity readings taken for all six panels at four of the locations surveyed were averaged for all readings taken from ten minutes to eight days (Figure 19). Readings taken in the panel center, the point where the hot jet struck the panels, show the greatest variation in conductivity between panels. Panel 51 could not be measured at that point, because a hole had been punched in its center. The conductivity readings taken 1.5 inches above the panel centers were similar to the measurements at the panel centers and could be made on panel 51 at this location. The conductivity of panel 47 which was exposed to a 900^{o}F jet at four inches distance for ten minutes increased by almost 2% as compared to panel 52 which was not exposed to the hot jet, at both these locations.

The conductivity of the remaining panels decreased when compared to panel 52 at these two locations. Again, the measurements at the panel centers and 1.5 inches above their centers were similar. The conductivity measurements taken in other locations showed less variation between the tested panels and the baseline. Readings taken 1.5-inches to the right of the panel centers and 1.5 from the right edge illustrate this. With the measurements farthest from the point of jet impingement, the differences in conductivity are probably lost in measurement error.

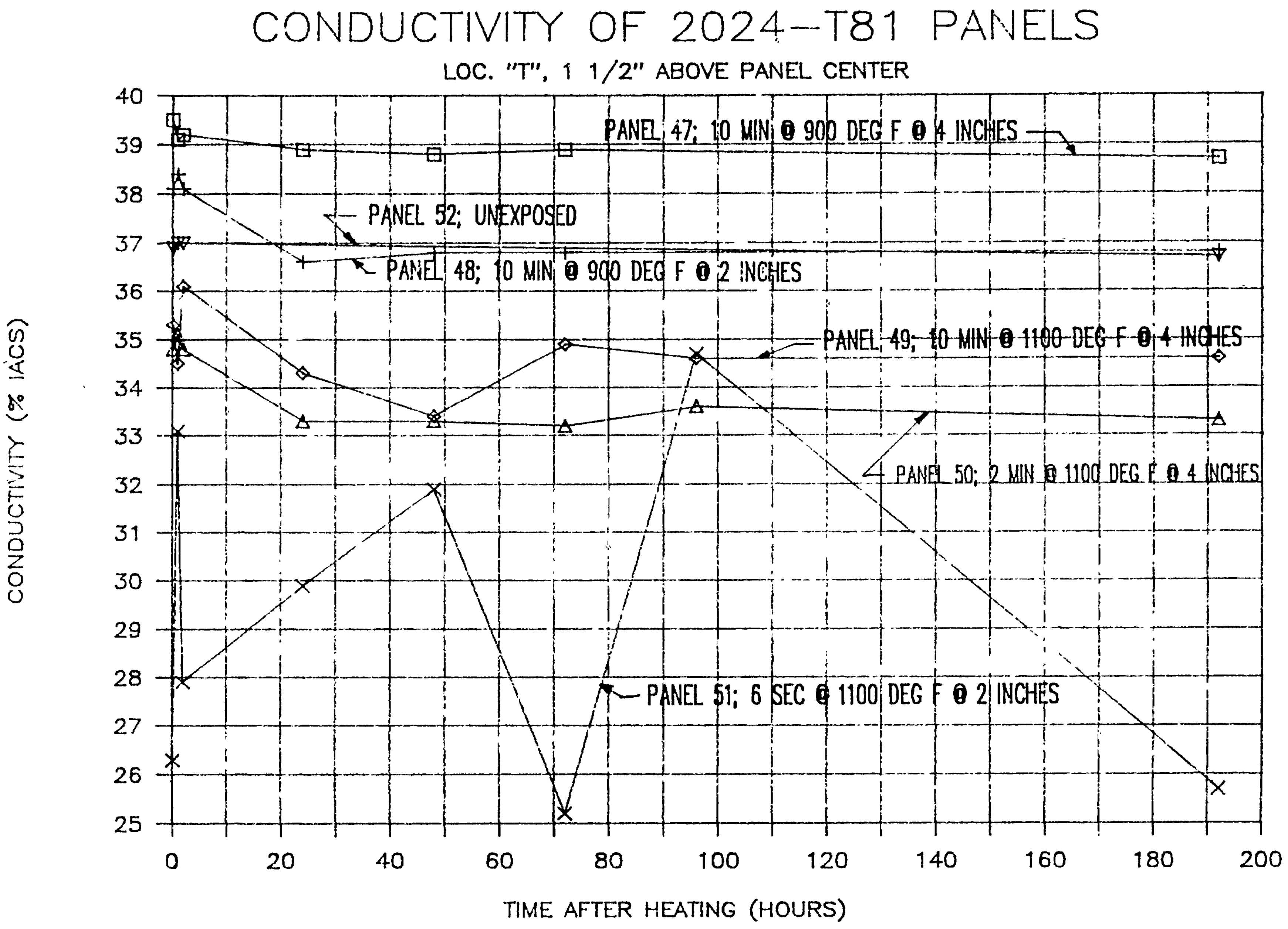
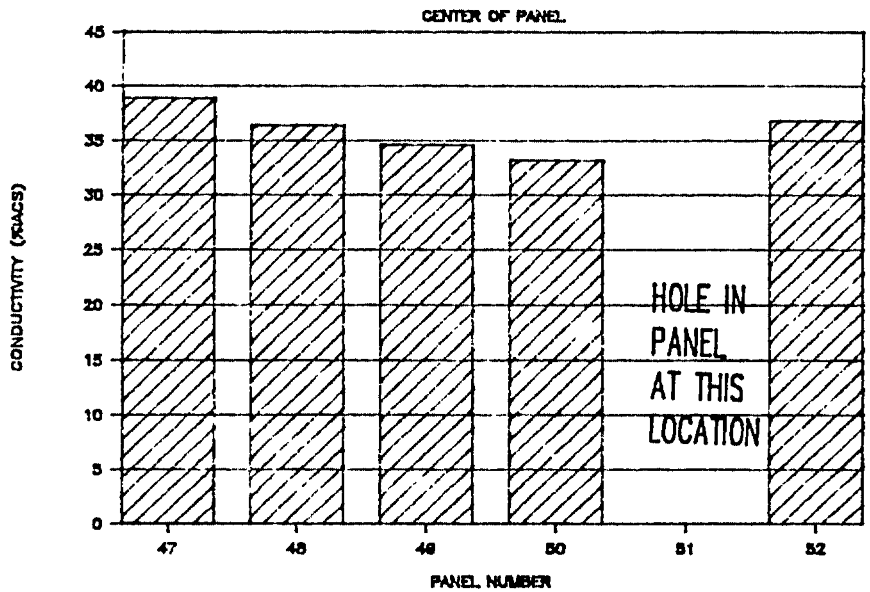
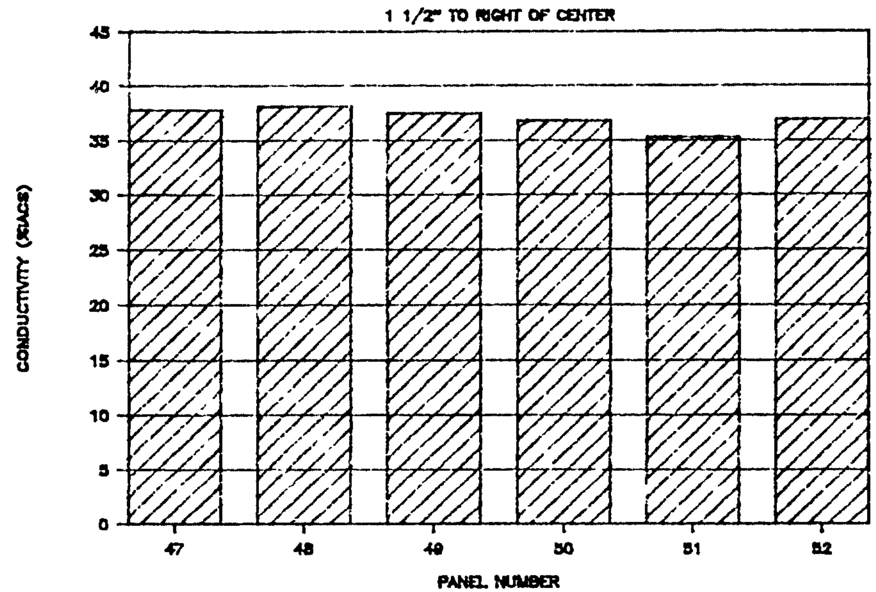
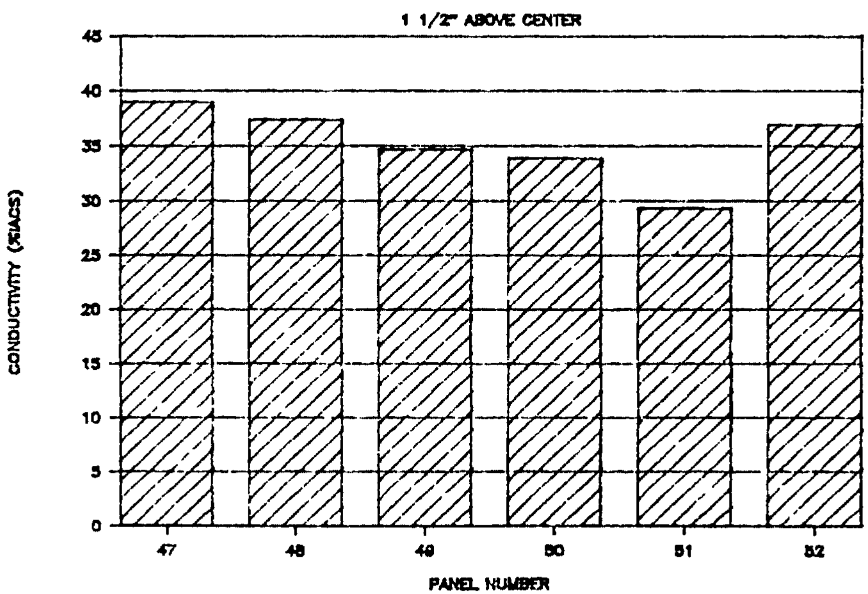
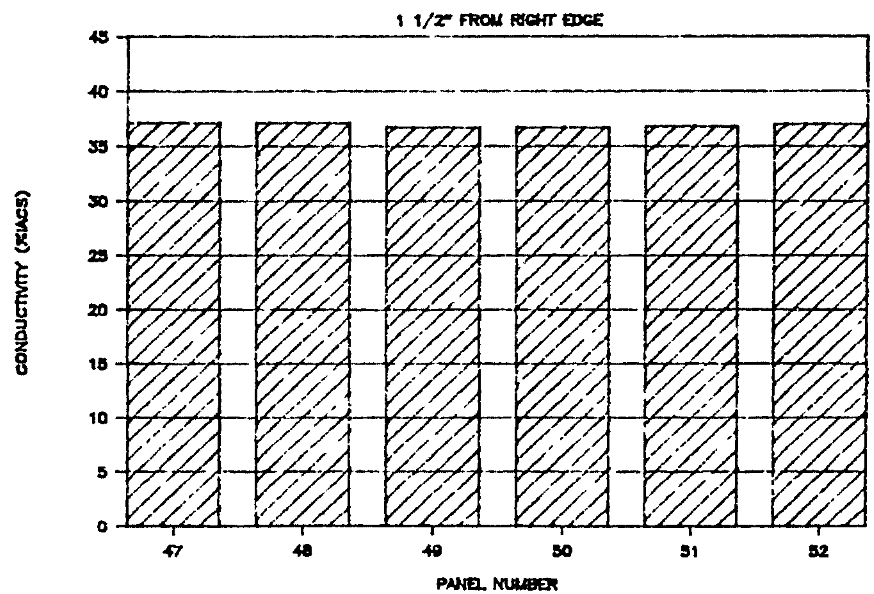


Figure 18. Effect of Time after Exposure on Panel Conductivity


CENTER OF PANEL
CONDUCTIVITY (%IACS)
45
40
35
30
25
20
15
10
5
0
HOLE IN
PANEL
AT THIS
LOCATION
47
48
49
50
51
52
PANEL NUMBER


1 1/2" TO RIGHT OF CENTER
CONDUCTIVITY (%IACS)
45
40
35
30
25
20
15
10
5
0
47
48
49
50
51
52
PANEL NUMBER


1 1/2" ABOVE CENTER
CONDUCTIVITY (%IACS)
45
40
35
30
25
20
15
10
5
0
47
48
49
50
51
52
PANEL NUMBER


1 1/2" FROM RIGHT EDGE
CONDUCTIVITY (%IACS)
45
40
35
30
25
20
15
10
5
0
47
48
49
50
51
52
PANEL NUMBER

5.0 ANALYSIS OF RESULTS

Additional studies, that were performed in other areas to better understand the test results explained in Section 4.0, are described below.

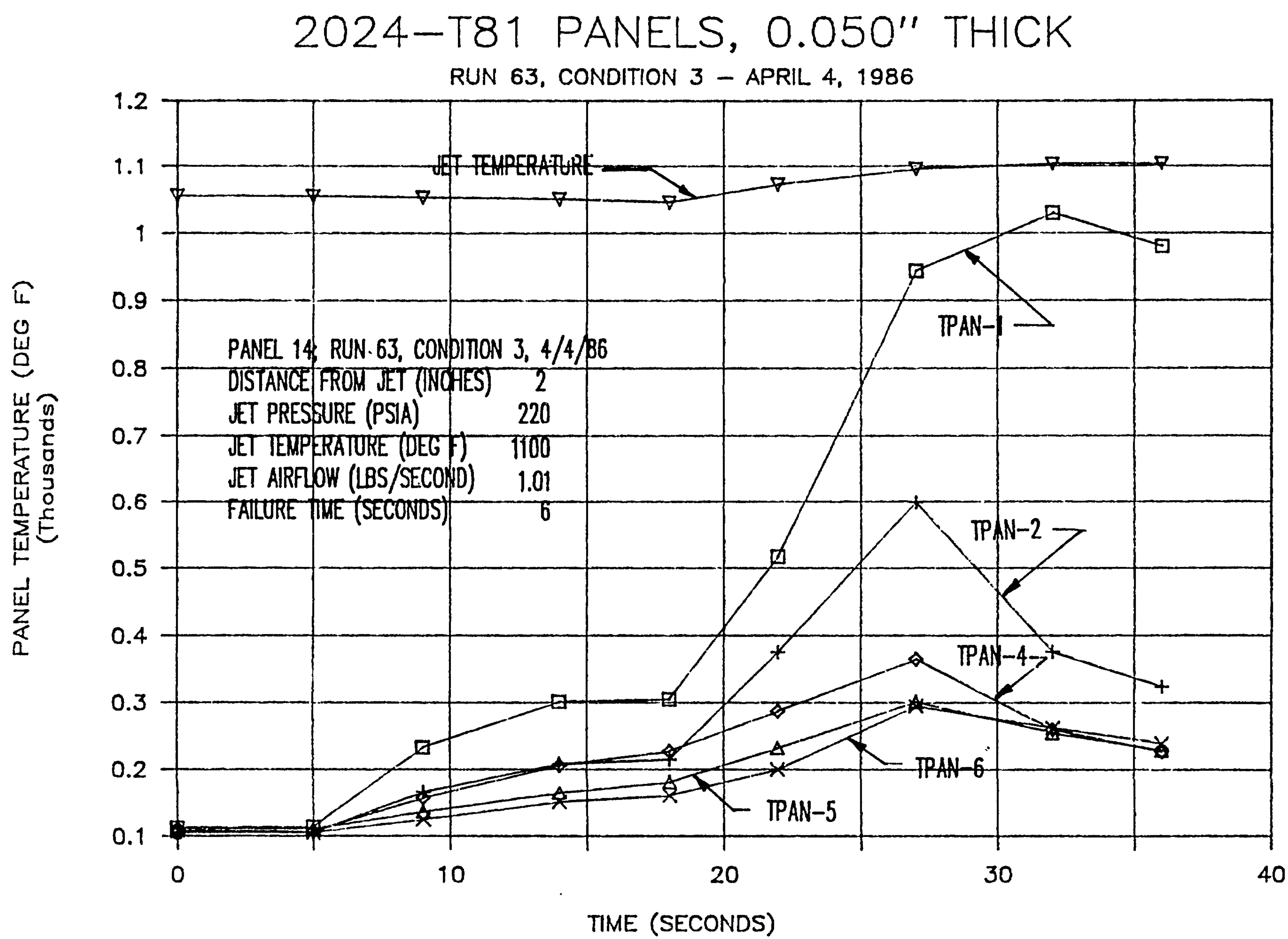
5.1 Backside Temperatures

A 2024-T81 panel failed within about six seconds when exposed to an 1100°F jet at a two-inch distance from the jet exit plane. The variation in jet and panel backside temperature with time was plotted (Figure 20). All temperatures shown preceding the opening of the sliding gate at five seconds were at about 100°F, except the jet temperature which was steady at about 1060°F. The gate was then opened, and the backside temperatures increased as the preheat airflow struck the panel during the time that the test technician was leaving the test cell. The bleed air heater system servo controller was increasing the jet airflow to its full one lb/second.

All of the panel backside thermocouples increased more rapidly with the hot jet striking the front of the panel, the center thermocouple, with TPAN-1 rising to nearly the jet temperature by the time that penetration had occurred, about the 25 second point on the plot. The uncertainty of the ModComp timing along with thermocouple and data system response time limit the accuracy of these measurements, but the center of the panel probably failed when TPAN-1 was exposed to a temperature below the melting point of the material because of a loss of strength due to its heating and the pressure due to jet impingement.

The temperature history of a panel failure which took much longer, allowing more transient temperature data to be acquired, was also plotted (Figure 21). In this case, a 0.032-inch thick 2024-T3 panel was exposed to a 1100°F jet at a distance of four inches from the jet exit plane. The upper half of the figure shows the entire ten minute test with failure occurring at about the 500-second mark. The lower half is the same data, truncated at 90 seconds and expanded.

Again, the backside thermocouples indicated about 100°F prior to the sliding gate being opened and began to rise when the gate was opened. At about the 32-second point the full one lb/second, 1100°F jet was striking the center of the panel, and all the backside thermocouples increased in temperature quite rapidly. Reviewing the video tape of this run, it appeared that a large dent formed in the center of the panel after about 30 seconds of jet impingement,


2024—T81 PANELS, 0.050" THICK
RUN 63, CONDITION 3 – APRIL 4, 1986
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
JET TEMPERATURE
PANEL 14, RUN-63, CONDITION 3, 4/4/86
DISTANCE FROM JET (INCHES) 2
JET PRESSURE (PSIA) 220
JET TEMPERATURE (DEG F) 1100
JET AIRFLOW (LBS/SECOND) 1.01
FAILURE TIME (SECONDS) 6
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40

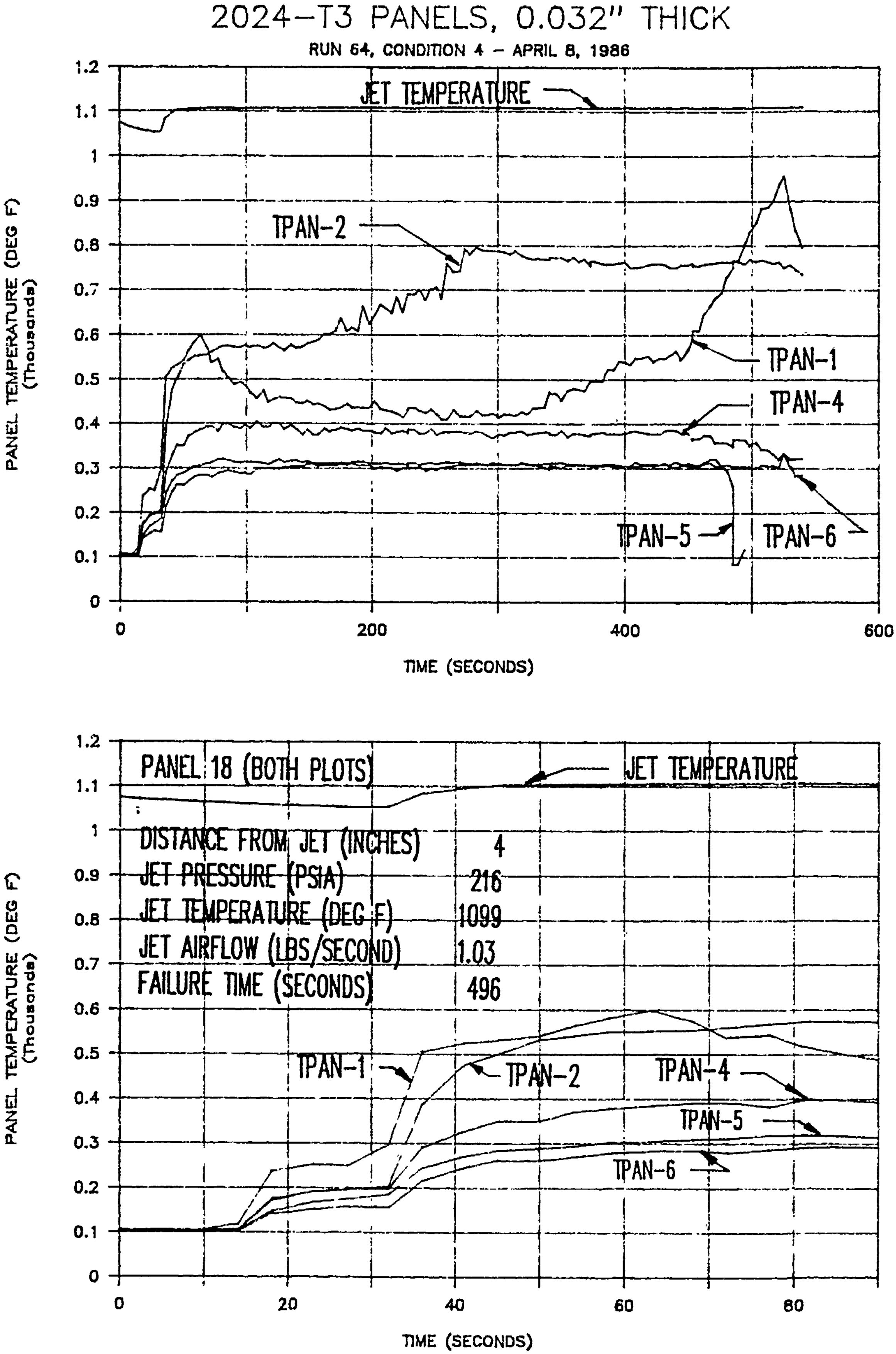


Figure 21. Panel Backside Temperature History

moving the panel center back, away from the jet. Hence, the center thermocouple, TPAN-1, read lower temperatures while the thermocouple two inches above the center, TPAN-2 continued to climb. After about 300 seconds, TPAN-2 leveled off at about 800°F. The thermocouples farther from the center of the panel had reached steady state at much lower temperatures in the first minute of the test. Between the 400 second mark and the panel failure, which occurred at about 500 seconds, TPAN-1 started to climb again, when the panel could elongate no further and the dent was no longer growing.

Failure occurred between 800° and 900°F, although the observed temperatures increased somewhat further before the jet airflow was terminated. Again, this was below the 935° to 1180°F melting range for 2024 alloys. The failure, as described earlier, was due to the pressure of the jet overstressing an area which had lost strength during its exposure to the hot jet.

5.2 Alloy Melting Point

With the uncoated panels, all alloys except the 6061-T6 failed under approximately the same conditions. Table 4, which is extracted from Reference 7, lists the melting point of these alloys. As shown, the temper of the material does not change the melting range, and 2024 and 7075 have approximately the same values. 6061 has a higher melting range, however, and this probably explains why none of the 6061 panels were not perforated.

5.3 Conductivity Data

Eddy current conductivity measurement is an established method of determining that aluminum materials have been properly heat treated. Reference 5 is a Boeing Process Specification covering the temper inspection of aluminum alloys. Table 5 was extracted from this specification and defines allowable conductivity ranges for various aluminum alloys. For the 2024-T81 panels, these should be a minimum of 38 and a maximum of 42 (%IACS).

Reference 7 states that absolute Conductivity, Hardness and Strength (CHS) values for a given alloy will change with exposure to high temperatures, as in an aircraft fire. It further states that the CHS can either increase or decrease, depending on the temperature and duration of the exposure: "For example, material exposed below the solution heat treatment temperature (~800°F) will show an increase in conductivity and a decrease in hardness and

Table 4. Melting Point Range for Alloys Tested

ALLOY	2024		6061		7075	
CONDITION	0	T4	0	T6	0	T6
MINIMUM (F^0)	935	935	1080	1080	890	890
MAXIMUM (F^0)	1180	1180	1205	1205	1175	1175

Extracted from Reference 7, Page 56

Table 5. Aluminum Alloy Conductivity and Hardness Limits

ALLOY AND TEMPER		CONDUCTIVITY (PERCENT IACS) MINIMUM	CONDUCTIVITY (PERCENT IACS) MAXIMUM	ROCKWELL HARDNESS R_E MINIMUM	ROCKWELL HARDNESS R_E MAXIMUM	ROCKWELL HARDNESS R_B 2/ MINIMUM	ROCKWELL HARDNESS R_B 2/ MAXIMUM
2014	O	48.5	51.0	52	60	--	--
	T3XX	31.5	35.0	95	102	68.0	80.0
	T4XXX	31.5	35.0	95	102	68.0	80.0
	T6XXX	35.0	40.0	101	108	78.5	89.5
2024	O	45.5	49.0	54	62	--	--
	T3XXX	29.0	32.0	96	104	70.0	83.5
	T4X	29.0	32.0 3/	96	104	70.0	83.5
	T6X	36.0	40.0	100	106	77.0	86.0
	T8XXX	38.0	42.0	100	106	77.0	86.0
2219	O	44.0	49.0	--	70	--	--
	T3XXX	26.0	31.0	92	--	64.5	--
	T37	27.0	31.0	93	--	65.5	--
	T4X	28.0	32.0	90	--	61.0	--
	T6X	32.0	35.0	93	--	65.5	--
	T8XXX	31.0	35.0	98	--	73.0	--
	T87	31.0	35.0	100	--	77.0	--
2224	T3511	29.5	33.5	96	104	70.0	83.5
2324	T39	29.0	32.0	100	106	77.0	86.0
3003	O	44.5	50.5	--	65 (R_H)	--	--
5052	O	34.0	37.0	--	70	--	--
	H34	34.0	37.0	66	--	--	--
6061	O	47.0	56.0	18	25	--	--
	T4XXX	36.0	45.5	68	--	--	--
	T6XXX	40.0	51.0	85 4/	102	53.5 4/	80.0
6063	O	57.0	65.0	--	70 (R_H)	--	--
	T1X	48.0	58.0	37	--	--	--
	T4X	48.0	58.0	40	--	--	--
	T5X	50.0	60.0	44	--	--	--
	T6X	50.0	60.0	70	--	--	--
7049 5/	O	44.0	50.0	--	70	--	--
	T73XXX	40.0	44.0	104	--	83.5	--
	T76XXX	38.0	44.0	106	--	86.0	--
7050 5/	O	44.0	50.0	--	70	--	--
	T736XX	40.0	44.0	105	111	85.0	92.0
	T76XXX	39.0	44.0	106	112	86.0	94.0

EXTRACTED FROM REFERENCE 5, Page 51.

strength with increased exposure time. At or above the solution's heat treat temperature, inversions occur in the CHS (Conductivity, Hardness and Strength) values in relatively short exposure times" (Reference 7, page 8).

The test results agree with this (Figure 19). Panel 47 had been exposed to a 900°F jet at a distance of four inches and experienced little visible damage. The jet probably had cooled to a temperature below the solution heat treatment temperature before it impinged on the panel. Hence, the conductivity increased. Panels 49, 50 and 51 were all exposed to 1100°F jets at distances ranging from two to four inches, and the impinging airflow was probably above the treatment temperature. Hence, the conductivity decreased.

Panel 48 showed the least change from the untested panel 52 and was exposed to a 900°F jet at two inches where the temperature at the point of impingement was probably closest to the treatment temperature.

Reference 7 uses these changes in conductivity to identify structural components which have lost strength and need replacement. No attempt is made to use the conductivity changes to reach conclusions concerning the temperature or duration of the material to excessive temperatures.

5.4 Effect of Improper Heat Treating of 2024-T81 Material

As noted in paragraph 4.4, conductivity measurements of panel 52 indicated that the material which was representative of an F-16 glove tank wall had probably been heat treated too long. Figure 22 is extracted from Reference 7 and shows the effect of excessive heat treating on 2024-T4 sheet. While the range of acceptable conductivities for this material are lower than for the T81, the effects of excessive treatment would be similar. With the T4 material, a conductivity 1.2% below the acceptable limit would imply an ultimate tensile strength from 0.4% to 1.6% higher than the specification material, depending on the temperature and exposure time. A similar increase would be expected with the T81 material.

During testing which simulated the F-16 bleed duct/fuel tank proximity, there was no perforation even when the jet was moved from four to six inches from the panel. Hence, even properly heat treated 2024-T81 material would probably not have failed at six inches.

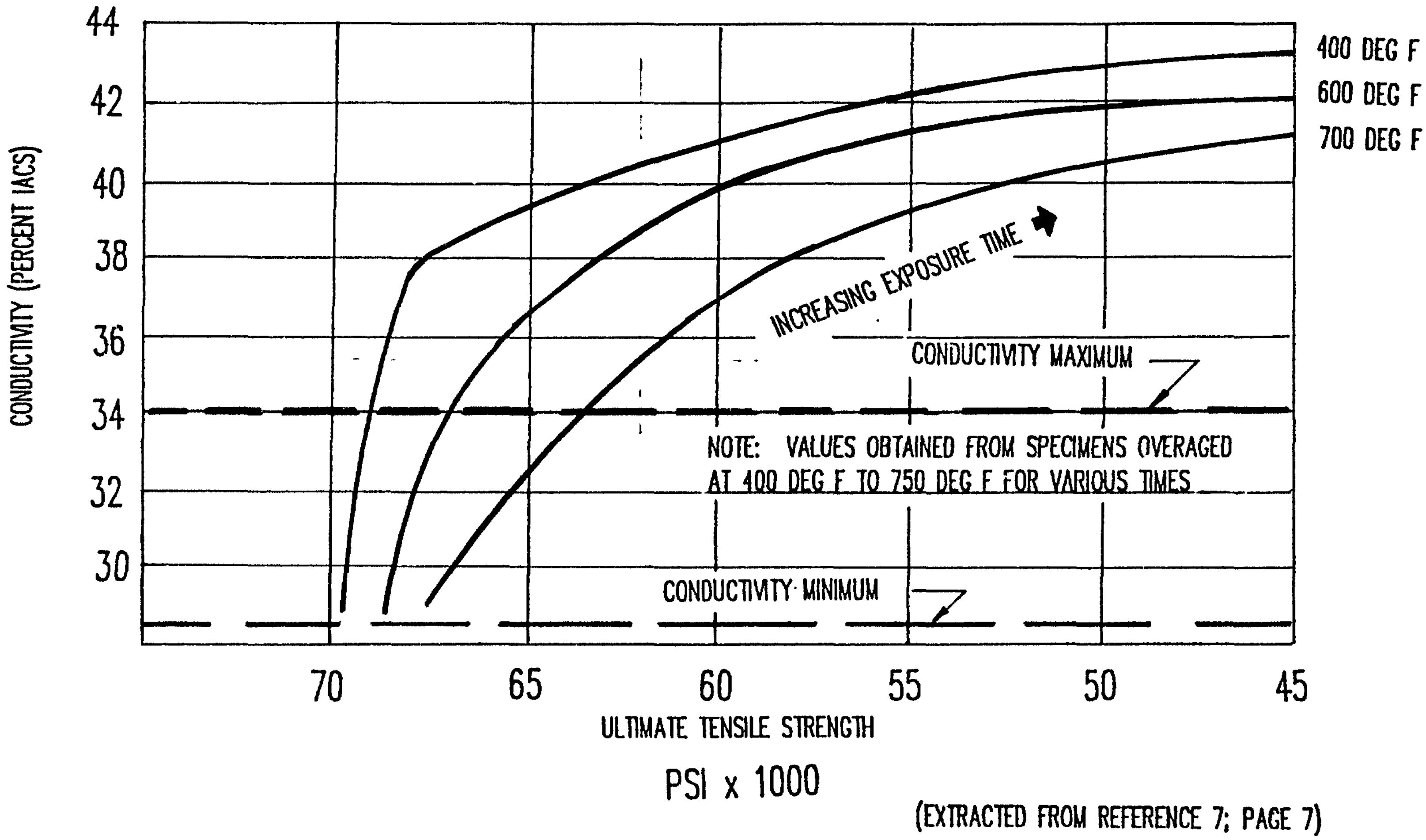


Figure 22. Conductivity versus Tensile Strength for Overaged 2024–T4 Bare Aluminum Alloy Sheet

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. VALUE OF TEST CONCEPT

During this test program, it was demonstrated the AEN bleed air heating system can be used to examine the ancillary hazards associated with hot bleed air in an aircraft engine compartment, most importantly, as they relate to Air Force aircraft operations.

2. INVESTIGATING THE F-16 MISHAP (Initial Objective)

During the first test phase, the hazard of an engine bleed air leak penetrating the side of the aft tank in an F-16 engine compartment was simulated. It was demonstrated that such an event was unlikely. With the range of bleed air temperatures anticipated in the F-16, and the six inches of clearance between the tank and the bleed duct that exist in the aircraft, panel failure did not occur. Higher bleed air temperatures and pressures than those tested can occur in fighter aircraft engines, and may, in fact, be capable of causing panel failure.

At about the same time, however, the Air Force Safety Investigation Board concluded that the aircraft had been lost for other reasons. Discovery of evidence of a titanium engine fire led them to conclude that the titanium fire had caused the apparent bleed air leak and fuel tank fire.

3. RESISTANCE OF AIRCRAFT ALUMINUM ALLOYS TO PENETRATION

During the second test phase, it was further demonstrated that, for a 1.0 lb/second jet, temperatures greater than 1000°F and distances between the bleed duct and tank wall of less than four-inches would be required to cause a failure to occur within ten minutes with any of the 0.050-inch thick materials. It was found that the 0.032-inch thick material would fail at slightly lower jet temperatures and slightly greater distances from the jet, while the 0.071-inch thick material failed under the same conditions as the 0.050-inch thick material, though taking a few seconds longer.

The results were about the same for the 2024-T3, 2024-T81 and 7075-T6 panels. The 6061-T6 panels resisted penetration even at one-inch distance from a 1100°F jet, the most severe case tested.

When penetration of the panels occurred, they failed with smooth deformation followed by shearing of the weakened material, a more dramatic effect than might be expected.

4. PERFORMANCE OF COATINGS

When insulating materials were applied to 2024-T81 panels for the third test phase, those materials had little effect on the tendency of the panels to fail. Temperatures measured on the backside of the insulated panels were affected briefly in their centers prior to the silicon material being eroded by the jet, and for the duration of the tests in those areas that did not erode. While it was concluded that the Martin Marietta coating provided more insulation, neither coating would provide significant protection against damage caused by a jet of leaking bleed air.

5. UTILIZATION OF ELECTRICAL CONDUCTIVITY MEASUREMENTS IN ACCIDENT INVESTIGATION

Conductivity meter tests indicated that an accident investigation team could employ these measurements to reach some general conclusions about the temperatures to which an aircraft panel had been exposed. Duration of the exposure seemed less significant than temperature. Whether these measurements were made within 24 hours or eight days after the incident was not significant, although variations were observed prior to the 24-hour point.

An increase in the conductivity of the panel indicated that the panel had been exposed to a temperature of less than its 800°F process temperature. This effect is somewhat like annealing the panel and, in the extreme, a conductivity of 45% to 49% IACS as with 2024-TO might result. A conductivity increase of 2%, as noted with panel 47, would not be outside the range of acceptable conductivity for this alloy and would probably not mean unacceptable loss of strength. Much longer exposure might increase the local conductivity beyond the 42% IACS upper limit for this alloy indicating an unacceptable loss of strength.

A decrease in conductivity of the panel indicated an exposure to temperatures greater than its process temperature. Unfortunately, it is impossible to identify the exact jet temperature without knowing the exact period of exposure, because the change diminishes as the exposure increases. This effect is like additional heat treating followed by annealing. If the temperature is above 800°F for a brief period, probably a few minutes, the effect is like additional heat treating, and the change in conductivity can be as large as 4% as in the case of panel 50 which was exposed to a 1100°F jet at four-inches distance for two minutes. Panel 49 was exposed to the same jet at the same distance for ten minutes and showed half the change in conductivity.

Conductivity in parts of the panel being examined which have not been exposed to heat are a better baseline than specification values for the material in determining changes. As noted in Table 5, the acceptable conductivity ranges for most alloys vary by 3 to 4%. When the magnitude of the changes observed due to heat damage is 1 or 2%, as in this test, little can be concluded referring to specification values.

6.2 Recommendations

1. ENGINE COMPARTMENT DESIGN CONSIDERATIONS

The results of these tests are relevant to surface temperature specifications in and around the engine where bleed air lines are routed, and in engine bay component and structural designs. The data acquired during this test program suggest that the materials tested would be safe six inches from a bleed duct (as in the F-16 installation) but marginal at four inches for the 0.050-inch thick materials and unacceptable with 0.032-inch thick material. Further, the silicon engine compartment insulating materials such as MA-25S and Crown Metro 64-1-2 do not provide additional protection, because they are rapidly eroded by the leaking hot bleed air.

Additional testing would be appropriate to study:

- the effects of simulated bleed leakage with higher temperature and pressure and/or greater flowrates; a parametric study with bleed air temperature, pressure and panel thickness, and spacing as variables is envisioned

- the effects of simulated bleed leakage on other materials and other surface treatments

2. ACCIDENT INVESTIGATION CONSIDERATIONS

Caution is advised in employing eddy current electrical conductivity measurements of damaged aircraft aluminum panels to analyze the cause of aircraft incidents. Although these measurements may be an acceptable means of determining whether materials have been overheated enough to loose their temper and should be replaced, factors such as those discussed below must also be considered.

These conductivity measurements should be made in areas around visible heat damage and compared with other undamaged parts of the same material, if possible, because the range of acceptable conductivities for a given material (38 to 42% IACS for 2024-T81) can be greater than the change observed after major damage (37 to 35% IACS for panel 49 which was exposed to an 1100^{o}F jet at four inches distance for ten minutes).

An increase in conductivity usually means that the material was exposed to a temperature lower than the process temperature employed in the heat treating (~800^{o}F) whereas decrease in conductivity probably means exposure to a temperature higher than the process temperature. Therefore, employing the information contained in this report to conclude the level or duration of high temperature exposure must be used with caution.

REFERENCES

1. McClure, J.D. and Springer, R.J., "Environmental and Operating Requirements for Fire Extinguishing Systems on Advanced Aircraft," JTCG/AS Report 74-T-002, November 1974.

2. Dirling, F.N. and Johnson, A.M., "AEN Operating Manual," Preliminary Draft, November, 1984.

3. Ledwick, T.L., "ModComp II Computer System Software Technical Manual," Preliminary Draft, November, 1984.

4. Ledwick, T.L., "ModComp II Computer System Software User's Manual," Preliminary Draft, November, 1984.

5. Wishart, T., "Temper Inspection of Aluminum Alloys," Boeing Process Specification BAC 5946, Revision "N", May 1985.

6. Machine Design, Materials Reference Issue, Volume 56, Number 8, April, 1984.

7. Hagemaier, D.J., "Evaluation of Heat Damage to Aluminum Aircraft Structures," McDonnell Douglas Paper 7120, presented to 1981 ATA Nondestructive Testing Forum, Phoenix, Arizona, September, 1981.

8. Britton, C.L., Flow Measurement Systems Memo to P. Hughes of SRL, 7 July, 1978.

APPENDIX A INFORMAL PRELIMINARY TEST PLAN FOR
F-16 BLEED LEAK/AFT FUEL TANK PENETRATION TEST

(Since rapid response in supporting the F-16 investigation was essential, a formal test plan was not submitted for approval prior to testing. This appendix includes, for record purposes, the test plan that was developed).

I. BACKGROUND

In a recent F-16 mishap, the scenario may have included a bleed air leak adjacent to the aft tank causing a fire or explosion. The AEN's bleed air heater system will be used for a simulation in which 12-inch square panels of material similar to the F-16's aft tank will be subjected to jets of hot air to determine whether failure occurs and, if so, how long it takes to occur.

II. APPROACH

The length of time required for various bleed air jets to penetrate the simulated tank panel will be determined for several combinations of bleed air temperature and pressure at several distances between the jet exit and test panel. These are identified on Table A-1. Temperature on the back side of the test panels will be monitored during these tests.

A simple "bench-test" fixture (see Figure 1) will be designed and constructed to allow the test to be conducted using AEN instrumentation and the AEN bleed air heating system:

1. Panels: To simulate the portion of the F-16 aft tank in question, 12-inch square panels of 2024 aluminum are being fabricated and heat treated to a T-81 condition.

2. Bleed duct: A section of 1.5-inch diameter, 0.035 wall, CRES tubing will be connected to the AEN bleed air heating system so that it is parallel with and alternately 6, 4, 2 and 1 inches away from the test panel. An 11/16 (0.6875) inch diameter hole will be drilled adjacent to the test panel so that a jet of simulated bleed air may be directed onto the midpoint of the panel. The

Table A-1. TEST CONFIGURATIONS

Test Number	Approximate Bleed Air Pressure (PSIA)	Bleed Air Temperature (deg. F.)	Hole Size (Dia. in inches)	Jet Airflow (lbs/sec)	Distance to target (inches)
1	70	900	0.6875	0.336	6
2	150	900	0.6875	0.720	6
3	225	900	0.6875	1.080	6
4	70	1000	0.6875	0.324	6
5	150	1000	0.6875	0.695	6
6	225	1000	0.6875	1.043	6
7	70	1100	0.6875	0.314	6
8	150	1100	0.6875	0.672	6
9	225	1100	0.6875	1.009	6
10	225	900	0.6875	1.080	4
11	225	1000	0.6875	1.043	4
12	225	1100	0.6875	1.009	4
13	225	900	0.6875	1.080	2
14	225	1000	0.6875	1.043	2
15	225	1100	0.6875	1.009	2
16	225	900	0.6875	1.080	1
17	225	1000	0.6875	1.043	1
18	225	1100	0.6875	1.009	1

CRES tubing will be long enough to re-enter the AEN through the side access panel in the number two test section.

A valve will be provided downstream of the jet orifice so that bleed airflow may be reduced, once the system has reached the desired temperature, to conserve bottle farm air.

III. INSTRUMENTATION

Instrumentation will consist of the six normal channels of bleed air heater data (along with run and condition number, time and date of acquisition):

TBHNAI	Bleed Air Temperature at bleed duct (Type K T/C)
PBHNOI	Bleed Htr. Nozzle Inlet Press. (0-1000 PSIA X'ducer)
PBHNAI	Bleed Heater Inlet Press. (0-500 PSIA X'ducer)
PBH-IN	Bleed Air Press. at Test Article(0-500 PSIA X'ducer)
TBHOUT	Bleed Heater Outlet Temp. (Type K T/C)
TBHNOI	Bleed Air Flow Nozzle Inlet Temp. (Type K T/C)

In addition, six channels of thermocouple data will be recorded from six type K thermocouples identified as TF16-1, TF16-2, TF16- 3, TF16-4, TF16-5 AND TF16-6. These thermocouples will be located on the back side of the test panel in a pattern around the point where the jet strikes the front side (Figure 1).

IV. DATA ACQUISITION

1. Tabular Data

An initial guess based on panel tests with a propane torch is that the test panels will fail in 2 to 10 minutes depending on the bleed airflow and temperature. The ModComp will be employed to acquire data records of the bleed airflow system parameters and panel temperatures along with the acquisition time at the rate of about one every 15 seconds. These data will also be stored on disk by the ModComp and will be subsequently transferred to IBM-PC "floppy" disks for rapid processing using LOTUS 1-2-3. A sample plot indicating the anticipated presentation of the data from these individual panel tests is included (Figure 2). In addition, these plots will be summarized for all panel tests as shown in Figures 3 and 4.

2. Oscillograph Data

A Honeywell Visicorder will be employed to acquire "quick-look" temperature vs. time data for the six channels of test panel temperature instrumentation.

3. Video Tape Data

The AEN Umatic format VCR system will be employed to record video of all test conditions using a tripod mounted video camera placed adjacent to the test rig in the AEN room.

4. Photographs

Color photographs will be made of the test rig and of selected test panels following failure.

5. CU data

A CU meter (crystal structural analysis device) will be borrowed from the Air Force Materials Laboratory to analyze selected failed panels for comparison with similar data to be acquired concerning the recovered F-16 tank surface.

V. TEST PROCEDURE

Bleed air temperatures will be run in ascending order, facility cool-off taking most of a shift where warm up occurs in minutes.

For each test condition, the procedure will be:

1. Start heating system and allow warm-up of heating system to desired temperature using "PREHEAT" (shop air bypass system with no flow to test article). Heat shield will be set between bleed duct and test panel.

2. Select desired airflow (see Table A-1) on controller and "TEST" position on PREHEAT/TEST switch. Allow bleed air delivery line and simulated bleed duct to reach desired temperature. Monitor TBHNAI.

3. When TBHNAI reaches desired temperature (within 20 deg. F.), start ModComp data acquisition, visicorder and slide shield out of way while noting time on time code on TV monitor.

4. Terminate test when penetration occurs or stable back-side panel temperature is reached without failure, noting time code again.

VI. DOCUMENTATION AND DATA PRESENTATION

While full documentation of this test program will be included with documentation of the current AEN test program, currently planned for about October of 1986, a preliminary data report will be prepared immediately following completion of testing. This will include:

1. Discussion of the test article, facility, procedures and instrumentation.

2. Description of all data available including video.

3. Plots of all panel back-side temperature vs time all indicating the point that heat was applied and the point at which failure occurred.

4. Preliminary analysis, results and conclusions.

5. Photographs of test set-up and failed panels.

6. CU data for failed panels.

Because the Air Force Safety Investigation Board must reach its conclusions much earlier, those data and conclusions available by the end of the first week's testing (April 4, 1986) will be forwarded to them at that time. This will be preliminary information and will not be considered to be formal Boeing test documentation.

VII. Schedules:

```
------------------------------------------------------------------------
Week  Starting    |  3/24/86   |  3/31/86   |   4/6/86   |  4/13/86   |
__________________|____________|____________|____________|____________|
                  |____________|            |            |            |
Test Planning     |____________|            |            |            |
                  |            |            |            |            |
Dsgn, Fab. &      |____________|          __| Prelim. report to       |
Build-up          |____________|          \/|   Review Board          |
                  |            |____________|            |            |
Test Conduct      |            |____________|            |            |
                  |            |            |____________|____________|
Prelim. Document'n|            |            |____________ ____________|
                  |            |            |            |            |
------------------------------------------------------------------------
```

APPENDIX B DATA REDUCTION EQUATIONS

Temperature data were reduced using normal type K thermocouple tables, included in ModComp data reduction software. Pressure data were reduced using calibration data acquired periodically as part of AEN operation, reduced to slope and Y intercepts and included in ModComp data reduction software. Event timing was produced by the ModComp internal clock which recorded the time that a data sample was acquired in hours, minutes and seconds (to the hundredth). The only other recorded data was the bleed system airflow:

$$W = \frac{P_o \, A \, C^* \, C_d}{\sqrt{T + 460}}$$

The manufacturer of the sonic nozzles installed in the AEN, Flow Measurement Systems, Inc., provides the following equation for calculation of sonic nozzle airflow (Reference 8):

Where: W = Airflow in lbs/second

Po	=	Nozzle inlet stagnation pressure
C*	=	Critical flow function for air
A	=	Nozzle throat area in square inches
Cd	=	Nozzle discharge coefficient
T	=	Nozzle inlet temperature, degrees Rankine

Reference 8 further states that the ratio of nozzle stagnation to measured static pressure is a function of the approach Mach number and hence of the ratio of nozzle throat to pipe diameter. Thus it is a constant for each nozzle. The Reference 8 memo provides diameters, areas, and stagnation to static pressure ratios for the original 3 nozzles installed in the AEN. Using the same methods, the bleed air heater system nozzle has been added to these:

Diameter	0.2964 inches
Area	0.0690 sq. inches
Po/P	1.0001

C* is obtained from NASA TN D-2565 and is relatively constant within the range of temperatures and pressures anticipated. It is equal to 0.5351 at 520 deg. F and 200 PSIA.

Cd is calculated based on Reynolds number and is obtained using:

$$NR = (4 * W)/(3.14159 * d * mu) \text{ and } C_d = 0.99738 - \frac{3.3058}{\sqrt{N_R}}$$

In the range of Reynolds numbers anticipated, Cd varies only from 0.993 to 0.996, however, so a constant 0.995 is employed in all these calculations.

Hence:

$$WBHTR = \frac{1.0001(0.0690)(0.5351)(0.995)(PBHNOI)}{\sqrt{TBHNOI + 460}} = \frac{0.03674(PBHNOI)}{\sqrt{TBHNOI + 460}}$$

APPENDIX C

PHOTOGRAPHS OF PANELS TESTED

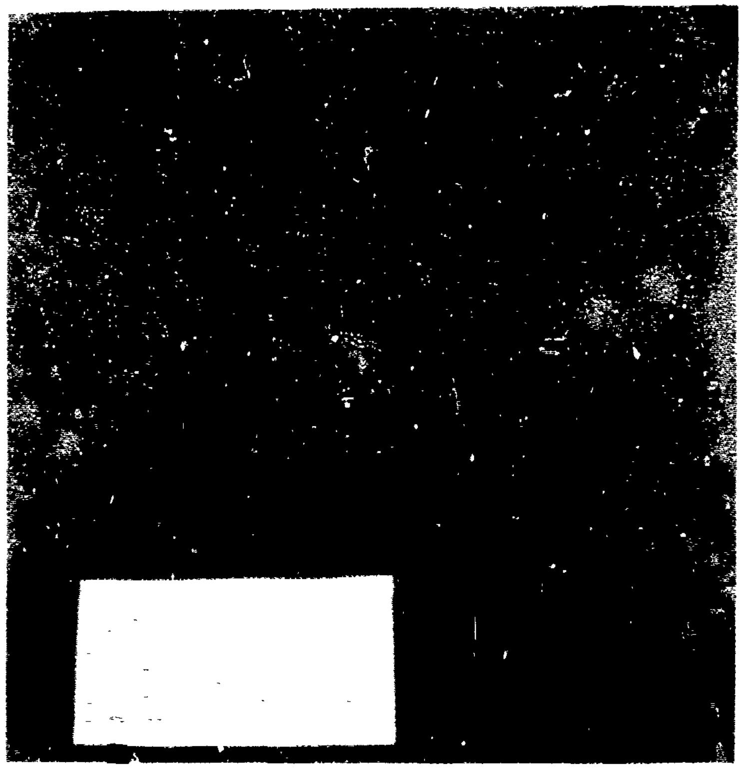


Figure C–1. Panel 1

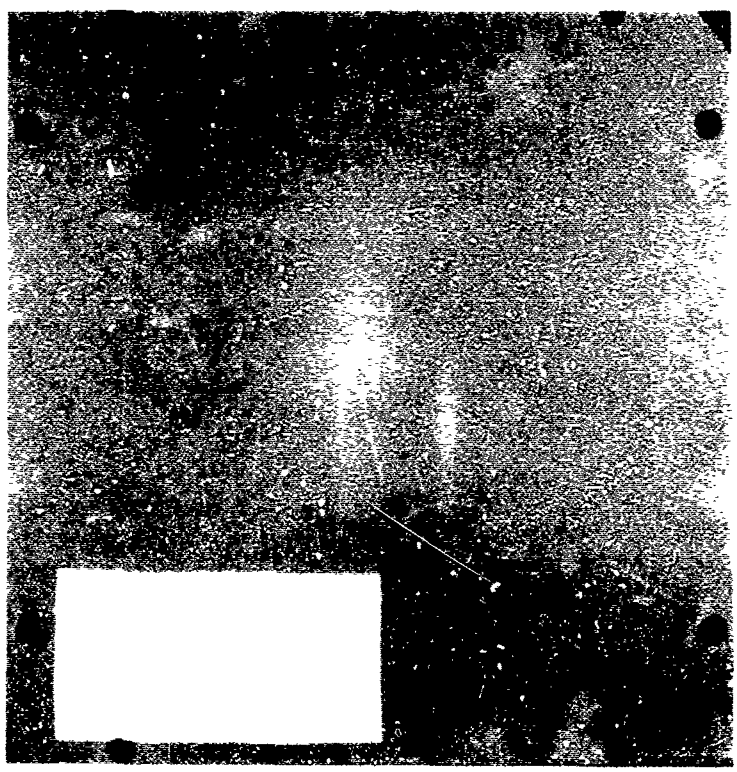


Figure C–2. Panel 2

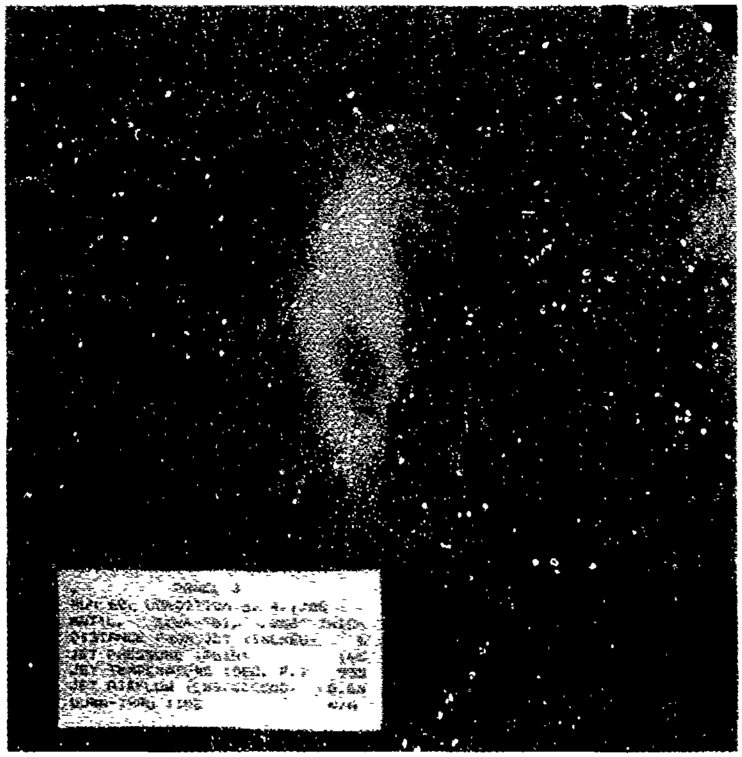


Figure C–3. Panel 3

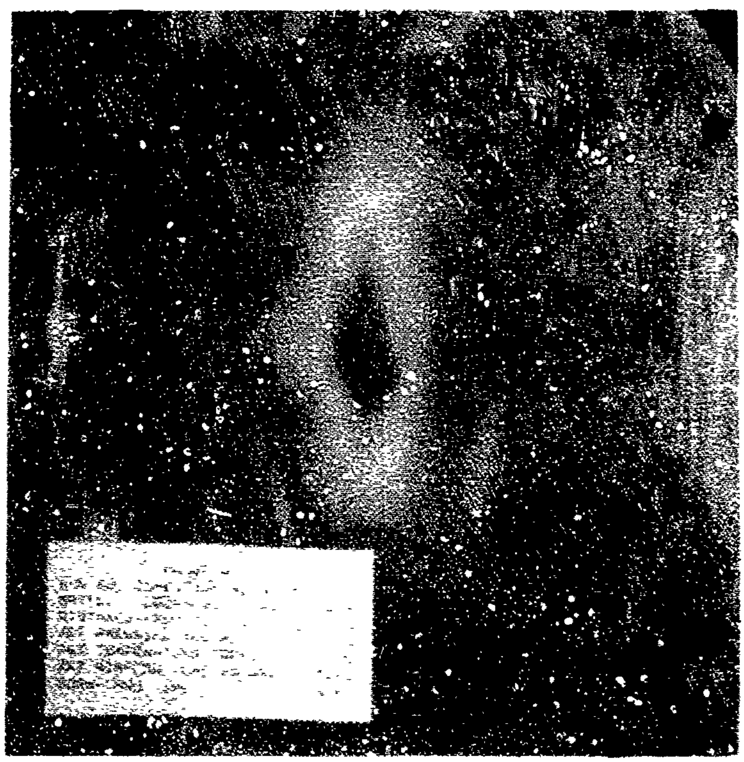


Figure C–4. Panel 4

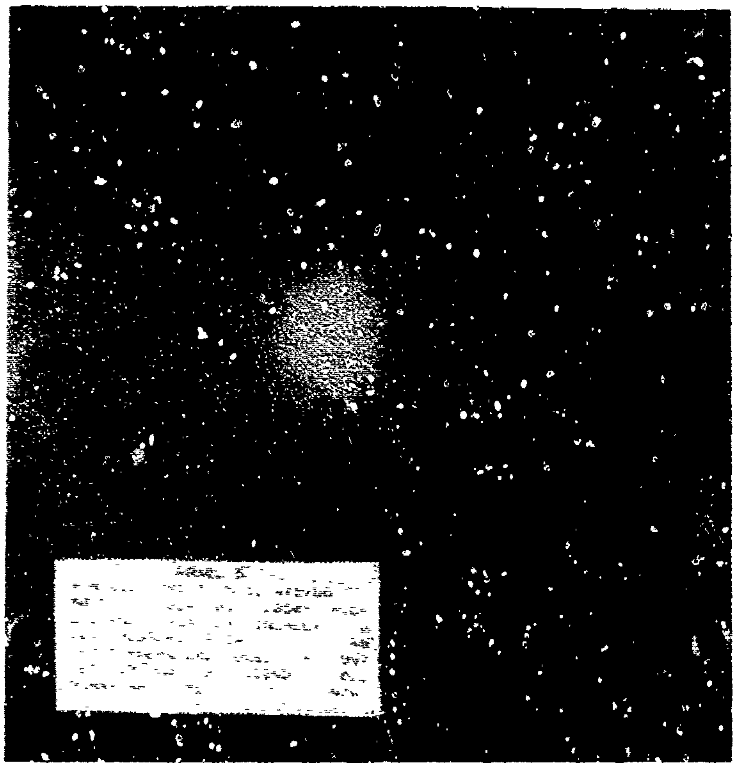


Figure C–5. Panel 5

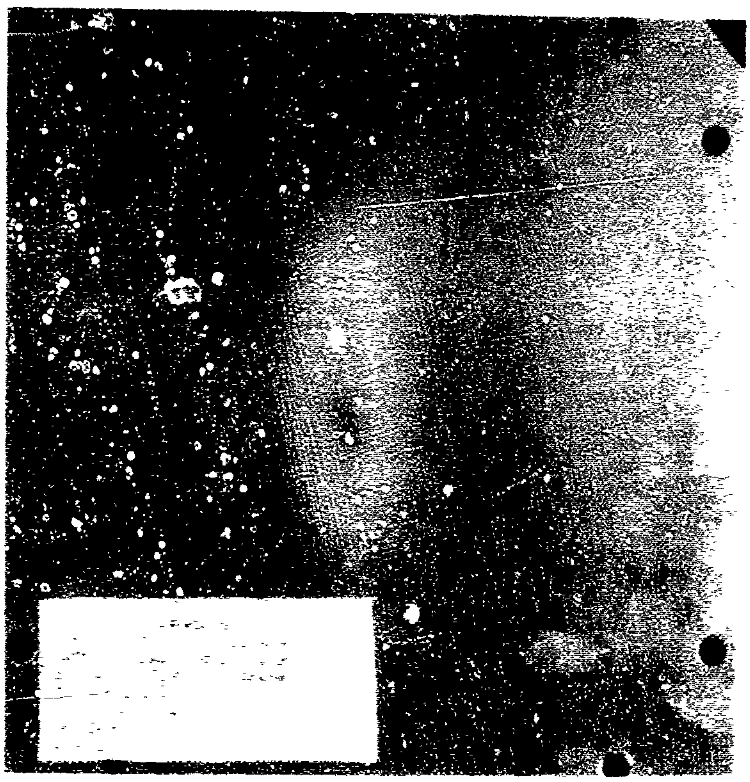


Figure C–6. Panel 6

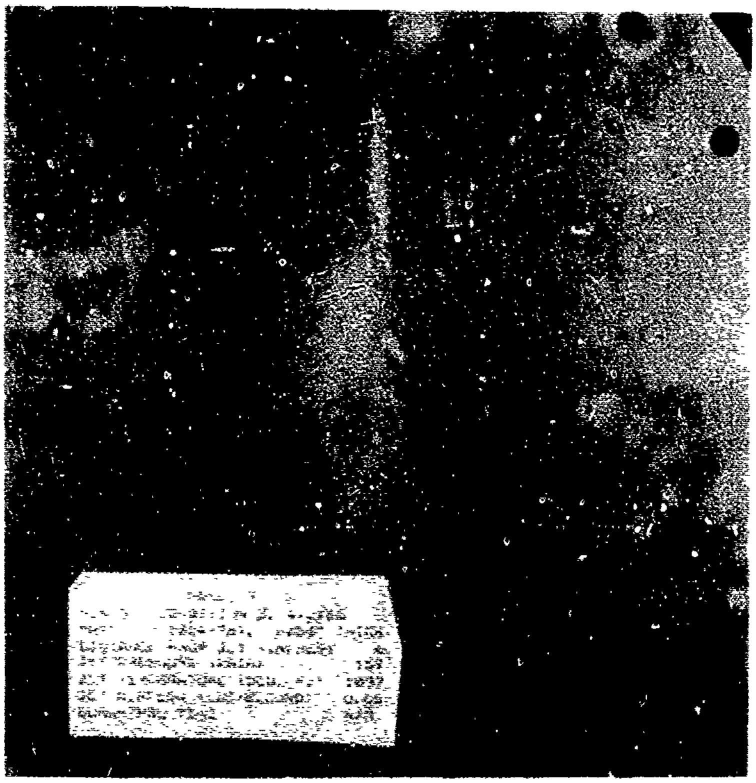


Figure C–7. Panel 7

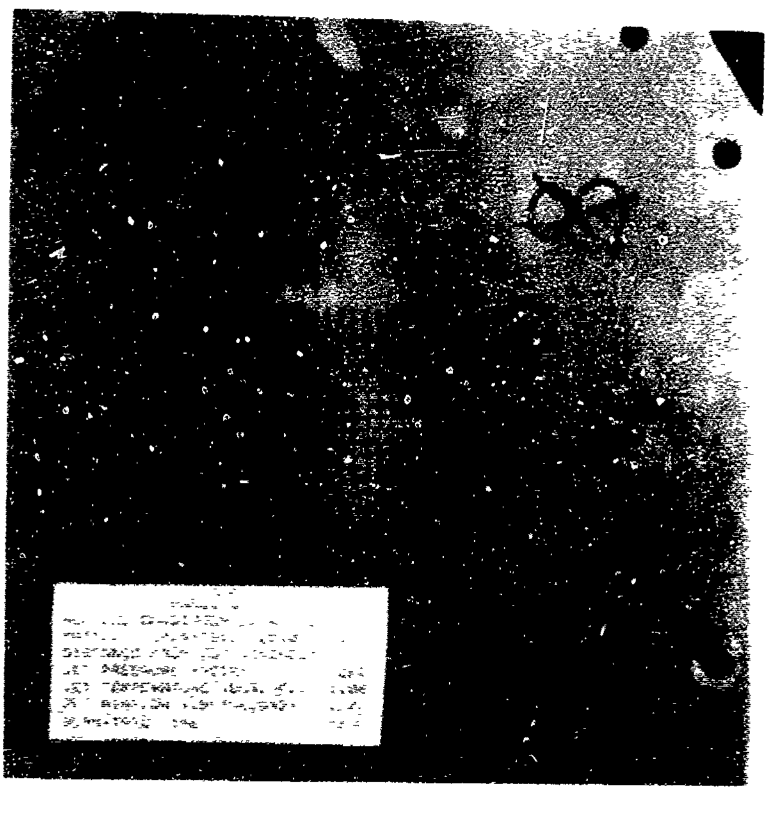


Figure C–8. Panel 8

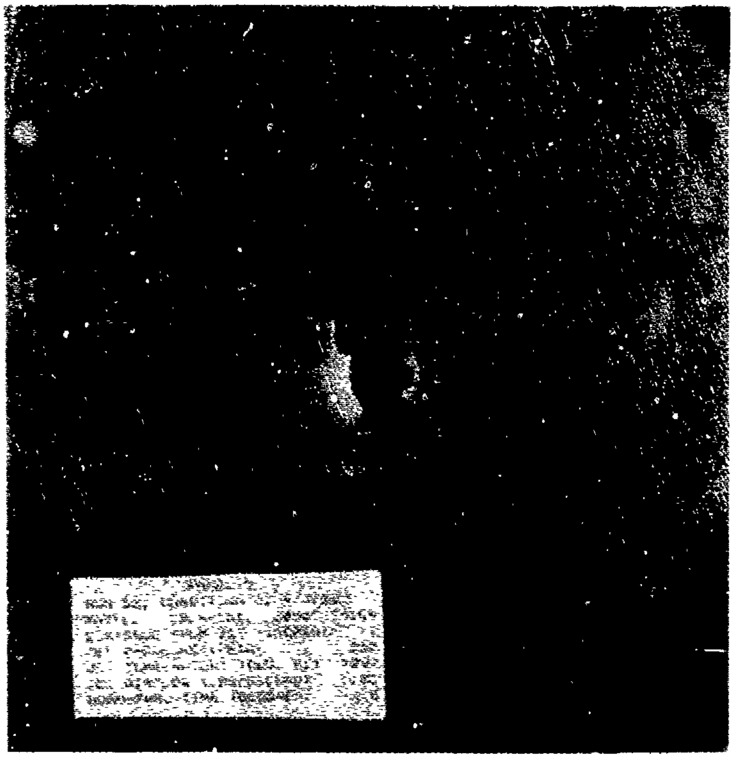


Figure C–9. Panel 9

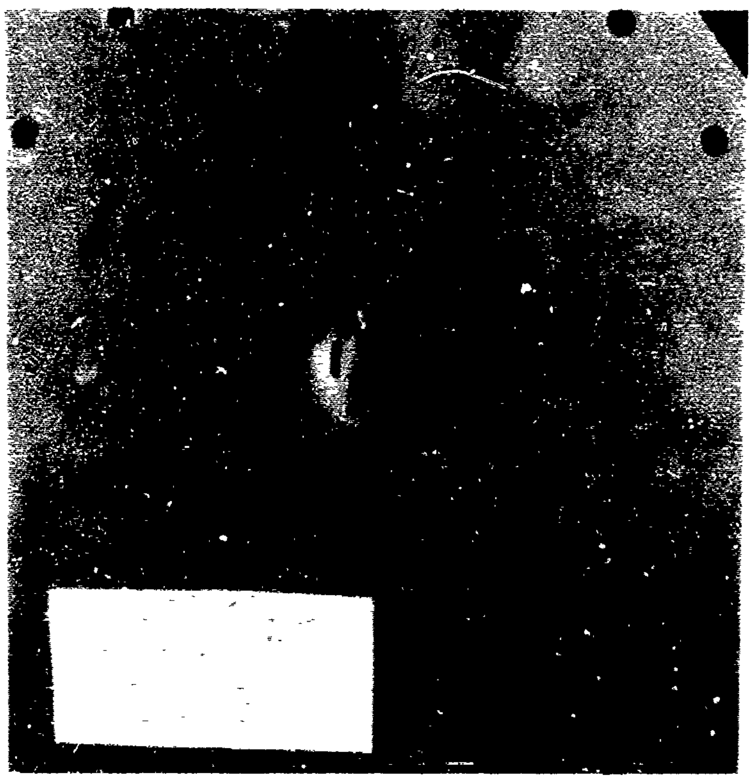


Figure C–10. Panel 10

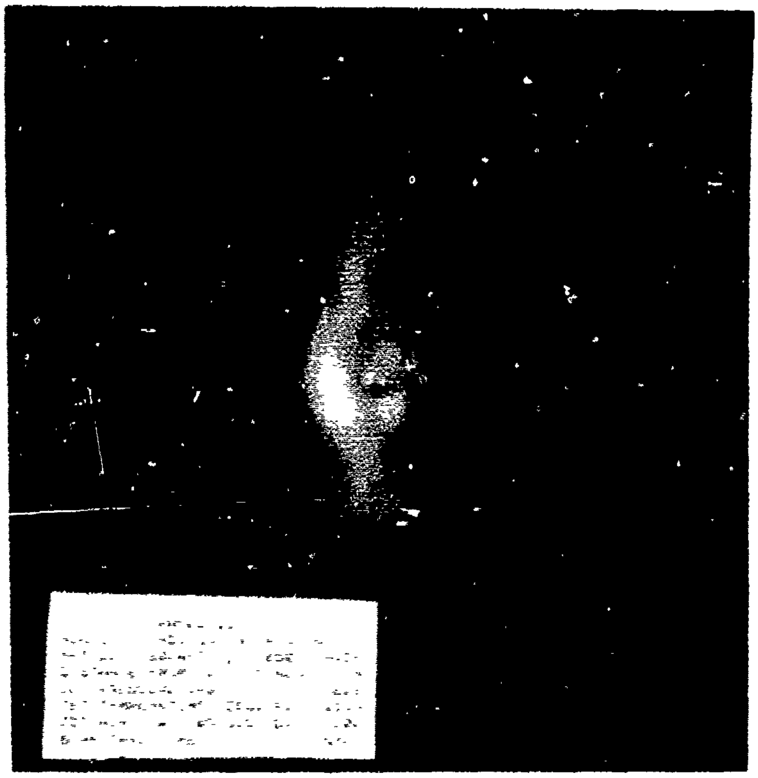


Figure C–11. Panel 11

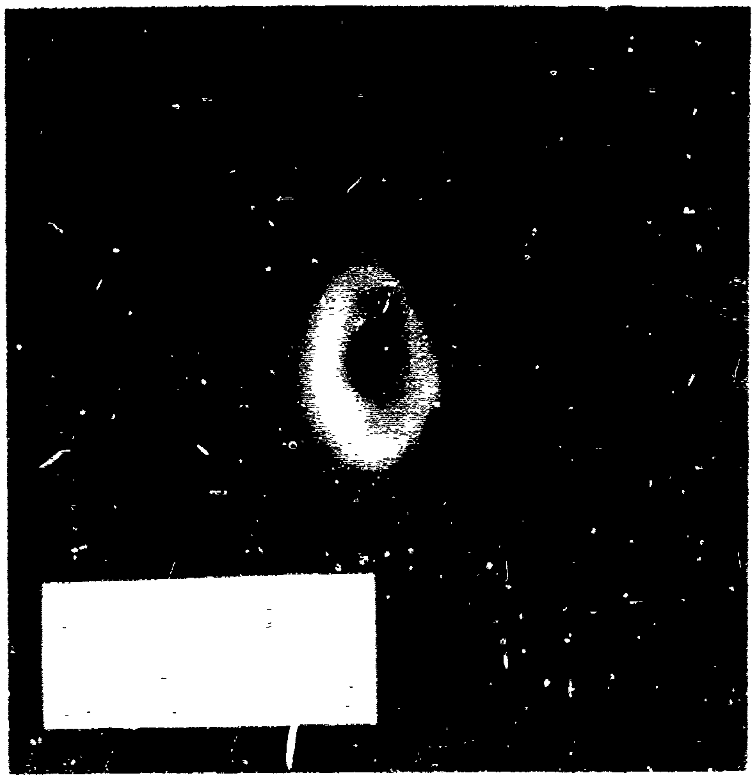


Figure C–12. Panel 12

Figure C–13. Panel 13

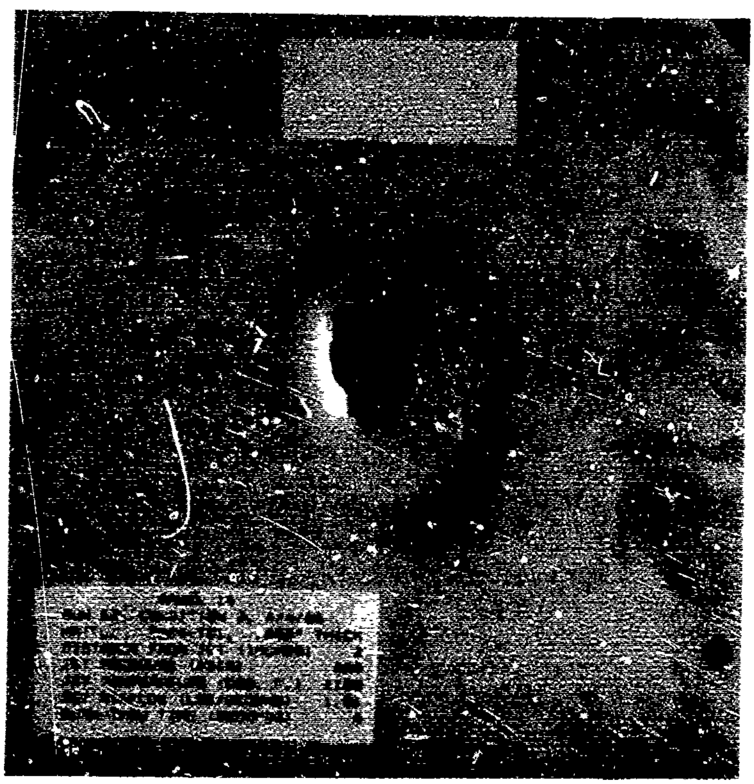


Figure C–14. Panel 14

Figure C–15. Panel 15

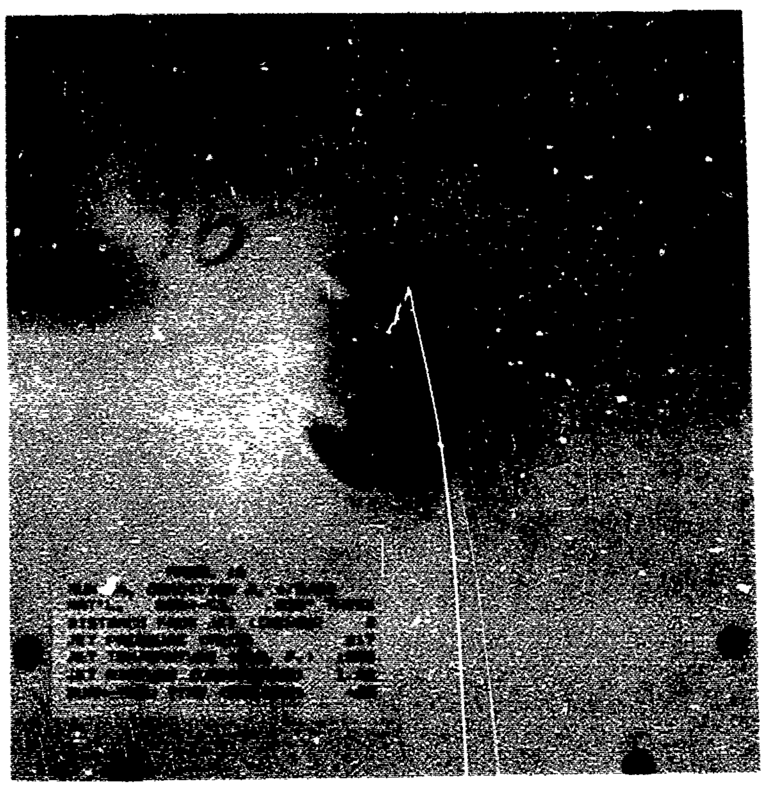


Figure C–16. Panel 16

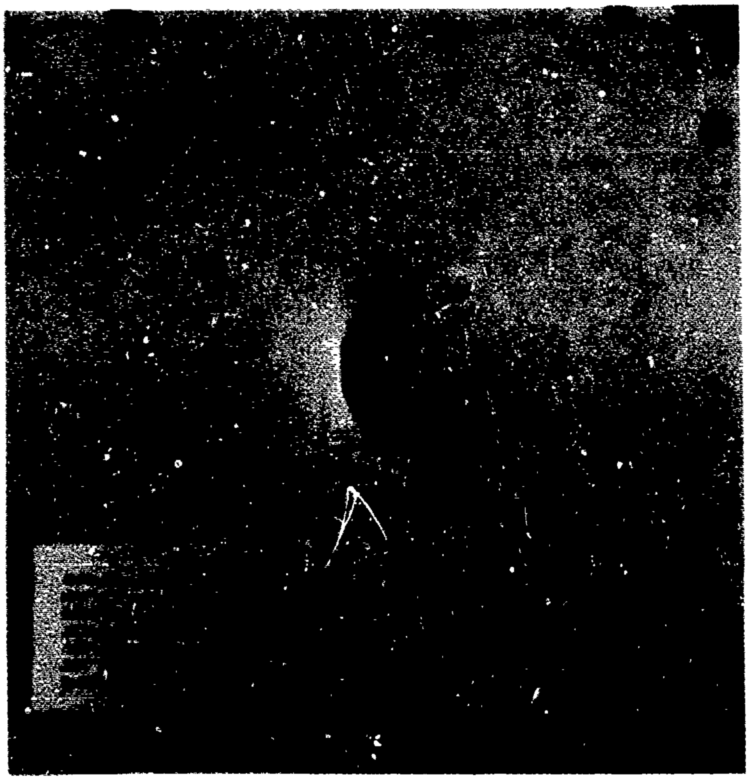


Figure C—17. Panel 17

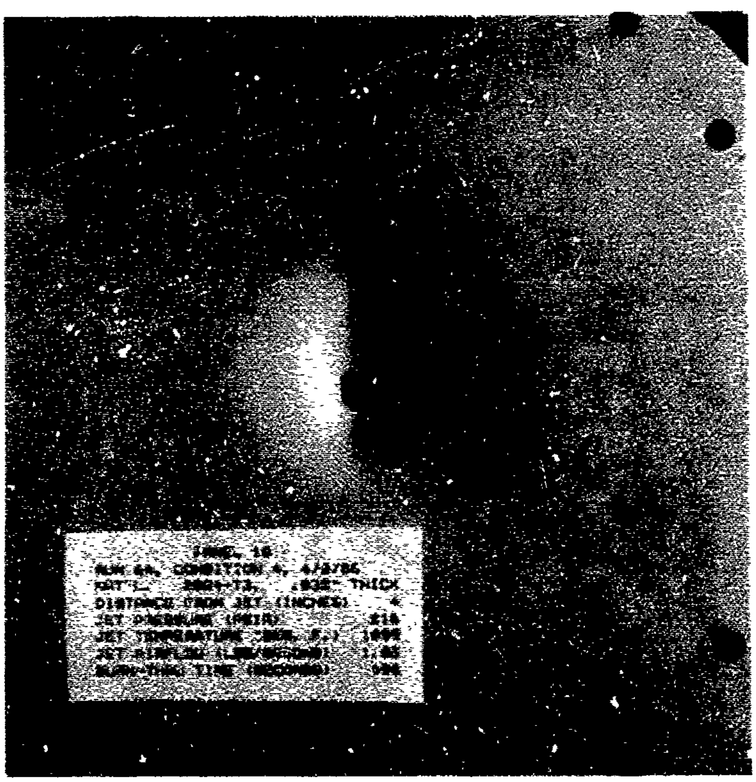


Figure C—18. Panel 18

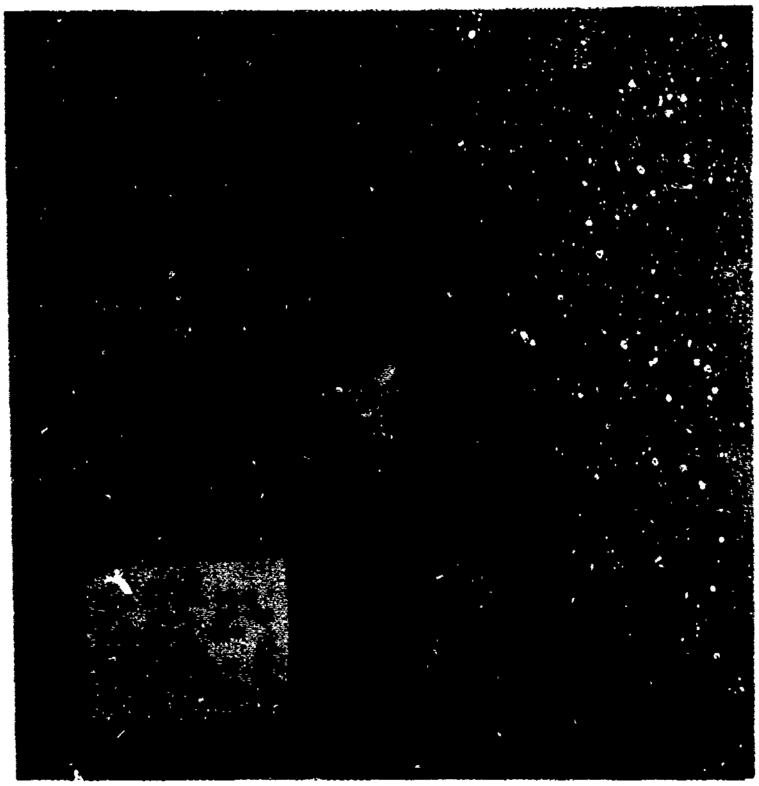


Figure C–19. Panel 19

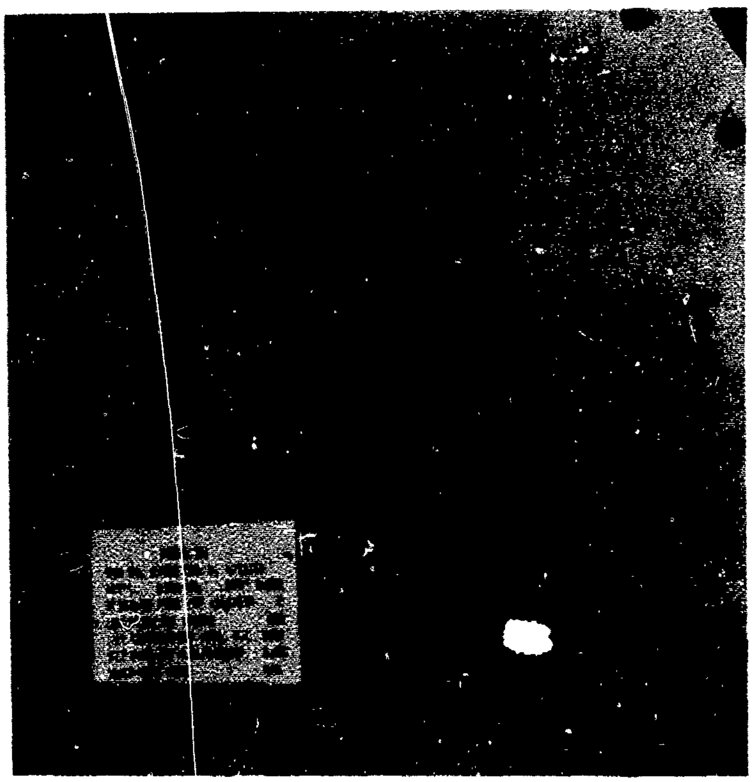


Figure C–20. Panel 20

Figure C–21. Panel 21

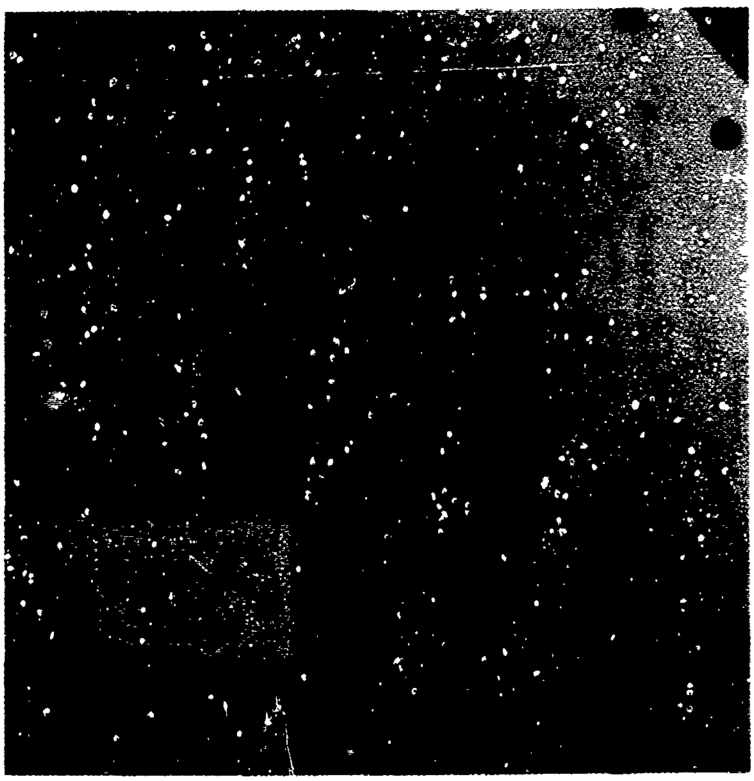


Figure C–22. Panel 22

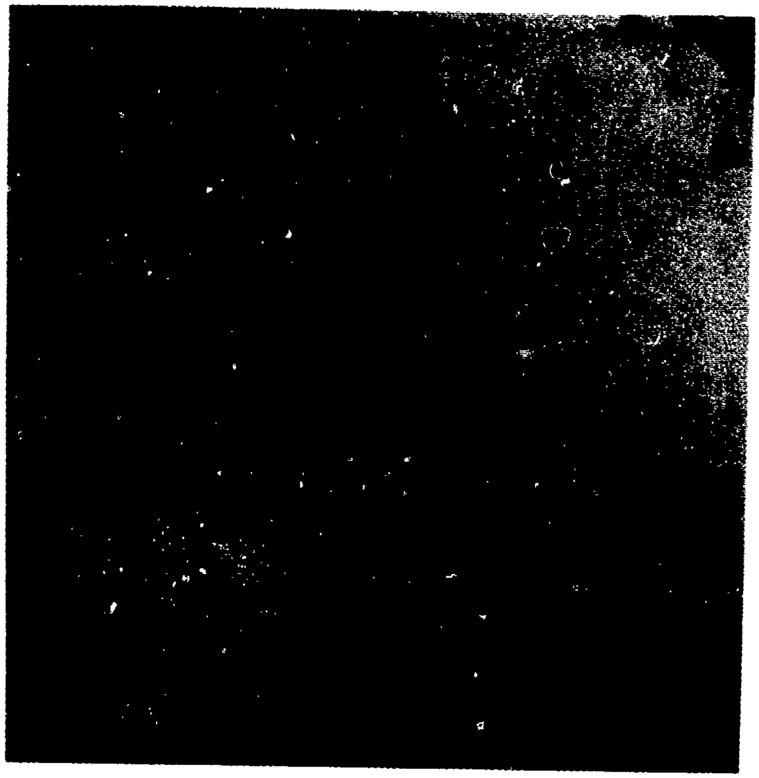


Figure C–23. Panel 23

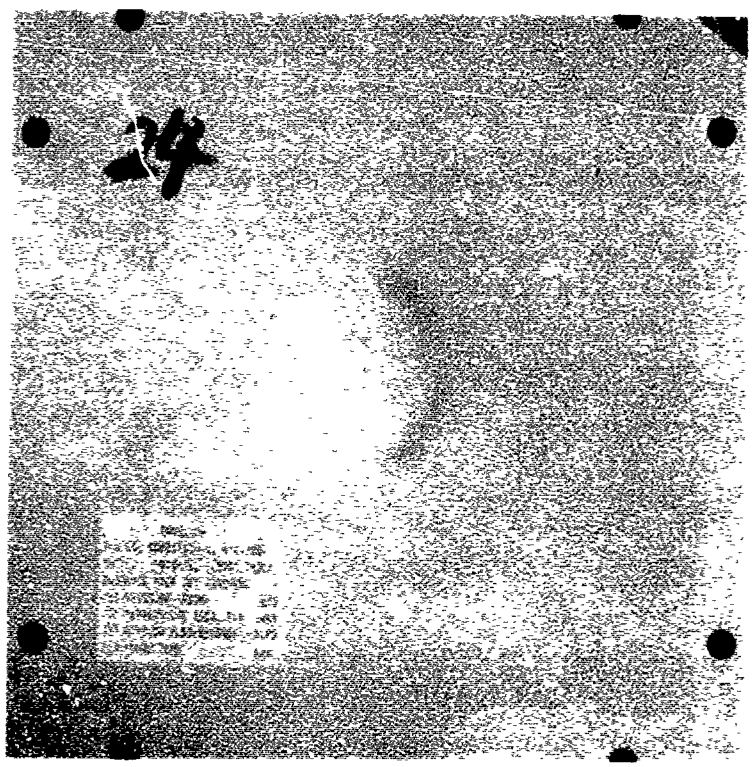


Figure C–24. Panel 24

Figure C–25. Panel 25

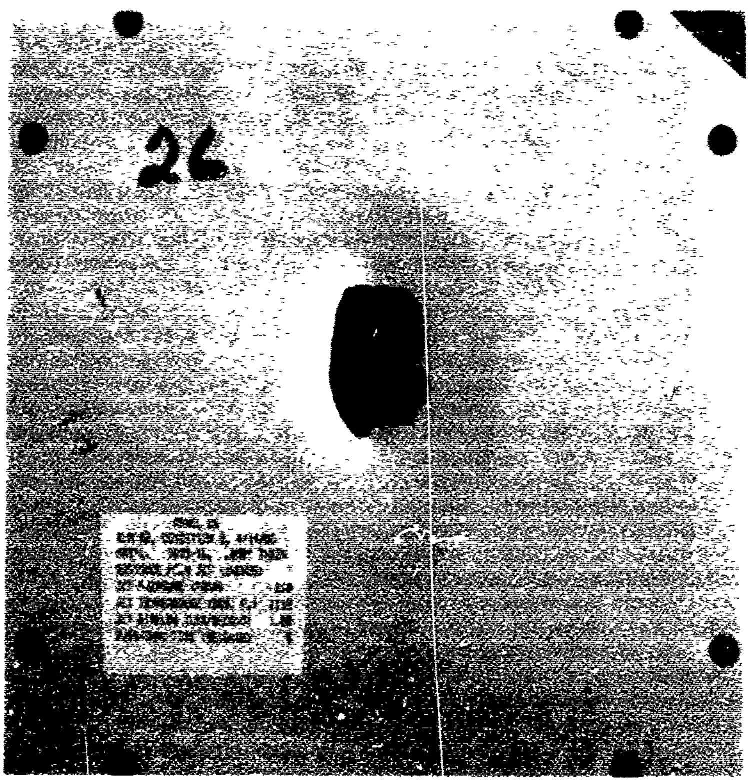


Figure C–26. Panel 26

Figure C–27. Panel 27

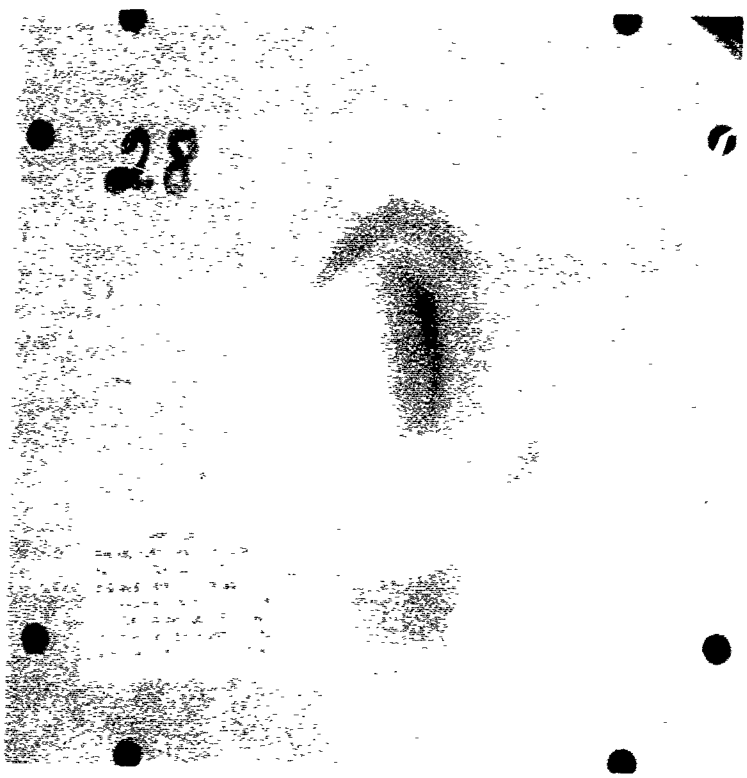


Figure C–28. Panel 28

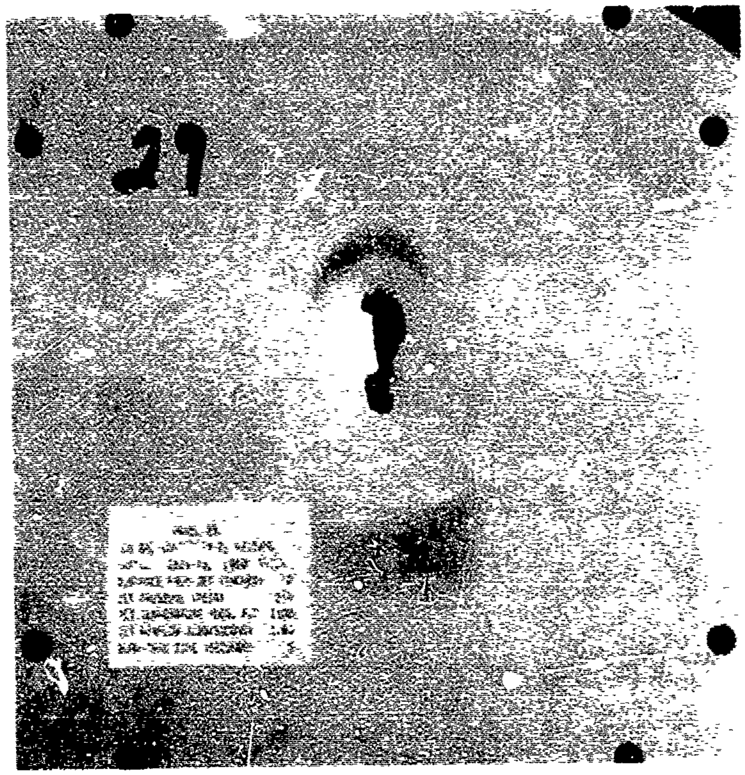


Figure C–29. Panel 29

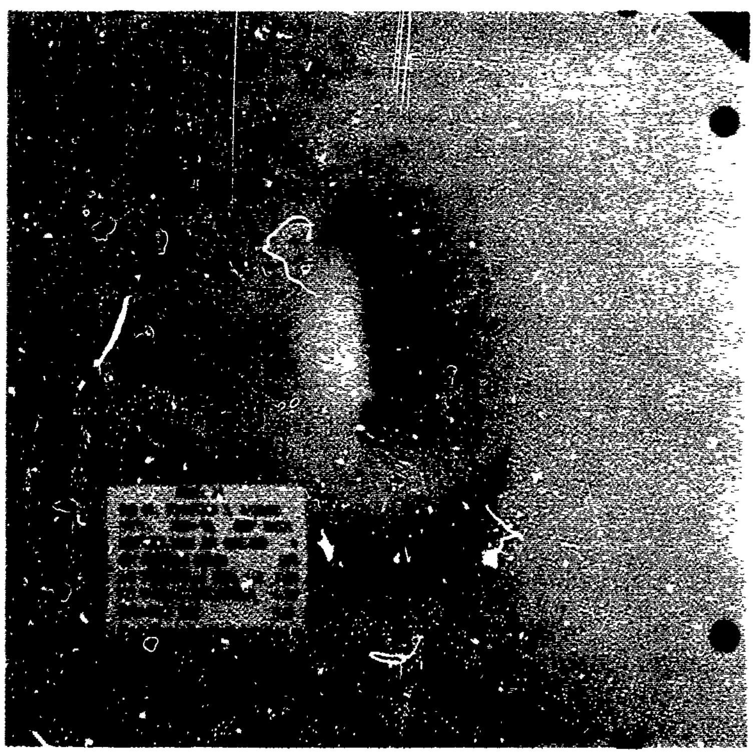


Figure C–30. Panel 30

Figure C–31. Panel 31

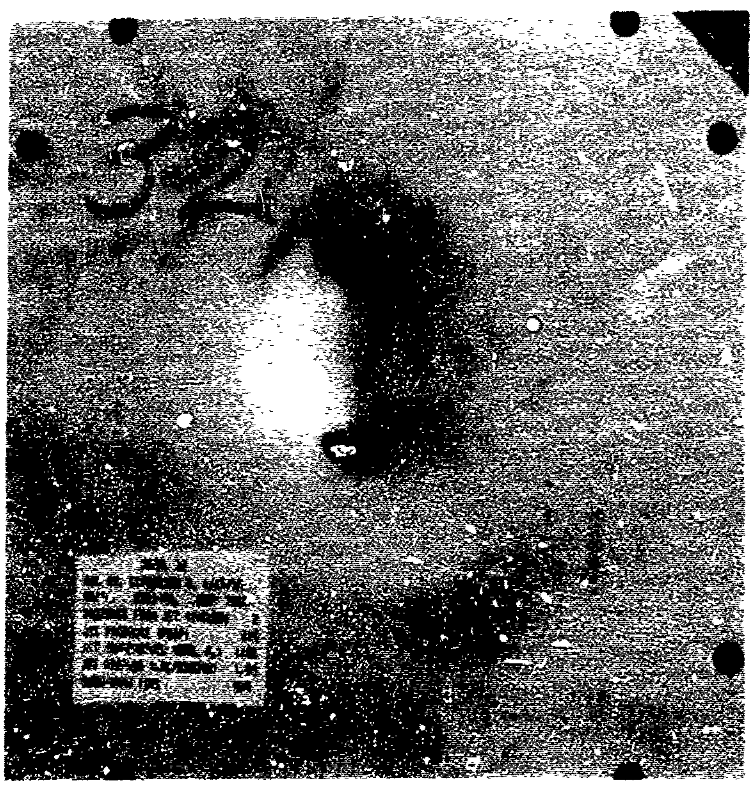


Figure C–32. Panel 32

Figure C--33. Panel 33

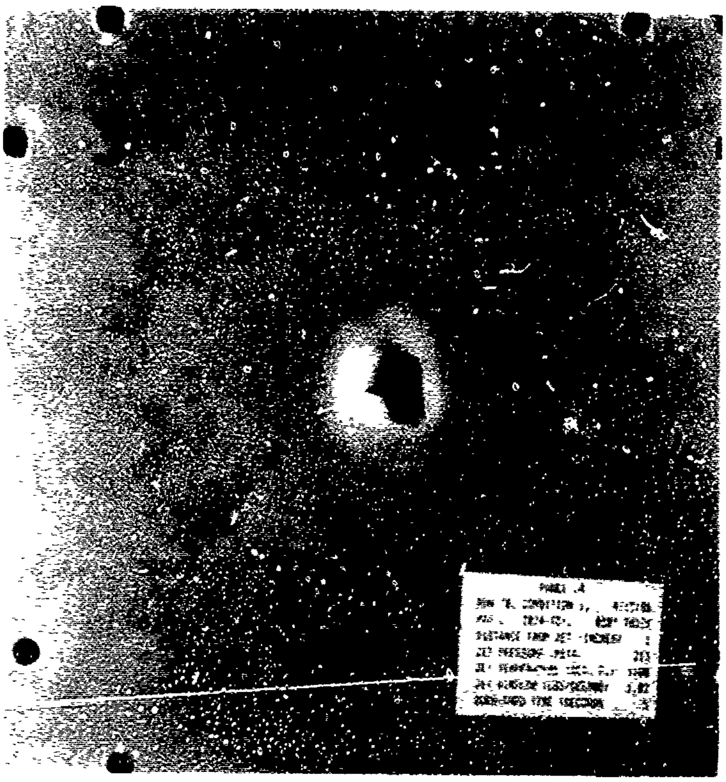


Figure C--34. Panel 34

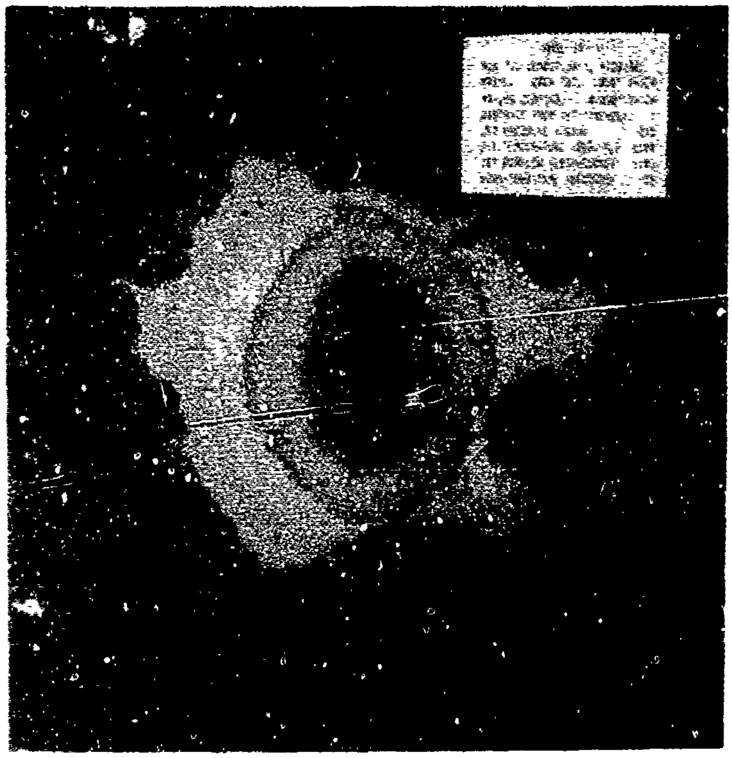


Figure C–35. Panel 35

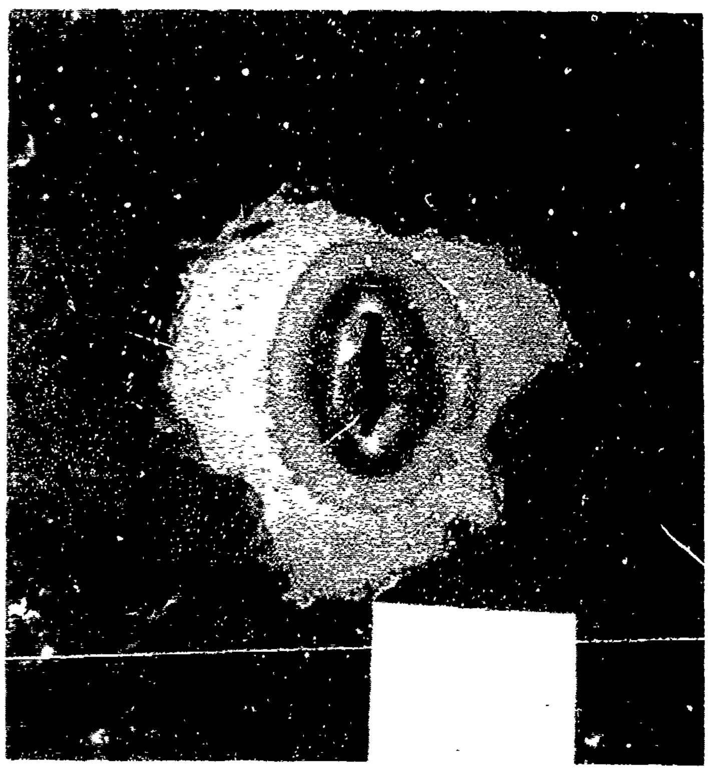


Figure C–36. Panel 36

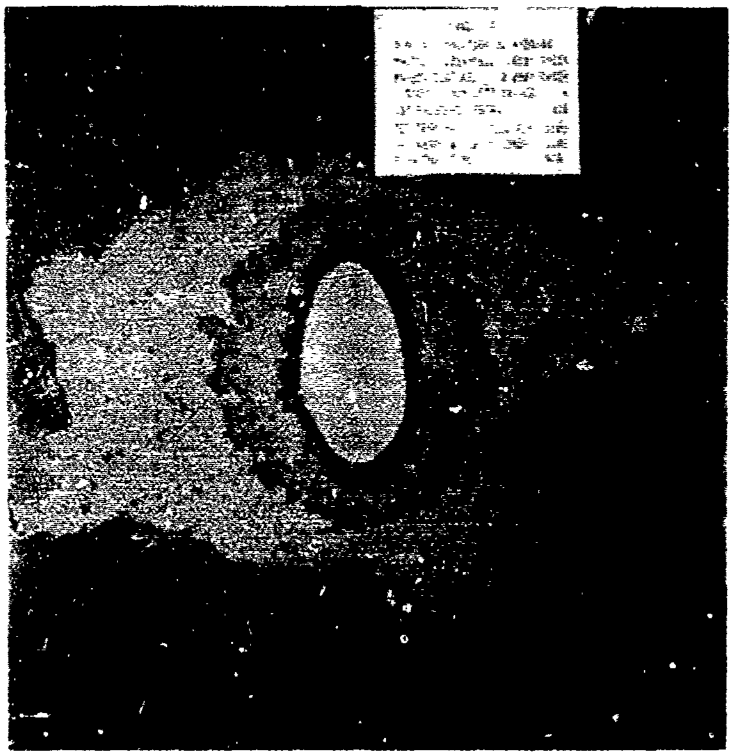


Figure C–37. Panel 37

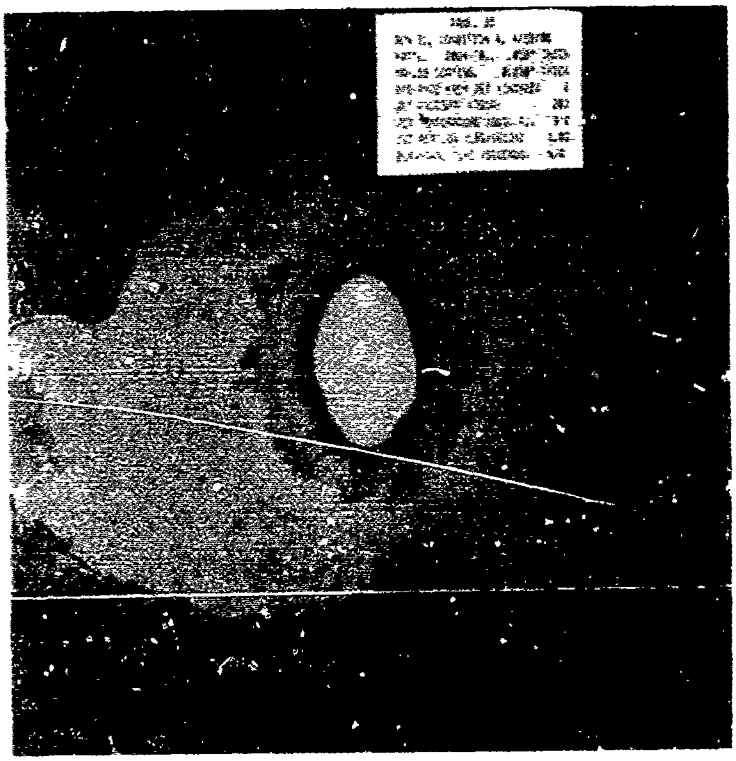


Figure C–38. Panel 38

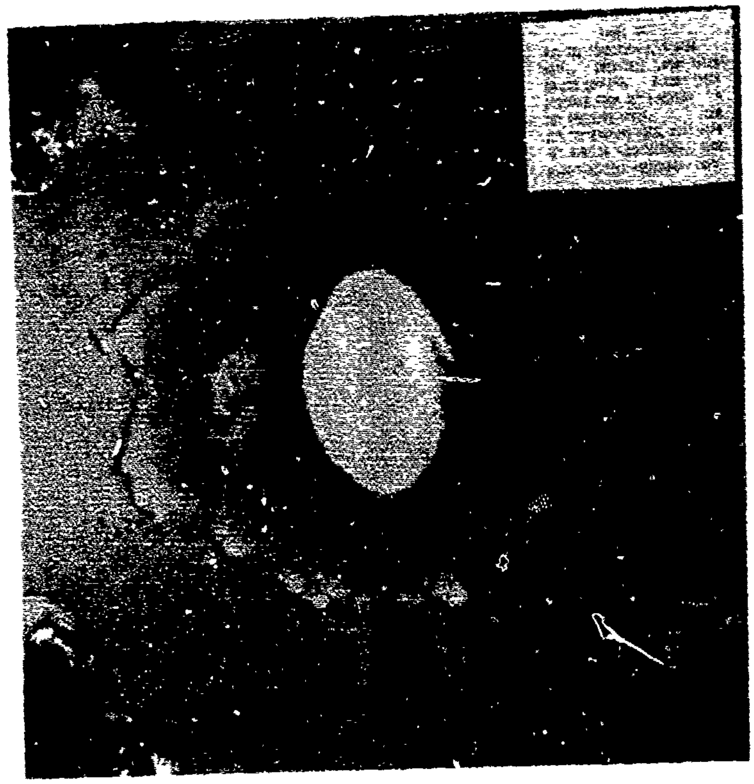


Figure C–39. Panel 39

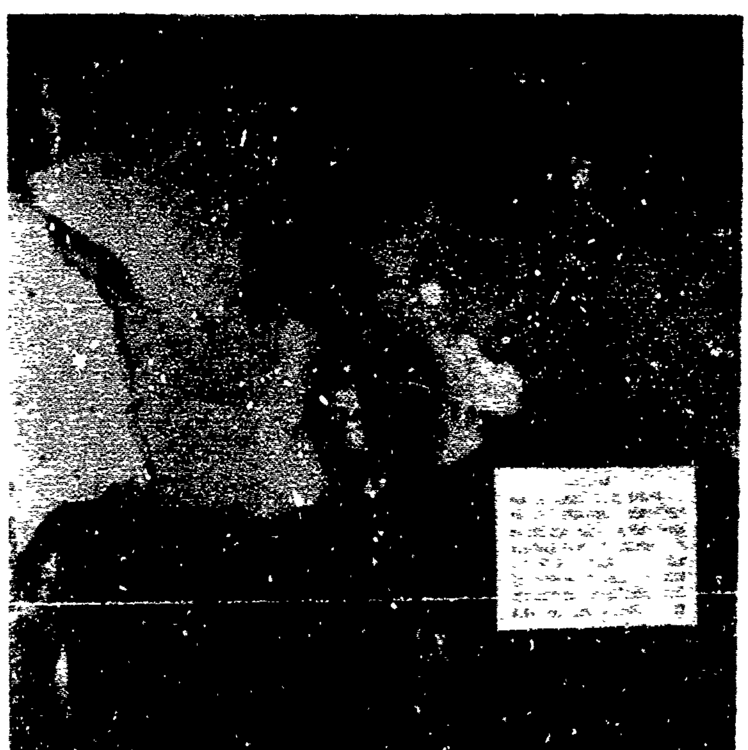


Figure C–40. Panel 40

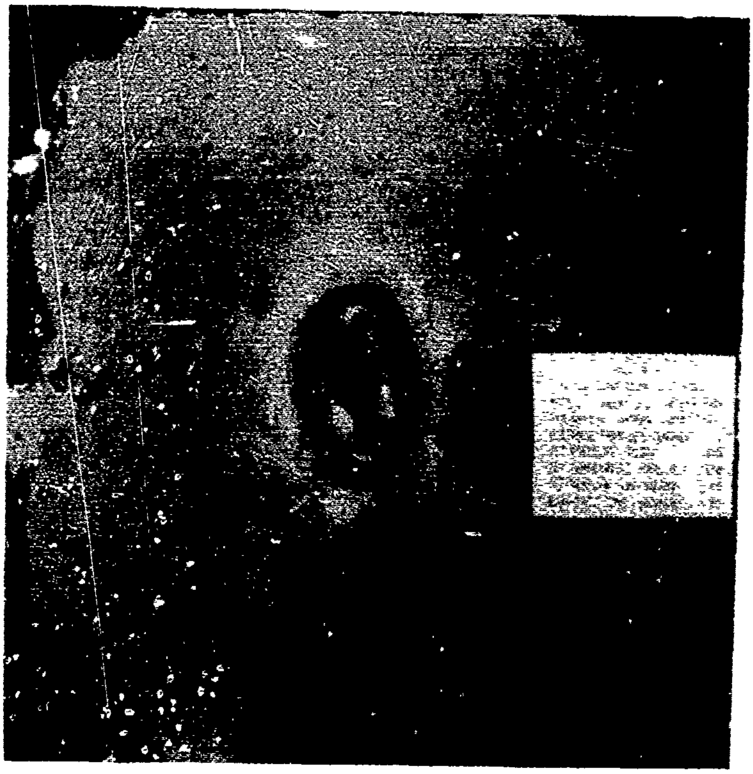


Figure C–41. Panel 41

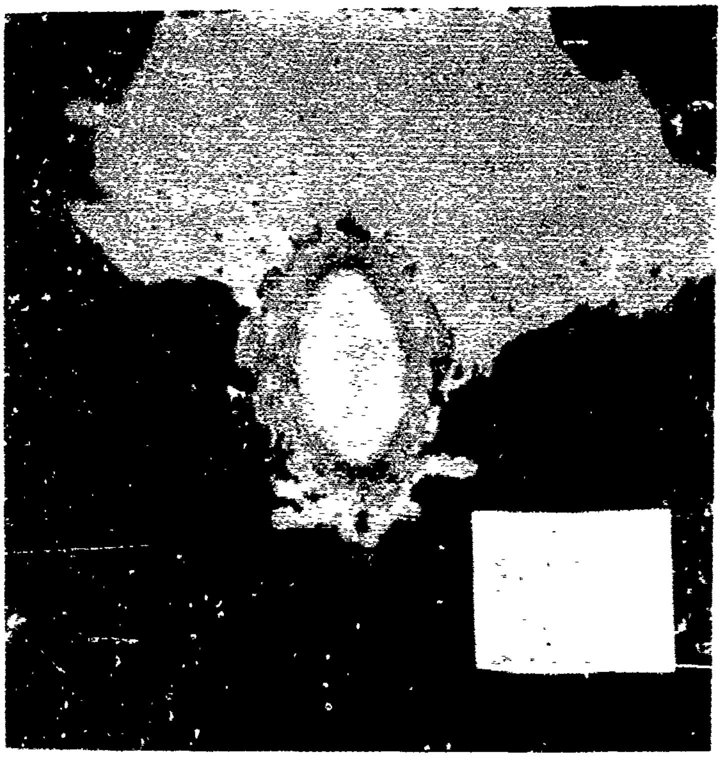


Figure C–42. Panel 42

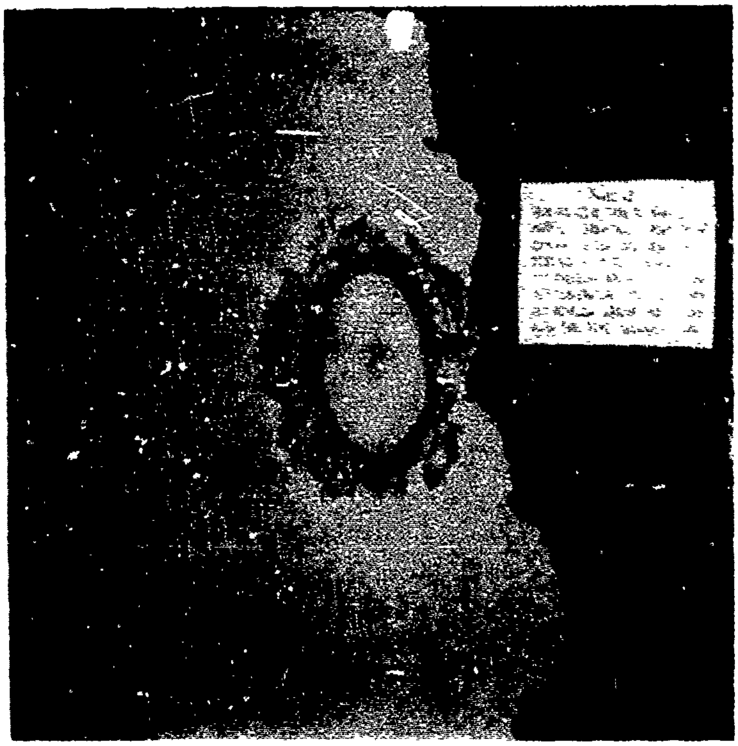


Figure C–43. Panel 43

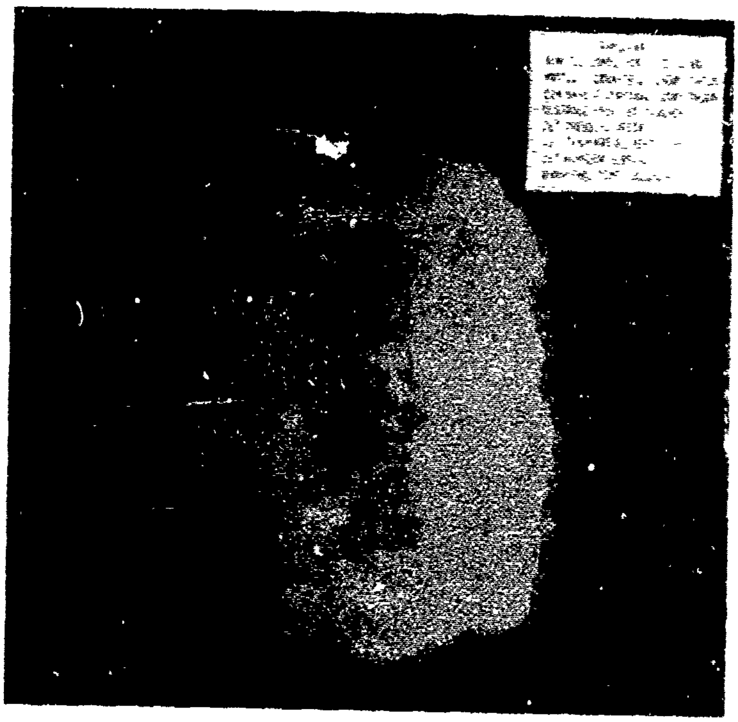


Figure C–44. Panel 44

Figure C—45. Panel 45

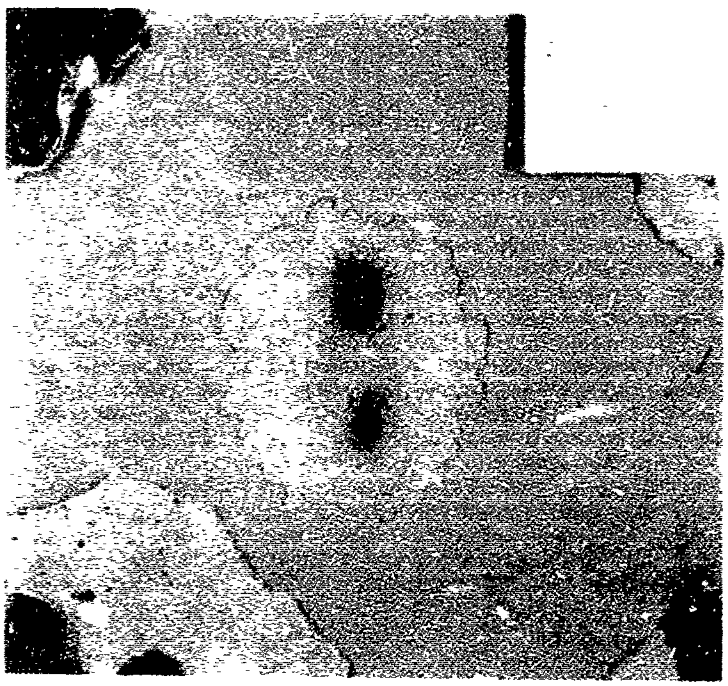


Figure C—46. Panel 46

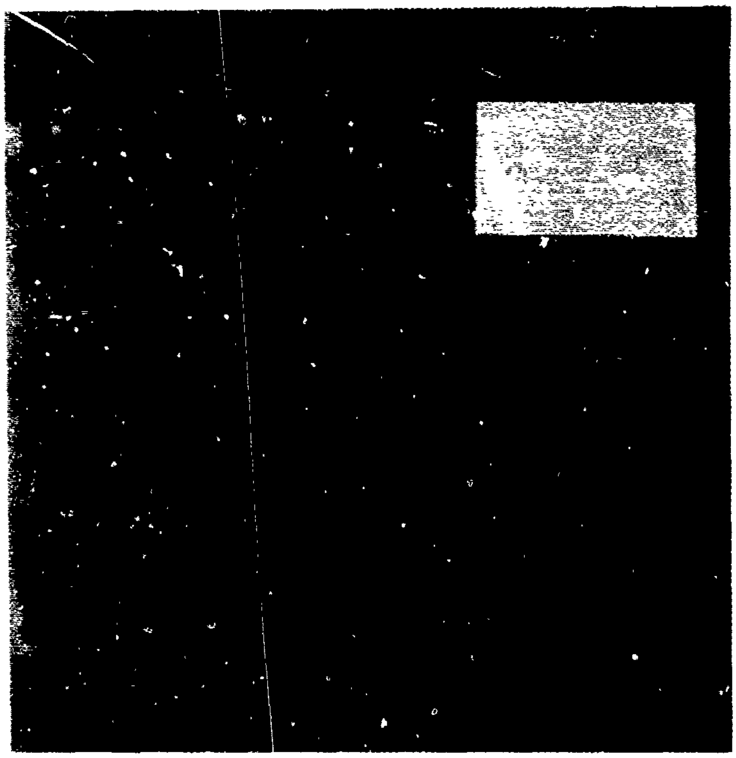


Figure C—47. Panel 47

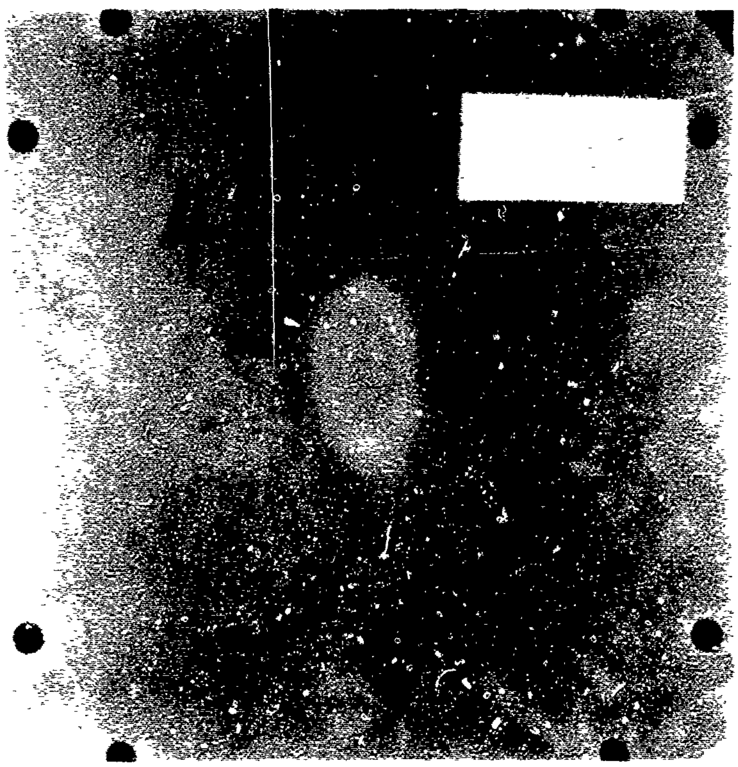


Figure C—48. Panel 48

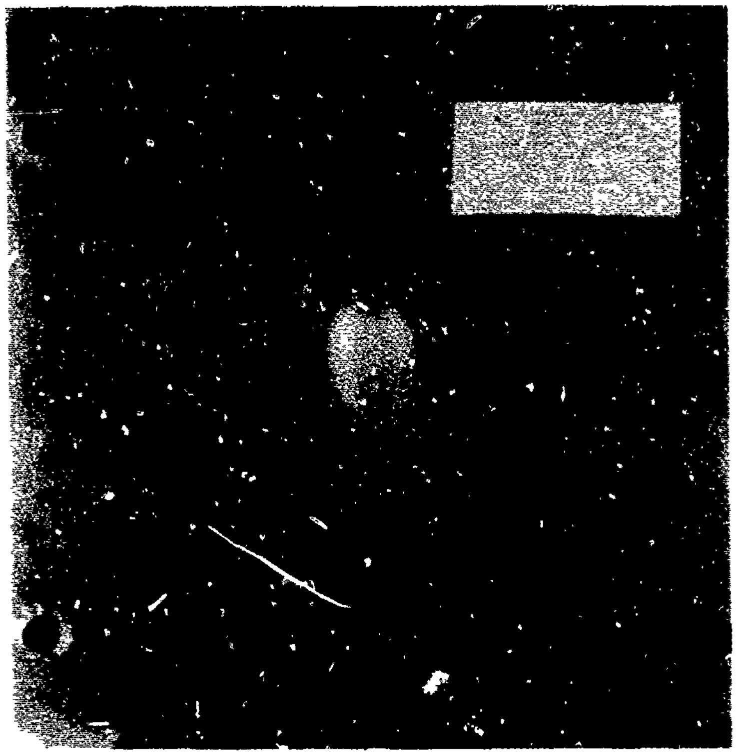


Figure C–49. Panel 49

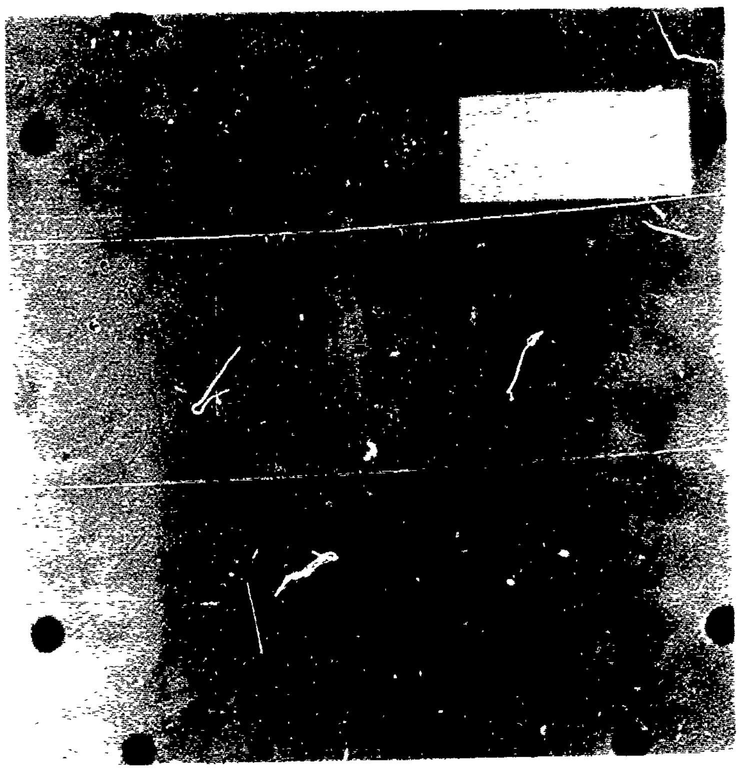


Figure C–50. Panel 50

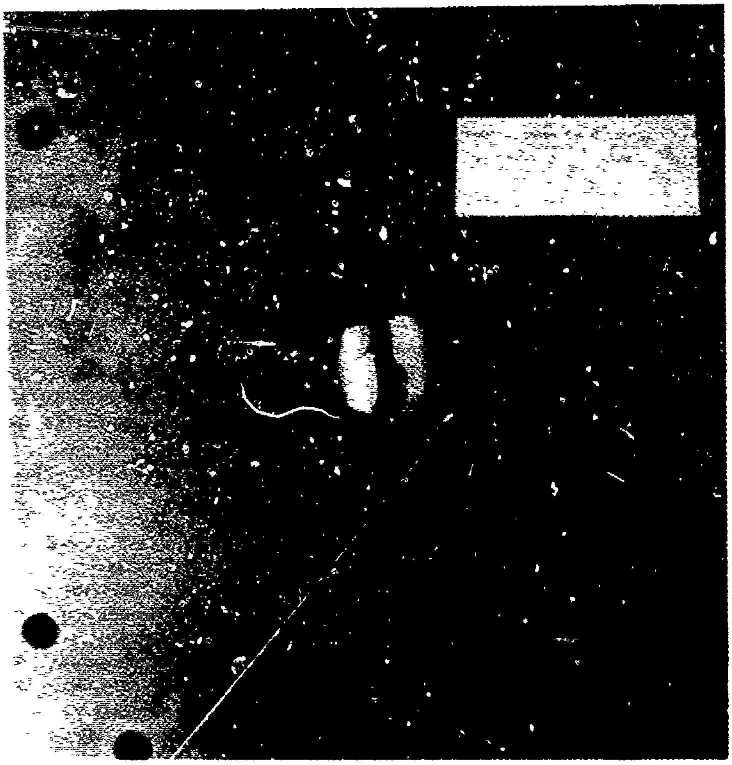


Figure C–51. Panel 51

LOCATIONS FOR READING ELECTRICAL CONDUCTIVITY METER ON PANELS (SEE FIGURE 7)

HOURS	C	T	R	B	L	MT	MR	MB	ML	TC	RC	BC	LC
PANEL 47													
0.167	39.5	39.5	37.5	37.3	38	37.2	37.2	37.5	37.3	37.3	37.3	37.4	37.3
1	39.4	39.1	38	38.5	38.2	37.2	37.3	37.3	37.5	37.4	37.3	37.6	37.7
2	39.5	39.2	38	38.4	38.1	37.2	37.2	37.3	37.1	37.3	37.4	37.3	37.3
24	38.9	38.9	37.7	37.8	37.8	36.8	37.2	37.1	36.8	36.8	36.9	36.9	36.9
48	38.2	38.8	37.6	37.9	37.7	36.9	37.2	36.9	36.9	37.1	36.9	36.9	37.2
72	38.3	38.9	37.5	37.9	37.8	36.8	36.9	36.9	36.8	36.8	36.8	36.8	36.8
192	38.3	38.7	38.2	38.2	38.1	37.1	36.9	36.9	37	37.2	37.3	37.2	37.1
AVG	38.9	39.0	37.8	38.0	38.0	37.0	37.1	37.1	37.1	37.1	37.1	37.2	37.2
PANEL 48													
0.167	37	38.1	38.1	38.2	38.1	37.3	37.1	37	37.3	37	37.1	37.1	37
1	37.2	38.4	38.6	38.9	38.6	37.8	37.4	37.3	37.9	37.5	37.4	37.5	37.5
2	36.8	38.1	38.3	38.4	38.3	37.2	37.1	37.1	37.4	37.2	37.7	37.2	37.4
24	35.9	36.6	38	38.1	38	37.4	36.9	36.9	36.9	36.8	36.9	36.7	36.9
48	35.9	36.8	38.1	37.7	38	36.9	36.9	36.9	37	37	37	37.4	36.8
72	35.9	36.8	37.8	37.8	38.3	37.3	37.2	36.9	37.1	37.1	36.9	36.9	37.1
192	35.9	36.8	38.1	37.6	38.1	37.1	37.2	36.9	37.2	36.7	36.8	36.9	36.9
AVG	36.4	37.4	38.1	38.1	38.2	37.3	37.1	37.0	37.3	37.0	37.1	37.1	37.1
PANEL 49													
0.167	35.4	35.3	37.3	37.5	37	36.7	36.2	36.5	36.8	36.1	36.3	36.6	36.1
1	35.6	34.5	37.8	38	37.7	37.7	36.8	38	37.4	36.7	37	37.2	37
2	35.2	36.1	37.8	38.2	37.4	37.4	36.8	37	37.4	36.9	37.2	37.1	36.8
24	34.5	34.3	37.6	37.7	36.8	37.3	36.6	37.1	37.3	36.7	36.8	36.7	36.6
48	34.1	33.4	37.6	37.6	37	37.1	36.8	37	37.1	36.5	36.9	36.8	36.8
72	34.1	34.3	37.4	37.2	36.8	37.3	36.5	36.4	36.9	36.7	36.4	36.5	36.2
96	33.9	34.6	37.1	37.9	37	37.3	36.6	36.7	37.1	36.5	36.6	36.4	36.3
192	34.1	34.6	37.3	37.1	36.4	36.9	36.4	36.4	36.8	36.3	36.5	36.6	36.4
AVG	34.6	34.7	37.5	37.7	37.0	37.2	36.6	36.9	37.1	36.6	36.7	36.7	36.5

LOCATIONS FOR READING ELECTRICAL CONDUCTIVITY METER ON PANELS (SEE FIGURE 7)

HOURS	C	T	R	B	L	MT	MR	MB	ML	TC	RC	BC	LC
PANEL 50													
0.167	33.8	34.8	36.7	37.3	37.1	36.2	36.2	36.5	36.2	36.3	36.4	36.6	36.5
1	33.8	35.1	37.1	37.3	37.3	36.5	36.8	36.8	36.7	36.9	36.8	37.4	36.9
2	34.1	34.8	37	37.2	37.1	36.5	36.8	36.9	36.6	36.6	36.8	37.2	37.1
24	33.2	33.3	36.8	36.9	36.9	36.4	36.4	36.6	36.3	36.5	36.8	37.1	36.4
48	32.8	33.3	36.8	36.8	36.9	36.4	36.6	36.8	36.2	36.4	36.6	36.8	36.7
72	32.9	33.2	36.5	36.4	36.2	35.9	36.4	36.5	36.2	35.9	36.5	36.4	36.2
96	32.5	33.6	36.8	36.8	36.9	36.3	36.5	36.8	36.4	36.6	37	37.1	36.6
192	32.7	33.3	36.6	36.6	36.4	36.2	36.3	36.4	36.4	36.3	36.4	36.5	36.7
AVG	33.2	33.9	36.8	36.9	36.9	36.3	36.5	36.7	36.4	36.4	36.7	36.9	36.6
PANEL 51													
0.167		26.3	35.3	35.7	34.9	36.6	36.4	36.5	36.2	36.2	36.7	36.5	36.4
1		33.1	35.7	36.4	35.3	36.9	36.9	37	36.8	36.9	37	37	37.5
2		27.9	35.6	35.9	35.3	36.7	36.9	36.1	36.7	37	37.1	37	37.2
24		29.9	35.2	35.9	35.3	36.8	36.9	36.9	36.8	37	36.9	37.1	36.8
48		31.9	35.3	35	35.2	36.8	36.7	37.2	36.5	36.8	36.9	37.1	36.9
72		25.2	34.9	35.7	34.6	36.2	36.5	36.4	36.3	36.4	36.3	36.5	36.4
96		34.7	35.3	36.1	34.5	36.6	36.9	36.8	36.6	36.8	36.8	36.9	36.9
192		25.7	34.9	35.5	34.3	36.4	36.4	36.5	36.3	36.4	36.5	36.8	36.3
AVG		29.3	35.3	35.8	34.9	36.6	36.7	36.7	36.5	36.7	36.8	36.9	36.8
PANEL 52													
0.167	36.8	36.9	36.9	36.9	36.9	37.1	36.9	37.1	36.9	37.2	36.9	36.8	36.9
1	36.8	37	36.9	36.8	36.8	36.9	37	36.9	37	36.8	37.1	36.7	36.7
2	36.9	37	37	37	37	37.1	37.1	37	36.9	37	36.9	36.9	36.8
192	36.8	36.7	36.7	36.8	36.7	36.9	36.9	36.8	36.7	36.7	37	36.9	36.8
AVG	36.8	36.9	36.9	36.9	36.9	37.0	37.0	37.0	36.9	36.9	37.0	36.8	36.8

APPENDIX E PLOTS OF PANEL BACKSIDE TEMPERATURES

Notes on Panel Backside Temperature Plots.

Pages E-3 through E-50 consist of plots of panel backside temperature, measured at locations identified on Figure 8, versus elapsed time, for all panels tested except as noted below:

PANEL 15

No plot was prepared for Condition 1 of Run 64 because of a failure in the ModComp data system. The next test condition, Run 64 Condition 2 employed similar pressures and temperatures, and the panel was placed two-inches from the jet rather than one-inch, as in Condition 1. Oscillograph traces indicated very similar traces for the two test conditions. In both cases, the failure occurred when TPAN-1 approached 900°F, a few seconds after the airflow controller established the intended test conditions. Hence, data for panel 16 can be employed as a close approximation of panel 15 data.

PANEL 34

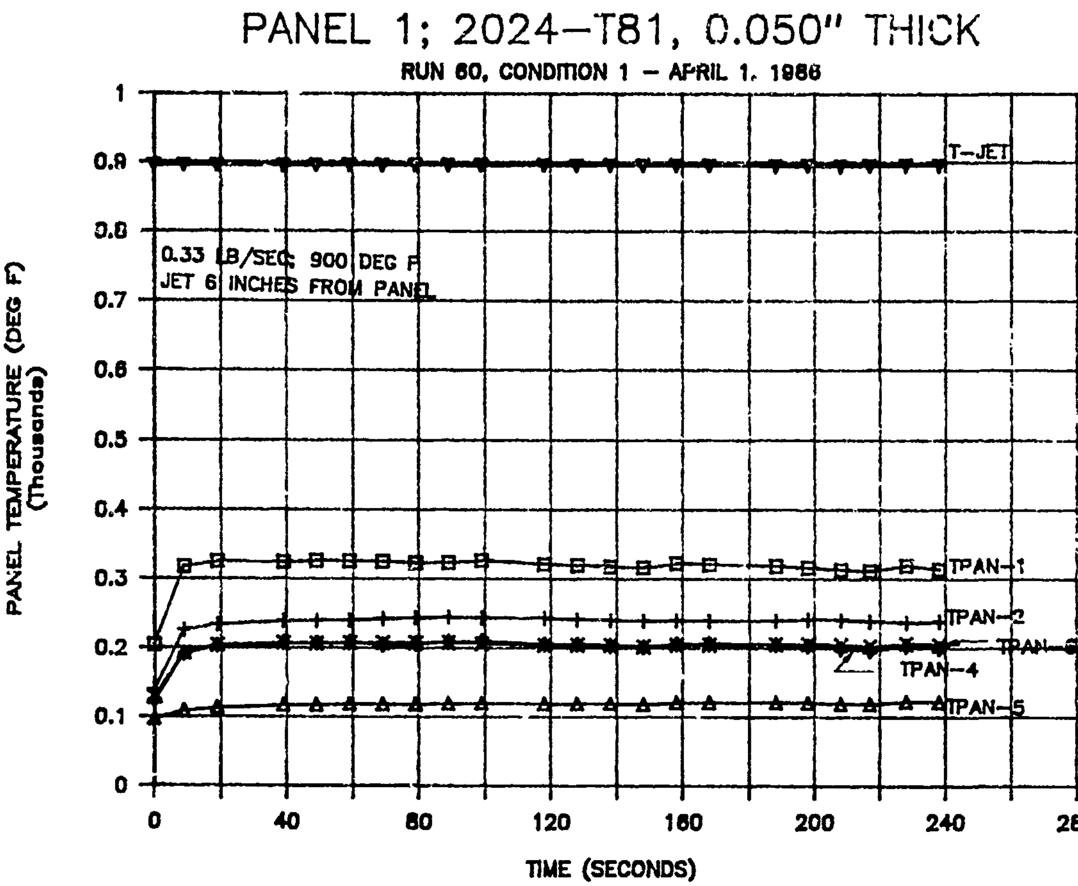
This was a visual demonstration run only. No data were recorded. Test conditions and panel were identical to those for panel 13.

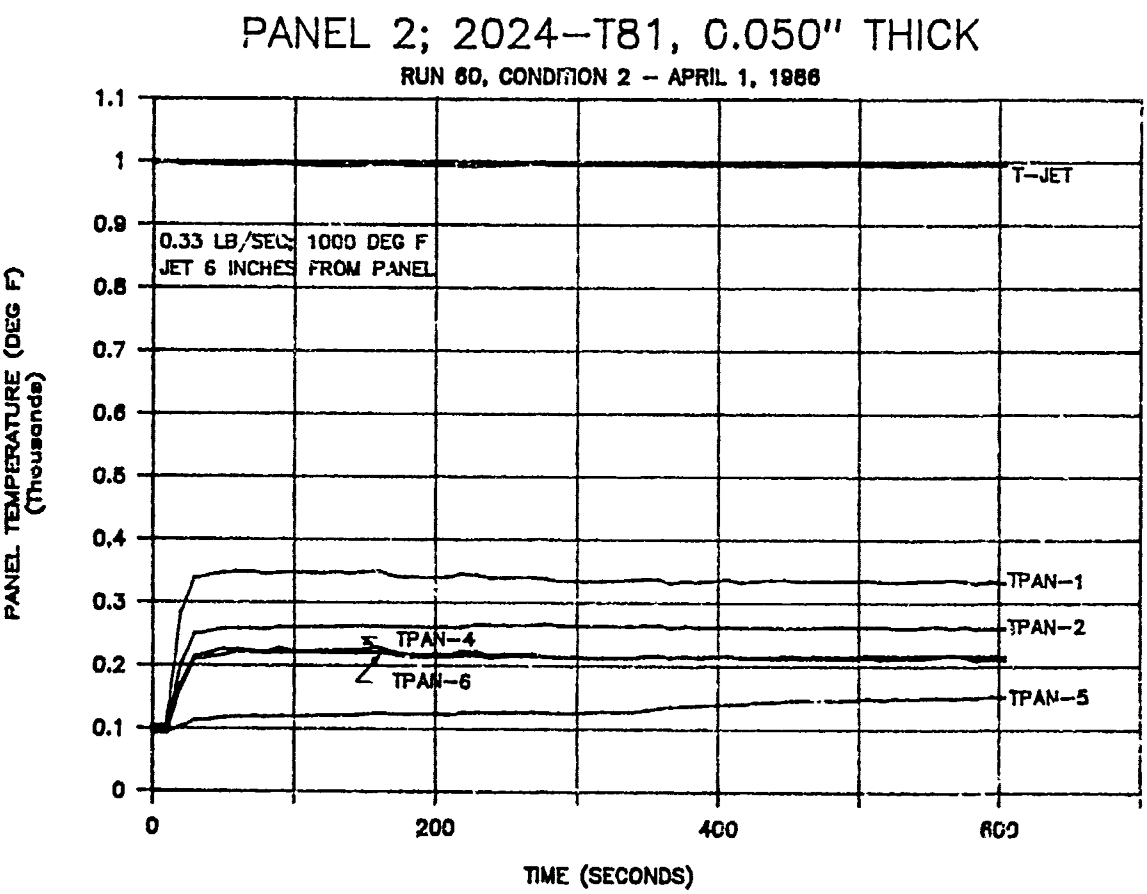
PANEL 51

No ModComp data were acquired for panel 51, because the data disk had become filled during the previous test condition. The panel 51 material and test conditions were identical to for panel 14.

PANEL 52

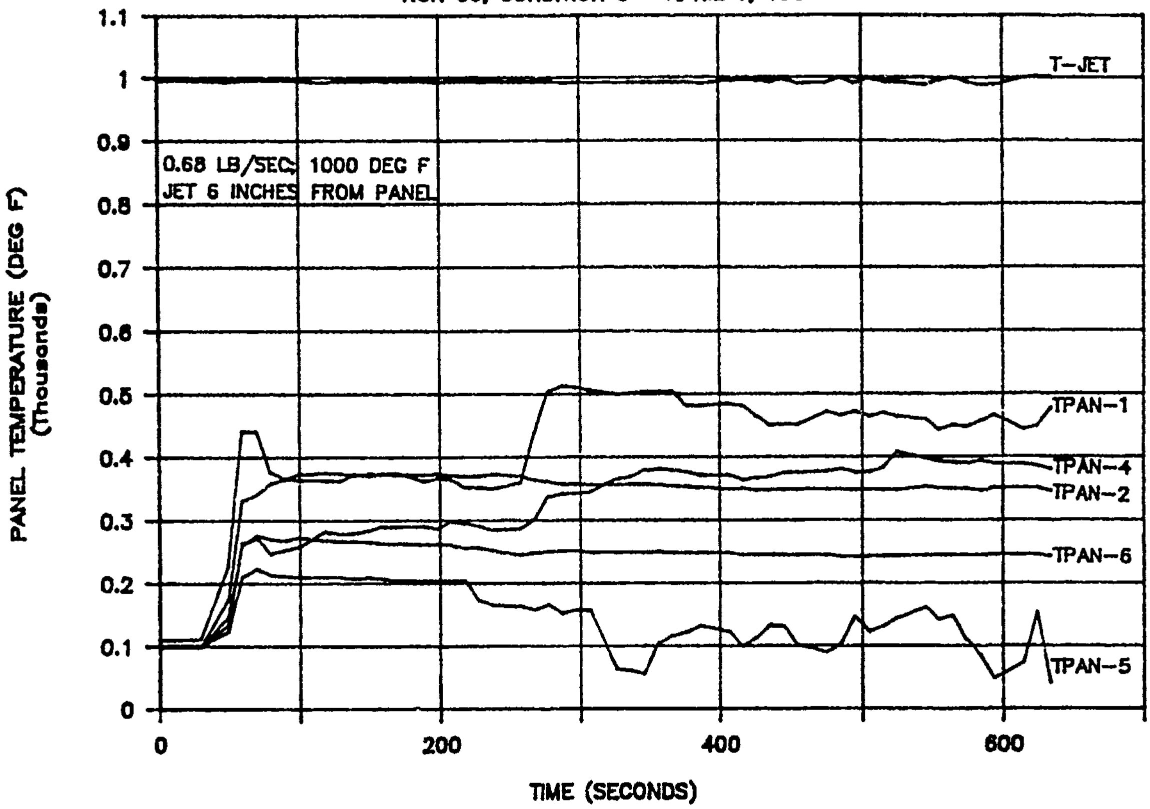
Panel 52 was the baseline for the conductivity measurements and was not subjected to elevated temperatures.


PANEL 1; 2024-T81, 0.050" THICK
RUN 60, CONDITION 1 - APRIL 1, 1986
0.33 LB/SEC; 900 DEG F
JET 6 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-6
TPAN-4
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 2; 2024-T81, 0.050" THICK
RUN 60, CONDITION 2 - APRIL 1, 1986
0.33 LB/SEC; 1000 DEG F
JET 6 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

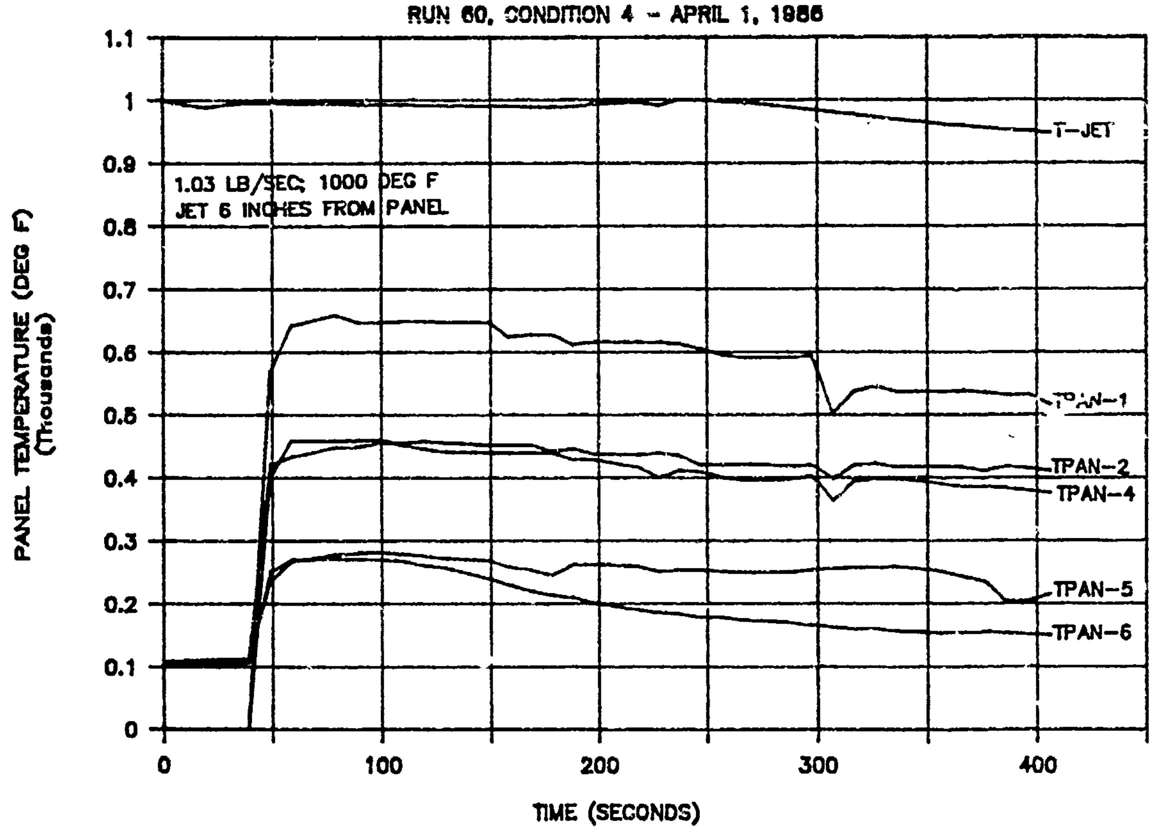
PANEL 3; 2024–T81, 0.050" THICK

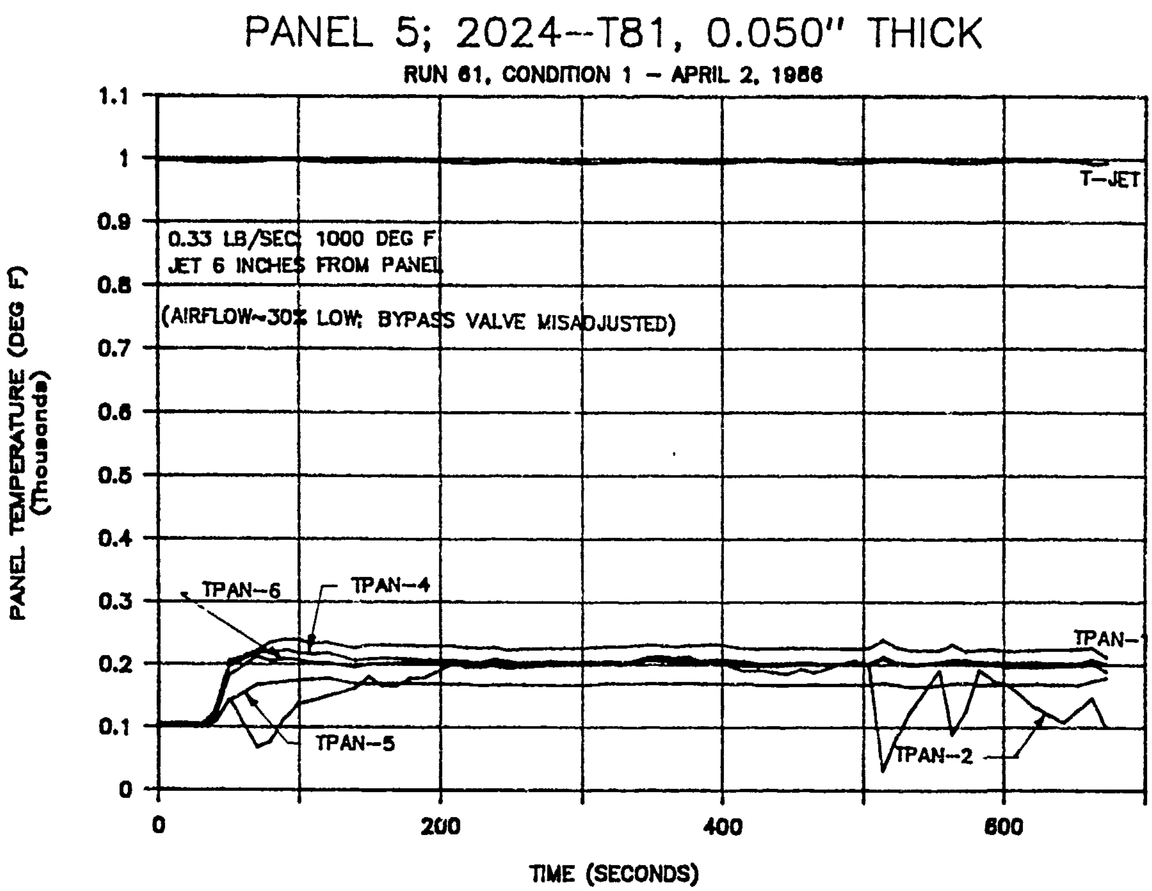
RUN 60, CONDITION 3 – APRIL 1, 1986

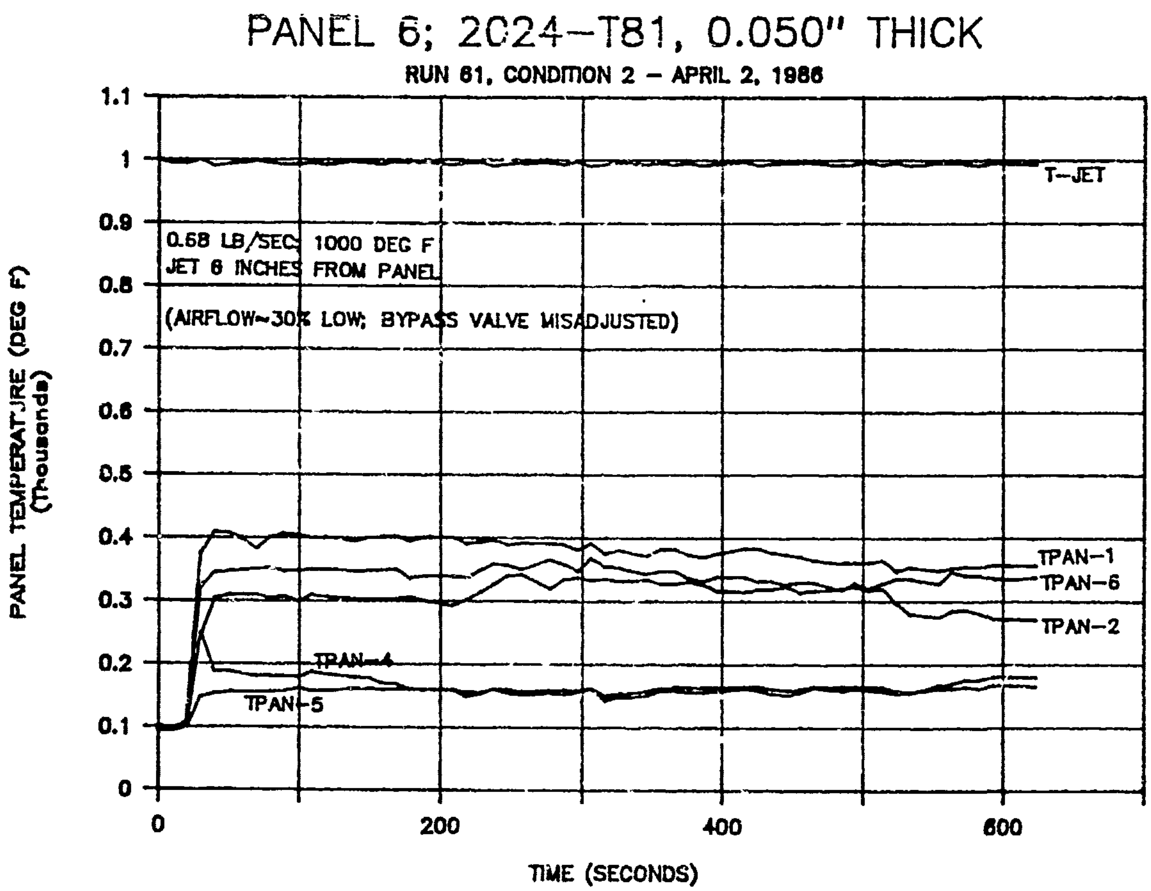


PANEL 4; 2024–T81, 0.050" THICK

RUN 60, CONDITION 4 – APRIL 1, 1986

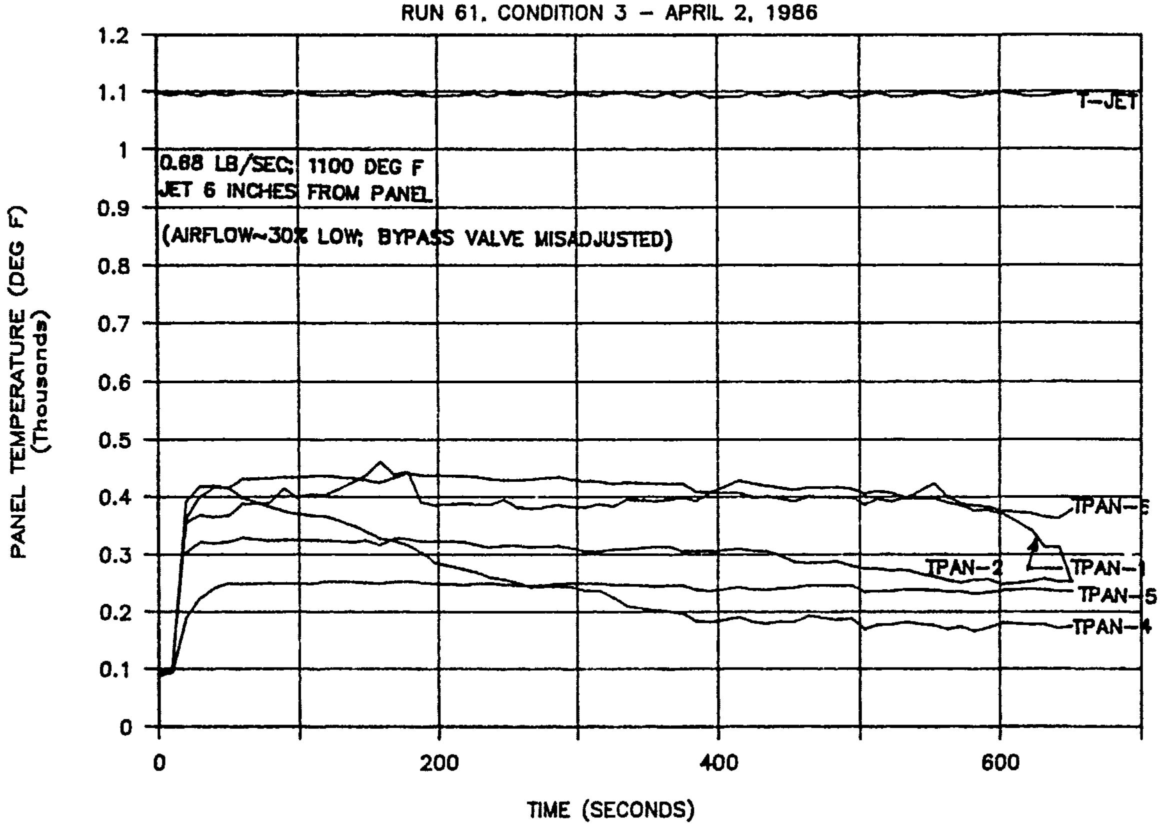



PANEL 5; 2024--T81, 0.050" THICK
RUN 61, CONDITION 1 - APRIL 2, 1986
0.33 LB/SEC; 1000 DEG F
JET 6 INCHES FROM PANEL
(AIRFLOW~30% LOW; BYPASS VALVE MISADJUSTED)
T-JET
TPAN-6
TPAN-4
TPAN-5
TPAN-2
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 6; 2024-T81, 0.050" THICK
RUN 61, CONDITION 2 - APRIL 2, 1986
0.68 LB/SEC; 1000 DEG F
JET 6 INCHES FROM PANEL
(AIRFLOW~30% LOW; BYPASS VALVE MISADJUSTED)
T-JET
TPAN-1
TPAN-6
TPAN-2
TPAN-4
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

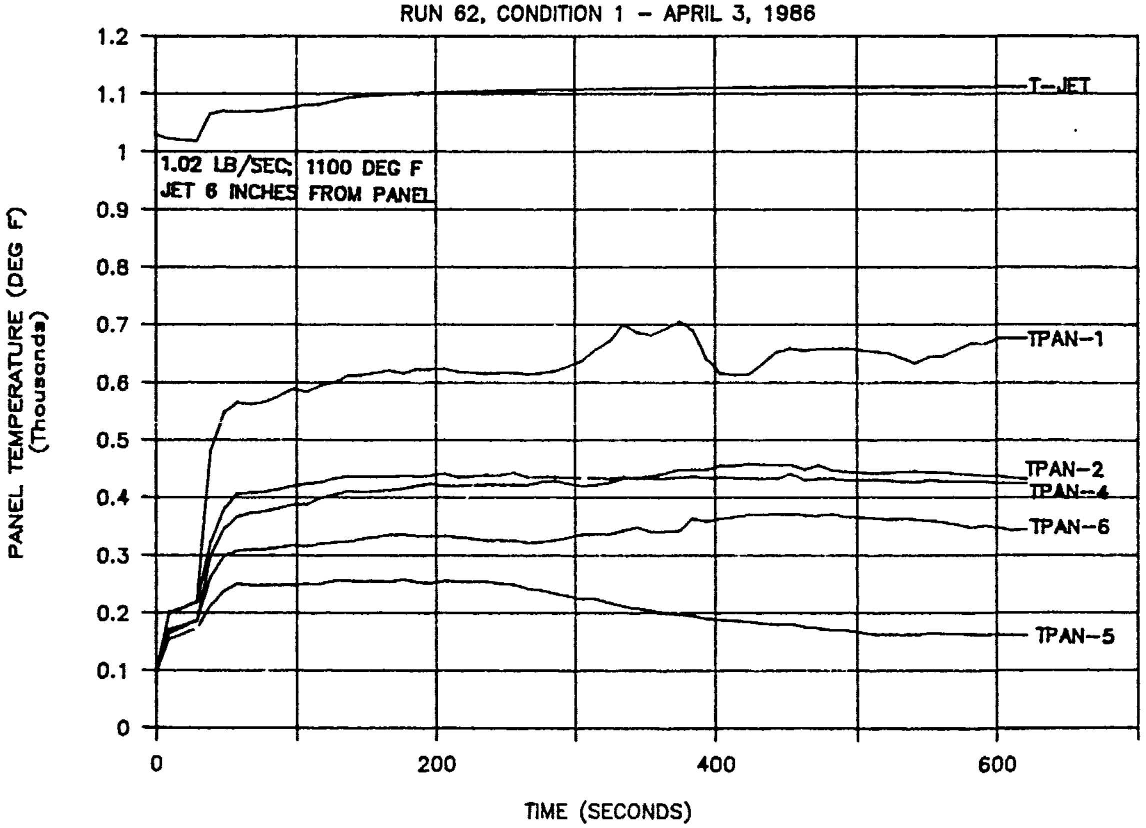
PANEL 7; 2024–T81, 0.050" THICK

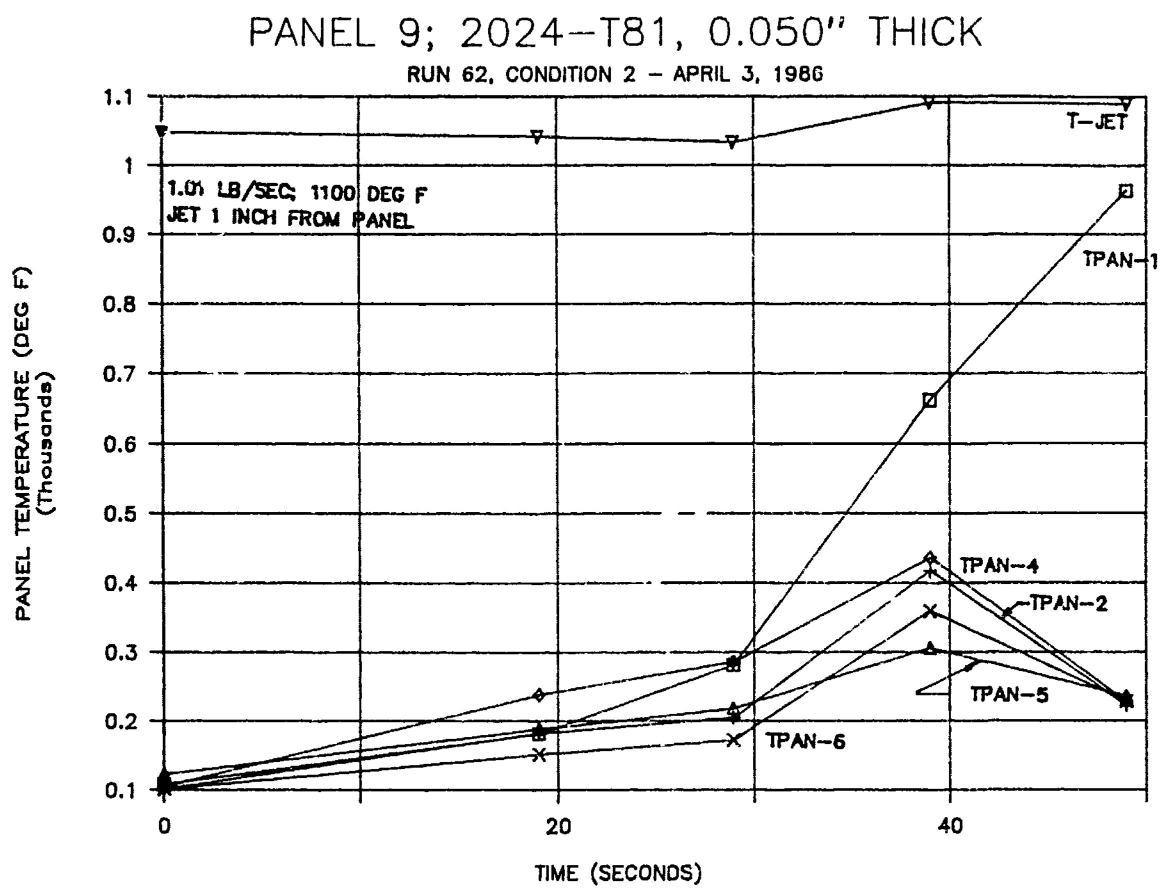
RUN 61, CONDITION 3 – APRIL 2, 1986



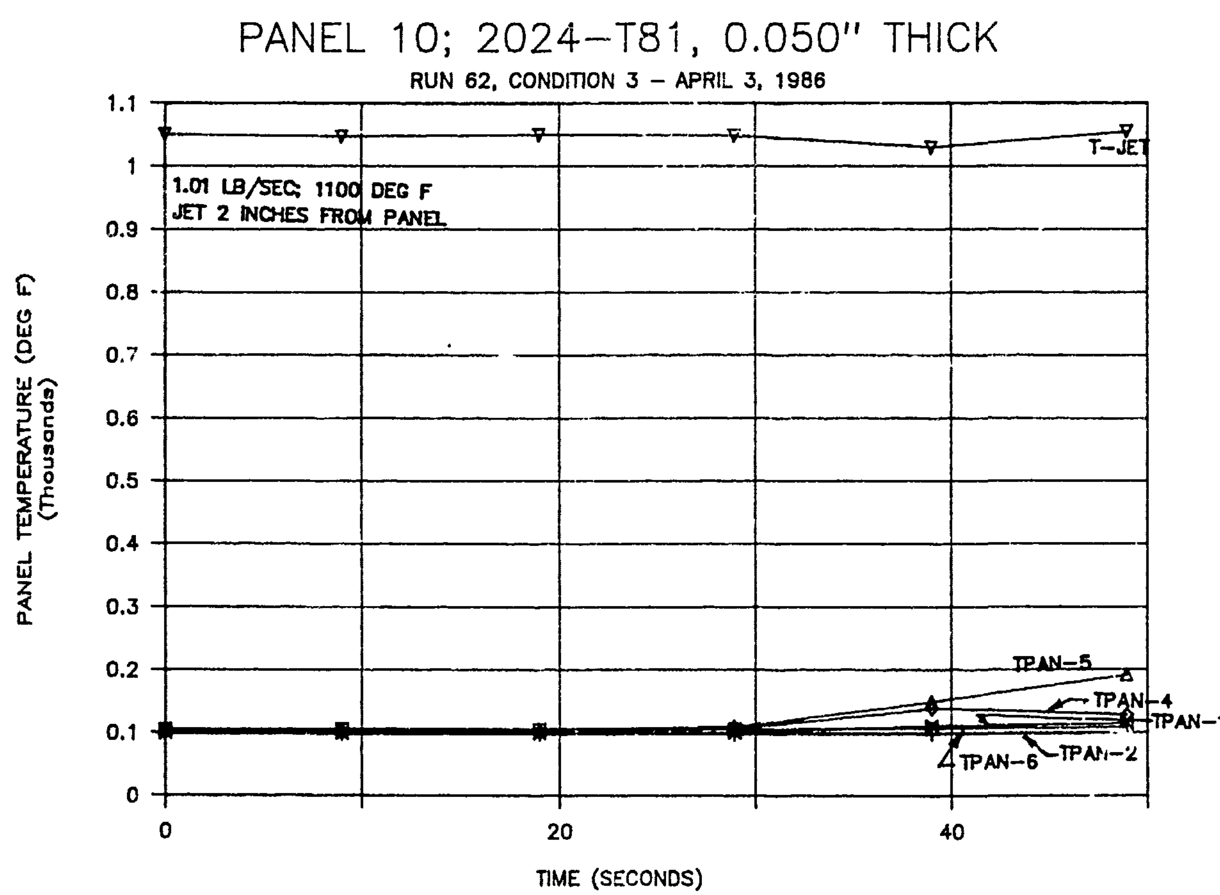
PANEL 8; 2024–T81, 0.050" THICK

RUN 62, CONDITION 1 – APRIL 3, 1986

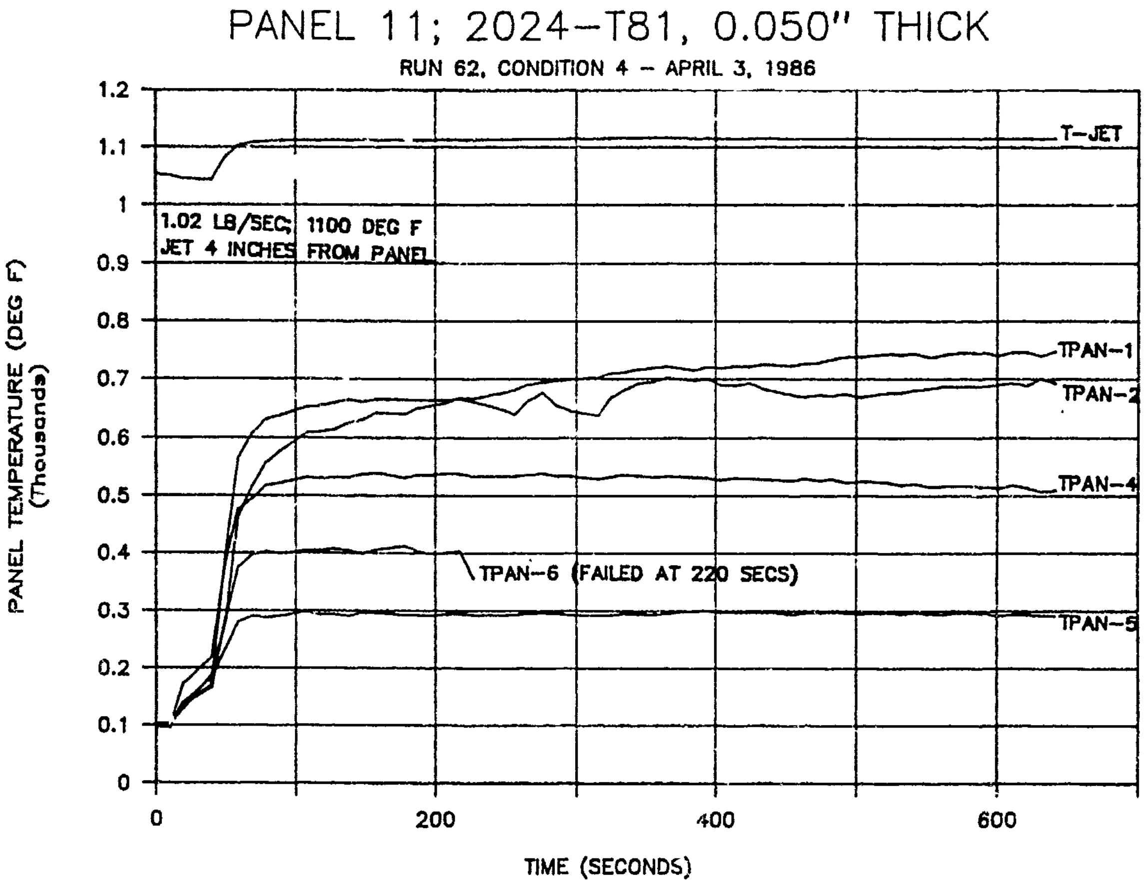




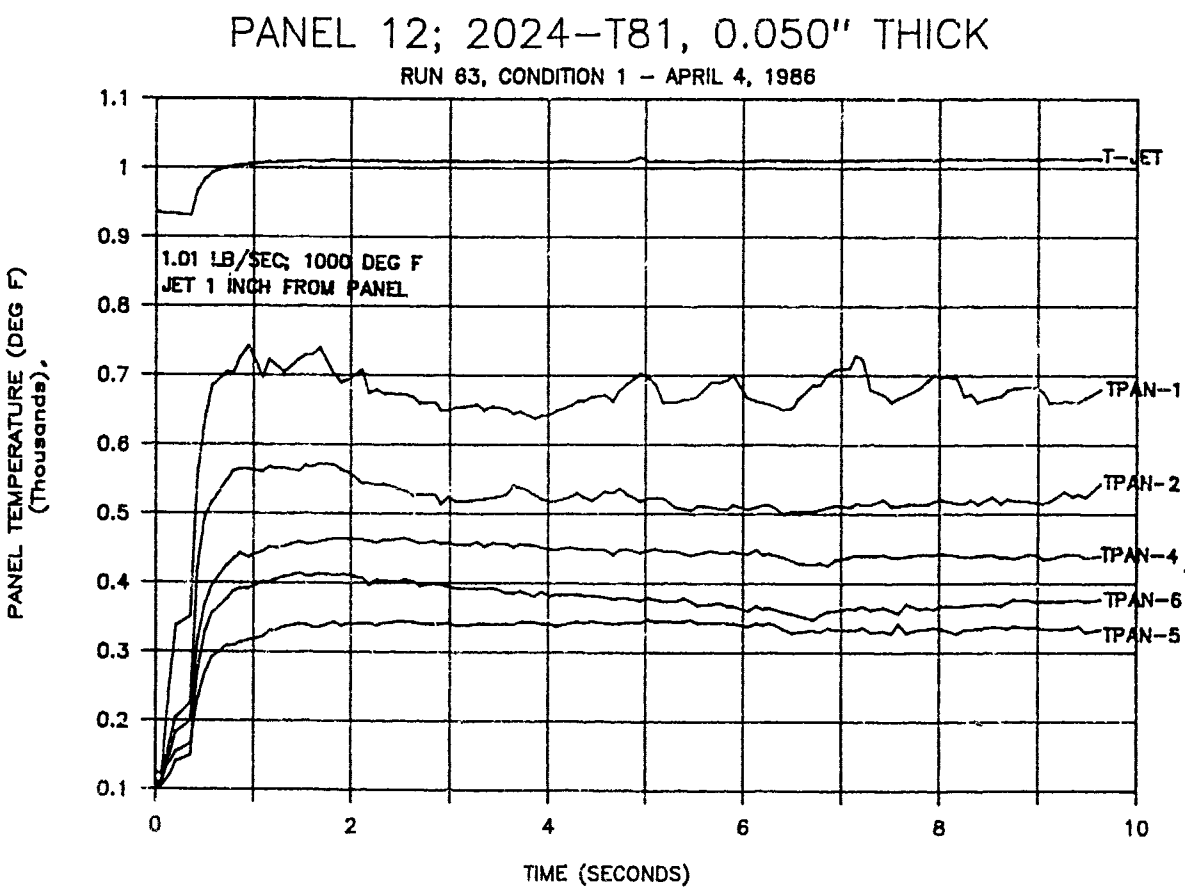
PANEL 9; 2024-T81, 0.050" THICK
RUN 62, CONDITION 2 - APRIL 3, 1986
1.01 LB/SEC; 1100 DEG F
JET 1 INCH FROM PANEL
T-JET
TPAN-1
TPAN-4
TPAN-2
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)



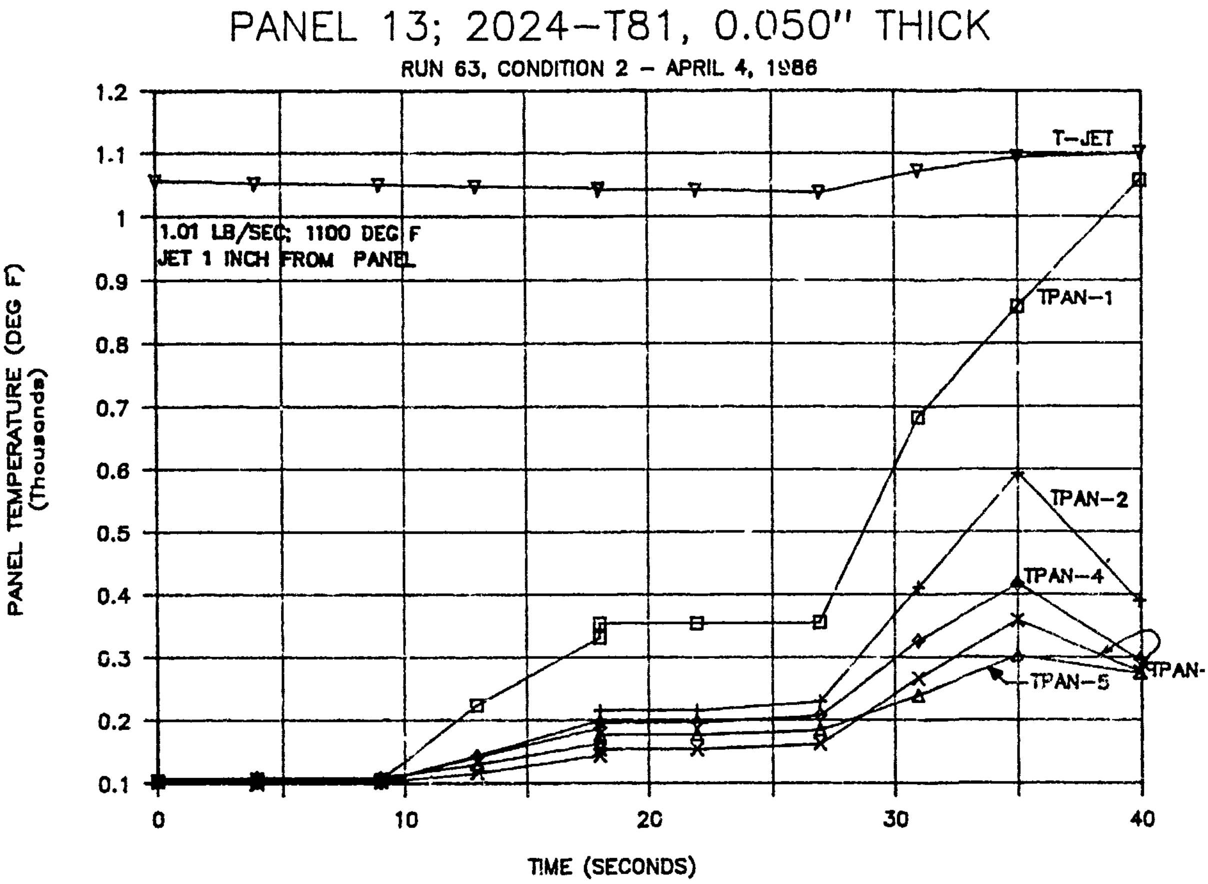
PANEL 10; 2024-T81, 0.050" THICK
RUN 62, CONDITION 3 - APRIL 3, 1986
1.01 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
T-JET
TPAN-5
TPAN-4
TPAN-1
TPAN-6
TPAN-2
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

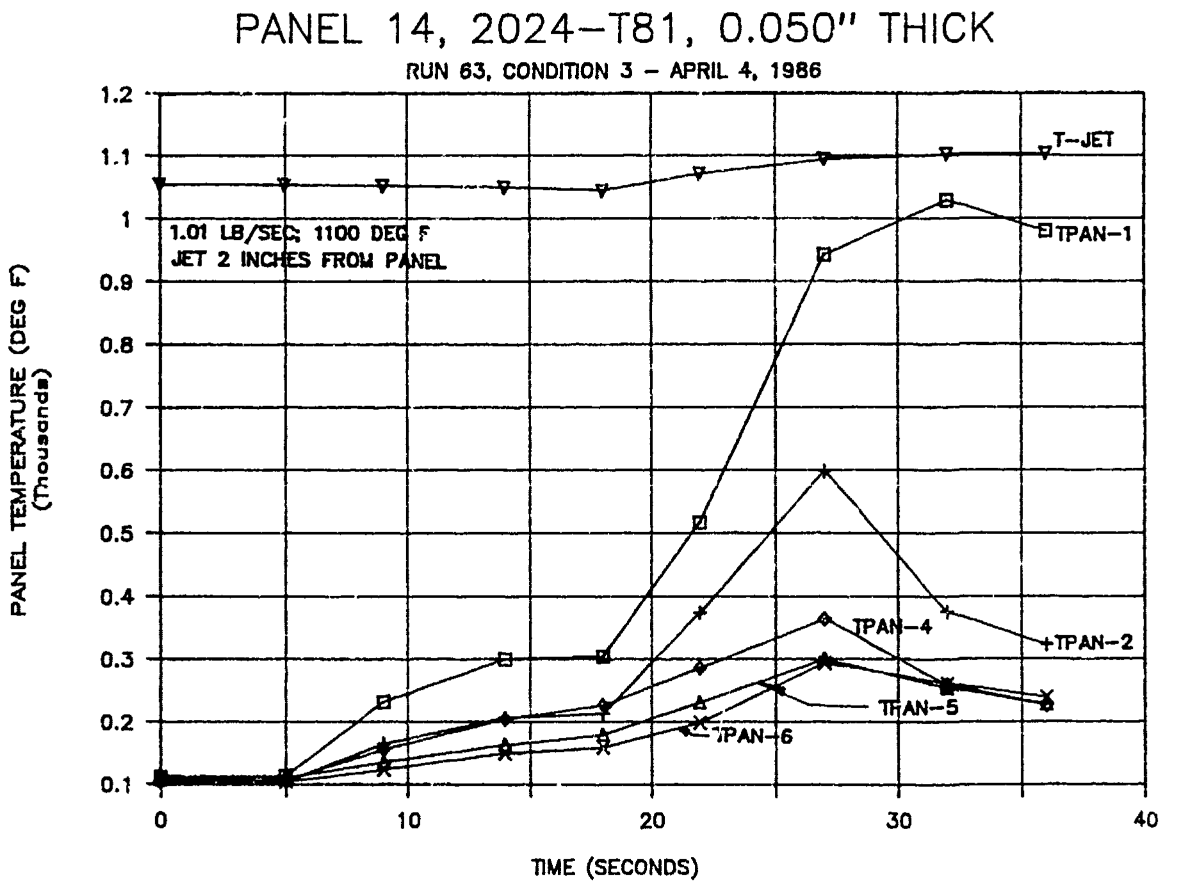


PANEL 11; 2024-T81, 0.050" THICK
RUN 62, CONDITION 4 - APRIL 3, 1986
1.02 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6 (FAILED AT 220 SECS)
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)



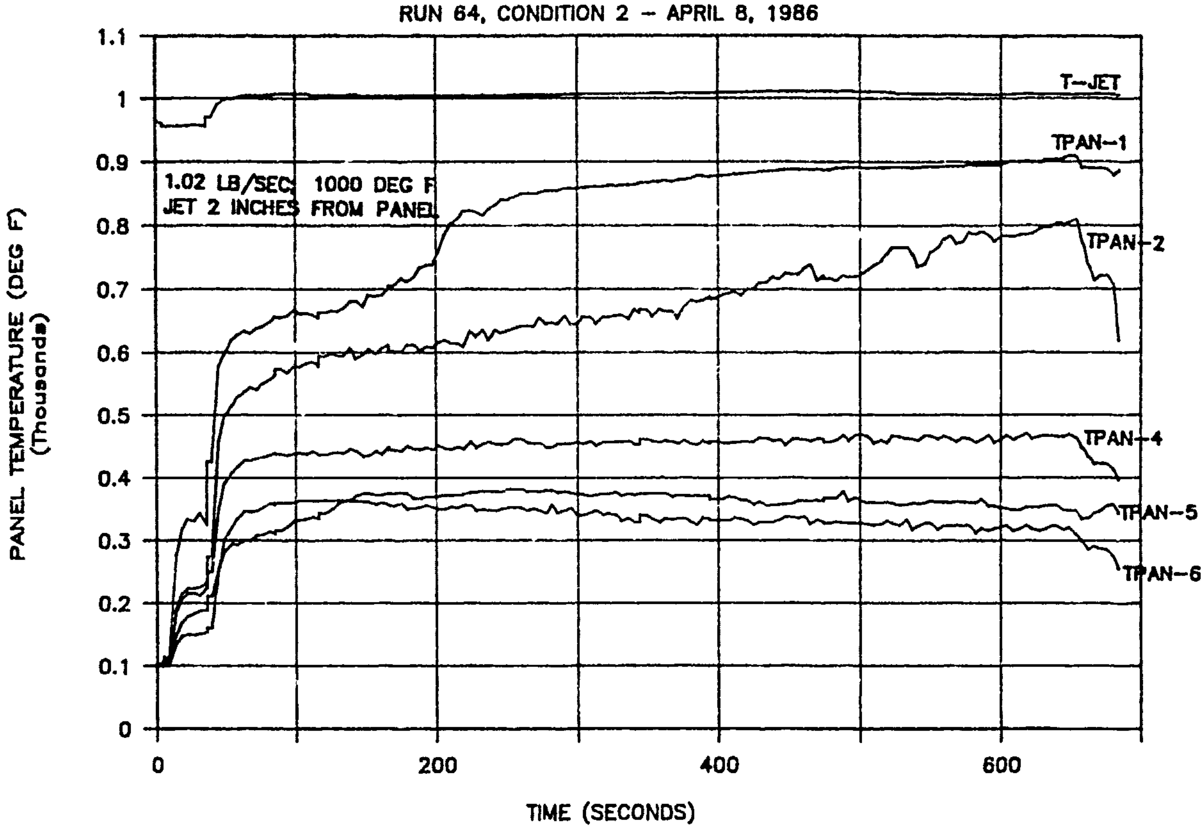
PANEL 12; 2024-T81, 0.050" THICK
RUN 63, CONDITION 1 - APRIL 4, 1986
1.01 LB/SEC; 1000 DEG F
JET 1 INCH FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 13; 2024-T81, 0.050" THICK
RUN 63, CONDITION 2 - APRIL 4, 1986
1.01 LB/SEC; 1100 DEG F
JET 1 INCH FROM PANEL
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
0
10
20
30
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2


PANEL 14, 2024-T81, 0.050" THICK
RUN 63, CONDITION 3 - APRIL 4, 1986
1.01 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
0
10
20
30
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2

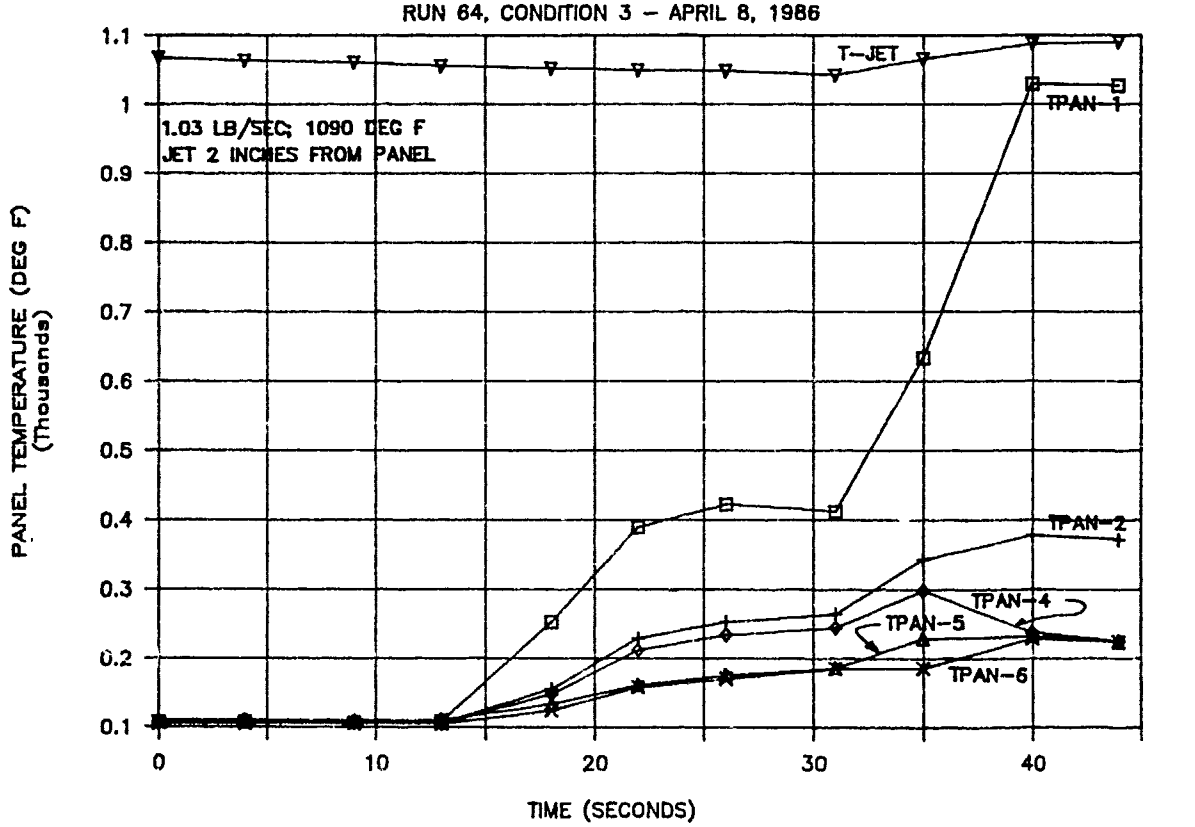
PANEL 16; 2024–T3, 0.032" THICK

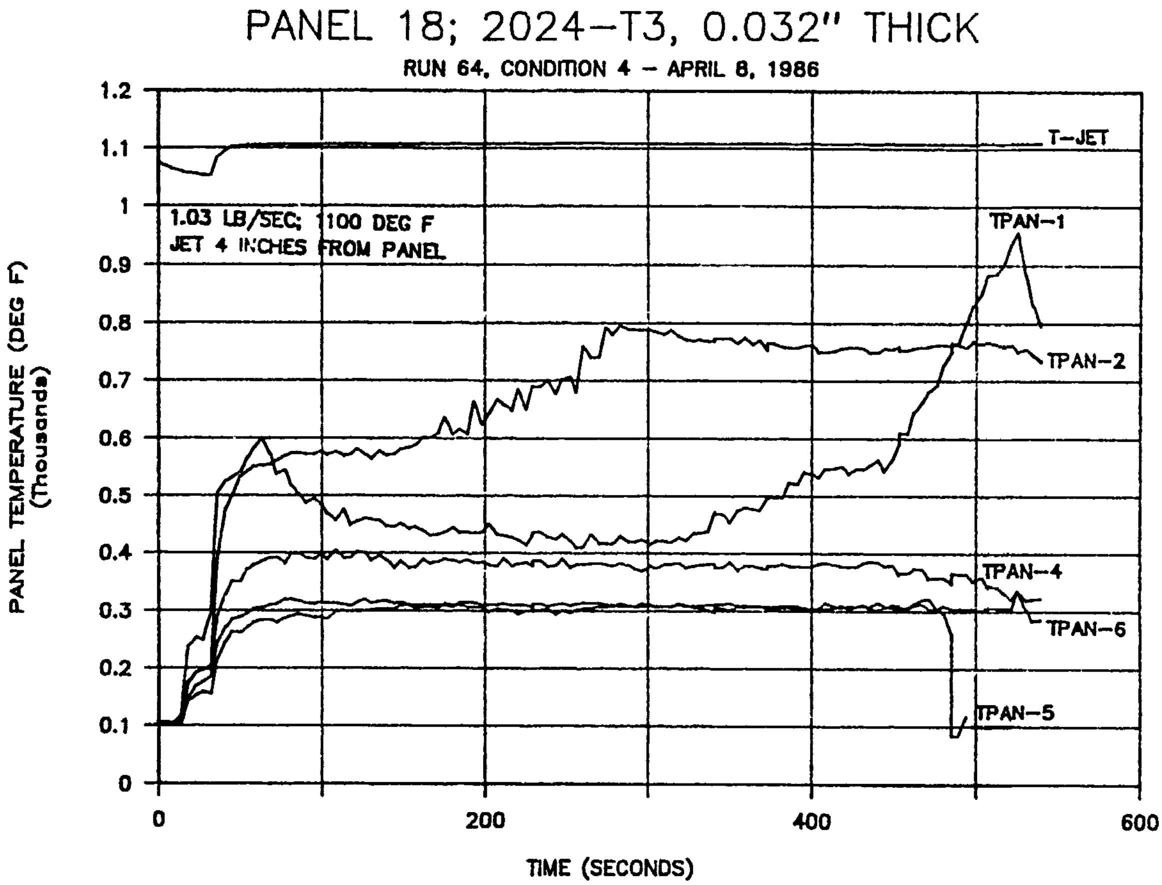
RUN 64, CONDITION 2 – APRIL 8, 1986



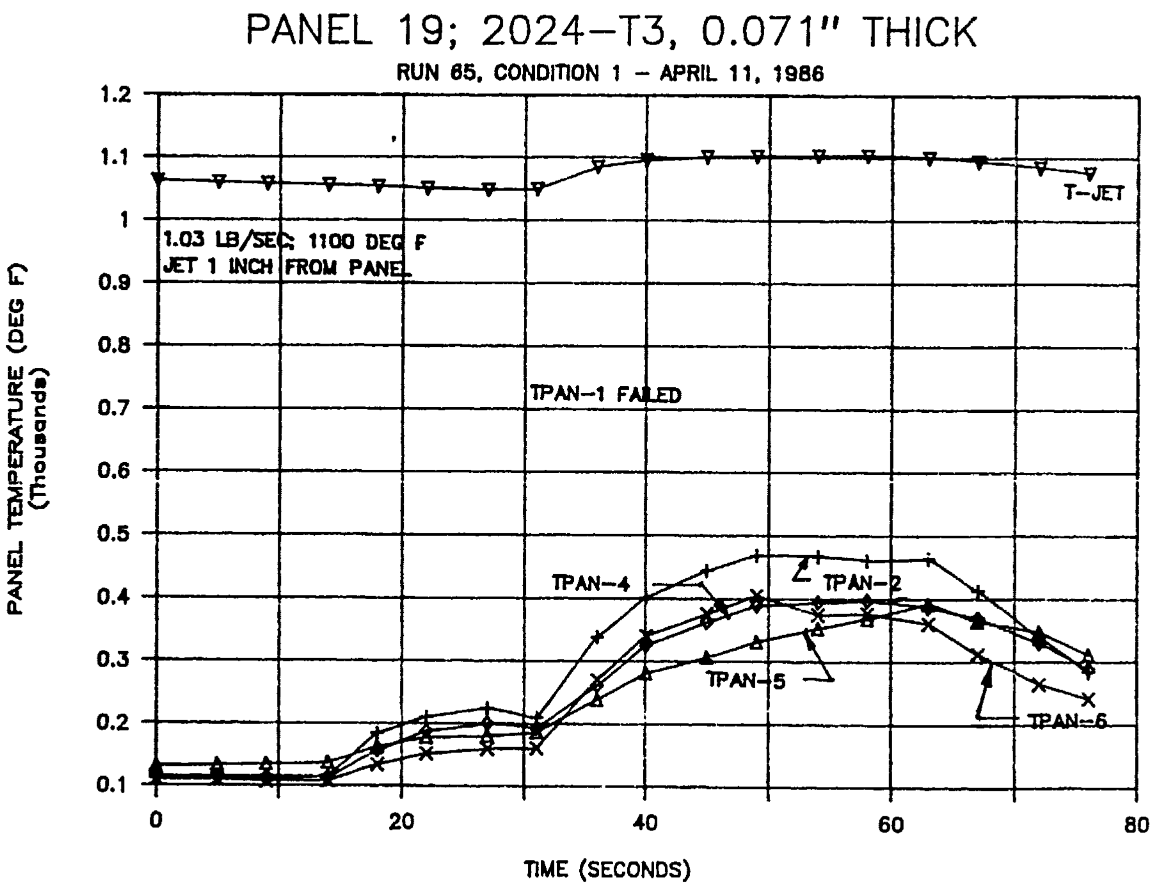
PANEL 17; 2024–T3, 0.032" THICK

RUN 64, CONDITION 3 – APRIL 8, 1986

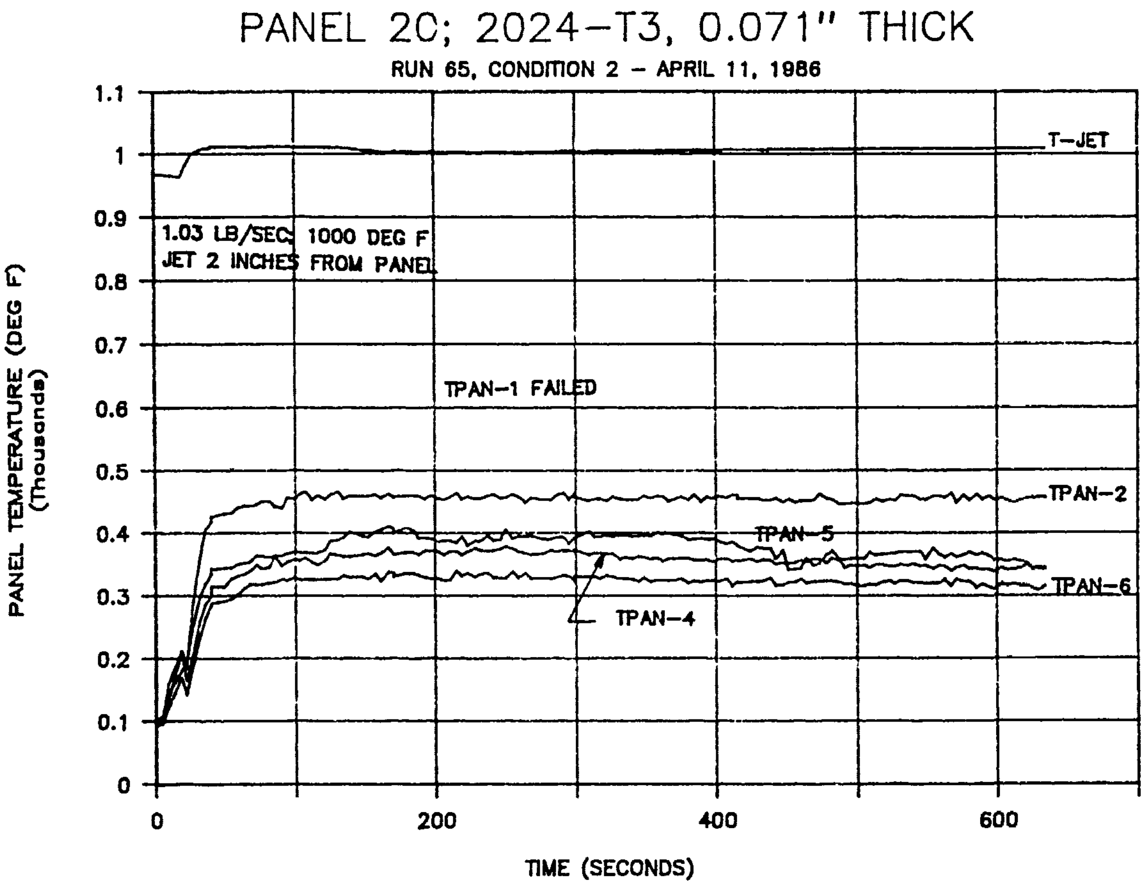




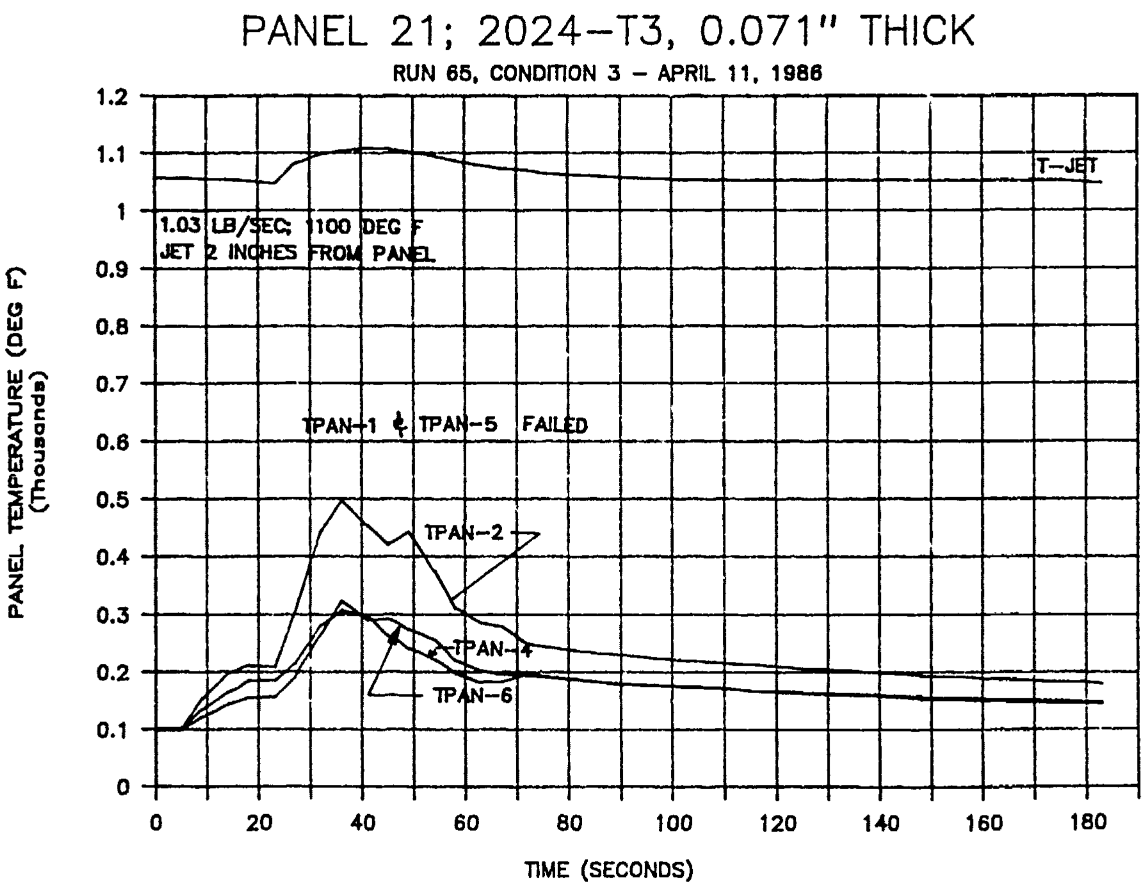
PANEL 18; 2024-T3, 0.032" THICK
RUN 64, CONDITION 4 - APRIL 8, 1986
1.03 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)



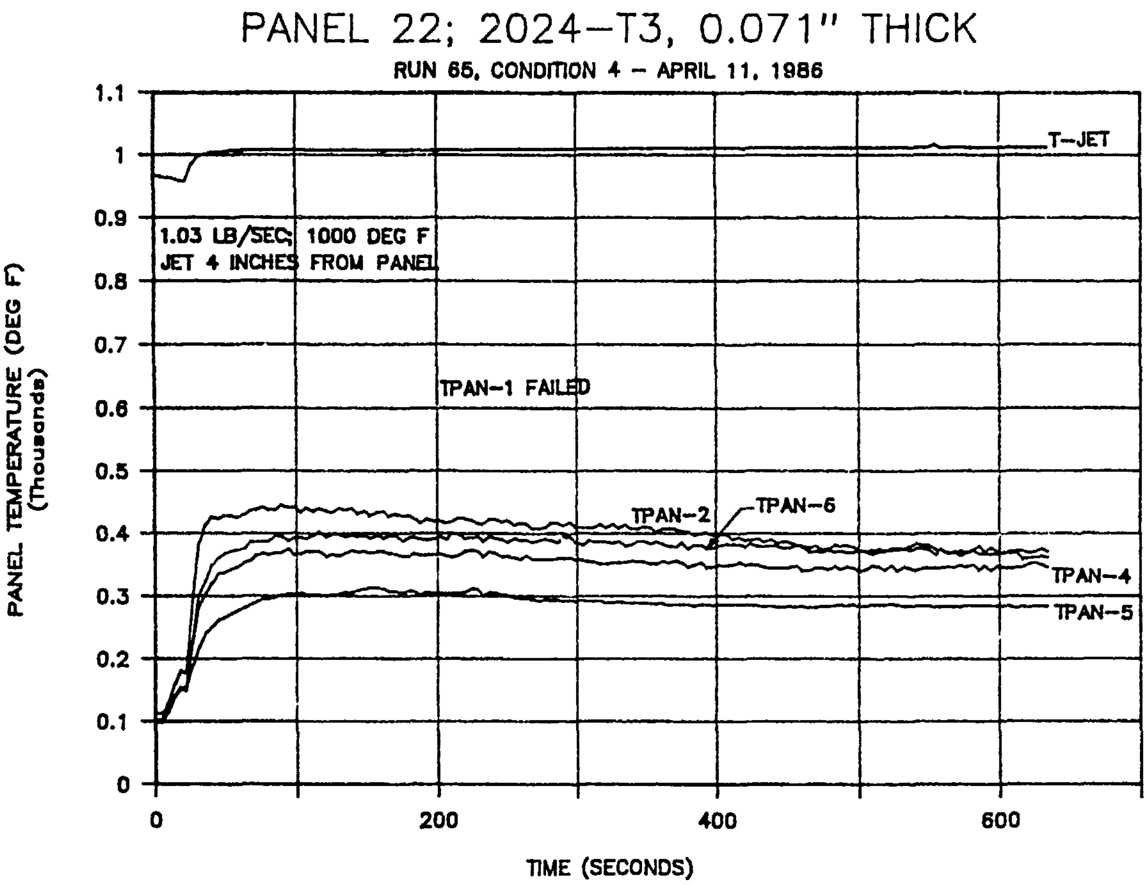
PANEL 19; 2024-T3, 0.071" THICK
RUN 65, CONDITION 1 - APRIL 11, 1986
1.03 LB/SEC; 1100 DEG F
JET 1 INCH FROM PANEL
T-JET
TPAN-1 FAILED
TPAN-4
TPAN-2
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

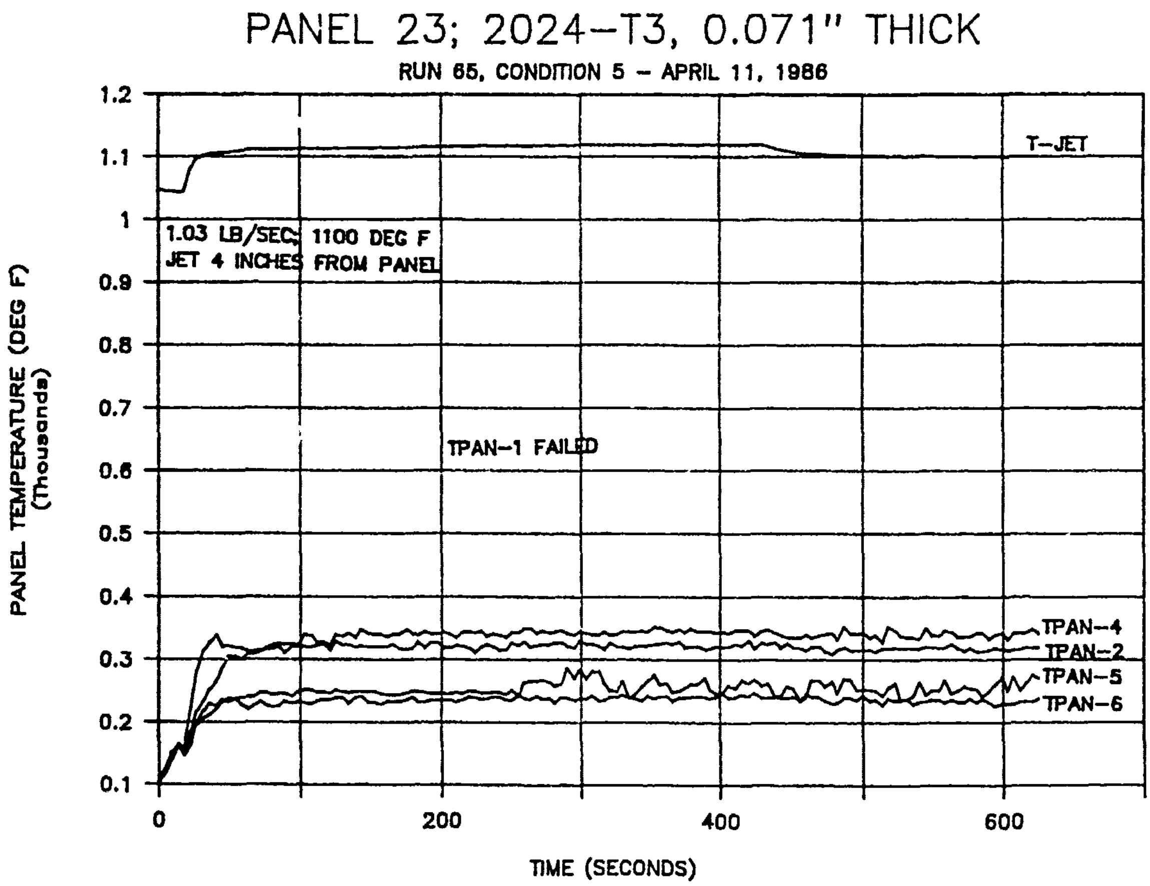


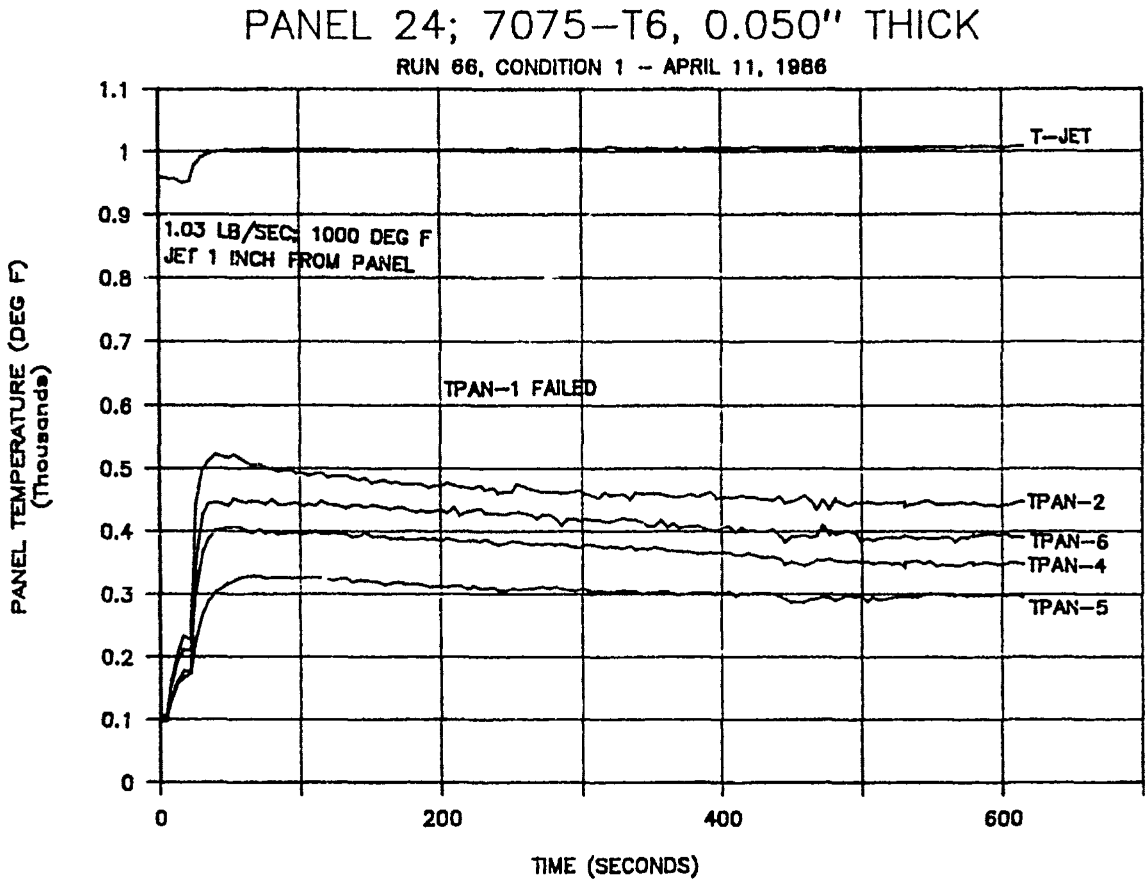
PANEL 20; 2024-T3, 0.071" THICK
RUN 65, CONDITION 2 - APRIL 11, 1986
T-JET
1.03 LB/SEC; 1000 DEG F
JET 2 INCHES FROM PANEL
TPAN-1 FAILED
TPAN-2
TPAN-5
TPAN-6
TPAN-4
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

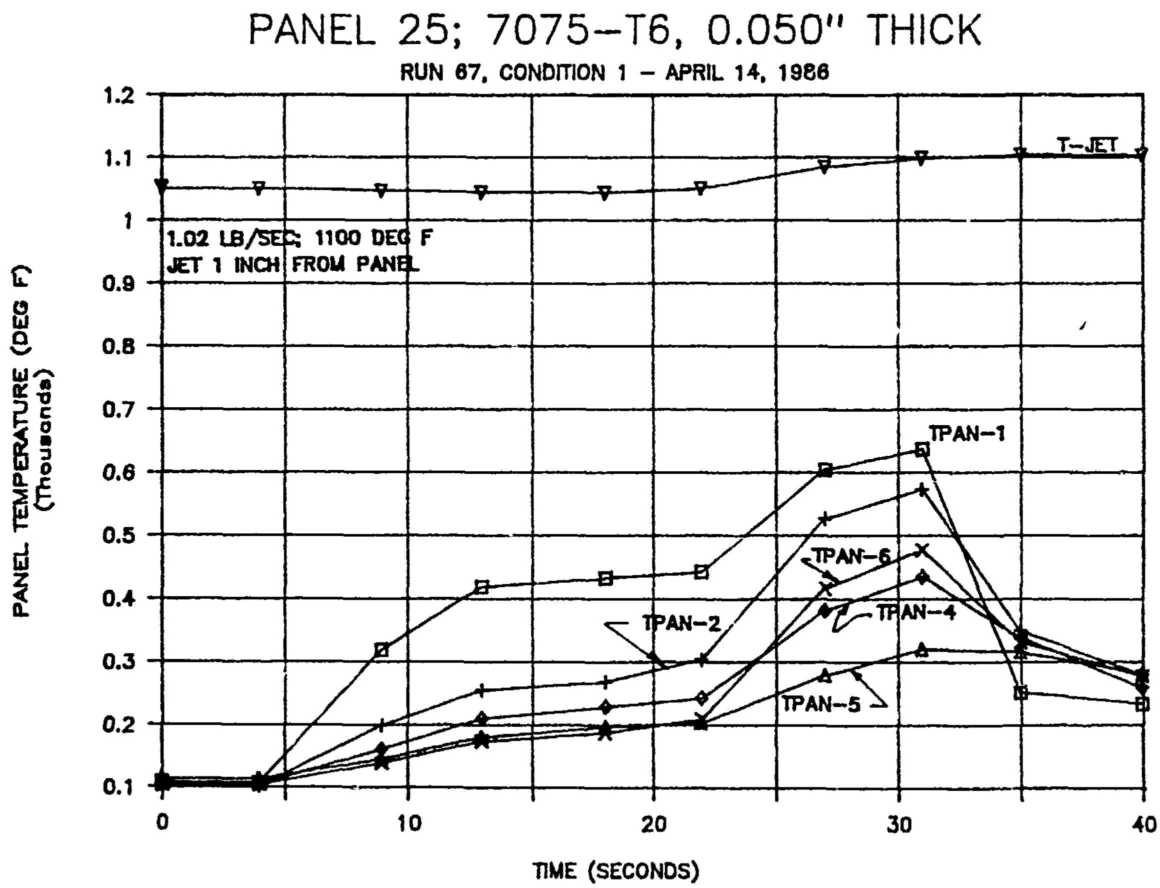


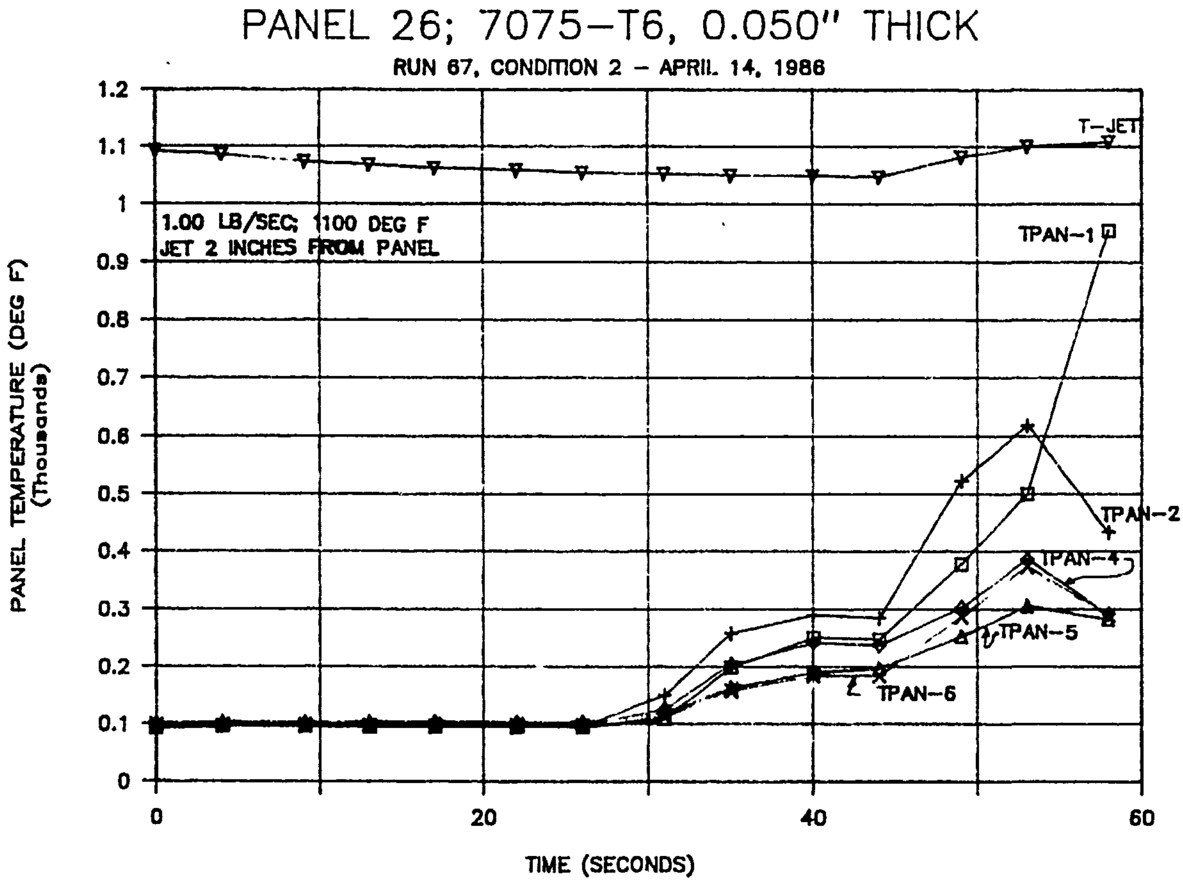
PANEL 21; 2024-T3, 0.071" THICK
RUN 65, CONDITION 3 - APRIL 11, 1986
T-JET
1.03 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
TPAN-1 & TPAN-5 FAILED
TPAN-2
TPAN-4
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

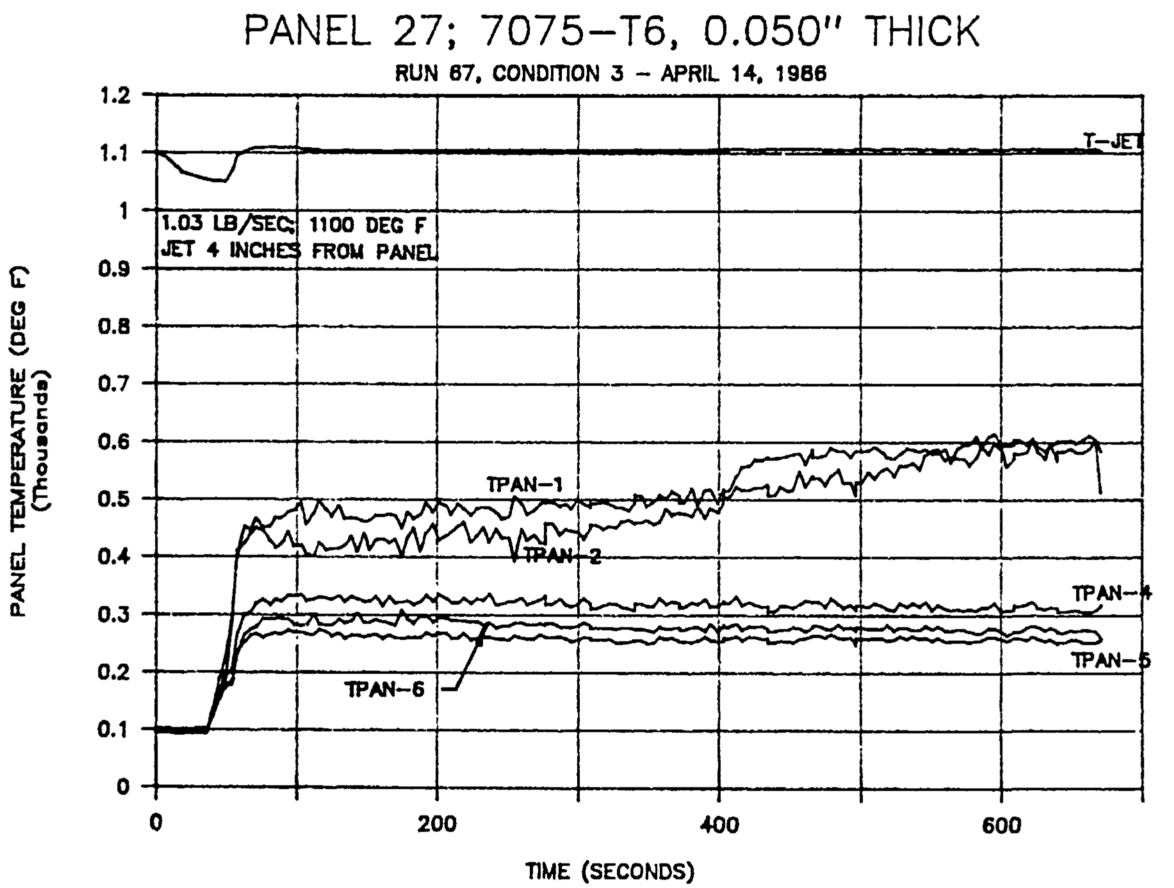

PANEL 22; 2024-T3, 0.071" THICK
RUN 65, CONDITION 4 - APRIL 11, 1986
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
1.03 LB/SEC; 1000 DEG F
JET 4 INCHES FROM PANEL
TPAN-1 FAILED
T-JET
TPAN-2
TPAN-6
TPAN-4
TPAN-5
0
200
400
600
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1

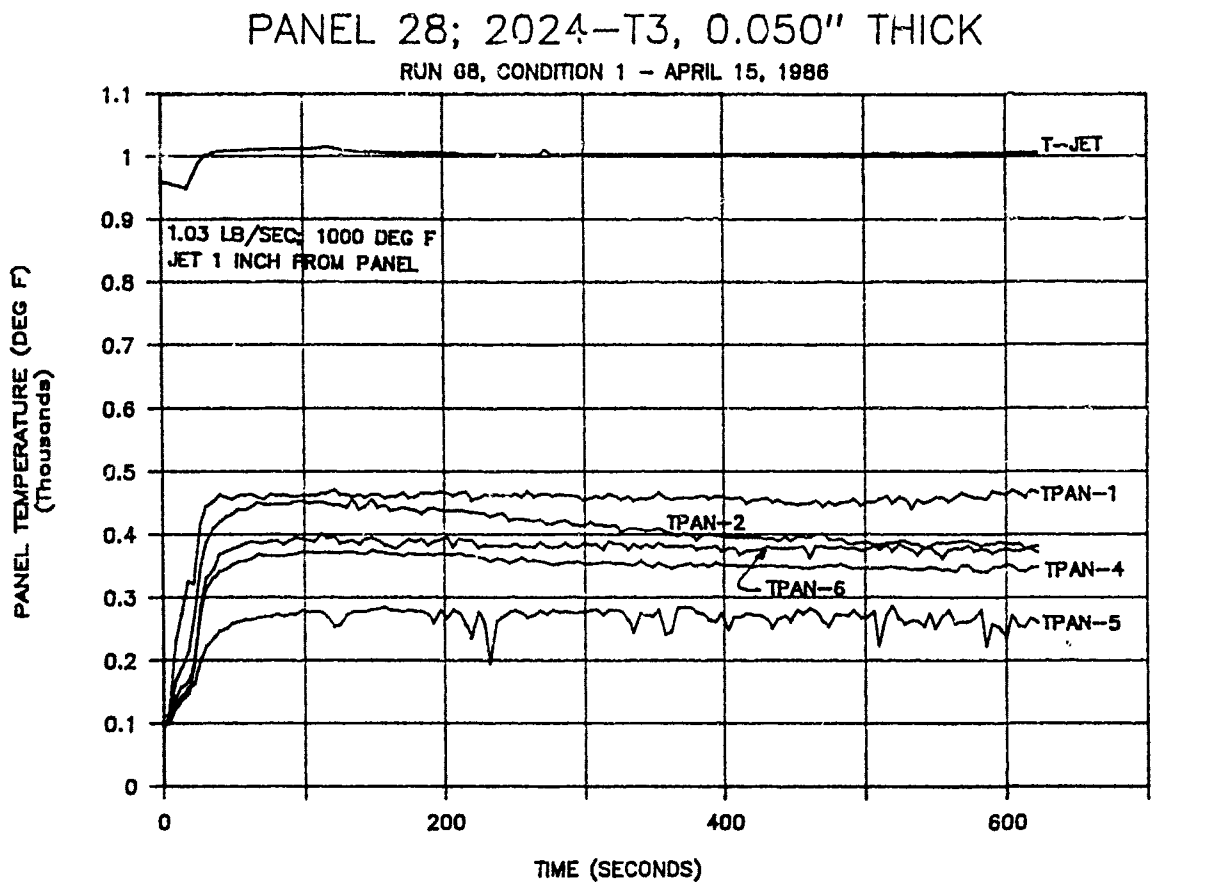

PANEL 23; 2024-T3, 0.071" THICK
RUN 65, CONDITION 5 - APRIL 11, 1986
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
1.03 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
TPAN-1 FAILED
T-JET
TPAN-4
TPAN-2
TPAN-5
TPAN-6
0
200
400
600
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2

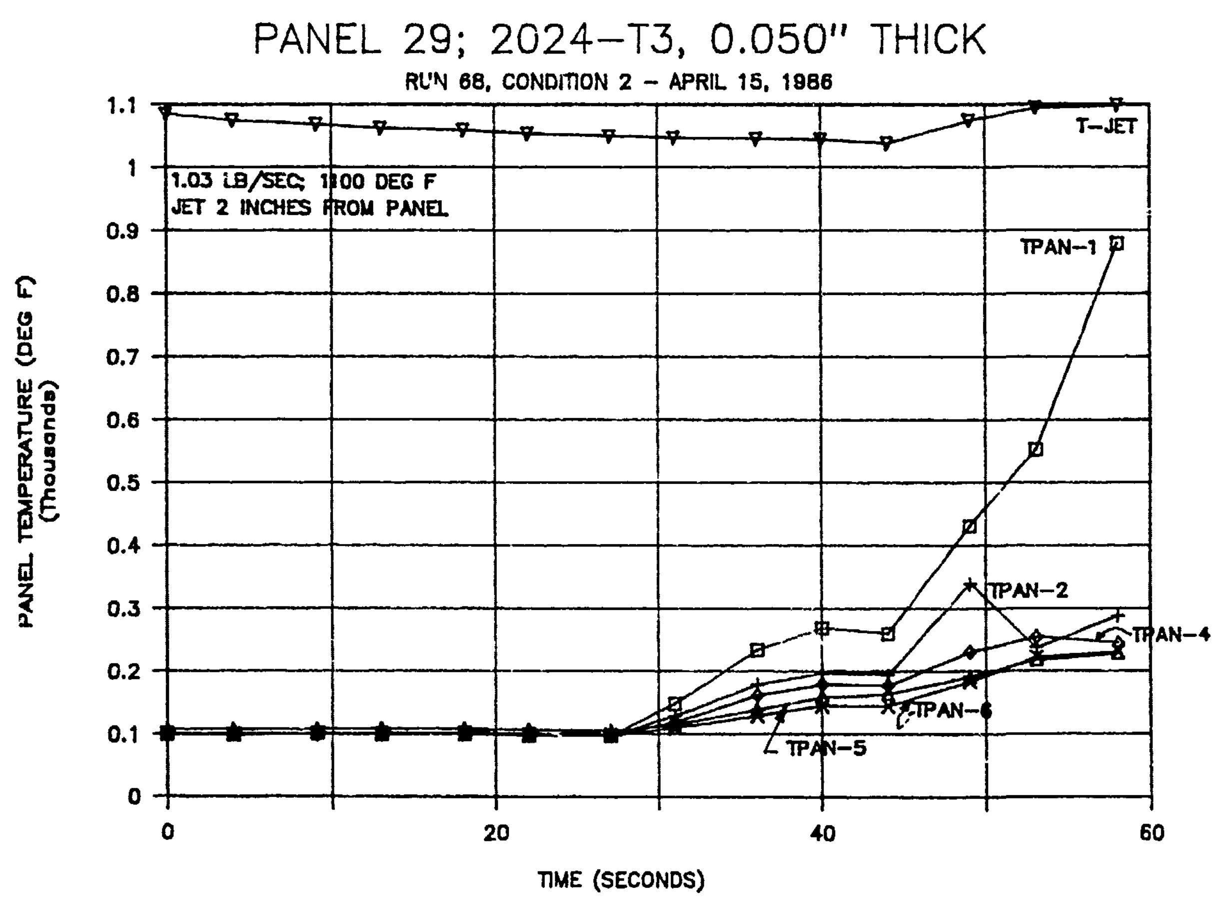

PANEL 24; 7075-T6, 0.050" THICK
RUN 66, CONDITION 1 - APRIL 11, 1986
1.03 LB/SEC; 1000 DEG F
JET 1 INCH FROM PANEL
TPAN-1 FAILED
T-JET
TPAN-2
TPAN-6
TPAN-4
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
200
400
600

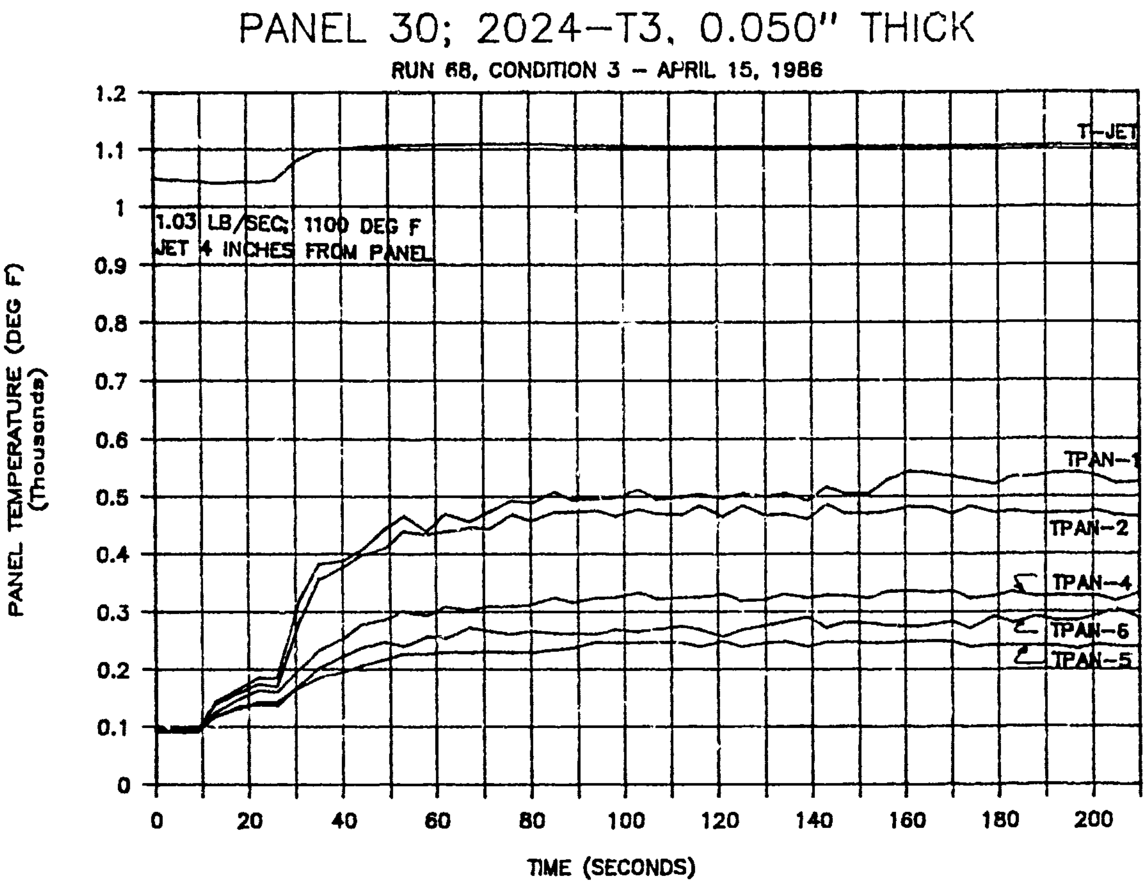

PANEL 25; 7075-T6, 0.050" THICK
RUN 67, CONDITION 1 - APRIL 14, 1986
1.02 LB/SEC; 1100 DEG F
JET 1 INCH FROM PANEL
T-JET
TPAN-1
TPAN-6
TPAN-2
TPAN-4
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
0
10
20
30
40

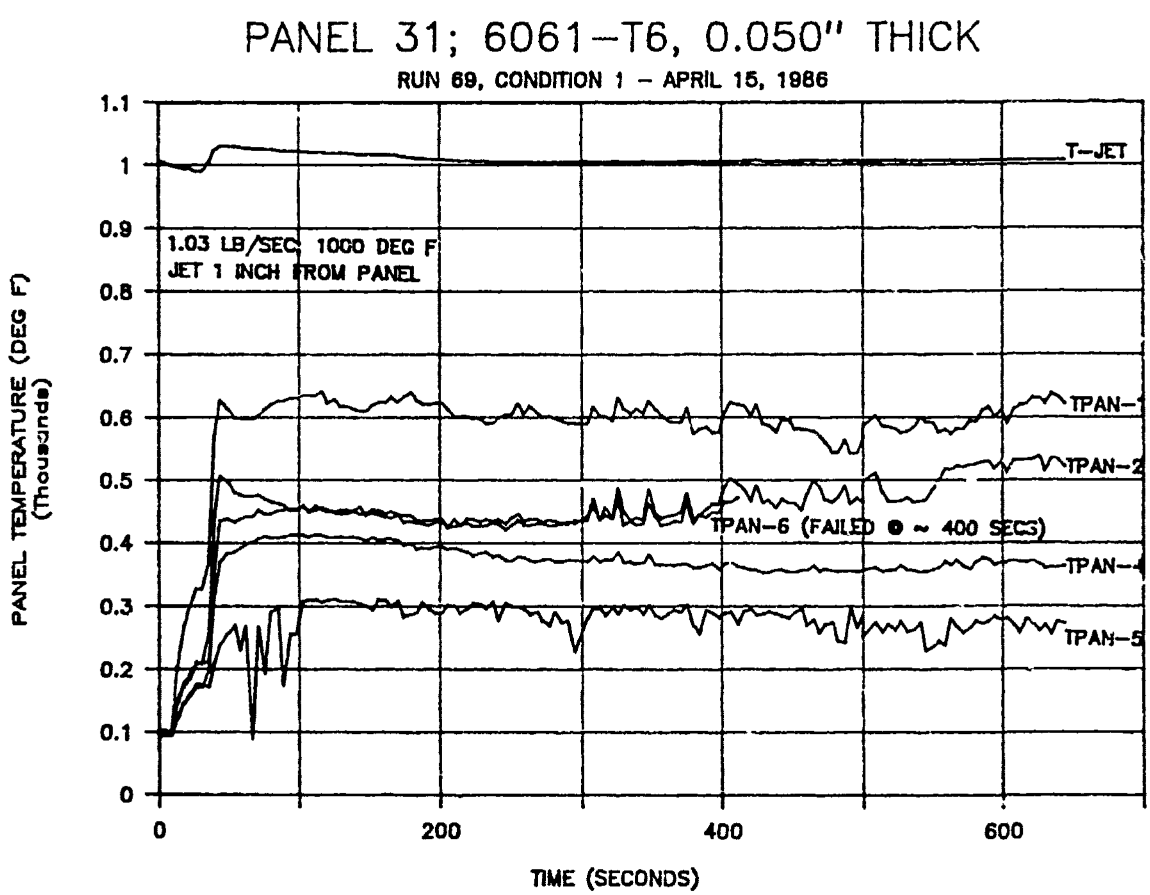

PANEL 26; 7075-T6, 0.050" THICK
RUN 67, CONDITION 2 - APRIL 14, 1986
1.00 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 27; 7075-T6, 0.050" THICK
RUN 67, CONDITION 3 - APRIL 14, 1986
1.03 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 28; 2024–T3, 0.050" THICK
RUN 68, CONDITION 1 – APRIL 15, 1986
1.03 LB/SEC; 1000 DEG F
JET 1 INCH FROM PANEL
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
T–JET
TPAN–1
TPAN–2
TPAN–4
TPAN–6
TPAN–5

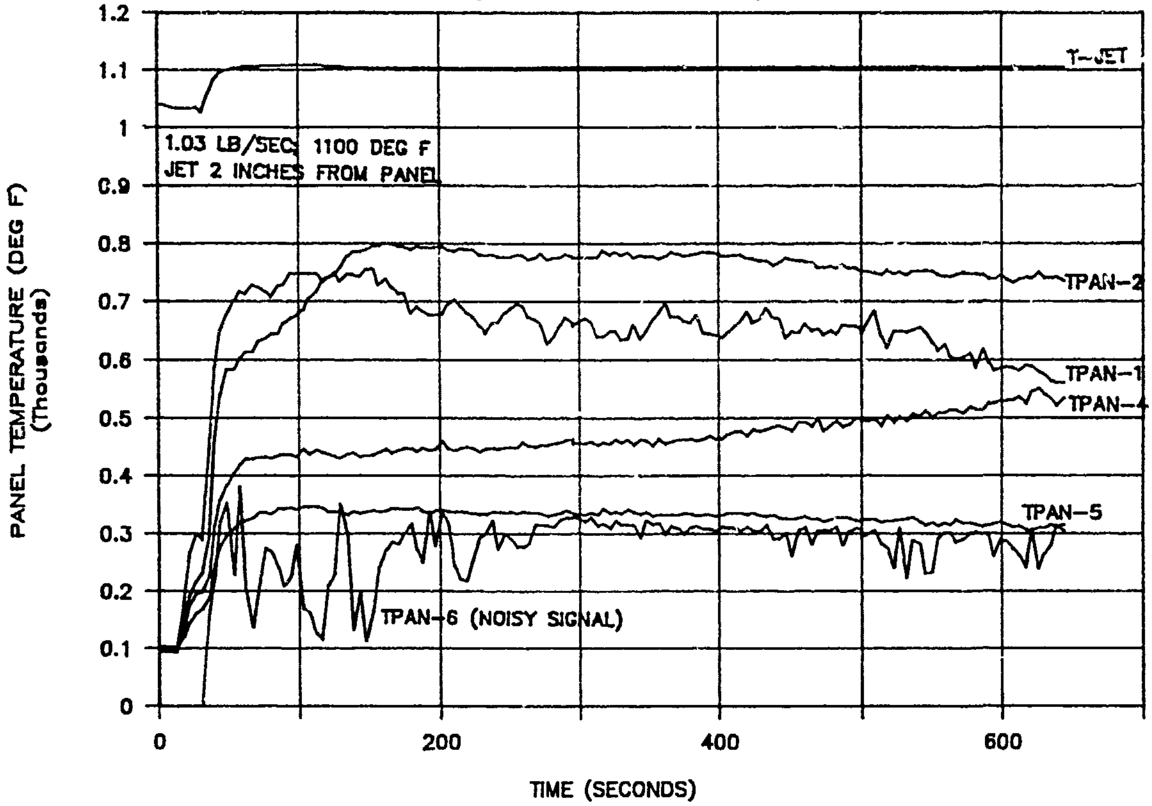

PANEL 29; 2024–T3, 0.050" THICK
RUN 68, CONDITION 2 – APRIL 15, 1986
1.03 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
T–JET
TPAN–1
TPAN–2
TPAN–4
TPAN–6
TPAN–5


PANEL 30; 2024-T3, 0.050" THICK
RUN 68, CONDITION 3 - APRIL 15, 1986
1.03 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 31; 6061-T6, 0.050" THICK
RUN 69, CONDITION 1 - APRIL 15, 1986
1.03 LB/SEC; 1000 DEG F
JET 1 INCH FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-6 (FAILED @ ~ 400 SECS)
TPAN-4
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

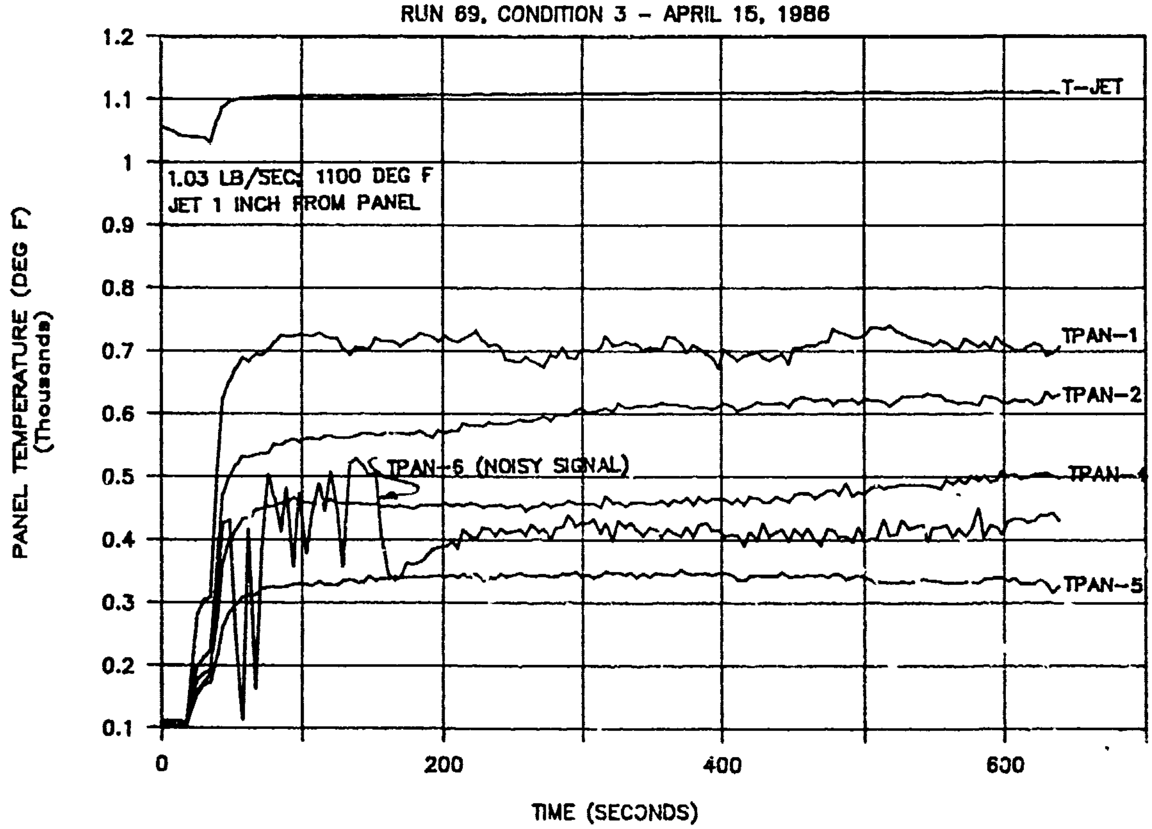
PANEL 32; 6061-T6, 0.050" THICK

RUN 69, CONDITION 2 - APRIL 15, 1986



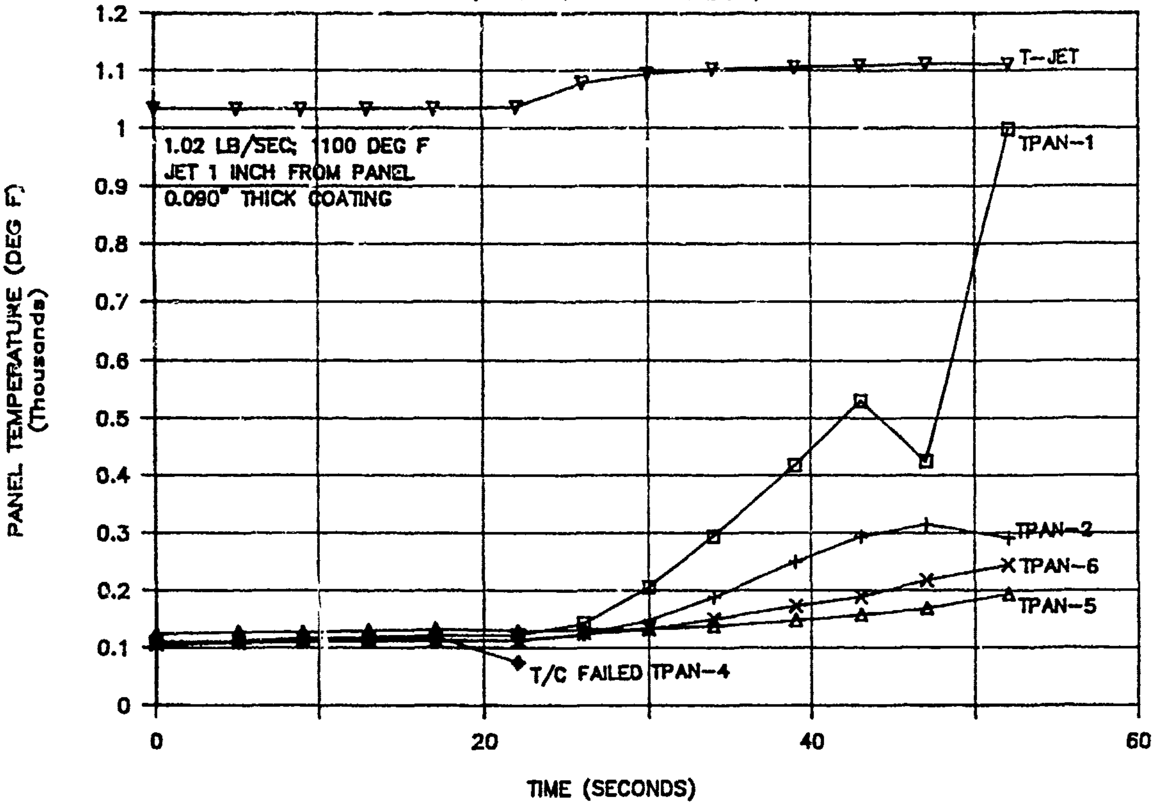
PANEL 33; 6061-T6, 0.050" THICK

RUN 69, CONDITION 3 - APRIL 15, 1986



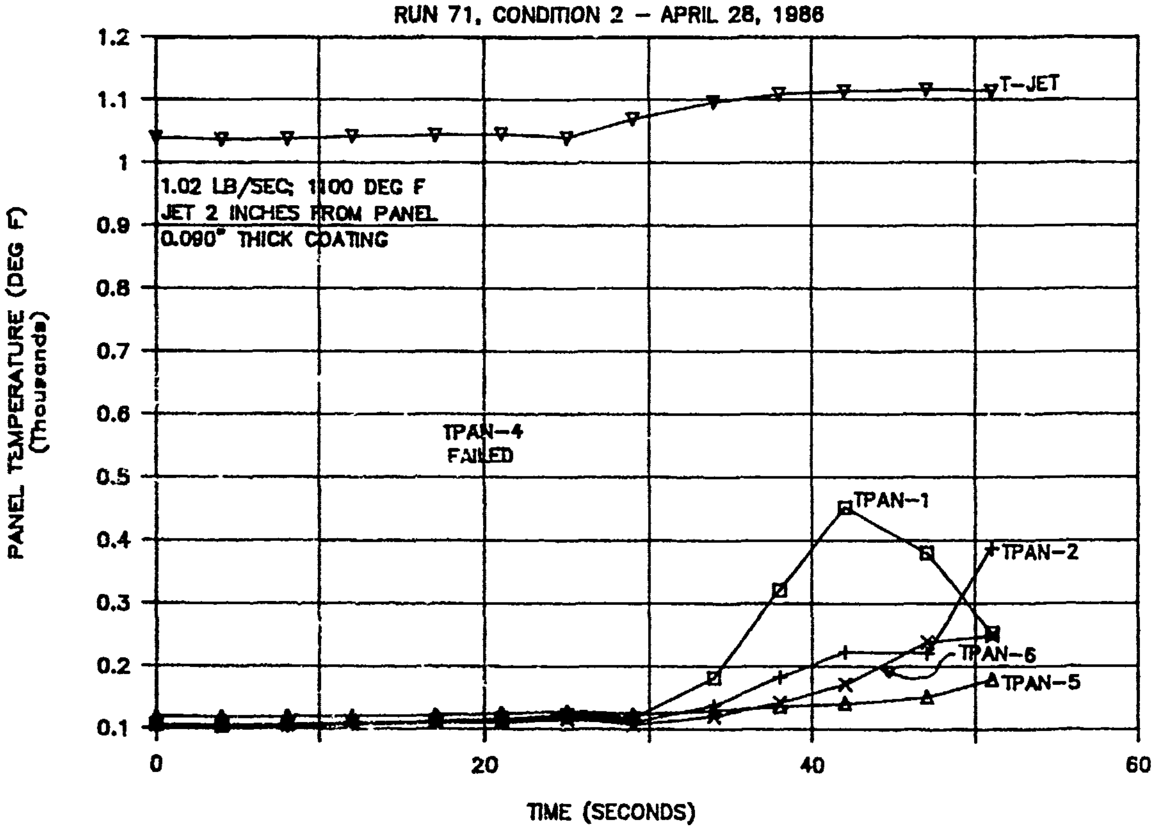
PANEL 35; 2024-T81 WITH MA-25S COATING

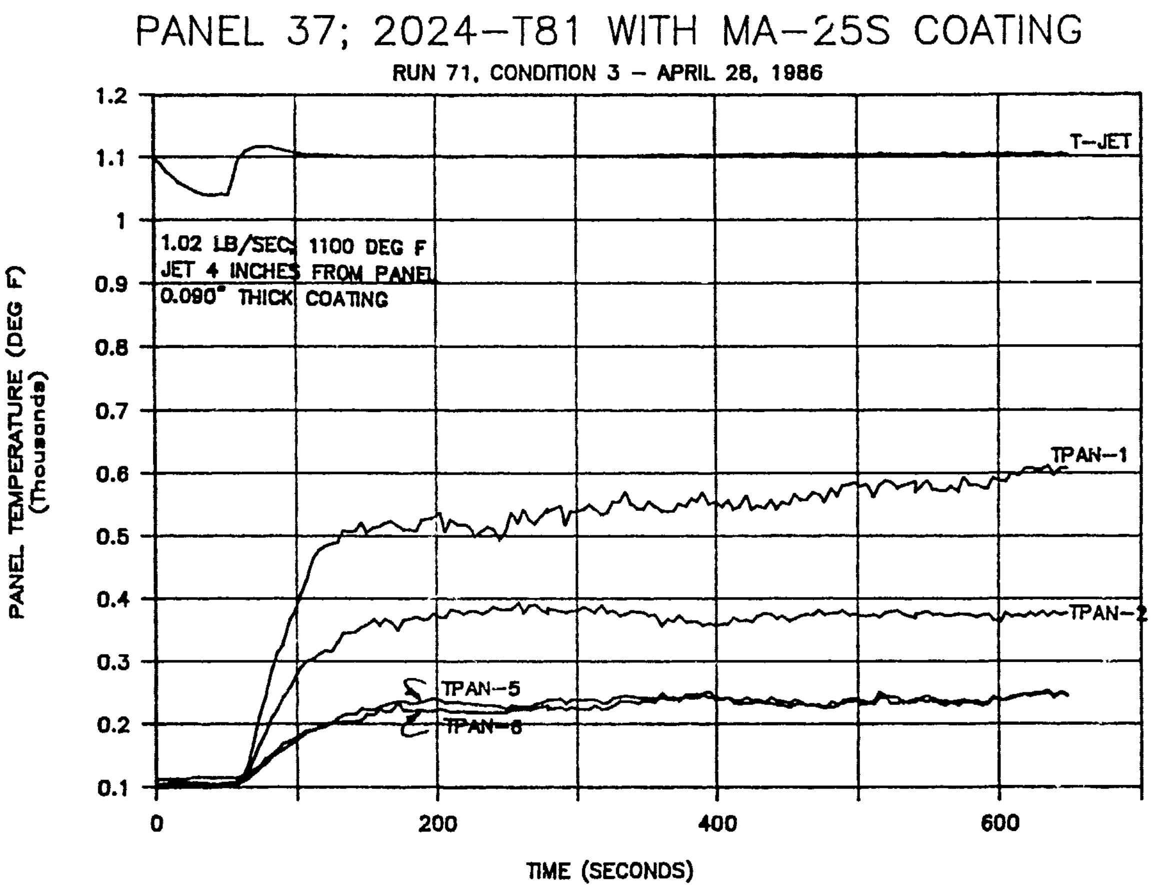
RUN 71, CONDITION 1 - APRIL 28, 1986

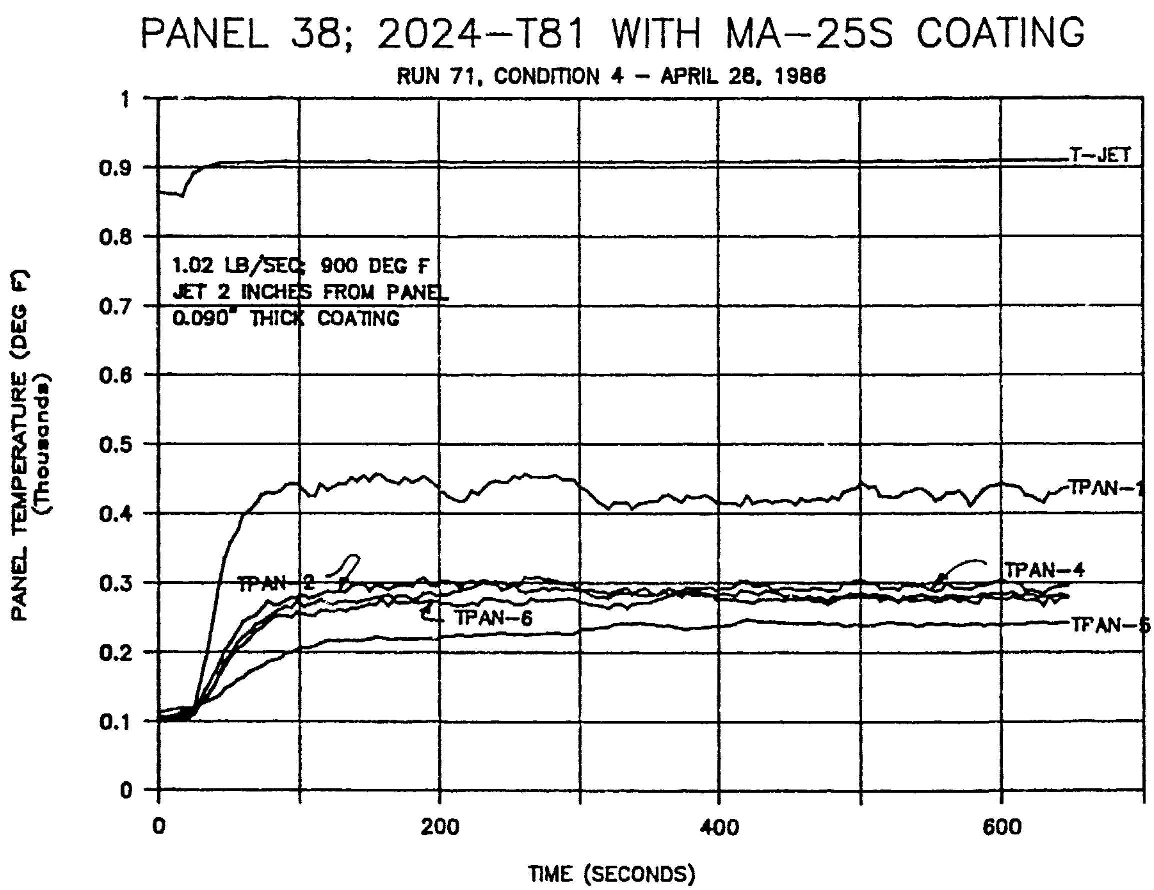


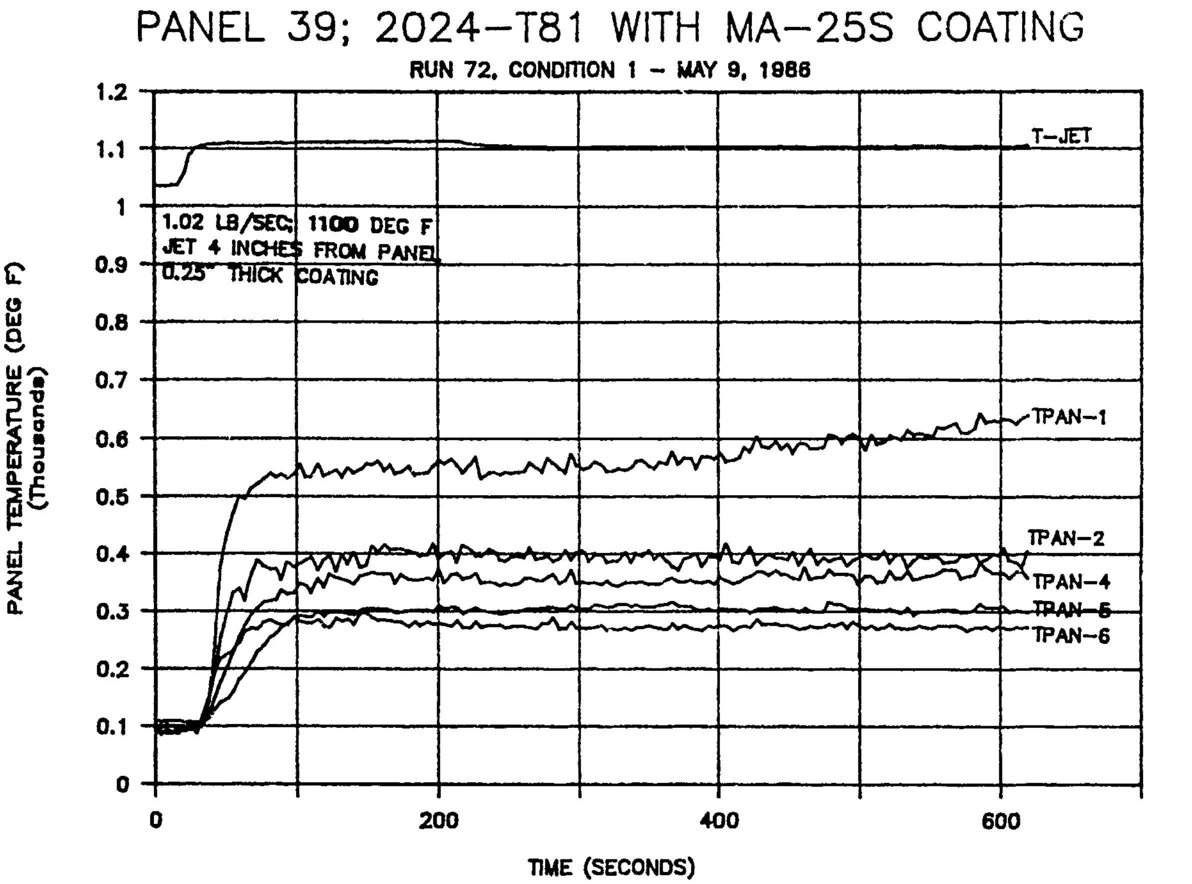
PANEL 36; 2024-T81 WITH MA-25S COATING

RUN 71, CONDITION 2 - APRIL 28, 1986

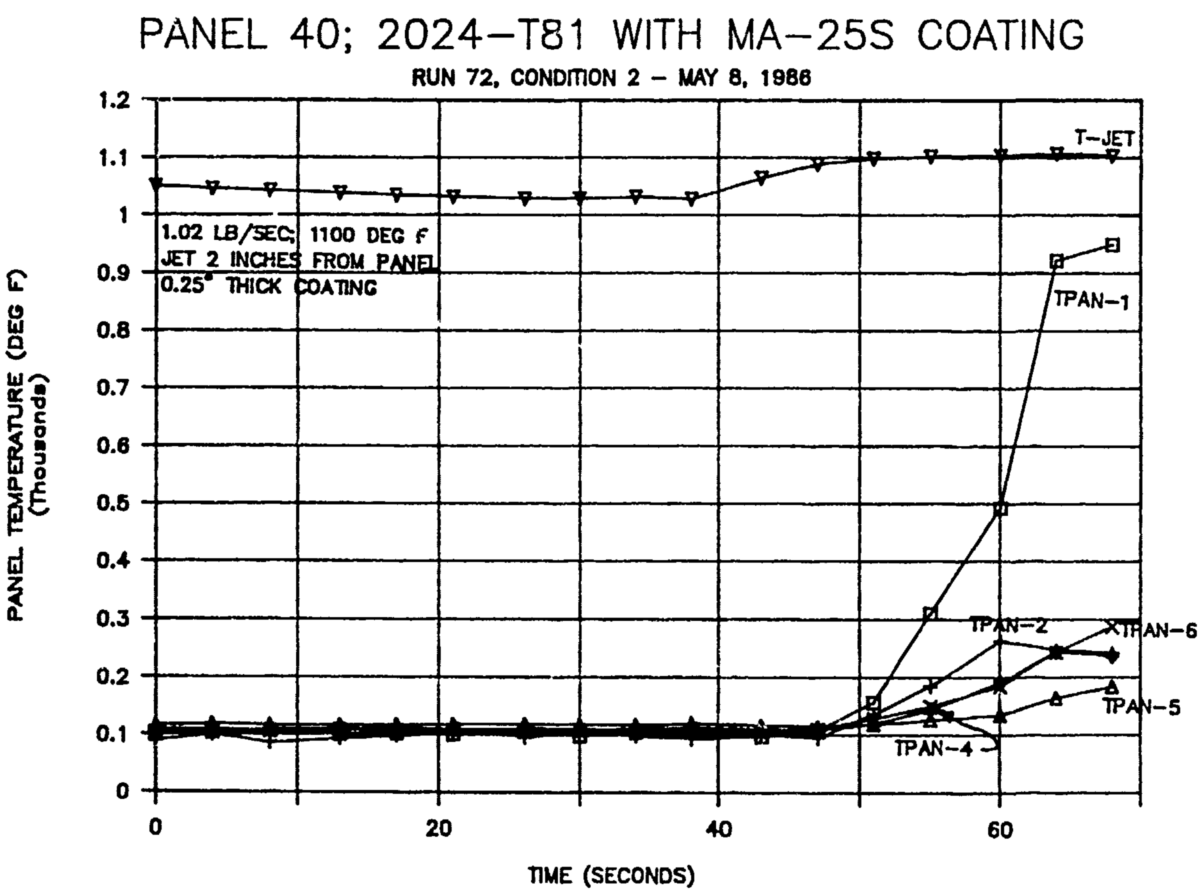



PANEL 37; 2024-T81 WITH MA-25S COATING
RUN 71, CONDITION 3 - APRIL 28, 1986
1.02 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
0.090" THICK COATING
T-JET
TPAN-1
TPAN-2
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

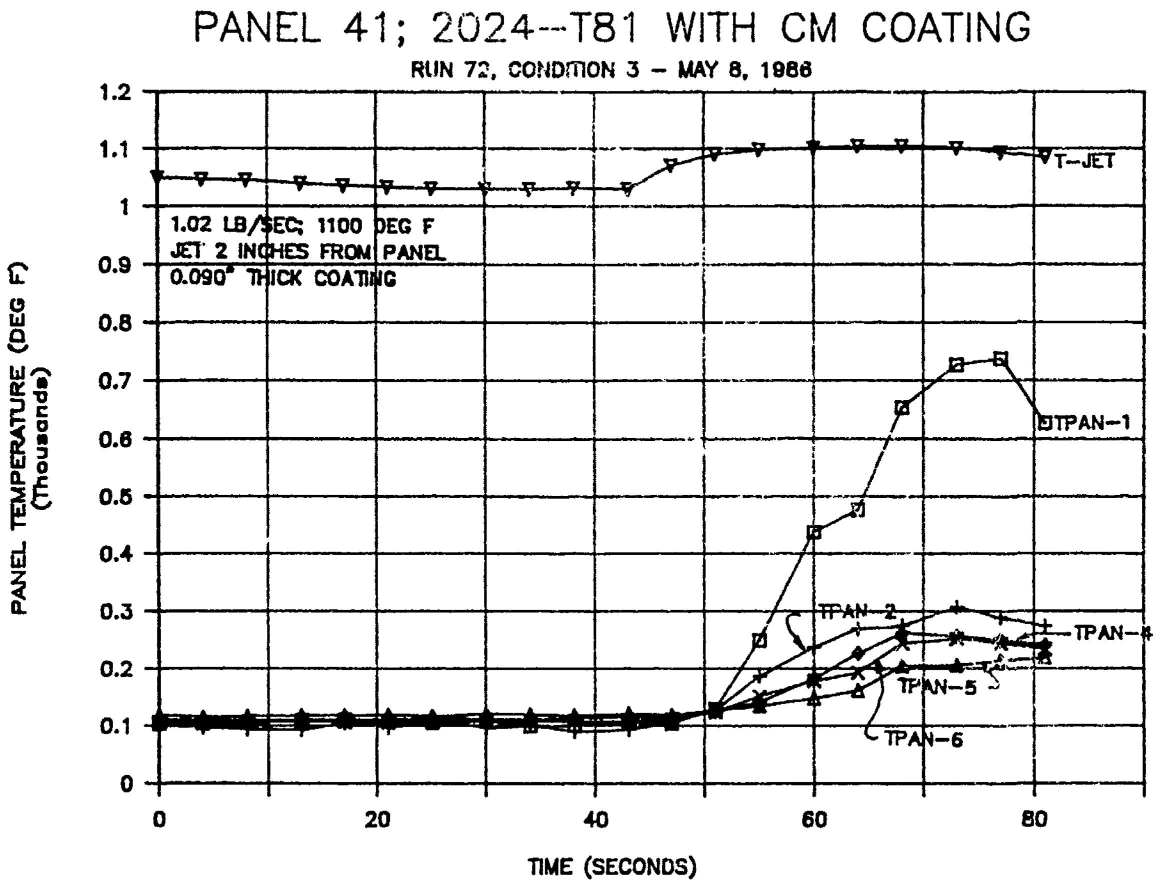

PANEL 38; 2024-T81 WITH MA-25S COATING
RUN 71, CONDITION 4 - APRIL 28, 1986
1.02 LB/SEC; 900 DEG F
JET 2 INCHES FROM PANEL
0.090" THICK COATING
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-6
TPAN-5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

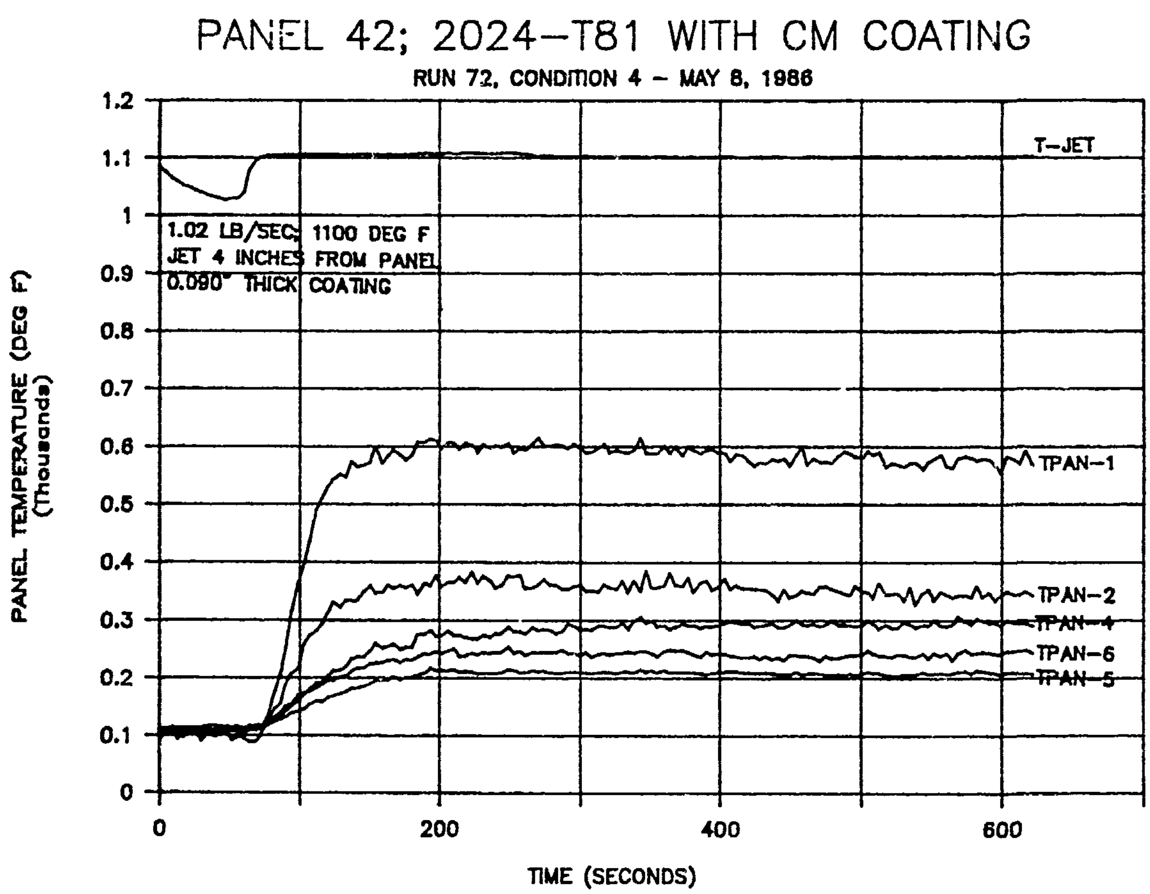


PANEL 39; 2024-T81 WITH MA-25S COATING
RUN 72, CONDITION 1 - MAY 9, 1986
1.02 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
0.25" THICK COATING
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)



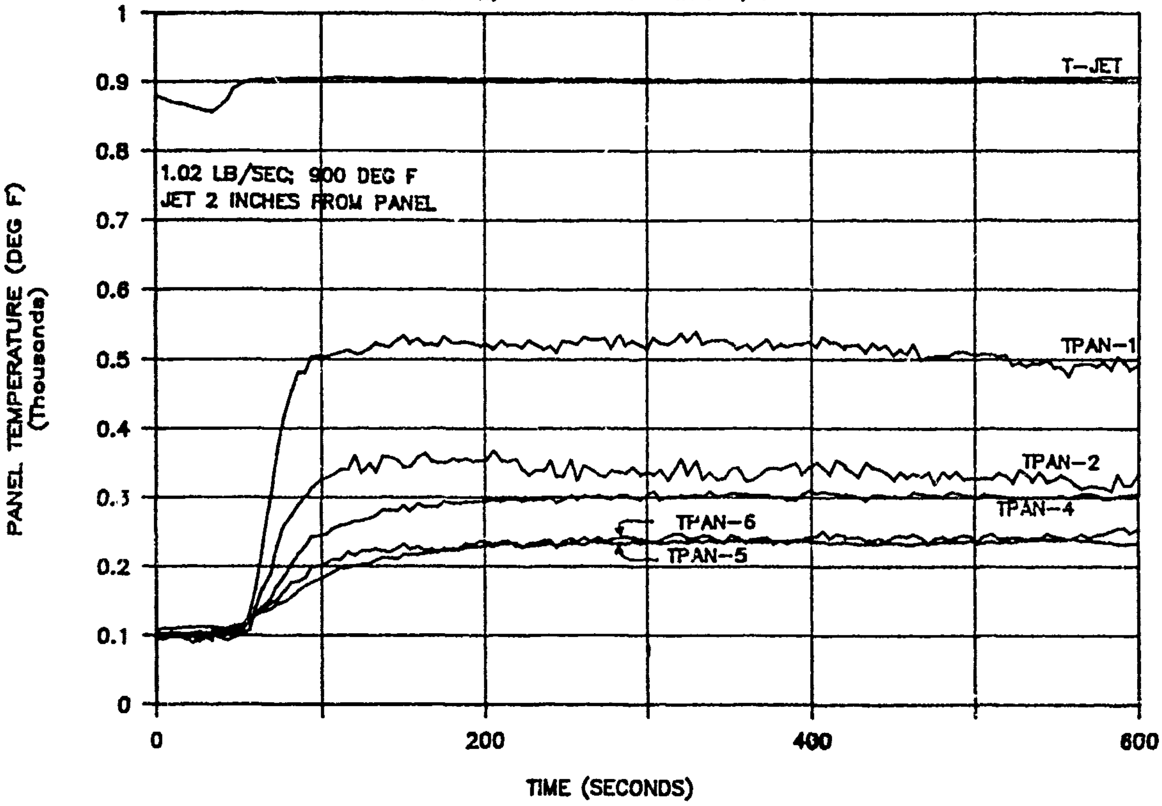
PANEL 40; 2024-T81 WITH MA-25S COATING
RUN 72, CONDITION 2 - MAY 8, 1986
1.02 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
0.25" THICK COATING
T-JET
TPAN-1
TPAN-2
TPAN-6
TPAN-5
TPAN-4
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 41; 2024--T81 WITH CM COATING
RUN 72, CONDITION 3 – MAY 8, 1986
1.02 LB/SEC; 1100 DEG F
JET 2 INCHES FROM PANEL
0.090" THICK COATING
T–JET
TPAN–1
TPAN–2
TPAN–4
TPAN–5
TPAN–6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 42; 2024–T81 WITH CM COATING
RUN 72, CONDITION 4 – MAY 8, 1986
1.02 LB/SEC; 1100 DEG F
JET 4 INCHES FROM PANEL
0.090" THICK COATING
T–JET
TPAN–1
TPAN–2
TPAN–4
TPAN–6
TPAN–5
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)

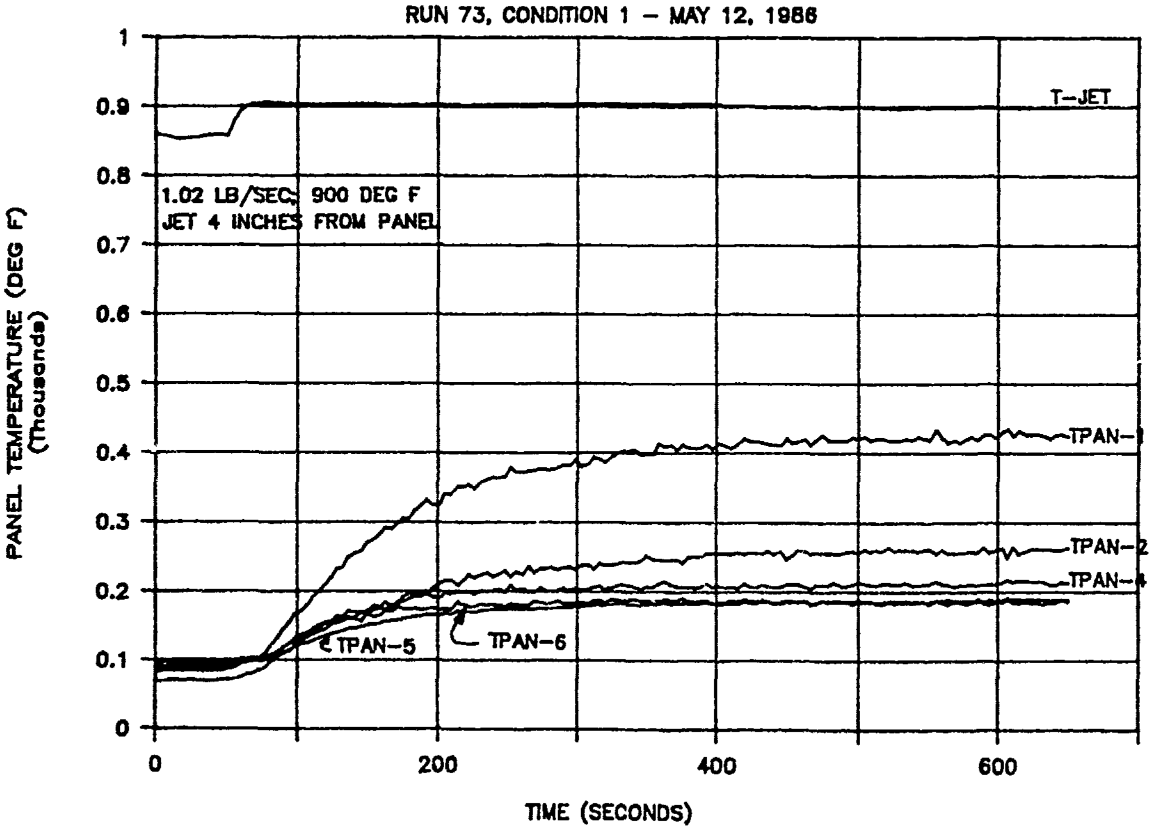
PANEL 43; 2024-T81 WITH CM COATING

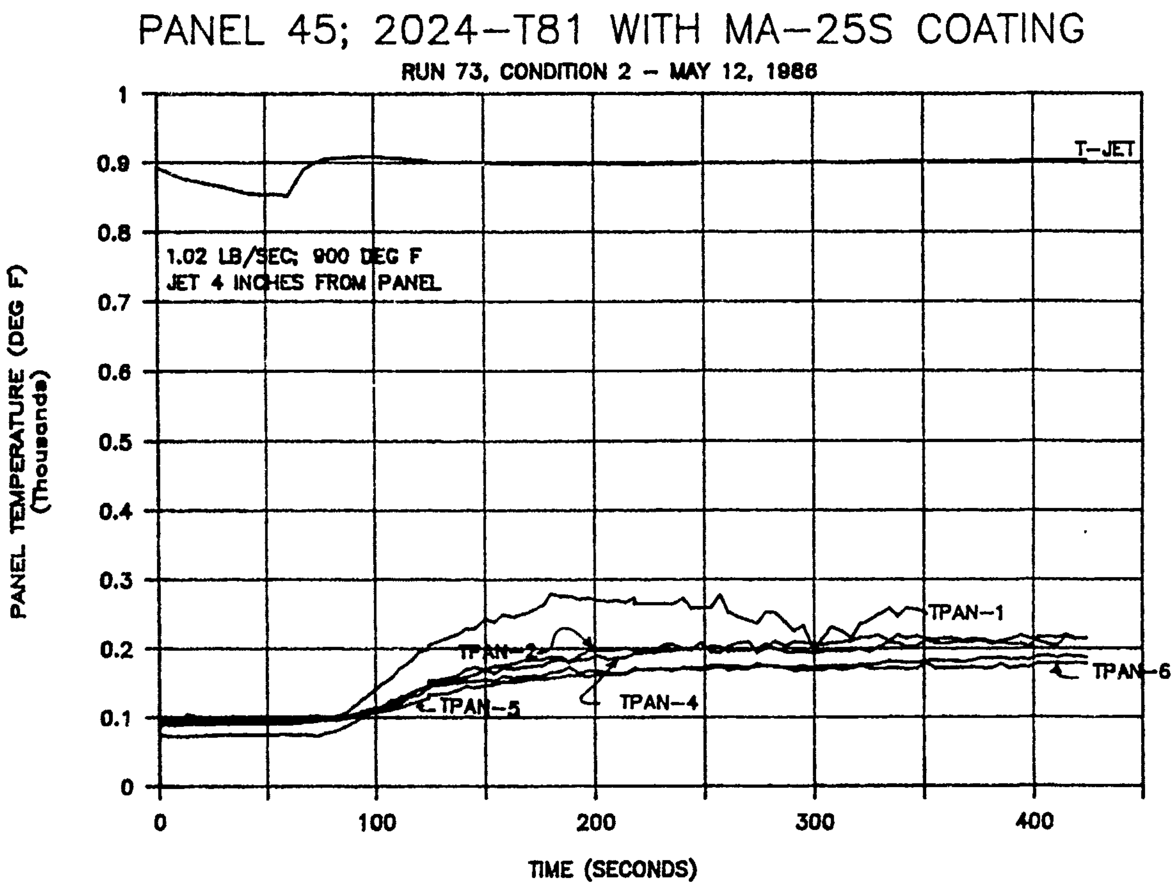
RUN 72, CONDITION 5 - MAY 8, 1986

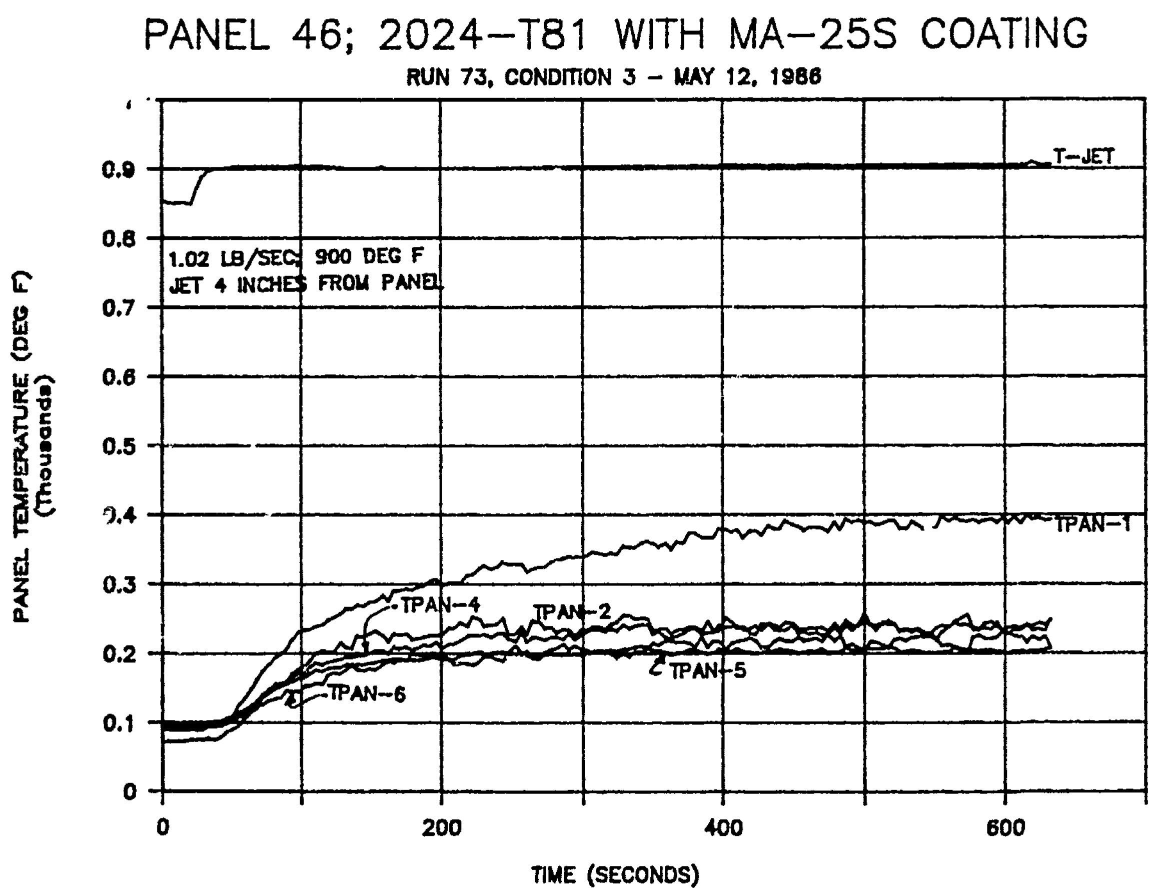


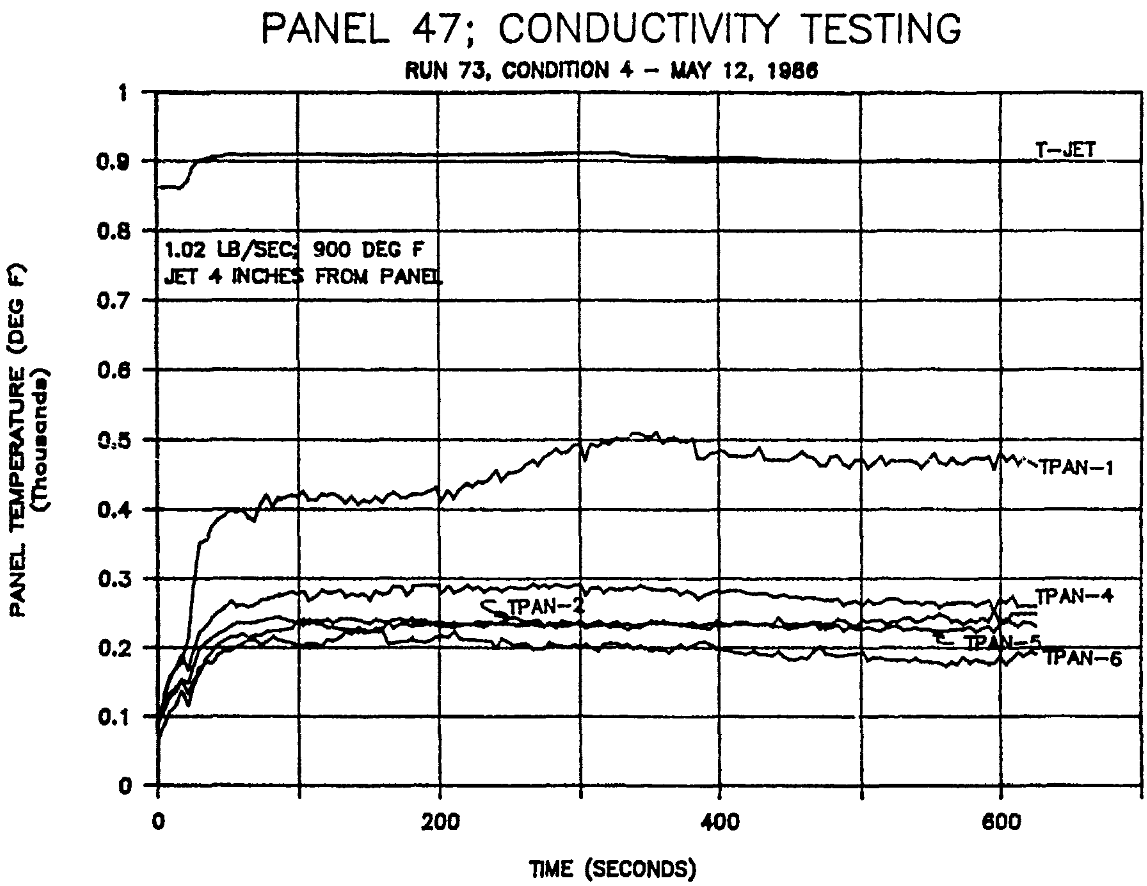
PANEL 44; 2024-T81 WITH CM COATING

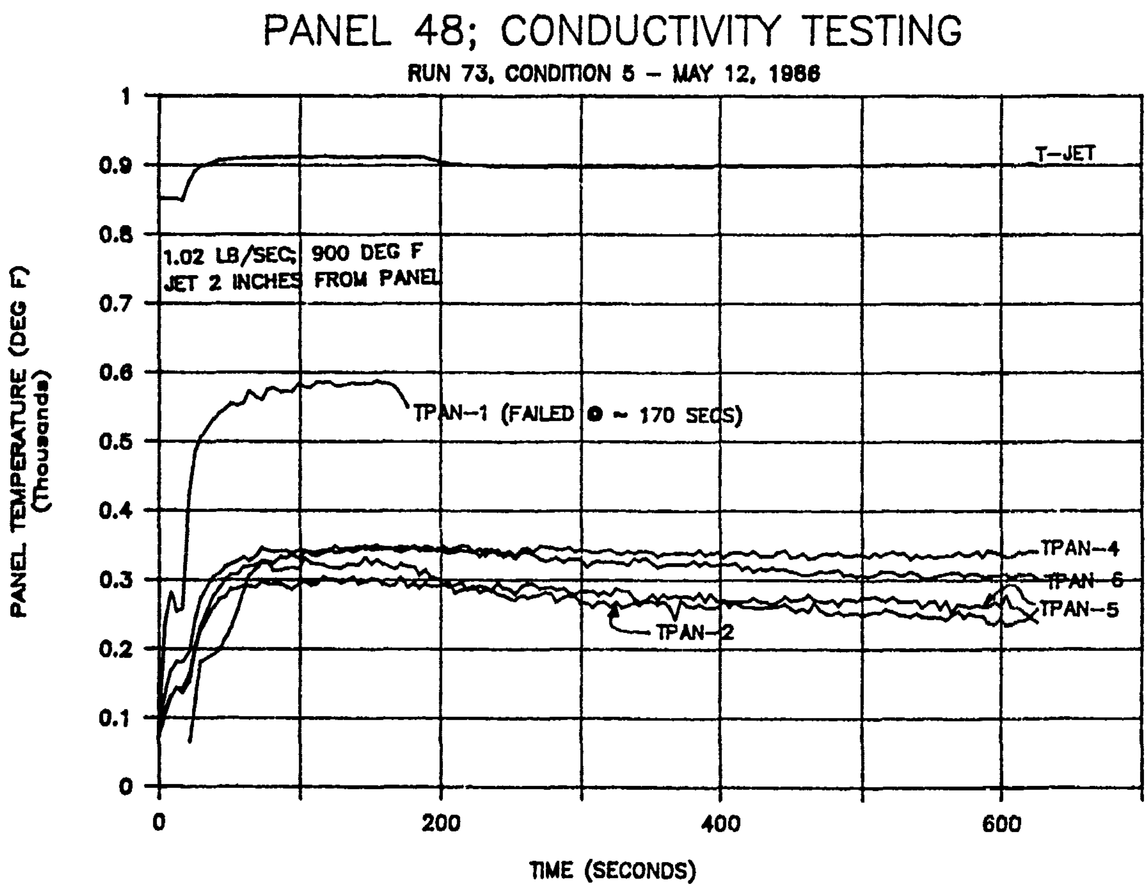
RUN 73, CONDITION 1 - MAY 12, 1986

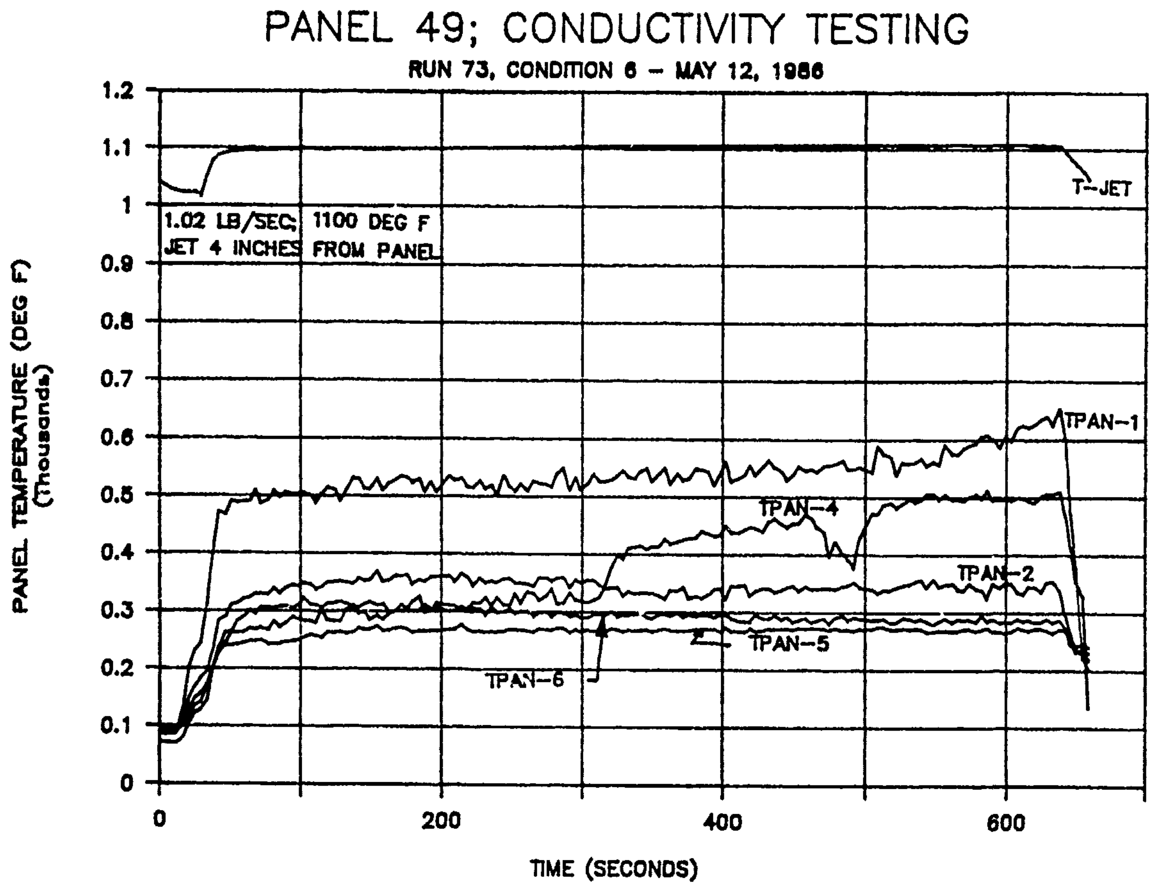


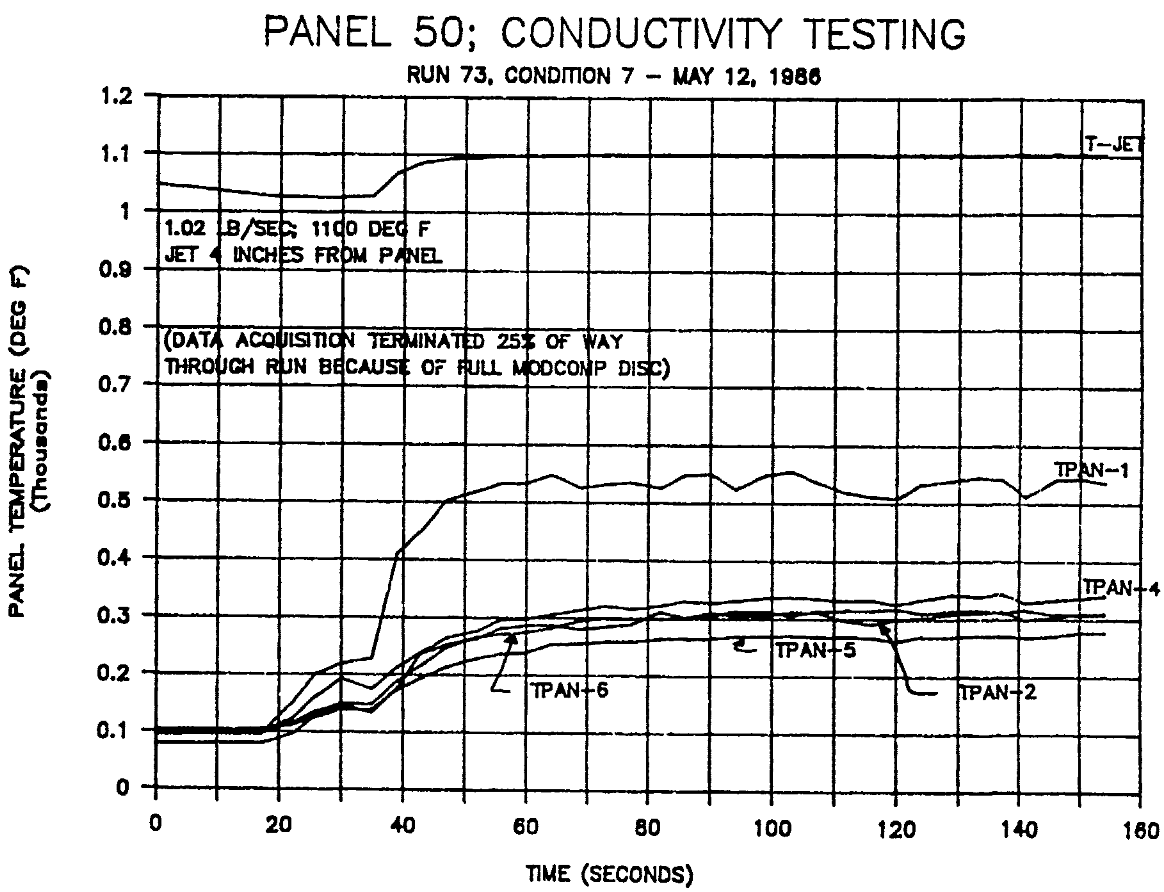

PANEL 45; 2024-T81 WITH MA-25S COATING
RUN 73, CONDITION 2 - MAY 12, 1986
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
1.02 LB/SEC; 900 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
100
200
300
400


PANEL 46; 2024-T81 WITH MA-25S COATING
RUN 73, CONDITION 3 - MAY 12, 1986
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)
1.02 LB/SEC; 900 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-4
TPAN-2
TPAN-5
TPAN-6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
200
400
600


PANEL 47; CONDUCTIVITY TESTING
RUN 73, CONDITION 4 - MAY 12, 1986
1.02 LB/SEC; 900 DEG F
JET 4 INCHES FROM PANEL
T-JET
TPAN-1
TPAN-2
TPAN-4
TPAN-5
TPAN-6
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)


PANEL 48; CONDUCTIVITY TESTING
RUN 73, CONDITION 5 - MAY 12, 1986
1.02 LB/SEC; 900 DEG F
JET 2 INCHES FROM PANEL
T-JET
TPAN-1 (FAILED @ ~ 170 SECS)
TPAN-4
TPAN-6
TPAN-5
TPAN-2
PANEL TEMPERATURE (DEG F)
(Thousands)
TIME (SECONDS)





U S Government Printing Office 1987 — 748-061/60802