Report No. NA-69-26
(DS-68-26)

FINAL REPORT

Project No. 520-001-06X

AN INVESTIGATION OF IN-FLIGHT FIRE PROTECTION WITH A TURBOFAN POWERPLANT INSTALLATION

APRIL 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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for

AIRCRAFT DEVELOPMENT SERVICE

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ABSTRACT

The potential explosive and fire hazards and methods of detecting and controlling in-flight fires on modern aircraft powerplant installations were investigated under full-scale simulated low altitude flight conditions. Modifications were made to the pod-mounted turbofan engine test article to extend the program scope beyond the normal range of variables present on the installation.

The test program consisted of five studies: (1) environmental conditions producing thermal ignition of combustible mixtures and ignition characteristics, (2) characteristics of nacelle fires, (3) system performance and installation requirements for fire and overheat detection, (4) requirements for extinguishing and controlling fires, and (5) effects of fires and explosions on the powerplant installation.

The results of this program are presented as fire safety design criteria and engineering data. The effects of environmental conditions and thermal ignition and the characteristics of ignition are reported as a function of the amount, location, and type of fluid leakage. The size, intensity, radiation level, and propagation rate of nacelle fires are related to flight condition, fluid type, and fluid leakage characteristics. Fire detection requirements and the feasibility of abbreviated and remotely located sensors are presented as a function of detector operating characteristics, available detection time, nacelle design, and fire characteristics. Fire extinguishing requirements are related to the location, size, intensity, and duration of the fires, flight conditions, nacelle ventilation, and the type extinguishing agent and container. The resistance of the nacelle and engine components to fire and explosive damage and means of controlling and preventing the spread of fire are reported.

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INTRODUCTION

Purpose

The purpose of the full-scale fire protection test program was to provide engineering data and design criteria for modern aircraft powerplant installations concerning (1) ground and in-flight potential explosive and fire hazards, (2) fire detection and extinguishment requirements, (3) methods of controlling fires, and (4) effects of fire on the powerplant.

This report is intended to provide (1) information for updating federal aviation regulations governing fire detection and extinguisher systems and powerplant fire integrity requirements, (2) fire safety design criteria to the aviation industry, and (3) engineering data for use in the certification of future powerplant installations.

Background

In-flight fire protection of aircraft powerplant installations has been a subject of concern to the aviation industry and to those associated with aviation safety for the past quarter of a century.

With the conversion from turbojet to turbofan engines for U. S. commercial jet transport airplanes, the Federal Aviation Administration (FAA) recognized a need for information concerning fire protection requirements for the turbofan powerplant installations. This recognition together with recent technical developments and design philosophy changes affecting powerplant fire protection in general resulted in the FAA initiating a full-scale test program in April 1962.

The first phase of this program involved the development of a facility large enough to house a pod-mounted powerplant installation and capable of aerodynamically simulating environmental flight conditions of modern jet-transport-type aircraft. Such a facility was developed under an FAA contract by the Naval Air Propulsion Test Center (NAPTC) at Trenton, New Jersey. This facility was completed and operational early in 1964.

The full-scale testing of a turbofan powerplant installation was begun in October 1964, and was completed at the end of September 1966. This report covers the results of this 2-year investigation.

The facility developed at NAPTC and used throughout the test program consisted of an open circuit induction-type wind tunnel (Figure 1). Ambient air is drawn through the 10-foot-diameter tunnel test section by ejector pumping action of the exhaust gas of two J-75 turbojet engines. The facility is capable of producing airflows around a powerplant installation in the speed range existing between takeoff and cruise flight of modern jet-transport-type aircraft and at limited simulated altitude conditions. A detailed description of this facility is presented in Appendix I.

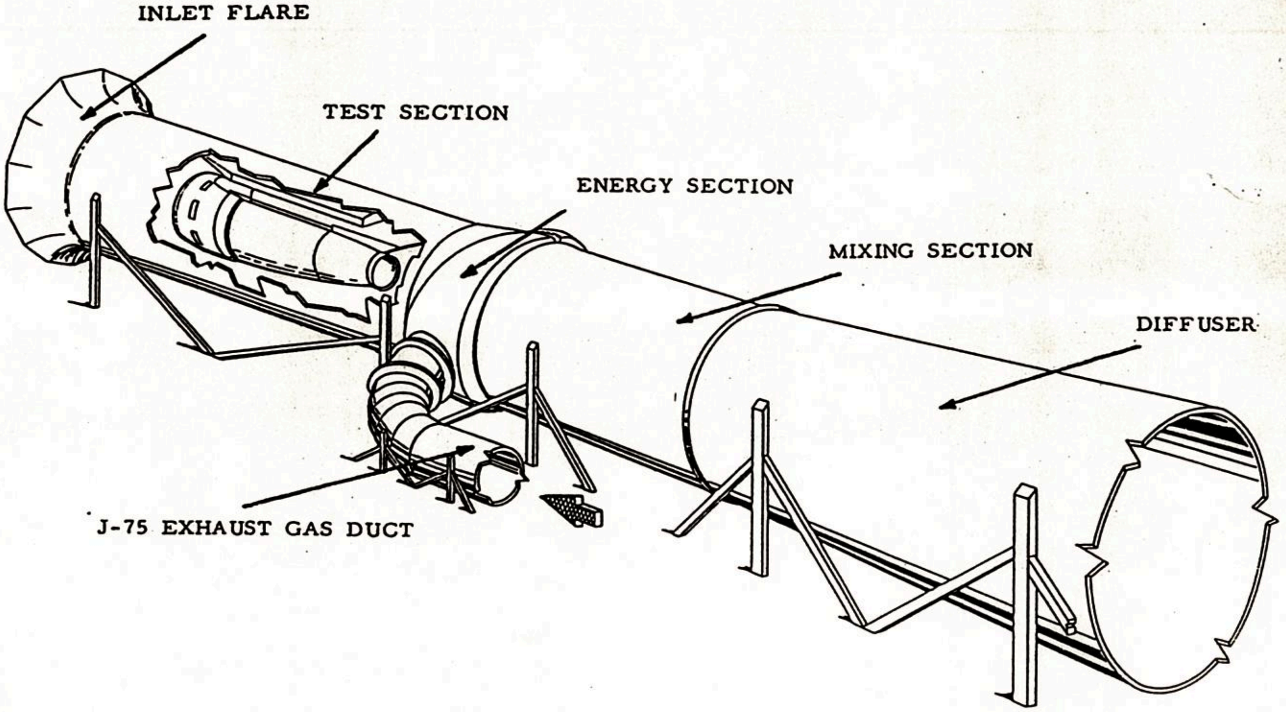


FIG. 1 - INDUCTION WIND TUNNEL FIRE TEST FACILITY

The Number 4 powerplant installation of a 720B aircraft was used as the test bed throughout the test program. The installation, including nacelle, strut, and a JT3D-1 turbofan engine, was installed in the tunnel test section with the strut faired to the upper surface (Figure 2). Station numbers (inch units) were assigned to the installation and are used throughout the report to identify axial locations along the nacelle, engine, and tunnel test section. Radial locations are identified by clock position from engine center line looking in the thrust direction of the engine. The axial locations of the various cowlings and engine cases are shown in Figure 2 and Appendix I.

The tunnel provided the airflow around the nacelle and the aerodynamic conditions within the nacelle similar to those which exist in flight over a range of Mach numbers from 0.1 to 0.7 and pressure altitudes from sea level to 10,000 feet. Close correlation of test and flight conditions was not of prime importance because the intent was not to test a specific configuration, but rather to develop generalized data applicable to a variety of configurations. The test section calibration for the turbofan powerplant installation and a comparison of in-flight and tunnel nacelle airflows are presented in Appendix II.

The nacelle airflows and air temperatures, nacelle skin temperatures, and engine case temperatures for the test powerplant installation operating under various simulated flight conditions are presented in Appendix III.

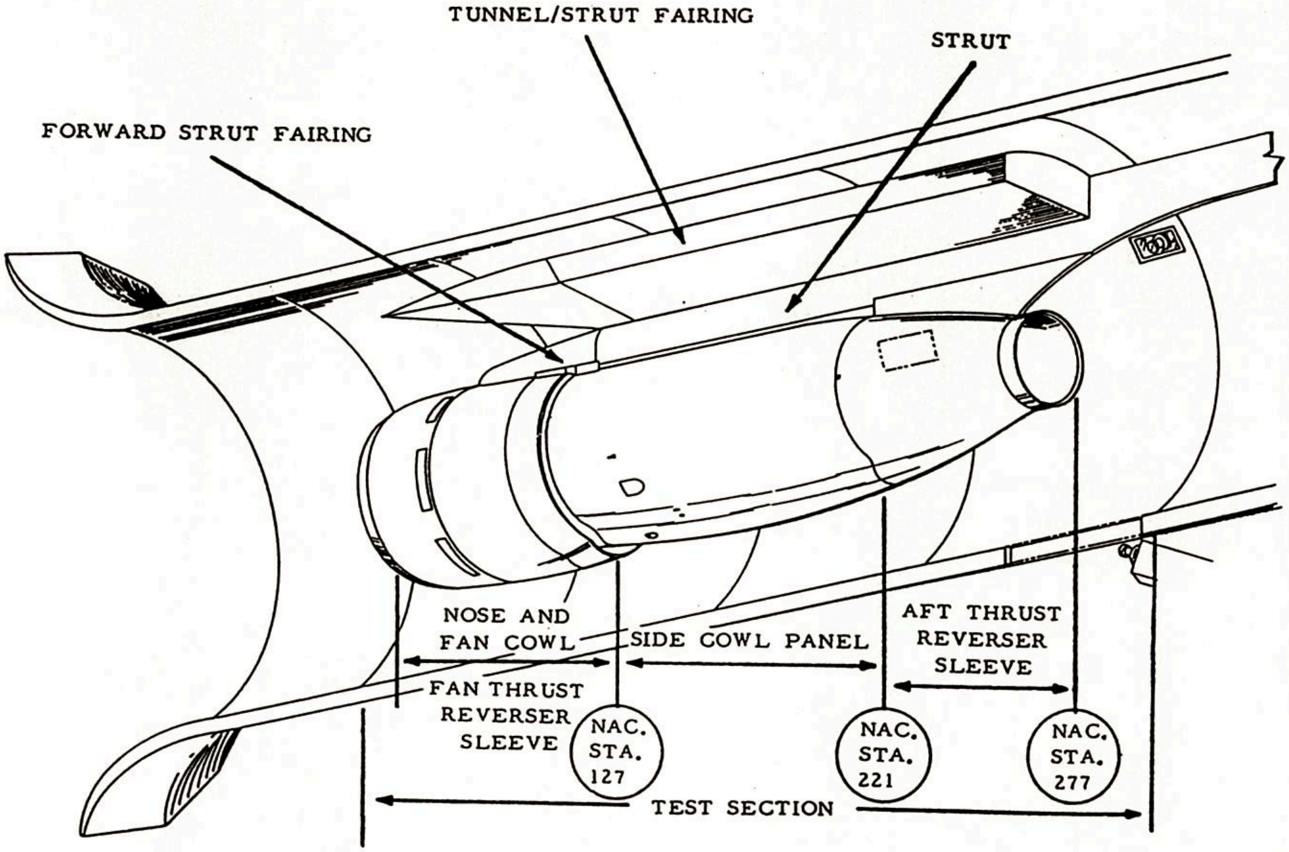


FIG. 2 - TURBOFAN INSTALLATION IN TEST SECTION

To facilitate presentation of the test results, the discussion has been divided into the following major sections with an appendix data supplement for each section:

1. Ignition Hazards.
2. Fire Characteristics.
3. Fire and Overheat Detection.
4. Fire Control and Extinguishment.
5. Fire Resistance and Damage.

DISCUSSION

Ignition Hazards

Introduction: Fire in an aircraft engine nacelle results from the thermal ignition of a fluid, leaking from a system carrying the flammable, contacting the engine hot surfaces. Hot gas, friction sparks, or electrical ignition would be expected only in cases involving an internal engine failure or a double failure of systems external of the engine case. The Ignition Hazard Study was therefore limited to the investigation of thermal ignitions by hot surfaces except for specialized tests requiring a spark ignition source.

The Ignition Hazard Study was further limited to the normal range of variables present on the test installation with the following exceptions: (1) the cooling air ventilation was controlled and varied beyond the normal range; (2) flammable fluids other than those normally used on the test installation were tested; (3) fluids were tested in areas where not normally located; (4) the engine was operated above the normal takeoff thrust setting; and (5) modifications were made to the engine compartments.

The specific objectives of the Ignition Hazard Test Program were to provide information on the following:

1. Limiting nacelle environmental conditions which result in thermal ignition.

2. The relative environmental conditions under which jet fuels, lubricating oils, and hydraulic fluids ignite.

3. The effects on ignition of elevating the temperature of lubricating oils.

4. The effects of the type of fluid leak on the environmental conditions resulting in ignition.

5. Potential hazards associated with separating ignition sources from flammable fluid systems without isolation.

Test Equipment and Procedures: The Ignition Hazard Study was conducted with the test installation in either (1) the production configuration, (2) an open engine compartment fireseal configuration, or (3) a controlled cooling airflow configuration (Appendix IV).

The flammable fluid systems used in this study were independent of the test engine systems and were capable of simulating failures over a wide range of line pressures, fluid temperatures, and flow rates. The type of fluid release used can be categorized as either a pressurized spray or solid stream or an unpressurized running stream. The pressurized-type release provided spray patterns ranging from hollow cones with extra fine atomization to full solid streams with coarse atomization. The unpressurized-type consisted of releasing the fluid through an open-end tube fitting so that the fluid would contact and flow on the hot engine case.

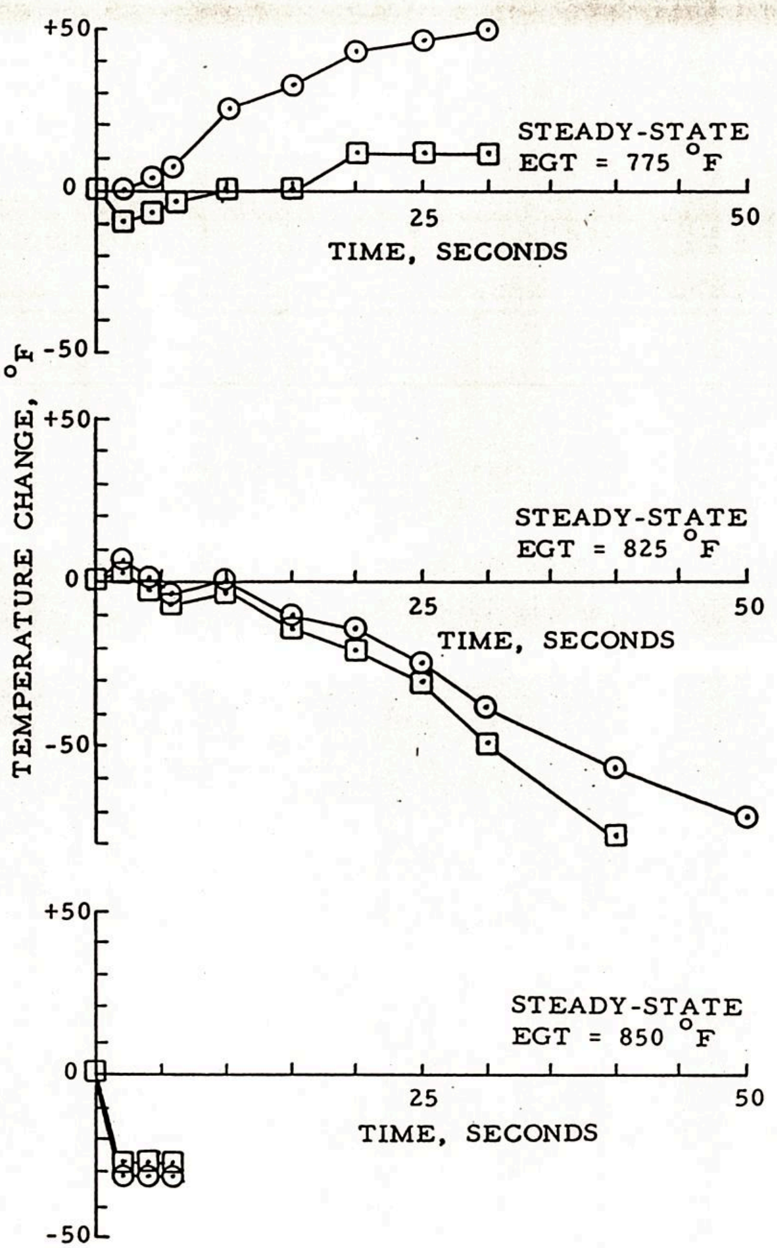
The test engine power setting for each ignition hazard test run was set according to the exhaust gas temperature. The relationship between engine case temperatures and exhaust gas temperatures is contained in Appendix IV and Reference 1. Appendix IV also contains detailed information on the fluid release systems and the test procedures followed.

The Ignition Hazard Investigation was conducted under both steady-state and transient conditions. During steady-state tests, the flammable fluids were released with the test engine power and tunnel airflow maintained constant. During transient tests, the fluids were released with the test engine power changing and the tunnel airflow either maintained constant or changing.

The effects of the transient engine operation on the turbine inlet case temperatures and nacelle air temperatures are illustrated for a typical series of test runs in Figures 3 to 5, inclusive. As the power was reduced to idle, the change in case temperature during the first 5 to 10 seconds was not substantial. At low initial steady-state power settings (exhaust gas temperature ≤ 775°F), the case temperature during the power transition gradually increased. At higher power settings, the case temperature showed an abrupt decrease during the power transition (exhaust gas temperature ≥ 850°F). As the power was reduced to idle, the air temperatures surrounding the turbine case generally increased while the air temperatures forward and aft of the turbine case tended to decrease.

The rate at which this transition to idle occurred also affected the nacelle temperature environment. As shown in Figure 6, at a transition rate less than the maximum as set by the fuel control (power lever retarded to idle in a 10-second period), the air surrounding the turbine case gradually decreased in temperature.

Ignition in Nacelle Compressor and Accessory Section (Zone II): The Ignition Hazard Study for simulated failures of systems carrying flammable fluids in Zone II is divided into four categories (Table I). The test conditions and results of the individual test runs in each of the four categories are contained in Appendix IV. Test Category I involved spray-type failures of the fuel system with a normal nacelle configuration and with the engine power and flight conditions maintained constant. Ignition of Type A (kerosene) and Type B (JP-4) jet fuels over a range of steady-state operating conditions did not occur in Category I test. This was true even though post-run examination revealed that during the higher release rate runs fuel had passed through the openings in the engine fireseal and accumulated in the hot section of the nacelle installation.

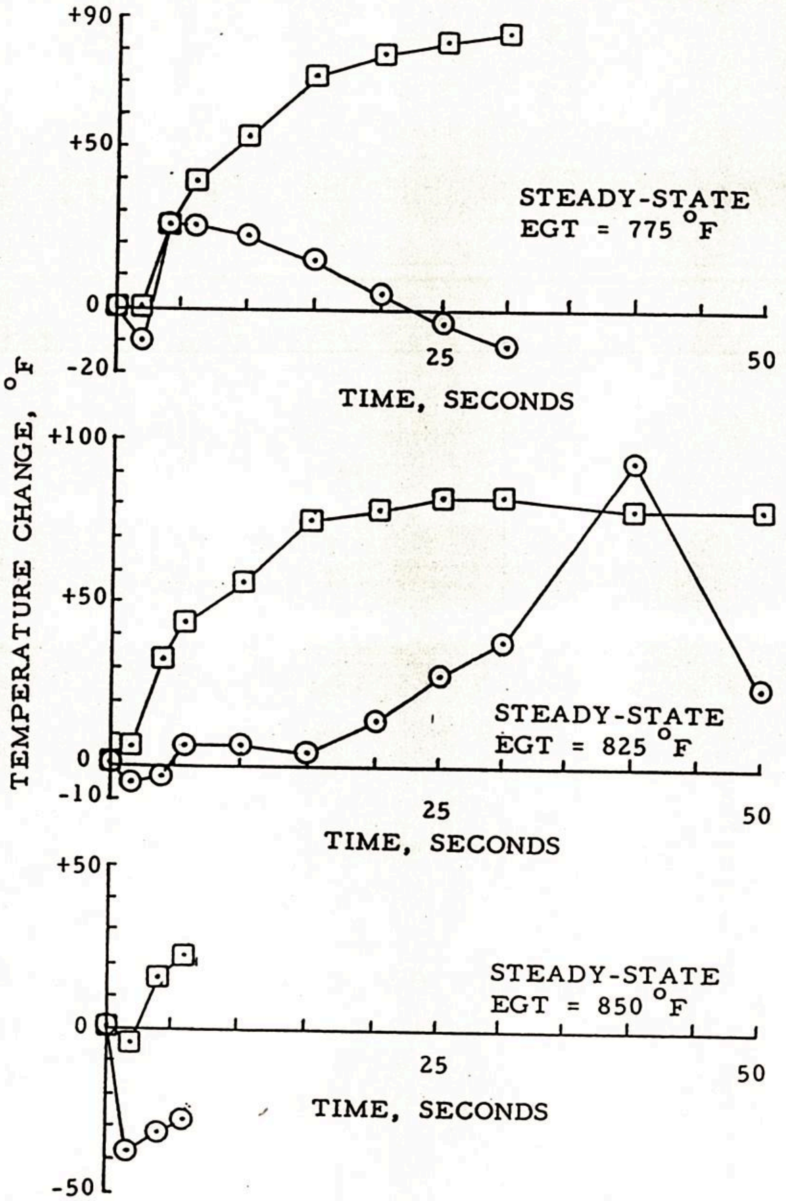


NOTE:

ZONE I, CATEGORY III TEST CONDITIONS (TABLE II)
FACILITY MACH NUMBER DECREASING FROM 0.5
0.3 GPM TYPE A JET FUEL @ 260 °F
POWER REDUCTION TO IDLE INITIATED AT ZERO TIME
TEMPERATURE LOCATION ON TURBINE CASE:
NAC. STA. NO. 201.1

CLOCK POSITION
9:30 ⊙——⊙
12:00 ⊡——⊡

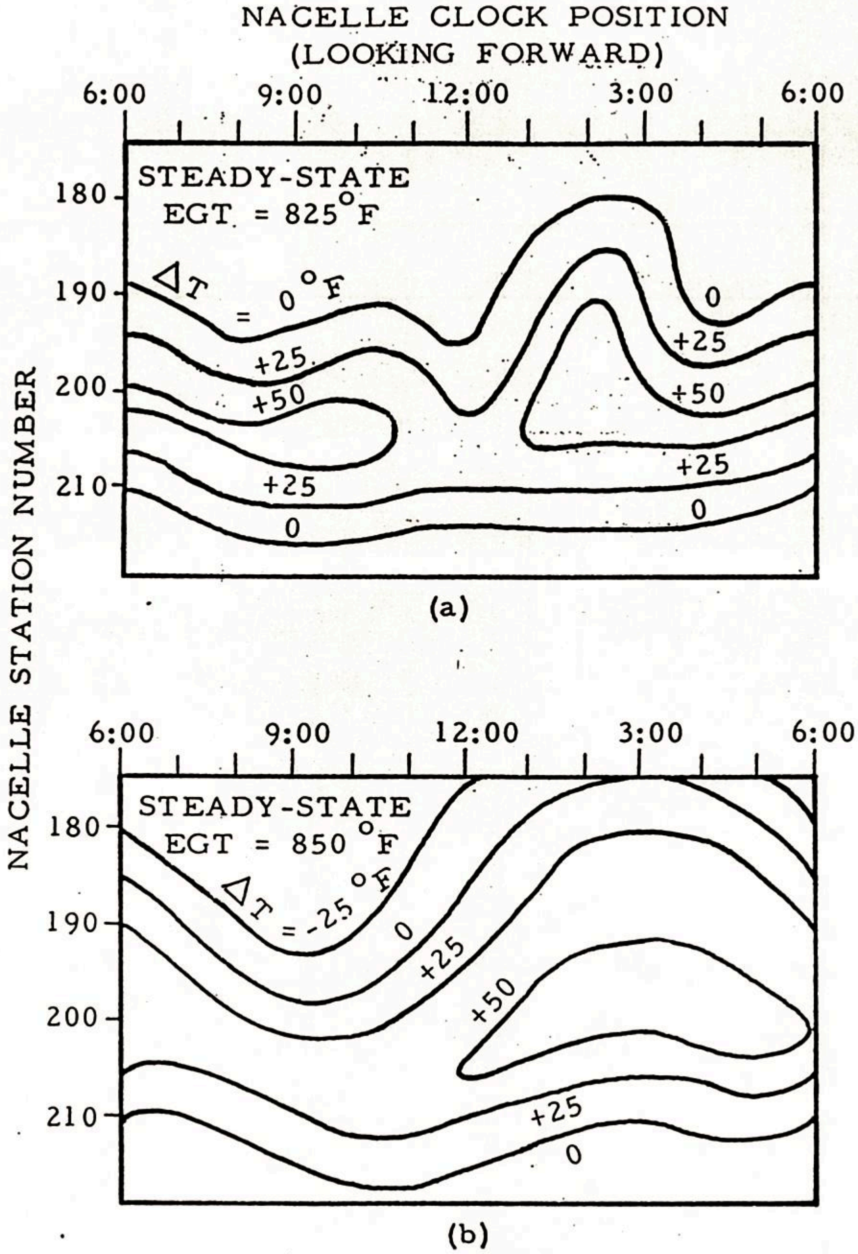
FIG. 3 - ENGINE CASE TEMPERATURE CHANGE FOR TRANSIENT FLIGHT CONDITIONS



NOTE:

ZONE I, CATEGORY III TEST CONDITIONS (TABLE II)
FACILITY MACH NUMBER DECREASING FROM 0.5
0.3 GPM TYPE A JET FUEL @ 260 °F
POWER REDUCTION TO IDLE INITIATED AT ZERO TIME
ZONE I AIR TEMPERATURE LOCATION:
CLOCK POSITION 10:00
NAC. STA.
NO. 191.5 ⊙——⊙
NO. 210.0 ⊡——⊡

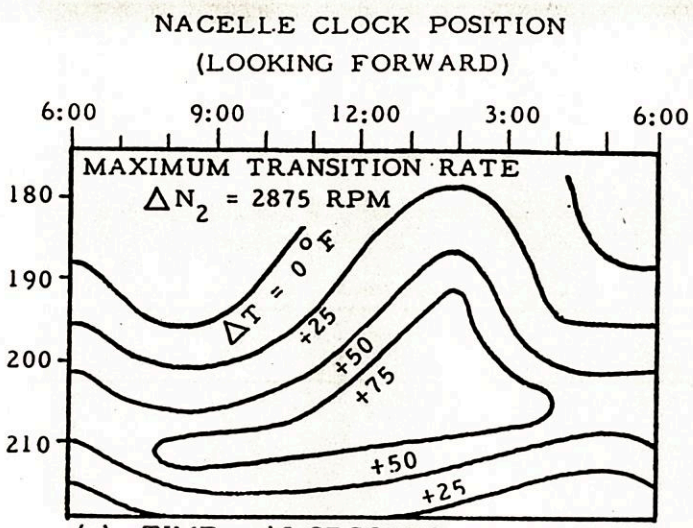
FIG. 4 - NACELLE AIR TEMPERATURE CHANGE FOR TRANSIENT FLIGHT CONDITIONS



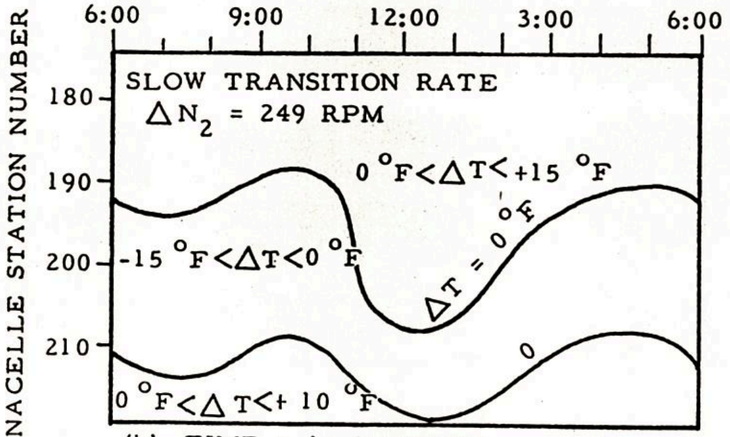
NOTE:

ZONE I, CATEGORY III TEST CONDITION (TABLE II)
0.5 FACILITY MACH NUMBER
0.3 GPM TYPE A JET FUEL @ 255 °F
MAXIMUM POWER TRANSITION RATE
ΔT = AIR TEMPERATURE CHANGE 5 SEC. AFTER INITIATING POWER REDUCTION TO IDLE

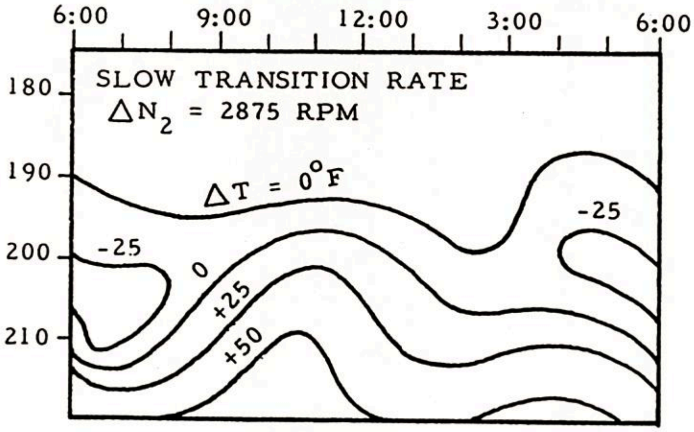
FIG. 5 - EFFECT OF TRANSIENT ENGINE OPERATION ON ZONE I NACELLE AIR TEMPERATURES



(a) TIME = 15 SECONDS



(b) TIME = 15 SECONDS



(c) TIME = 52 SECONDS

NOTE:

ZONE I, CATEGORY III TEST CONDITION (TABLE II)
0.5 FACILITY MACH NO.
INITIAL EXHAUST GAS TEMPERATURE OF 825 °F
0.3 GPM TYPE A JET FUEL @ 255 °F
ΔT = AIR TEMPERATURE CHANGE FOR TIME PERIOD INDICATED AFTER INITIATING POWER REDUCTION TO IDLE

FIG. 6 - VARIATION OF ZONE I NACELLE AIR TEMPERATURE CHANGE WITH RATE OF TRANSIENT ENGINE OPERATION

TABLE I

IGNITION HAZARD TEST CATEGORIES FOR NACELLE COMPRESSOR AND ACCESSORY SECTION (ZONE II)

	Category			
	I	II	III	IV
Installation Configuration	Production	Production	Production	Open Engine Compartment Fireseal
Simulated Flight Condition	Steady-State	Steady-State	Transient	Steady-State
Simulated System Failure	Pressurized Spray	Unpressurized Running	Unpressurized Running	Pressurized Spray
Fluids Tested:				
Jet Fuel	Type A Type B	Type B	Type B	Type A
Hydraulic Fluid	None	Mil-H-5606	Mil-H-5606	None

Category II tests involved simulated running-type failures of the fuel and hydraulic systems with a normal nacelle configuration and with the engine power and flight conditions maintained constant. Jet fuel, Type B, and Mil-H-5606 hydraulic fluid were released in Zone II above the engine diffuser case to run down both sides of the engine. At no time during Category II runs did ignition occur under the steady-state operating conditions.

Categories II and III were combined into a single series of test runs. Following the Category II portion of the test run, the engine power was reduced to idle while the fluid continued to flow. This portion of the run was classified as Category III and involved simulated running-type failures of the fuel and hydraulic systems with the normal nacelle configuration and under the transient operating conditions. Both Type B jet fuel and Mil-H-5606 hydraulic fluid ignited during the transition from high engine power to idle. The hydraulic fluid ignited at a lower initial engine power setting than the jet fuel. Thermocouples installed in the nacelle compartments indicated that ignition occurred aft of the engine fireseal and rapidly propagated through openings in the fireseal above the engine into Zone II.

Category IV test was with spray-type failures of the simulated fuel system in a modified nacelle under constant engine power and flight conditions. The nacelle modifications consisted of increasing the ventilation in Zone II by installing additional cooling airblast tubes and removing the cowl portion of the engine fireseal. Ignition did not occur during any of the four tests with Type A jet fuel, although the fuel again accumulated in the combustor and turbine section of the nacelle.

Ignition in Nacelle Combustor and Turbine Section (Zone I): The Ignition Hazard Study for simulated failures of systems carrying flammable fluids in Zone I is divided into six test categories in Table II. The results of the individual test runs in each of the six categories are contained in Appendix IV.

Test Category I involved spray-type failures of the lubricating oil and hydraulic systems with the nacelle in a normal configuration and with the engine power and flight conditions maintained constant. The fluids tested under these conditions were Mil-L-7808 and Mil-L-23699 lubricating oils and Mil-H-5606 hydraulic fluid. During one of the test runs with Mil-L-7808 oil, ignition occurred. The oil had been preheated above the normal maximum 250°F operating temperature to 600°F. Oil at this elevated temperature would not normally be expected except when the failure causing the fluid leak also causes the oil to become overheated. Ignition also occurred during one of the test runs in which hydraulic fluid was released at normal temperature. This run was repeated under approximately the same conditions without ignition occurring.

TABLE II

IGNITION HAZARD TEST CATEGORIES FOR NACELLE COMBUSTOR AND TURBINE SECTION (ZONE I)

	Category					
	I	II	III	IV	V	VI
Installation Configuration	Production	Production	Production	Controlled Cooling Airflow	Controlled Cooling Airflow	Controlled Cooling Airflow
Simulated Flight Condition	Steady-State	Steady-State	Transient	Steady-State	Transient	Steady-State
Simulated System Failure	Pressurized Spray	Unpressurized Running	Unpressurized Running	Unpressurized Running	Unpressurized Running	Pressurized Spray
Fluids Tested:						
Jet Fuel	None	Type A Type B	Type A Type B	Type A Type B	Type B	Type A Type B
Lubricating Oil	Mil-L-23699 Mil-L-7808	Mil-L-23699 Mil-L-7808	Mil-L-23699 Mil-L-7808	Mil-L-7808	None	None
Hydraulic Fluid	Mil-H-5606	Mil-H-5606 Jet Aircraft Commercial Fire Resistant	Mil-H-5606 Jet Aircraft Commercial Fire Resistant	Mil-H-5606	None	None

Category II testing involved the running type failures of simulated fuel, lubricating, and hydraulic systems with a normal nacelle configuration and with the engine power and flight conditions maintained constant. Type A and Type B jet fuels, Mil-L-7808 and Mil-L-23699, lubricating oils, Mil-H-5606 hydraulic fluid, and a jet aircraft commercial-type, fire-resistant hydraulic fluid were released as a solid stream in Zone I at the turbine inlet to run down both sides of the engine case. Ignition of Type A and Type B fuels did not occur during runs conducted under the steady-state operating conditions of the Category II test. During runs with the two types of lubricating oils, three ignitions occurred. All the ignitions occurred approximately 6 seconds after Mil-L-23699 oil was first released onto the turbine inlet case with engine exhaust gas temperature settings of 860°F and above. Ignition also occurred during one of the Category II runs with Mil-H-5606 released with the engine set at 860°F exhaust gas temperature. Ignition of the fire resistant hydraulic fluid did not occur during test runs under the Category II test conditions.

Categories II and III were combined into a single series of test runs. Following the Category II portion of the run, the engine power was reduced to idle while the fluid continued to flow. This portion of the run was classified as Test Category III and involved simulated running type failures of the fuel, lubricating, and hydraulic systems with a normal nacelle configuration and under transient operation. During test runs with Type A and Type B fuels, ignition occurred with initial engine exhaust gas temperature settings of 750°F and above, and 825°F and above for the respective fuels. The minimum engine exhaust gas temperature setting required to ignite the fuels decreased as the initial facility Mach number was lowered. As the initial exhaust gas temperature was decreased with all other conditions remaining the same, the ignition time tended to increase.

As previously discussed, the transition from a high engine power to idle normally occurred at the maximum rate set by the engine fuel control. During several Category III runs with Type A jet fuel, the transition was controlled at a slower rate. The results of these tests indicated that ignition occurred with lower initial engine power settings when the transition rate was maximum.

Category III test results with Type A jet fuel also indicated that ignition occurred under the lower initial engine power settings when the nacelle was tightly sealed and the ventilation rate was minimum. When seam leakage around the side doors increased the nacelle ventilation above normal, ignition did not occur. Restoring the seams to a normal seal resulted in ignition occurring with a lower temperature environment.

Mil-L-7808 and Mil-L-23699 lubricating oils ignited during Category III test runs with initial engine exhaust gas temperature settings of 750°F and above, and 820°F and above, respectively. The minimum engine exhaust gas temperature setting required to ignite the oils decreased as the initial facility Mach number was lowered. During Category III runs with hydraulic fluids, Mil-H-5606 ignited with initial engine exhaust gas temperature settings as low as 675°F. Again, as the initial facility Mach number was lowered, the minimum engine exhaust gas temperature setting required to ignite the hydraulic fluid decreased. Also, as the initial exhaust gas temperature setting was decreased with all other conditions remaining the same, the ignition time normally increased. Ignition on the jet aircraft, commercial-type, fire-resistant hydraulic fluid did not occur with the test engine operating at initial exhaust gas temperature settings of 865°F.

Test results under Category III test conditions generally indicated that Mil-H-5606 hydraulic fluid was the more easily ignited of the fluids tested followed by Type A jet fuel and Mil-L-7808 lubricating oil, Mil-L-23699 oil, and Type B jet fuel being, of the fluids ignited, the most resistant to ignition.

A comparison of the results of the Category II and III portions of the runs indicates that ignition was more likely to occur under the transient engine power reduction conditions.

Category IV tests involved the running-type failure of simulated fuel, lubricating, and hydraulic systems with a modified nacelle configuration and with the engine power and flight conditions maintained constant. The nacelle modifications were made to provide a test environment for simulating installations with higher engine pressure ratios. Such installations may have components of flammable fluid systems located near a hot surface due to high case temperature as far forward as the compressor case. These modifications consisted of the following items:

1. Sealing the nacelle combustor and turbine section by diaphragms to prevent air exchange with the nacelle compressor and accessory section and the aft thrust reverser sleeve.

2. Installing an annular plenum chamber in the forward nacelle combustor section connected to an external supply of compressed air.

3. Providing vent holes in the aft turbine section nacelle skin.

4. Installing an obstruction to collect and puddle fluids running down one side of the engine case.

These modifications resulted in controlled movement of air from the perforated annular plenum, over the hot engine case, and out the nacelle skin openings (Appendix IV, Figure 4.1).

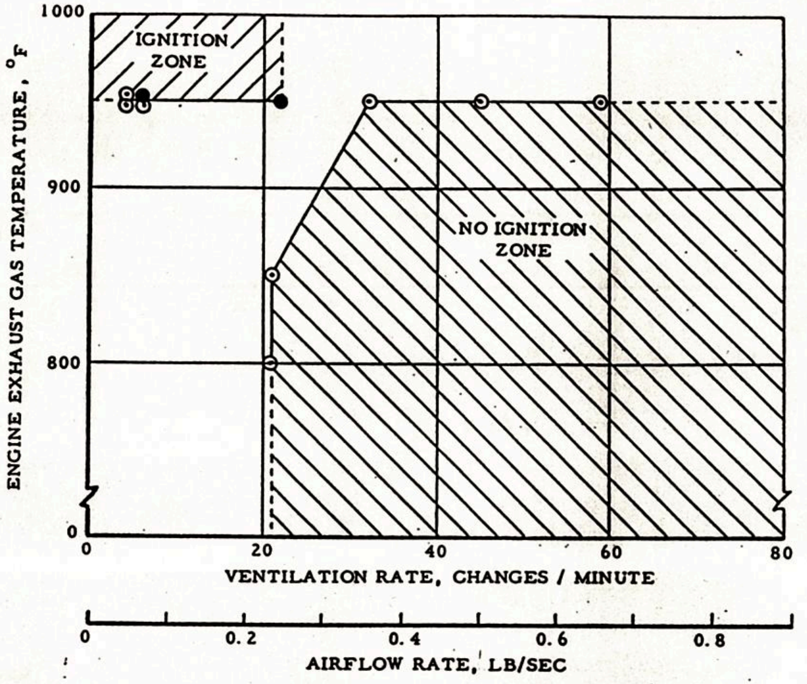
Type A and Type B jet fuels, Mil-L-7808 lubricating oil, and Mil-H-5606 hydraulic fluid were released above the engine as a solid stream at the plane of the turbine inlet to run down both sides of the engine case.

The results of Category IV tests are shown in Figures 7 to 9, inclusive. The ignition boundary was not precisely defined due to the limited number of tests conducted. The undefined conditions for ignition are shown in these figures as the region between the ignition zone and the no-ignition zone. There were three test runs conducted above the ignition boundary line conditions of Figure 7 in which Type A jet fuel did not ignite. All three runs involved fuel release rates which gradually increased to constant rates ranging from 0.04 to 0.3 gpm. In subsequent tests, when the release rate was increased beyond 0.3 gpm with all other conditions remaining essentially the same, ignition occurred.

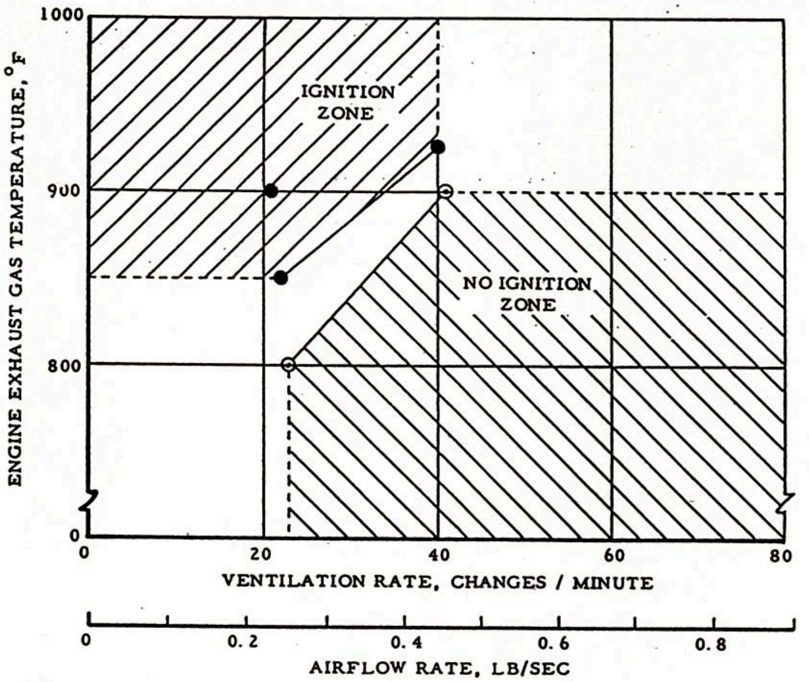
Likewise, during one of the test runs with Type B jet fuel, ignition did not occur under conditions above the ignition boundary line shown in Figure 8. This was attributed to the exit vent openings being unplugged during this run and the resulting changes in the convection currents within the compartment. The isothermal patterns for this run show that the average air temperature was 55°F lower than for a test run under the same conditions with the vent holes plugged and during which ignition occurred..

Mil-L-7808 lubricating oil did not ignite during the Category IV test runs. Four tests runs were conducted with an exhaust gas temperature setting of 950°F and ventilation rates ranging from 6 to 41 compartmental changes per minute.

Figure 9 shows four Category IV test runs in which Mil-H-5606 hydraulic fluid did not ignite under conditions above the ignition boundary line. One of the two runs with a ventilation rate of 3 compartmental changes per minute involved a fluid release rate which gradually increased to a 0.03-gpm constant flow. When the rate was increased to 0.1 gpm in the next test run, ignition occurred. The second low ventilation test run in which ignition did not occur followed a test in which an explosive ignition had opened the cowl door seams and a nacelle blowout panel. Since the cowl door and blowout panel were not repaired and resealed (as per normal procedure) until after the run, this second test run was conducted with increased air leakage which resulted in an overall 10°F average lower compartmental air temperature. The two remaining tests during which ignition did not occur above ignition boundary conditions are considered to be a result of a buildup of residue on the hot engine case during preceding tests. When the surface was cleaned, ignition occurred with the same engine exhaust gas temperature setting and higher air ventilation rates.



(a) UNPRESSURIZED RUNNING TYPE FUEL RELEASE (ZONE I, CATEGORY IV TEST CONDITIONS)

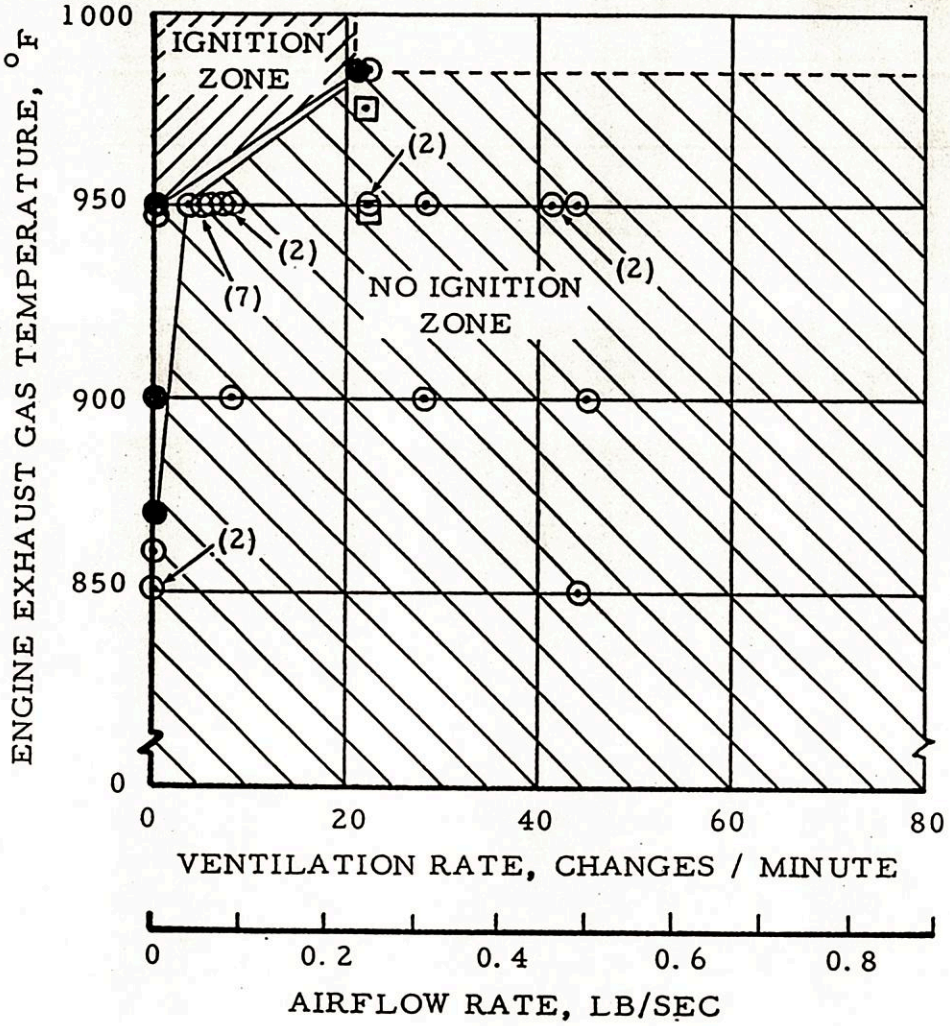


(b) PRESSURIZED SPRAY TYPE FUEL RELEASE (ZONE I, CATEGORY VI TEST CONDITIONS)

LEGEND

⊙ NO IGNITION
● IGNITION

FIG. 7 - EFFECT OF NACELLE VENTILATION ON THE IGNITION OF TYPE A JET FUEL



LEGEND

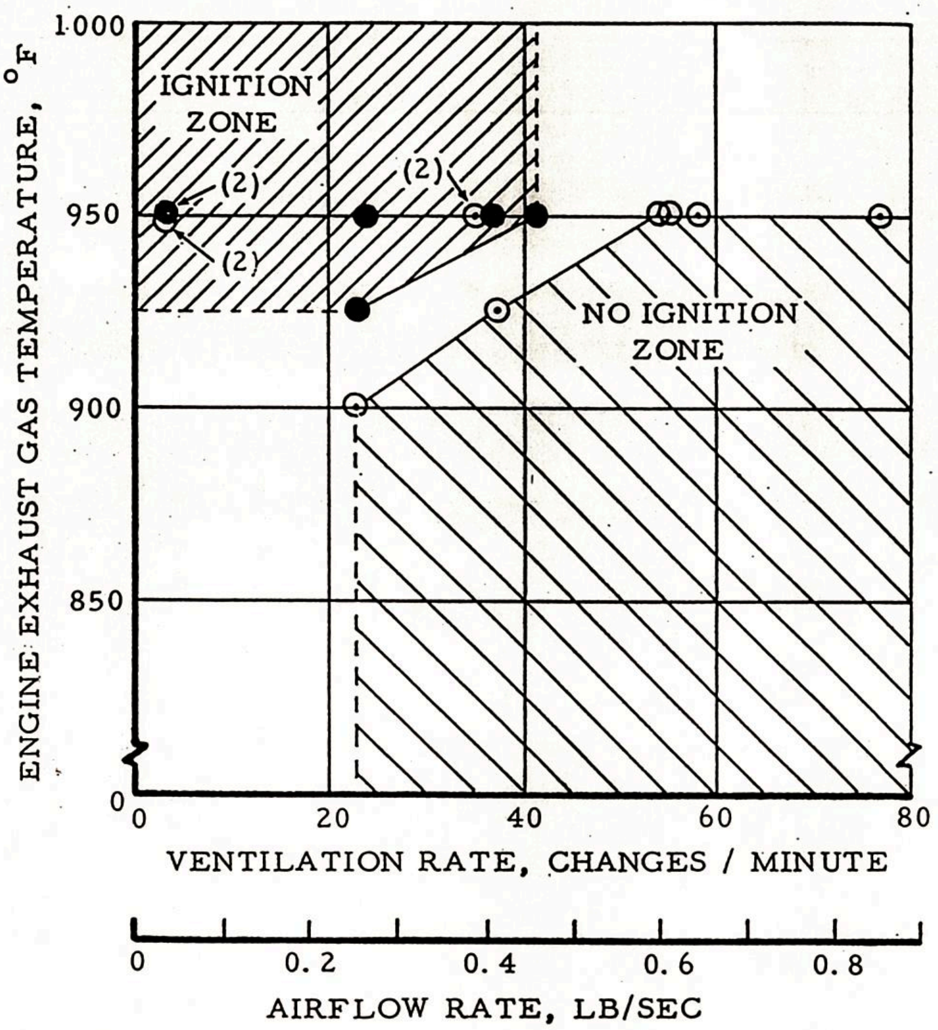
(x) NUMBER OF TEST RUNS

⊙ NO IGNITION } UNPRESSURIZED RUNNING TYPE

● IGNITION } FUEL RELEASE (ZONE I, CATEGORY IV)

⊡ NO IGNITION , PRESSURIZED SPRAY TYPE FUEL RELEASE (ZONE I, CATEGORY VI)

FIG. 8 - EFFECT OF NACELLE VENTILATION ON THE IGNITION OF TYPE B JET FUEL



LEGEND

(x) NUMBER OF TEST RUNS
⊙ NO IGNITION } UNPRESSURIZED RUNNING TYPE
● IGNITION } FUEL RELEASE (ZONE I, CATEGORY IV)

FIG. 9 - EFFECT OF NACELLE VENTILATION ON THE IGNITION OF MIL-H-5606 HYDRAULIC FLUID

Test results generally indicated that Mil-H-5606 hydraulic fluid was the more easily ignited of the fluids tested under Category IV conditions followed by Type A jet fuel, Mil-L-7808 lubricating oil, and Type B jet fuel being the most difficult to ignite.

Jet fuel, Type B, ignited with minimum ventilation during a Category IV test with an engine exhaust gas temperature which did not result in ignition under Category II conditions (running-type failure with a normal nacelle configuration and constant engine power and flight conditions). Mil-H-5606 hydraulic fluid ignited with lower engine exhaust gas temperature settings during Category II tests than during Category IV tests with ventilation rates above 23 compartmental changes per minute.

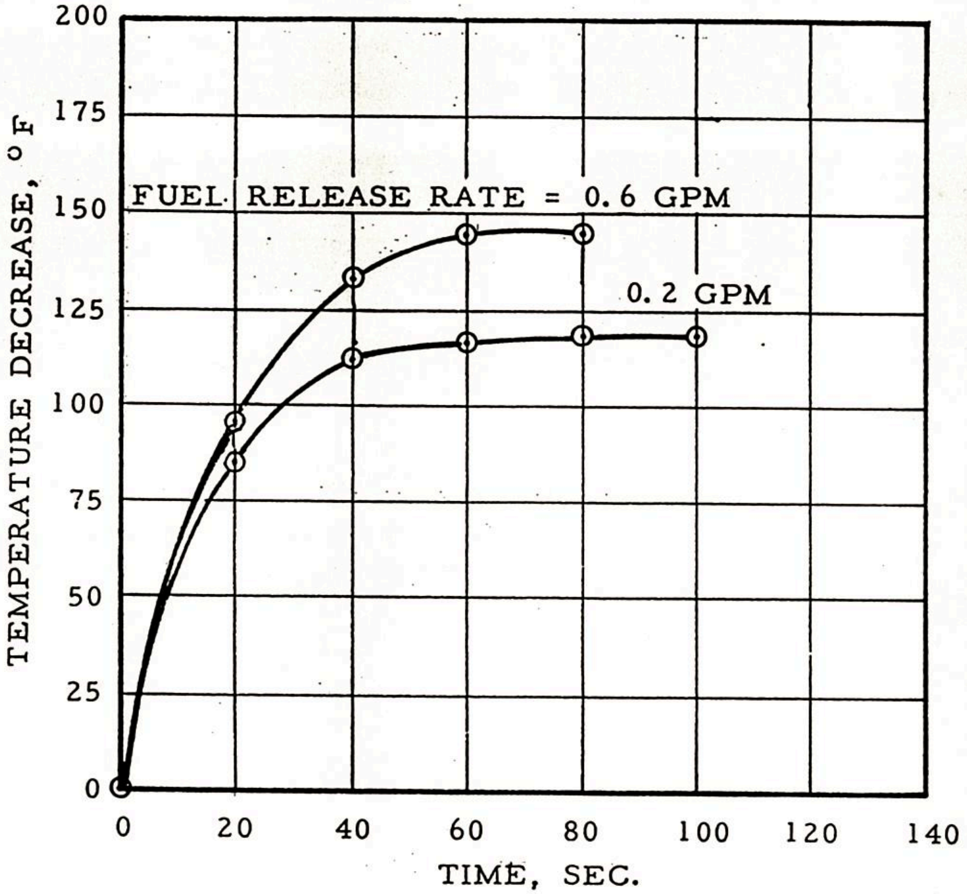
A study of the surface temperature effects of releasing fluids onto the turbine case was made during Category IV test runs. In Figure 10, the surface temperature at a location on the turbine case decreased 100°F to 200°F and stabilized in a time period ranging from 1 to 2 minutes after initially releasing the jet fuel. The maximum measured decrease in the surface temperature was in the 100°F to 200°F range during the majority of the Category IV test runs. However, 300°F to 400°F surface temperature decreases were measured during several of the test runs involving hydraulic fluid and Type B jet fuel at a high release rate.

The surface areas affected by releasing the fluids at several rates and under varying test conditions are shown in Figures 11 to 13, inclusive. Increasing the fluid release rate did not substantially increase the amount of affected surface area, but under some test conditions did increase the amount of cooling within the affected area (Figures 12a and 13b). Mil-H-5606 had a greater cooling effect than either Type B jet fuel or Mil-L-7808 lubricating oil. Likewise, Type B jet fuel had a greater cooling effect than Type A jet fuel.

Test Category V involved the running-type failures of the simulated fuel system with the Category IV nacelle configuration and with transient engine power operation. The two Category V test runs were conducted following Category IV test runs by reducing the engine power to idle while Type B jet fuel continued to leak. Both test runs were with a minimum ventilation rate and an initial engine exhaust gas temperature setting of 850°F. Ignition occurred in both cases; 1-1/2 seconds and 3 seconds after initiating the engine power reduction. In comparison, the lowest exhaust gas temperature setting in which Type B jet fuel ignited under the steady-state engine operating conditions of Category IV runs was 870°F and occurred with minimum ventilation.

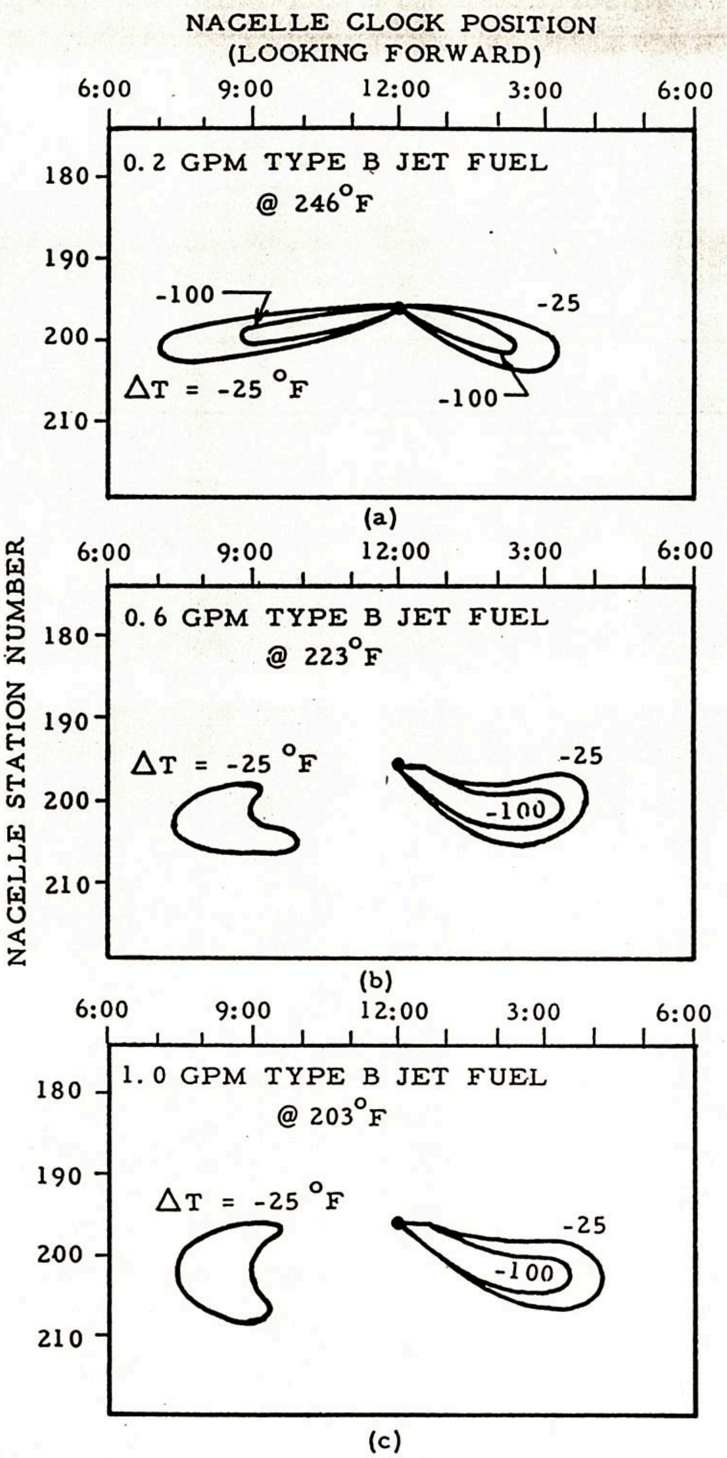
NOTE:

ZONE I, CATEGORY IV TEST CONDITION (TABLE II)
0.4 FACILITY MACH NUMBER
950 °F EXHAUST GAS TEMPERATURE
TYPE B JET FUEL @ 225 ± 25 °F
3 TO 4 COMPARTMENTAL AIR CHANGES PER MINUTE



CASE TEMP. LOCATION:
NAC. STA. NO. 200.8
NAC. CLOCK POSITION 1:30

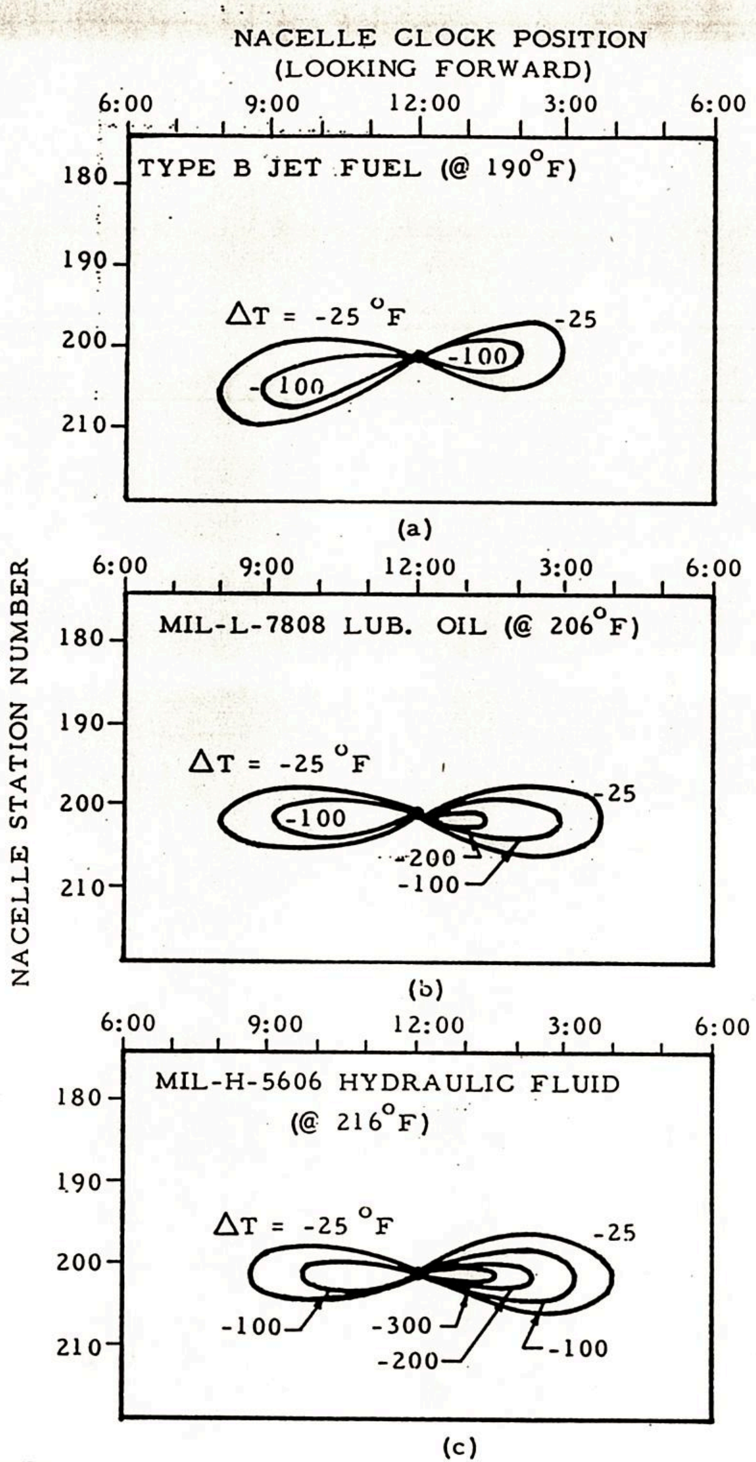
FIG. 10 - EFFECT OF RELEASING FUEL ON ZONE I ENGINE CASE TEMPERATURE



NOTE:

ZONE I, CATEGORY IV TEST CONDITION (TABLE II)
0.4 FACILITY MACH NUMBER
950 °F EXHAUST GAS TEMPERATURE
3 to 4 COMPARTMENTAL AIR CHANGES PER MINUTE
ΔT = STABILIZED CASE TEMPERATURE CHANGE DUE TO FUEL CONTACTING SURFACE

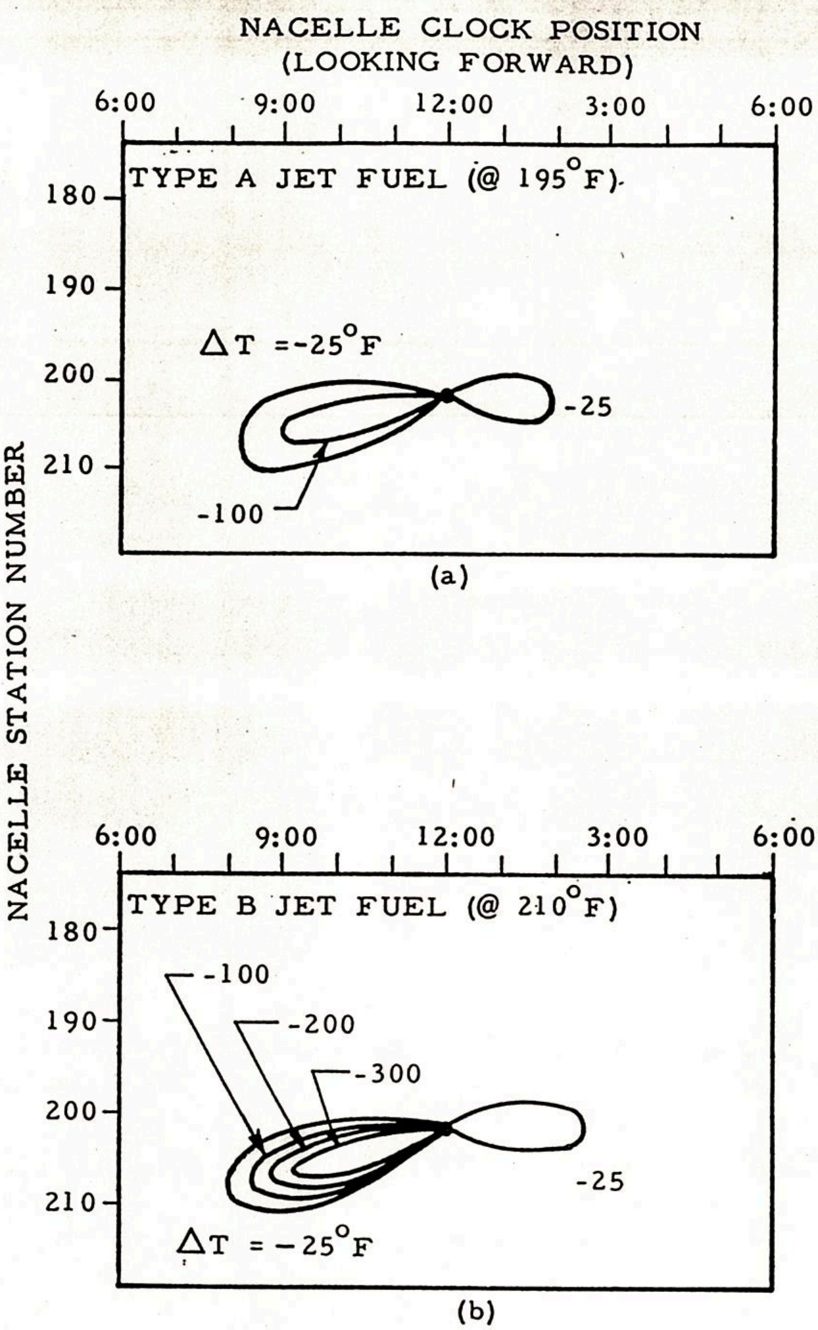
FIG. 11 - VARIATION OF ZONE I ENGINE CASE TEMPERATURE CHANGE WITH FUEL RELEASE RATE



NOTE:

ZONE I, CATEGORY IV TEST CONDITION (TABLE II)
0.4 FACILITY MACH NUMBER
950°F EXHAUST GAS TEMPERATURE
0.3 GPM FLUID RELEASE RATE
41 COMPARTMENTAL AIR CHANGES PER MINUTE
ΔT = STABILIZED CASE TEMPERATURE CHANGE DUE TO FLUID CONTACTING SURFACE

FIG. 12 - EFFECT OF FLUID TYPE ON ZONE I ENGINE CASE TEMPERATURE



NOTE:

ZONE I, CATEGORY IV TEST CONDITION (TABLE II)
0.4 FACILITY MACH NUMBER
950°F EXHAUST GAS TEMPERATURE
1.0 GPM FLUID RELEASE RATE
41 TO 45 COMPARTMENTAL AIR CHANGES PER MINUTE
ΔT = STABILIZED CASE TEMPERATURE CHANGE DUE TO FUEL CONTACTING SURFACE

FIG. 13 - EFFECT OF FUEL TYPE ON ZONE I ENGINE CASE TEMPERATURE

Test Category VI was the same as Test Category IV except for fuel being spray released onto the upper surface of the engine. The test involved the spray-type failures of the simulated fuel system with the modified nacelle configuration and with steady-state engine power and flight conditions.

The results of Category VI test runs are also shown in Figures 7 and 8. Jet fuel, Type A, ignited at lower engine exhaust gas temperatures and at a higher ventilation rate when released as a spray as compared to an unpressurized solid stream-type release. The ignition boundary line for a spray-type release of jet fuel, Type B, was not determined. However, results indicate that a spray release has an ignition boundary defined by either the same or higher environmental temperature conditions when compared to the unpressurized solid stream-type release. Under Category VI conditions, jet fuel, Type A, again ignited under lower environmental temperature conditions than Type B fuel.

The surface temperature cooling effect of spray releasing fuels onto the turbine case was greater than test runs with an unpressurized running-type release. Local surface temperature decreases as high as 600°F to 700°F were measured at a location in line with the spray nozzle.

Ignition Characteristics: The thermal ignitions were in the form of an explosion with over-pressures and high velocity flame propagation. The explosive force was frequently sufficient to cause failure of the side cowl doors at the hinges and latches partially opening the nacelle and to move the aft thrust reverser sleeve to a cracked-open position.

A study of the severity of the explosive ignitions was made based on flame propagation rates during ignitions in Zone I under Categories IV, V, and VI test conditions. Each ignition during these test categories is classified in Appendix IV using a scale ranging from a violent Explosion Number 1 to a mild Explosion Number 7. This scale was developed on the basis of the time increment required for the temperature wave to travel through a measured angle away from the location of ignition around the engine as described in Appendix IV. The scale then represents average flame propagation rates ranging from approximately 150 fps for Scale Number 1 to 20 fps for Scale Number 7.

The results of this study generally indicated that the greater the time period during which the flammable fluid was released prior to ignition, the more violent the explosion. For example, two Category IV test runs with Mil-H-5606 hydraulic fluid released under essentially the same conditions resulted in ignition 12 seconds after initiating the fluid release in one case and 91 seconds in the other. The severity of ignition ranged from a mild explosion (Scale Number 6) for the test run having a short fluid release time to a violent explosion (Scale Number 1) for the test run with the long duration fluid release.

Increasing the compartmental cooling air ventilation did not necessarily decrease the severity of ignition. For example, the above referenced Category IV test runs with Mil-H-5606 were conducted with ventilation rates of 3 compartmental changes per minute. When these test runs were repeated with the fluid release rate increased threefold and a ventilation rate of 41 compartmental changes per minute, a violent explosion (Scale Number 2) again occurred.

The two test runs under the transient simulated flight conditions of Category V were violent explosions (Scale Number 1). Both runs were with an unpressurized running-type release of Type B jet fuel and with the controlled cooling air shutoff (minimum ventilation).

The three occurrences of ignition under Category VI test conditions were all violent explosions (Scale Number 2). The three runs involved pressurized spray releases of Type A jet fuel with cooling air ventilation rates ranging from 21 to 40 compartmental changes per minute.

A comparison was made between the scale used to classify the explosive ignitions and the rate of compartmental air temperature rise following ignition as measured by high response thermocouples. The results showed close agreement between the two measurements with temperatures increasing at rates ranging from 7000°F per second for Scale Number 1 ignitions to 3000°F per second for Scale Number 7 ignitions.

Two test runs were conducted to determine potential hazards associated with separating ignition sources from flammable fluid systems without isolation. The first run was conducted with the cowl door portion of the engine fireseal removed and with a simulated spray leak of Type B jet fuel at a 9:00 o'clock position in the nacelle forward area (Nacelle Station Number 145) and a spark ignitor at a 6:00 o'clock position in the aft compartment (Nacelle Station Number 190). Ignition occurred as the engine power was reduced from maximum cruise to idle. Fuel had been released with the spark ignitor energized for approximately 5-1/2 minutes at a rate of 1.0 gpm prior to ignition. The two blowout panels which had been built into the forward end of each of the side cowl doors were blown out by the explosive force of the ignition. Over-pressures ranging from 1 to 4-1/2 psi were recorded in the nacelle around the diffuser case. A study of the thermocouple responses to the temperature waves indicated that the flame propagated around the engine from the ignition source at velocities ranging from 30 to 75 fps; forward toward the left blowout panels at velocities up to 100 fps; and forward toward the right blowout panel at velocities approaching 175 fps.

The second test run was conducted with the engine fireseal installed and the nacelle in the production configuration without blowout panels. The simulated fuel leak and ignition locations were the same as for the first test run. Ignition occurred while the test engine was still at maximum cruise power approximately 15 seconds after initiating the 1.0-gpm fuel release and energizing the ignitor. The fire traveled through the annular opening in the fireseal and spread throughout the forward compartment. The explosive force opened the right side cowl door such that the seam remained open approximately one-fourth of an inch at the forward hinge point. Over-pressures ranging from 2-1/4 to 4-3/4 psi were measured around the diffuser case. The thermocouple response study of this run indicated that although the fireseal slowed the flame front down, the fire had entered the forward compartment at a 9:00 o'clock location within 0.2 second after ignition. The flame propagation rate ranged from 20 to 30 fps in the aft compartment to 50 to 125 fps in the forward compartment.

Fire Characteristics

Introduction: Engineering data on the characteristics and the environmental effects of nacelle fires are considered essential to determining the requirements for and adequacy of fire protection for an aircraft engine installation. This is particularly important, from a design point of view, for incorporating fire protection provisions which will assure timely detection and adequate resistance to fires. A phase of the test program was therefore established to define the characteristics of nacelle fires and to provide information on the effects of the fuel leak, flight conditions, and burning duration on the fire characteristics. The specific objectives of this investigation were to determine the temperature environment, radiation levels, and flame patterns present during nacelle fires as a function of the size and location of the fuel leak, the type fuel, the flight speed and engine power, and the duration of the fire.

The investigation was limited to environmental conditions present on the test engine installation in a production configuration and to the wind tunnel simulated flight capabilities. The investigation was further limited to the following: (1) simulated spray-type fuel leaks; (2) jet fuels, Type A and Type B; (3) simulated failures external to the engine case in which the engine installation was intact at ignition; and (4) radiation measurements at four locations in the nacelle compressor and accessory section by sensors sensitive to visible radiation.

Test Equipment and Procedures: A fuel system independent of the test engine was used throughout this study to spray jet fuel into the nacelle. Nozzles with low to high line pressures were used to provide patterns ranging from a relatively coarse full-cone spray to a fine spray. A spark discharge (transformer output rated at 10,000 volts and 23 milliamperes) was used to ignite the fuel spray.

The basic procedure normally used in each test consisted of the following sequence of events:

1. Facility Mach number and engine power stabilized.

2. Spark ignitor activated.

3. Fuel spray release initiated (approximately 5 seconds after Event 2).

4. Spark ignitor deactivated and fuel release discontinued.

5. Test engine retarded to idle.

6. Fire extinguishant discharged (secondary CO_2 system) if required.

With the exception of the fuel release duration, the time increments between events were maintained essentially the same throughout this phase of testing. The fuel release duration varied from 10 to 160 seconds. The Fire Characteristics Investigation was conducted under steady-state simulated flight conditions with the test engine power and tunnel airflow maintained constant during the fuel release period.

The nacelle temperature environment and flame patterns were determined from thermocouple measurements. The radiation environment in the nacelle compressor and accessory section was measured by flame sensors sensitive to the relative intensity of radiation produced in the upper and lower half of the visible wave lengths range. Prior to installation on the test engine, the sensors were calibrated against the 5-inch-diameter pan fire used in the response time test of Technical Standard Order (TSO) C-79 (Reference 2).

Appendix V of this report contains detailed information on the fuel release system, nacelle thermocouples, radiation sensors, and test procedures and conditions for the Fire Characteristics test runs.

Effect of Fuel Release Rate on Nacelle Fires: Tests were conducted with Type B jet fuel released and spark ignited at rates from 0.1 to 1.5 gpm at the seven nacelle locations described in Table III. The percentages of free air volume in the compressor and accessory section with air temperatures above 500°F, 1000°F, and 1500°F are plotted in Figures 14 and 15 as a function of the fuel release rate for typical fire locations. The percentages were calculated from compartmental isothermal patterns of stabilized air temperatures (temperature level following the initial rapid rise as discussed on page 36) during the fires. Defining the size and intensity of the fire as the volumes where air temperatures were above 500°F and 1500°F, respectively, the maximum intensity fires occurred at lower fuel release rates than the maximum size fires. The maximum intensity fire also occurred at fuel release rates less than 1.0 gpm. The 1.0-gpm fire was, therefore, considered to be burning rich. The fires at Location 5 are shown to have affected a greater nacelle volume than the fires at Location 3. This was due to the larger heat loss through the drain vent for the Location 3 fires.

The effect of the rate at which fuel was released in the nacelle compressor and accessory section on the temperature environment aft of the engine fireseal is shown in Figure 16. Under these conditions, the fire size and intensity in the nacelle combustion and turbine section continued to increase with fuel release rate to the maximum tested rate of 1.5 gpm.

Effect of Simulated Flight Conditions on Nacelle Fires: The effects of a fire on the temperature environment in the nacelle compressor and accessory section are shown in Figures 17 to 19, inclusive, as a function of the facility Mach number and engine power setting. The

TABLE III

NACELLE FUEL RELEASE LOCATIONS

Location Number	Description of Nozzle Locations	Nacelle Station Number	Clock Position
1	Above fuel oil cooler, spray directed toward cowl panel	165	2:00
2	Aft main fuel inlet line, spray directed aft onto diffuser case	155	10:30
3	Side of pressurizing and dump valve, spray directed aft toward engine fireseal and drain vent	165	6:00
4	Below main fuel filter, spray directed aft and onto cowl panel	135	7:00
5	Above bleed valve control, spray directed onto engine case	145	9:00
6	Aft of engine fireseal, above drain tank, spray directed aft and onto engine case	180	5:30
7	Aft fuel deicing heater, spray directed vertically upward between cowl panel and engine case	132	8:30

NOTE:
TEST ENGINE AT MAXIMUM CRUISE POWER
JET FUEL TYPE B
FUEL RELEASE DURATION 10 SECONDS

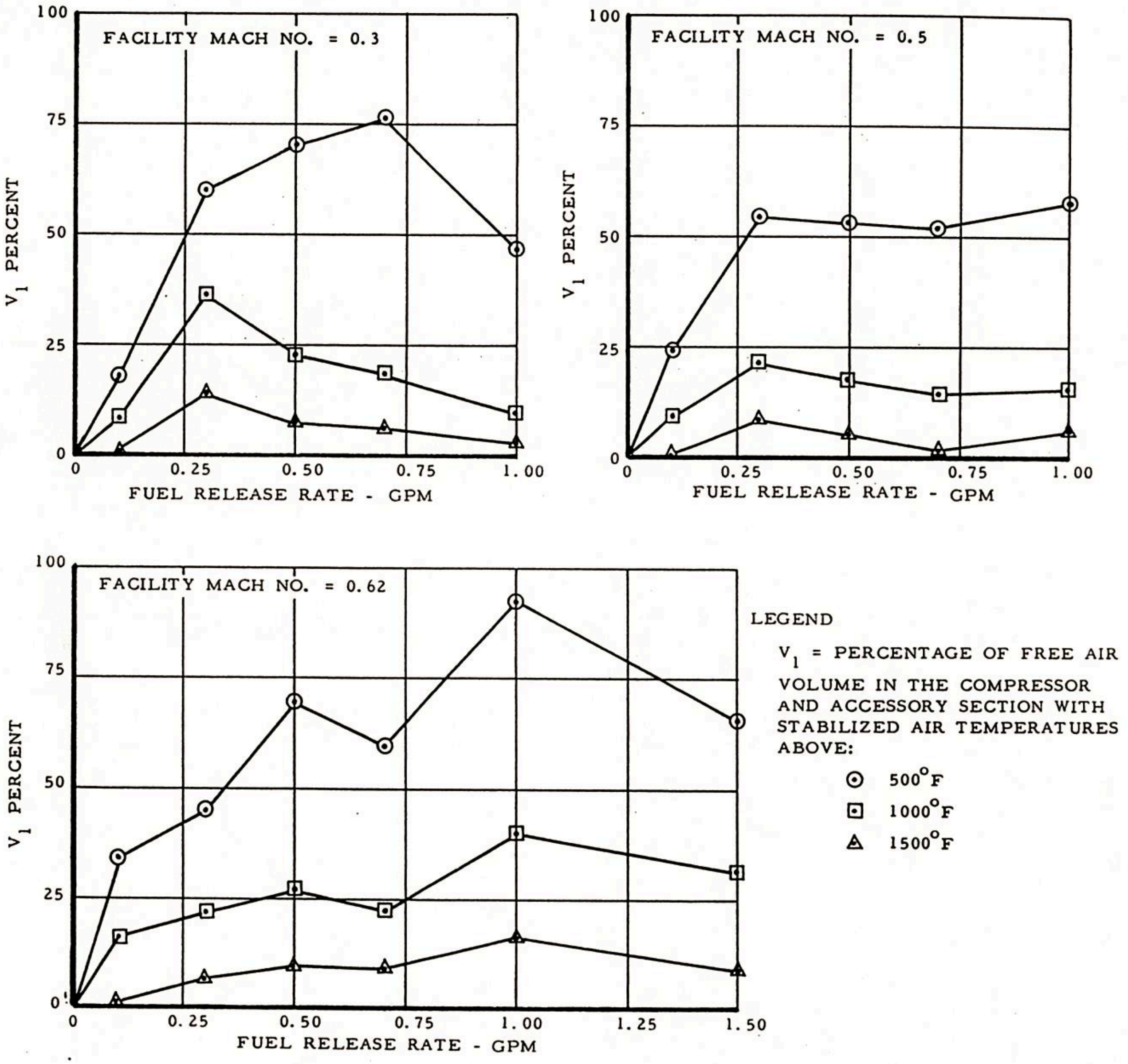
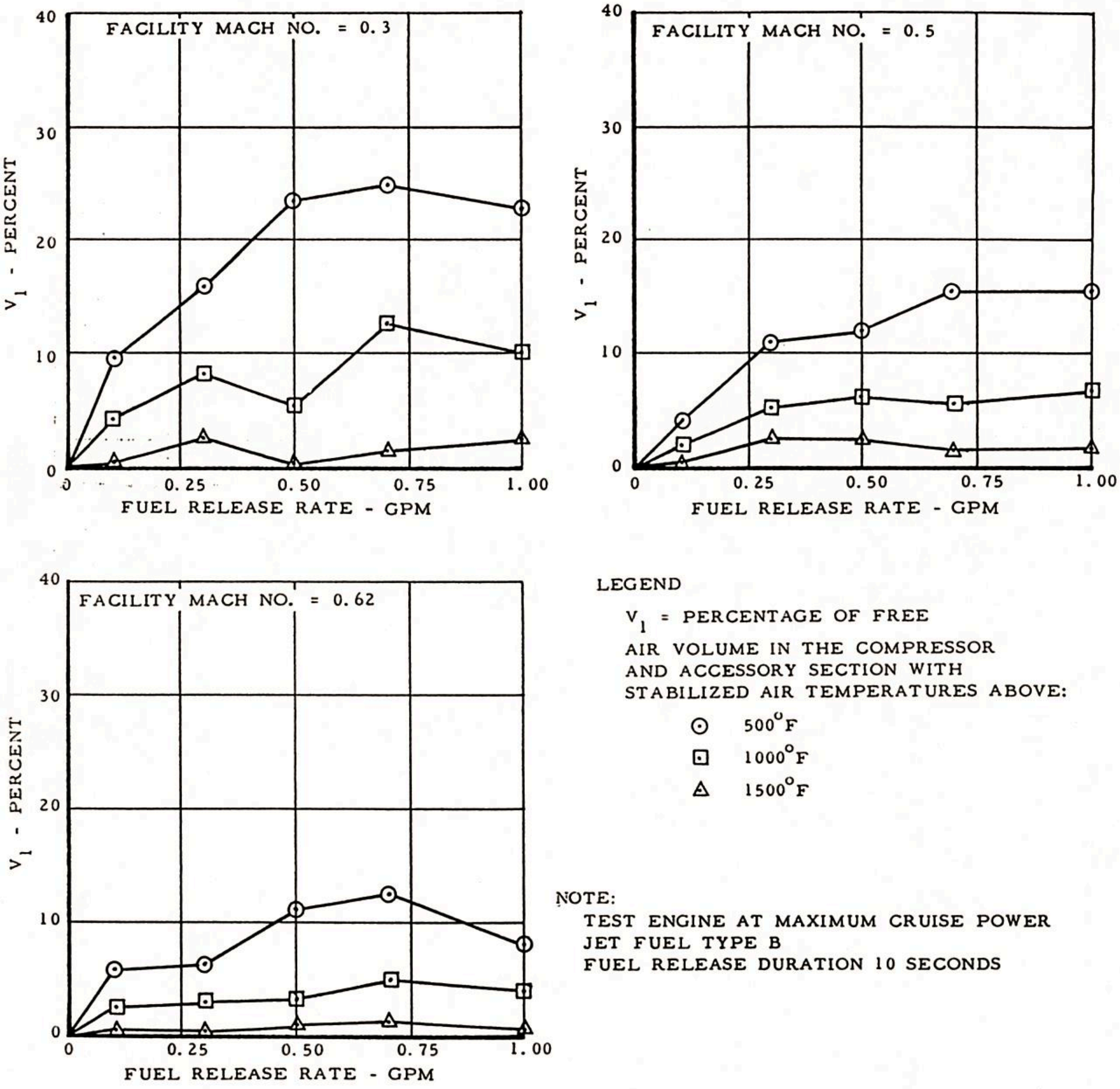


FIG. 14 - EFFECT OF FUEL RELEASE RATE ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 5

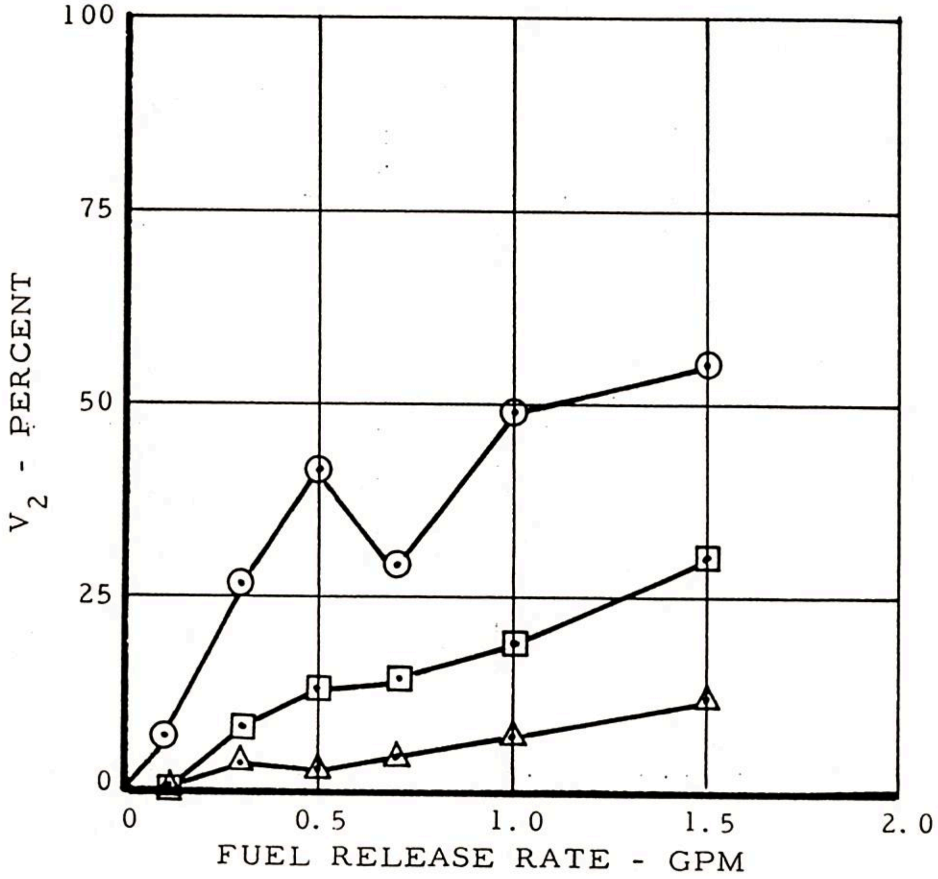


NOTE:
TEST ENGINE AT MAXIMUM CRUISE POWER
JET FUEL TYPE B
FUEL RELEASE DURATION 10 SECONDS

FIG. 15 - EFFECT OF FUEL RELEASE RATE ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 3

NOTE:

FACILITY MACH NO. = 0.62
TEST ENGINE AT MAXIMUM CRUISE POWER
JET FUEL TYPE B
FUEL RELEASE DURATION 10 SECONDS

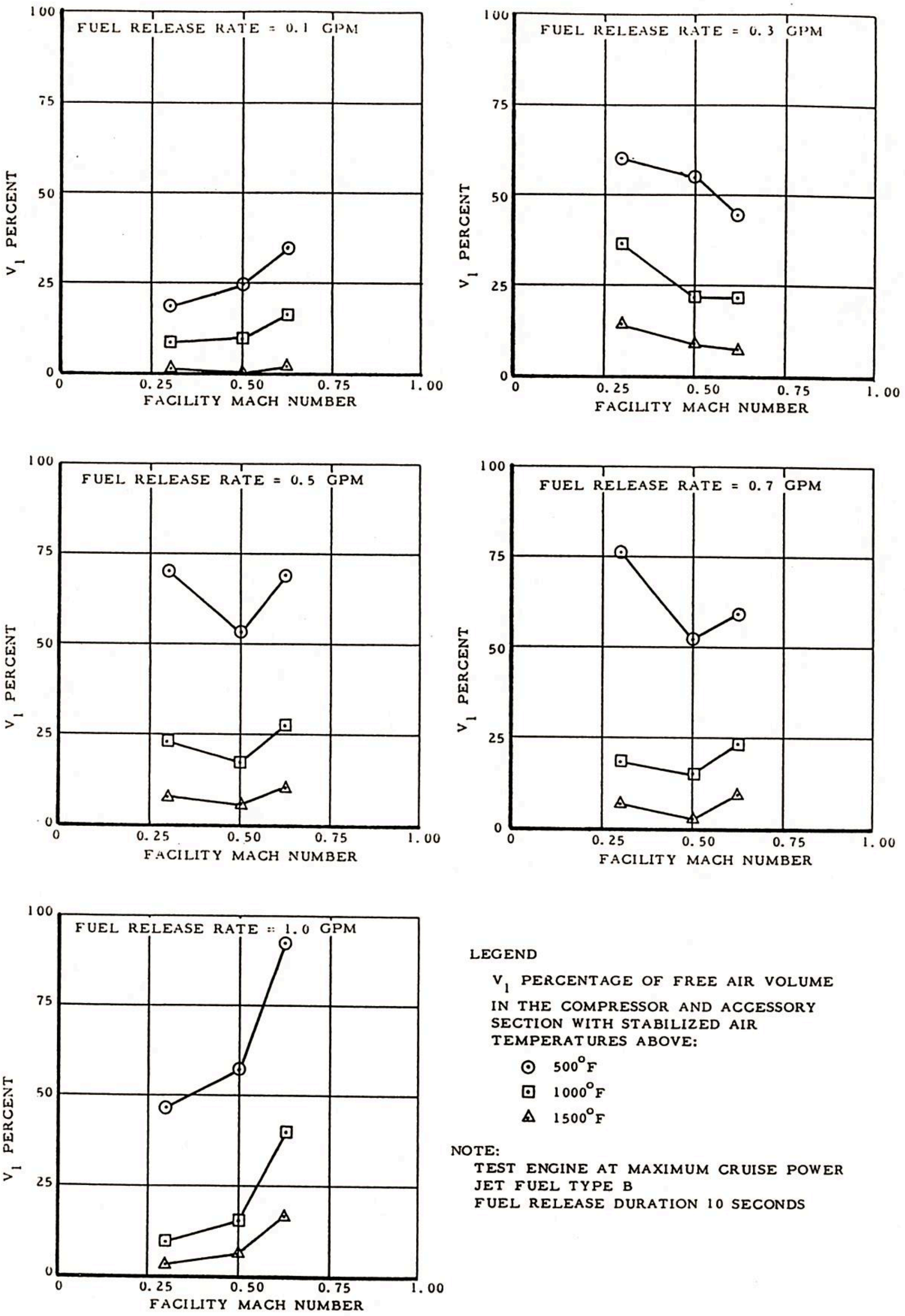


LEGEND

V_2 = PERCENTAGE OF FREE AIR VOLUME IN THE COMBUSTOR AND TURBINE SECTION WITH STABILIZED AIR TEMPERATURES ABOVE:

⊙ 500°F
⊡ 1000°F
△ 1500°F

FIG. 16 - EFFECT OF FUEL RELEASE RATE ON NACELLE ENVIRONMENT (ZONE I) FOR FIRES AT LOCATION 5



NOTE:
TEST ENGINE AT MAXIMUM CRUISE POWER
JET FUEL TYPE B
FUEL RELEASE DURATION 10 SECONDS

FIG. 17 - EFFECT OF MACH NUMBER ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 5 FOR SEVERAL FUEL RELEASE RATES

NOTE:
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

LEGEND

V_1 = PERCENTAGE OF FREE AIR VOLUME IN THE COMPRESSOR AND ACCESSORY SECTION WITH STABILIZED AIR TEMPERATURES ABOVE:

⊙ 500°F
⊡ 1000°F
△ 1500°F

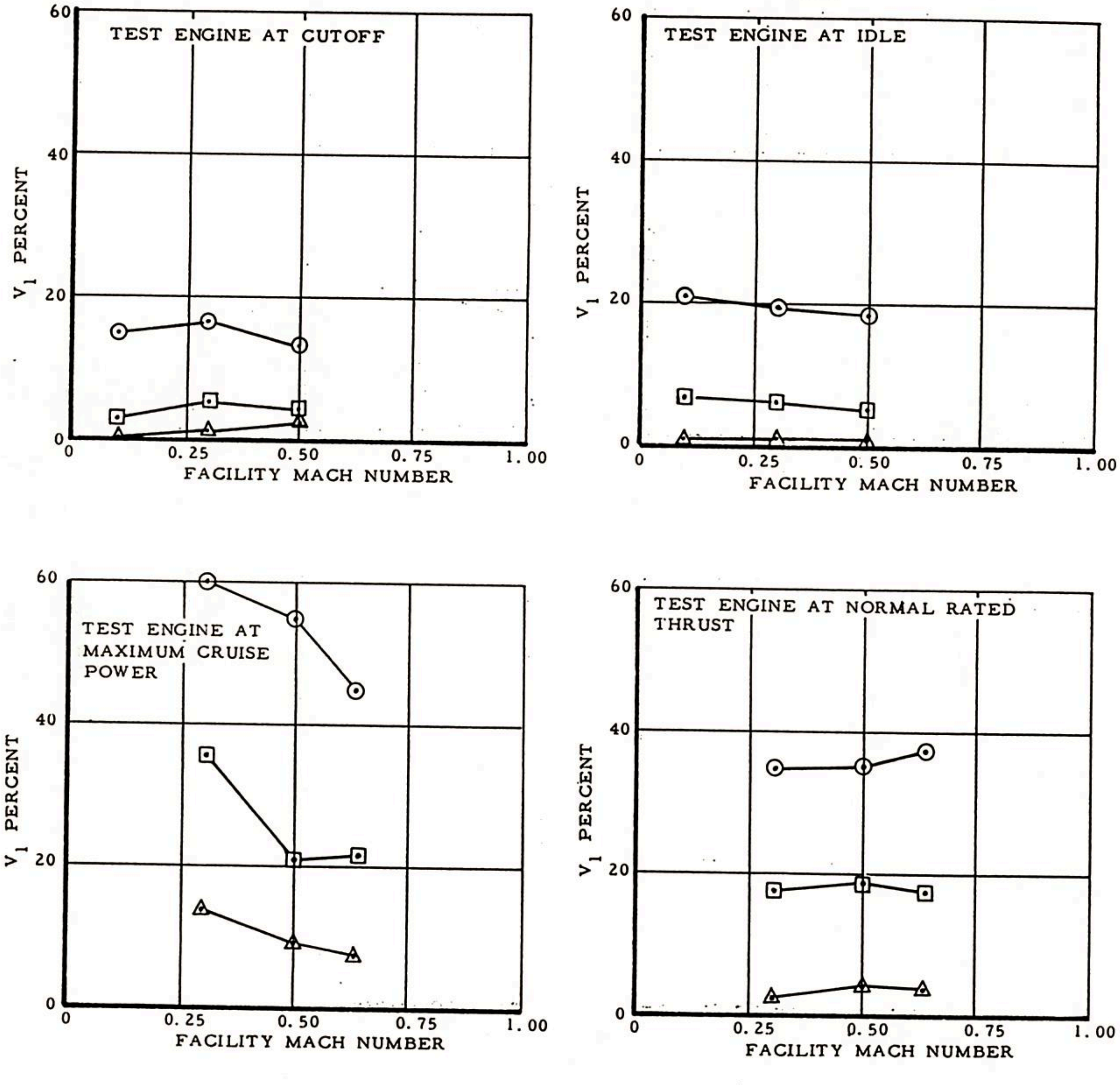


FIG. 18 - EFFECT OF MACH NUMBER ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 5 FOR SEVERAL ENGINE POWER SETTINGS

NOTE:

JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS
TEST ENGINE AT:
CO = CUT OFF (WINDMILLING)
I = IDLE
MC = MAXIMUM CRUISE POWER
NR = NORMAL RATED THRUST
TO = TAKE OFF THRUST

LEGEND

V_1 = PERCENTAGE OF FREE AIR VOLUME IN THE COMPRESSOR AND ACCESSORY SECTION WITH STABILIZED AIR TEMPERATURES ABOVE:

⊙ 500°F
▣ 1000°F
△ 1500°F

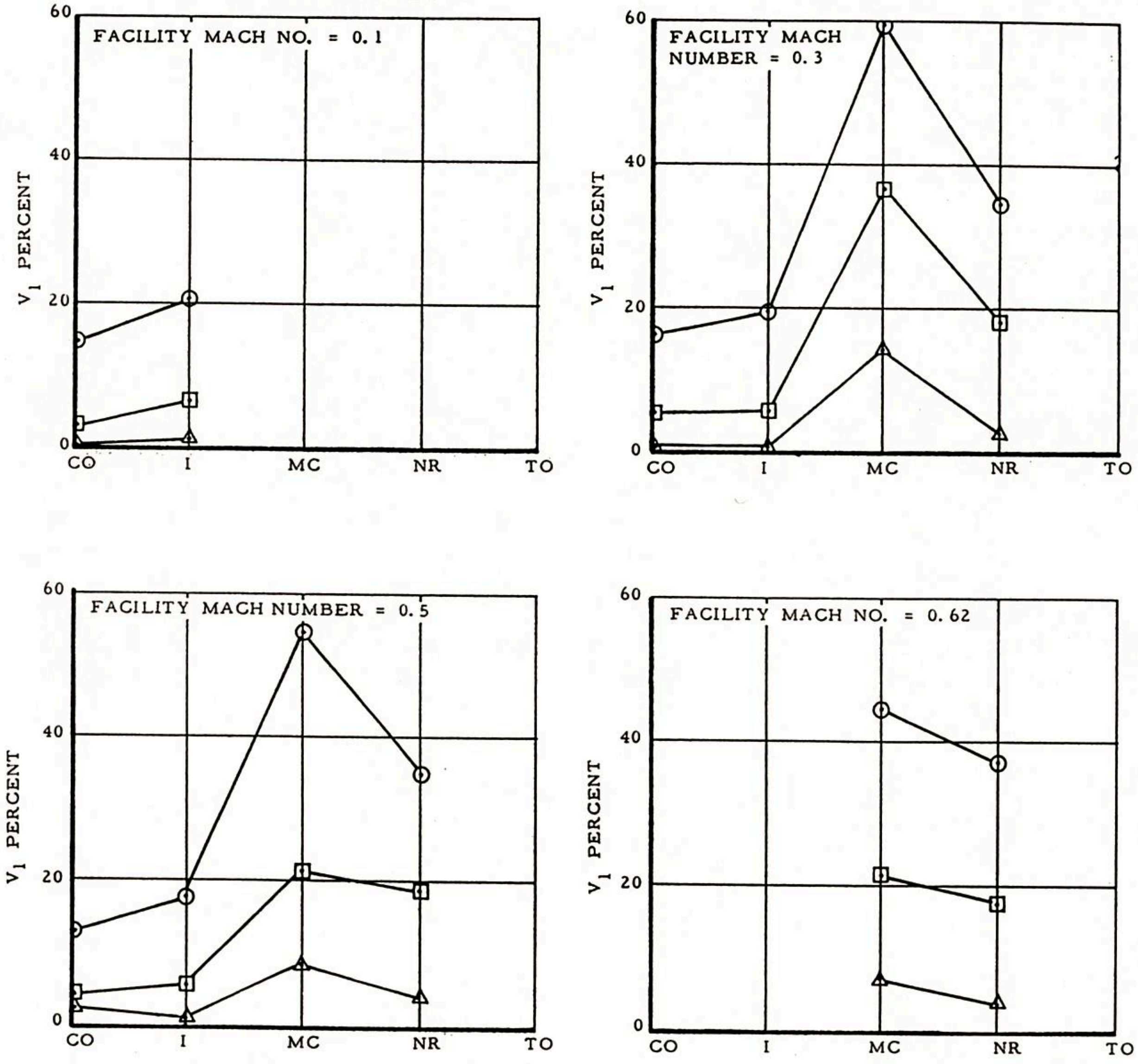


FIG. 19 - EFFECT OF ENGINE POWER SETTING ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 5

facility Mach number had little or no effect on the fire size and intensity for engine power settings of cutoff, idle, and normal rated thrust. However, for maximum cruise engine power, the size and intensity decreased as the Facility Mach Number was increased from 0.3 to 0.62. The size and intensity of the fire was affected by the engine power settings with the maximum occurring during the test runs at maximum cruise rating.

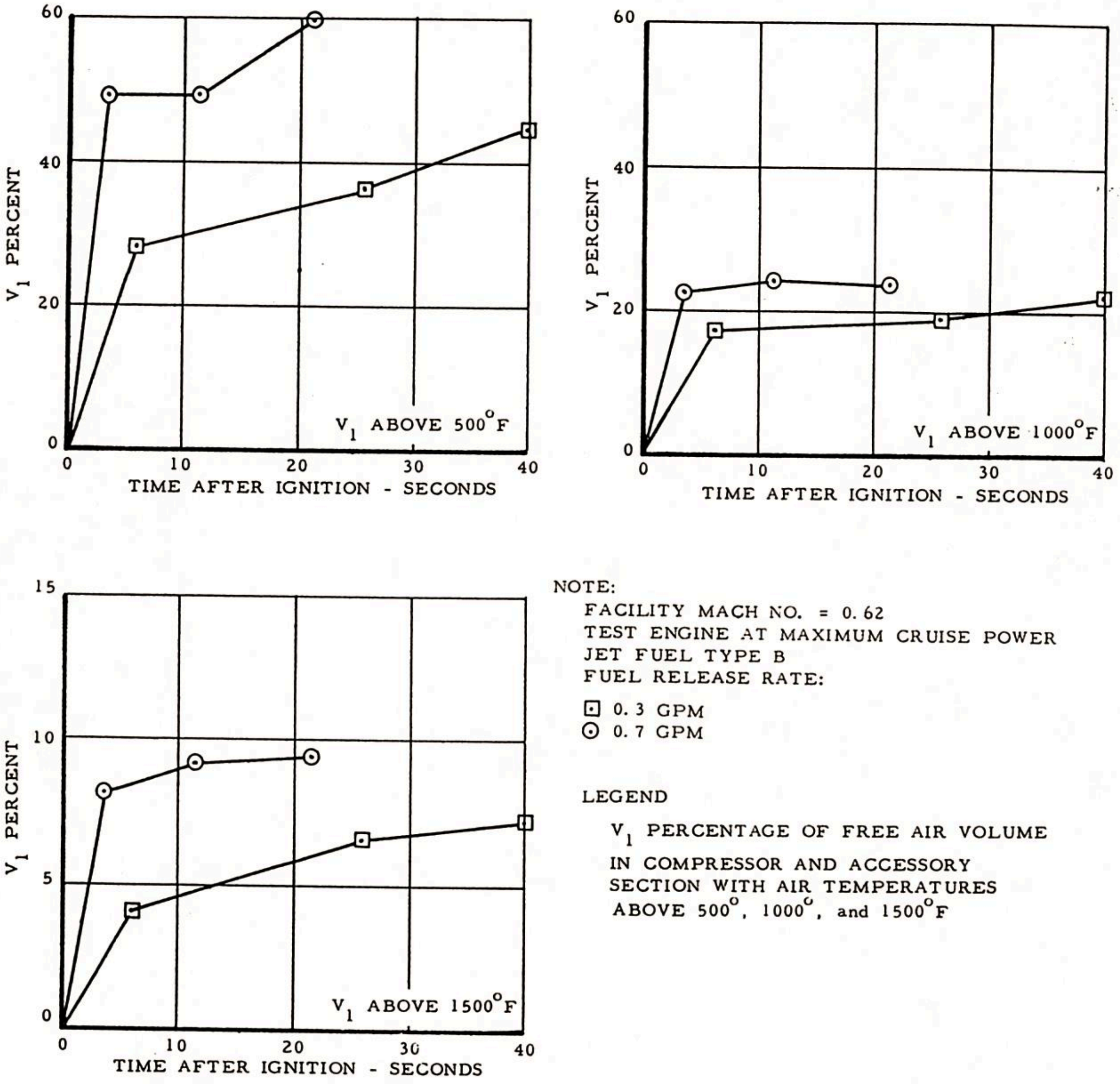
Effects of Fire Duration on Nacelle Environment: As shown in Figure 20, the largest change in the size and intensity of the fire occurred during the first 4 seconds after ignition (the time constant of the air thermocouples was approximately 1-1/2 seconds). The spray-type fuel fires normally resulted in this rapid stabilization of the air temperature environment in the compartment where fuel was released and ignited except when:

1. The fire burnt through seals or seams and allowed additional air into the nacelle.

2. The fuel release location was near an area where the cooling air exited the nacelle.

In the first case, a shift in the stabilized environment occurred as the air leakage changed. In the second case, the majority of heat was lost with the cooling air and only a small amount of heat remained within the nacelle and the temperature environment increased at a much slower rate.

Effect of Fuel Release Location on Nacelle Fires: Typical temperature rises in the two nacelle sections are presented in Figures 21 to 27, inclusive, for 10-second duration fires resulting from releasing fuel at each of the seven locations. The fires originating in the nacelle compressor and accessory section are shown to have spread toward the three cooling air exits (Appendix III). Fires resulting from releasing fuel at Locations 2, 5, and 7 tended to spread toward the chimney into the forward strut fairing and toward the openings in the vertical engine fireseal above the engine. The fires originating at Location 1 spread upward toward the holes in the top of the engine fireseal. Sufficient heat passed through the engine fireseal during the above 10-second fires at Locations 5 and 7 to increase the air temperature above the engine in the aft compartment by more than 200°F. Fires resulting from releasing fuel at Locations 3 and 4 spread toward the drain vent area. The fire originating in the combustor and turbine section (Location 6) is shown to have spread aft and upward around the engine.



NOTE:

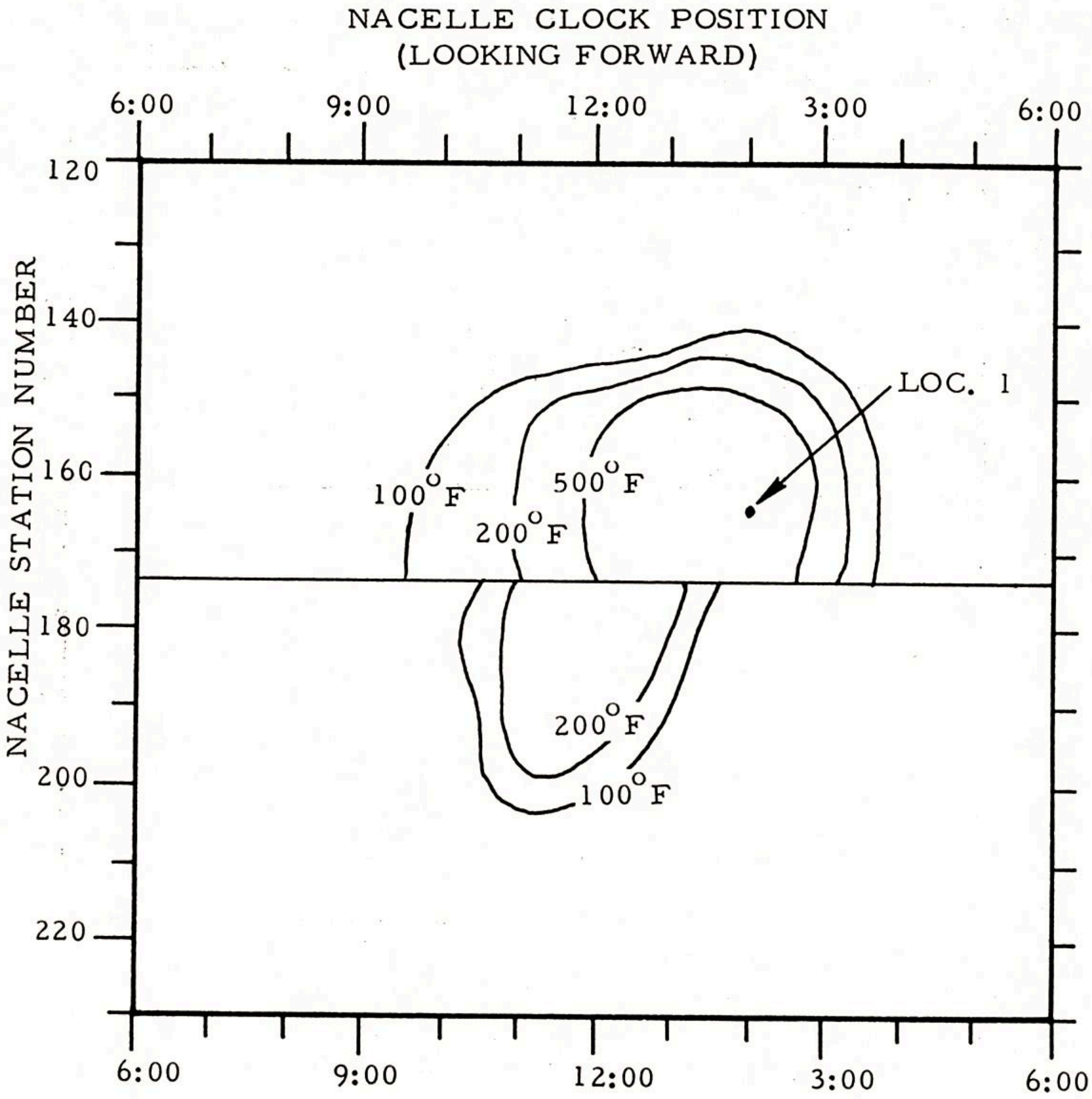
FACILITY MACH NO. = 0.62
TEST ENGINE AT MAXIMUM CRUISE POWER
JET FUEL TYPE B
FUEL RELEASE RATE:

⊡ 0.3 GPM
⊙ 0.7 GPM

LEGEND

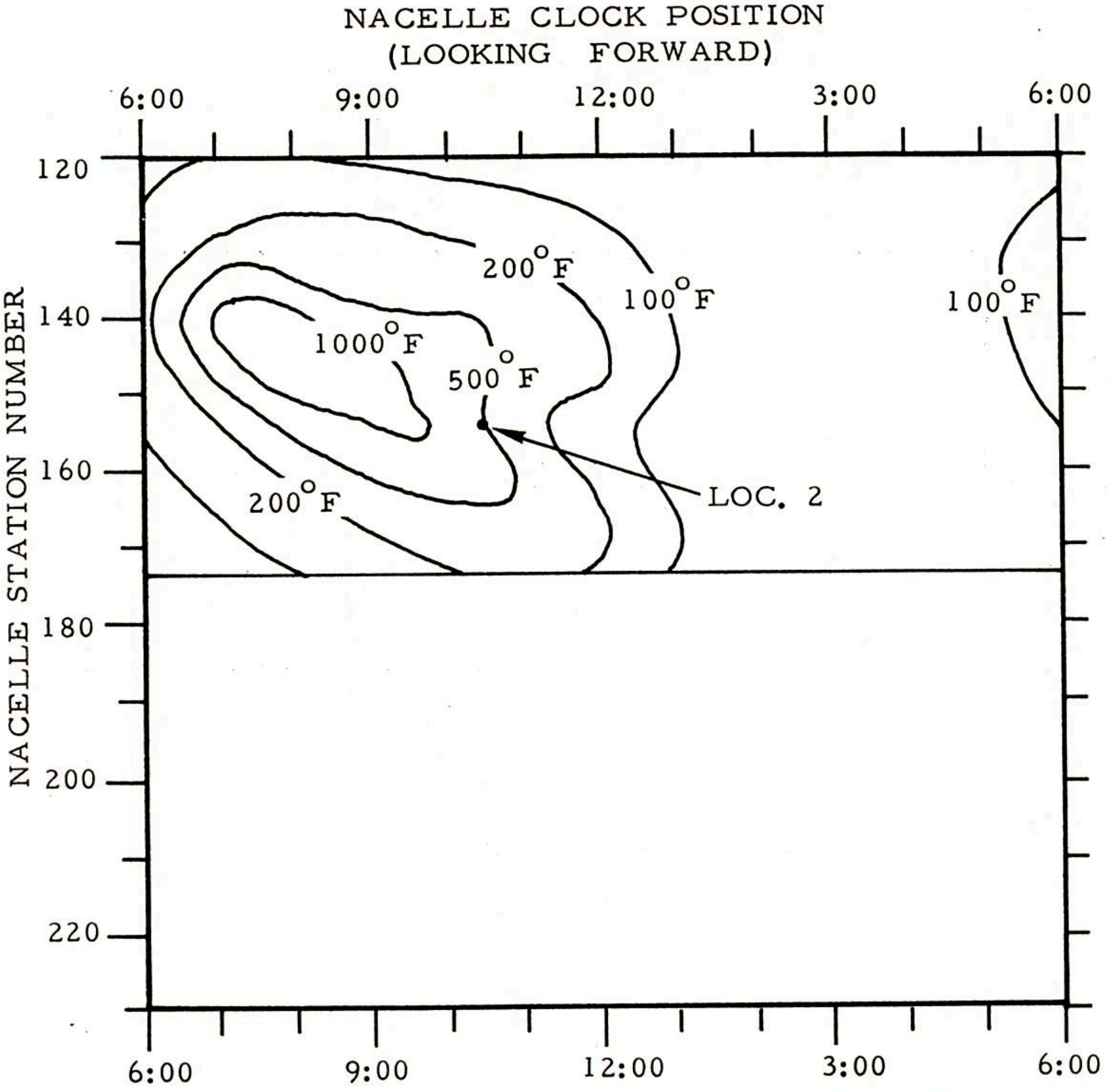
V_1 PERCENTAGE OF FREE AIR VOLUME IN COMPRESSOR AND ACCESSORY SECTION WITH AIR TEMPERATURES ABOVE 500°, 1000°, and 1500°F

FIG. 20 - EFFECT OF FIRE DURATION ON NACELLE ENVIRONMENT (ZONE II) FOR FIRES AT LOCATION 5



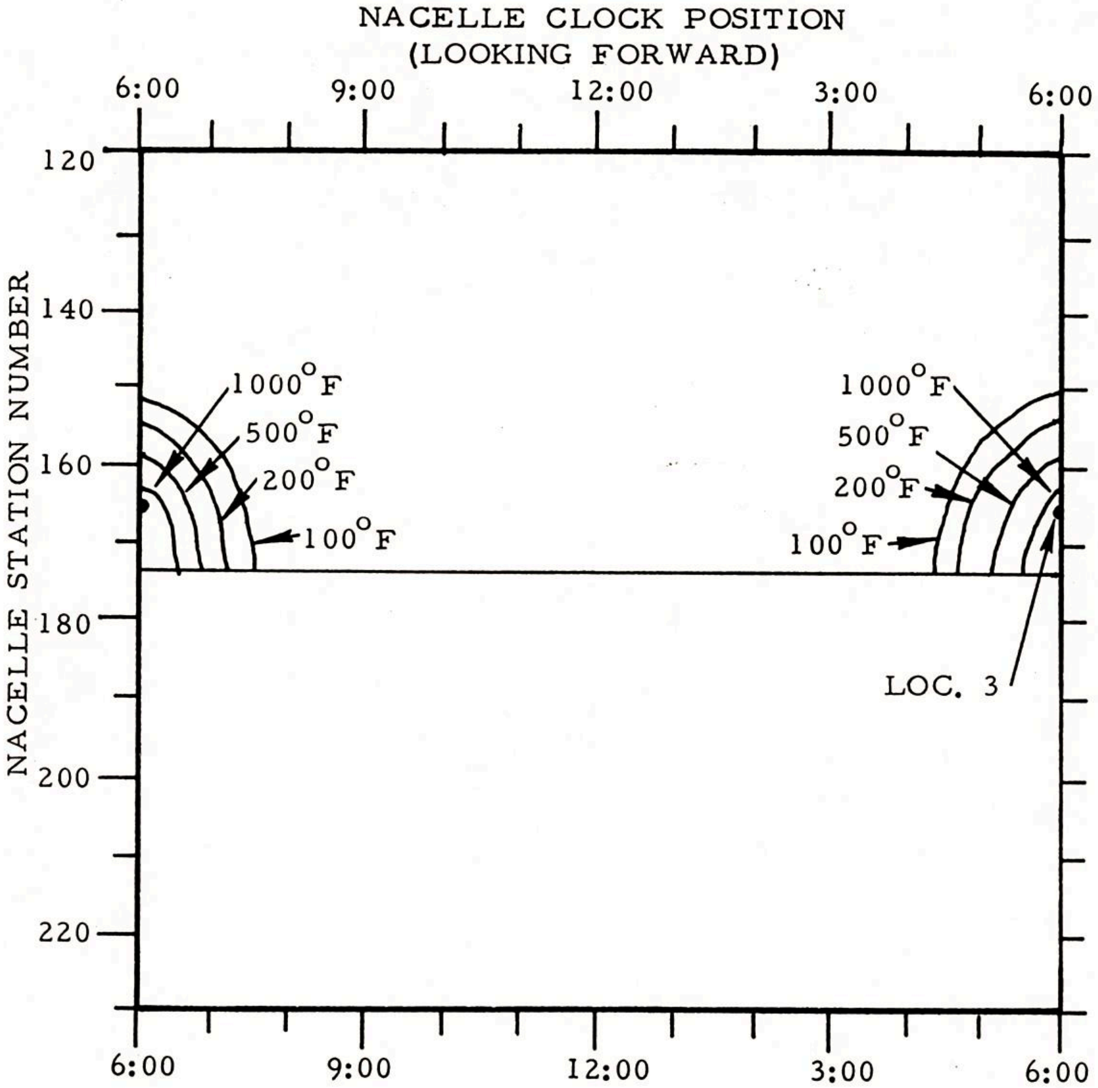
NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 21 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 1



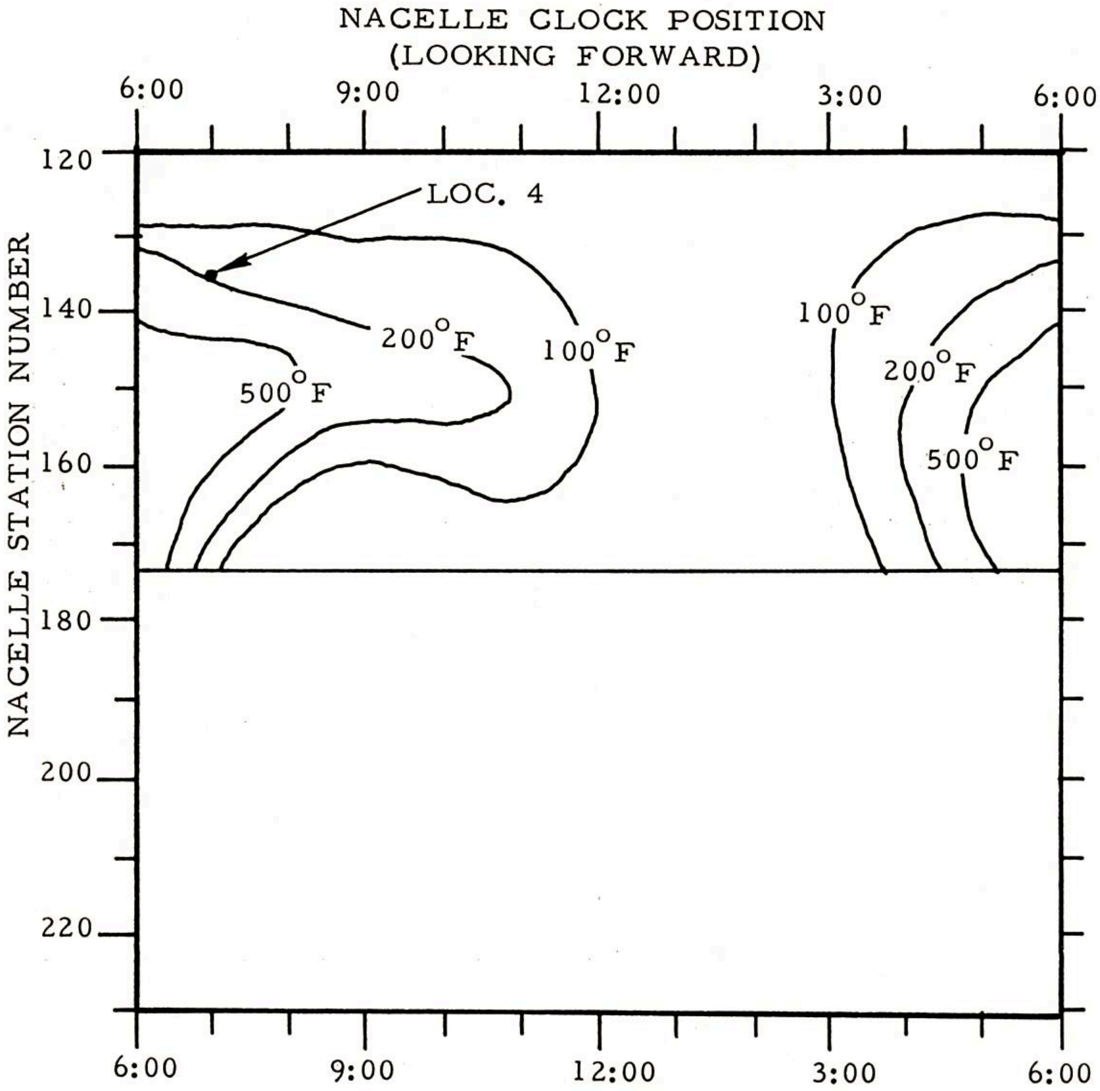
NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 22 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 2



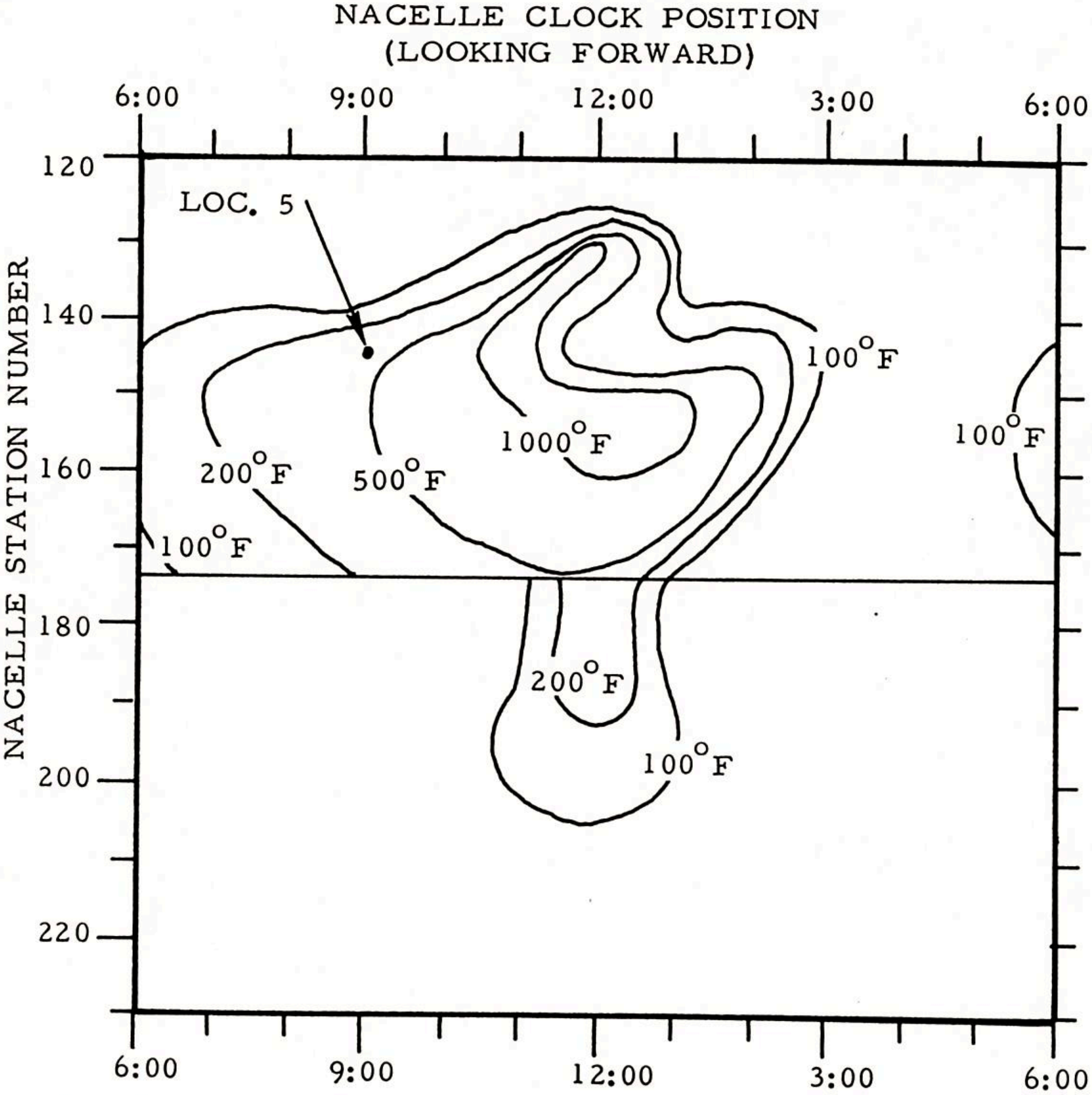
NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 23 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 3



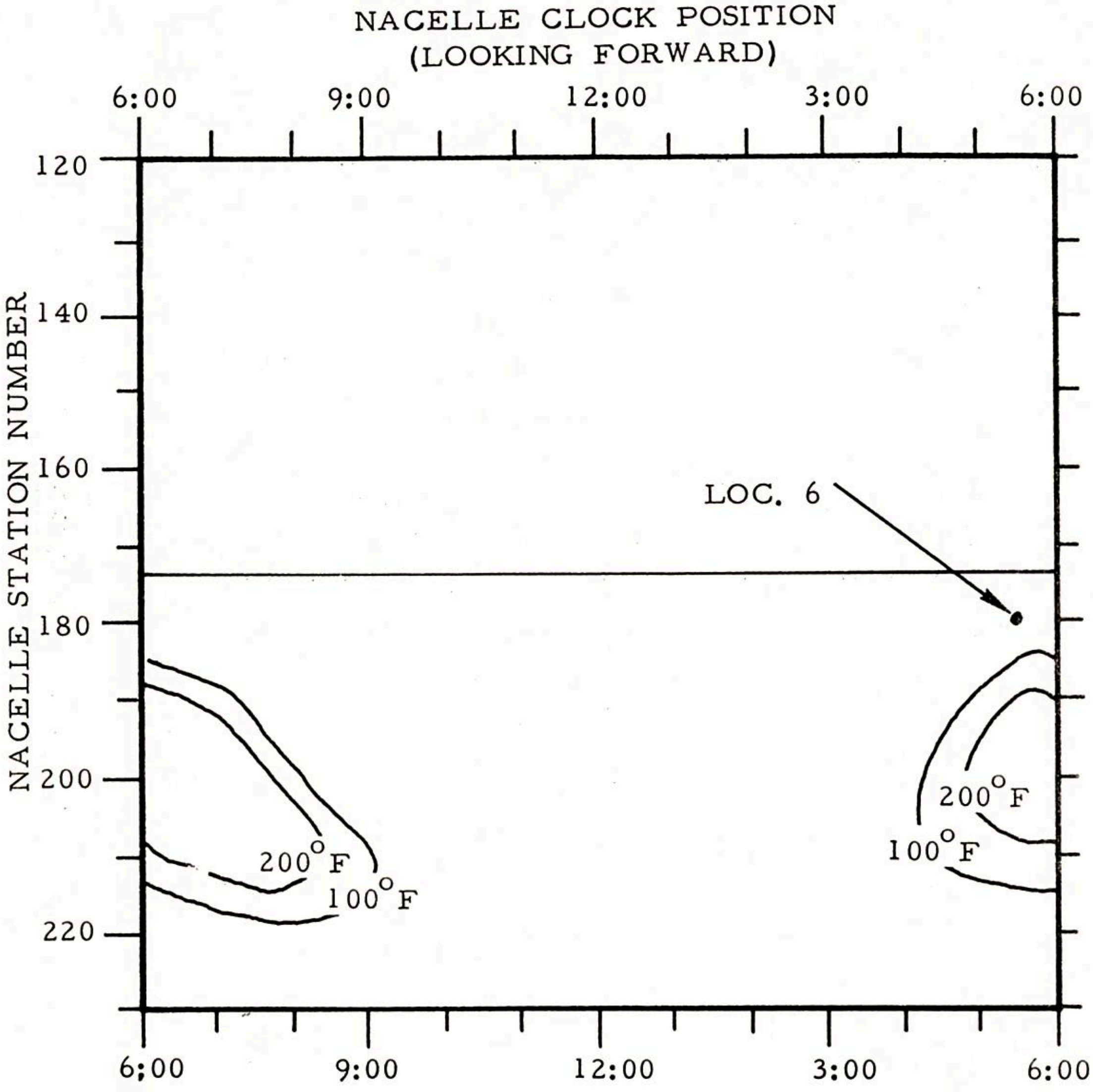
NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 24 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 4



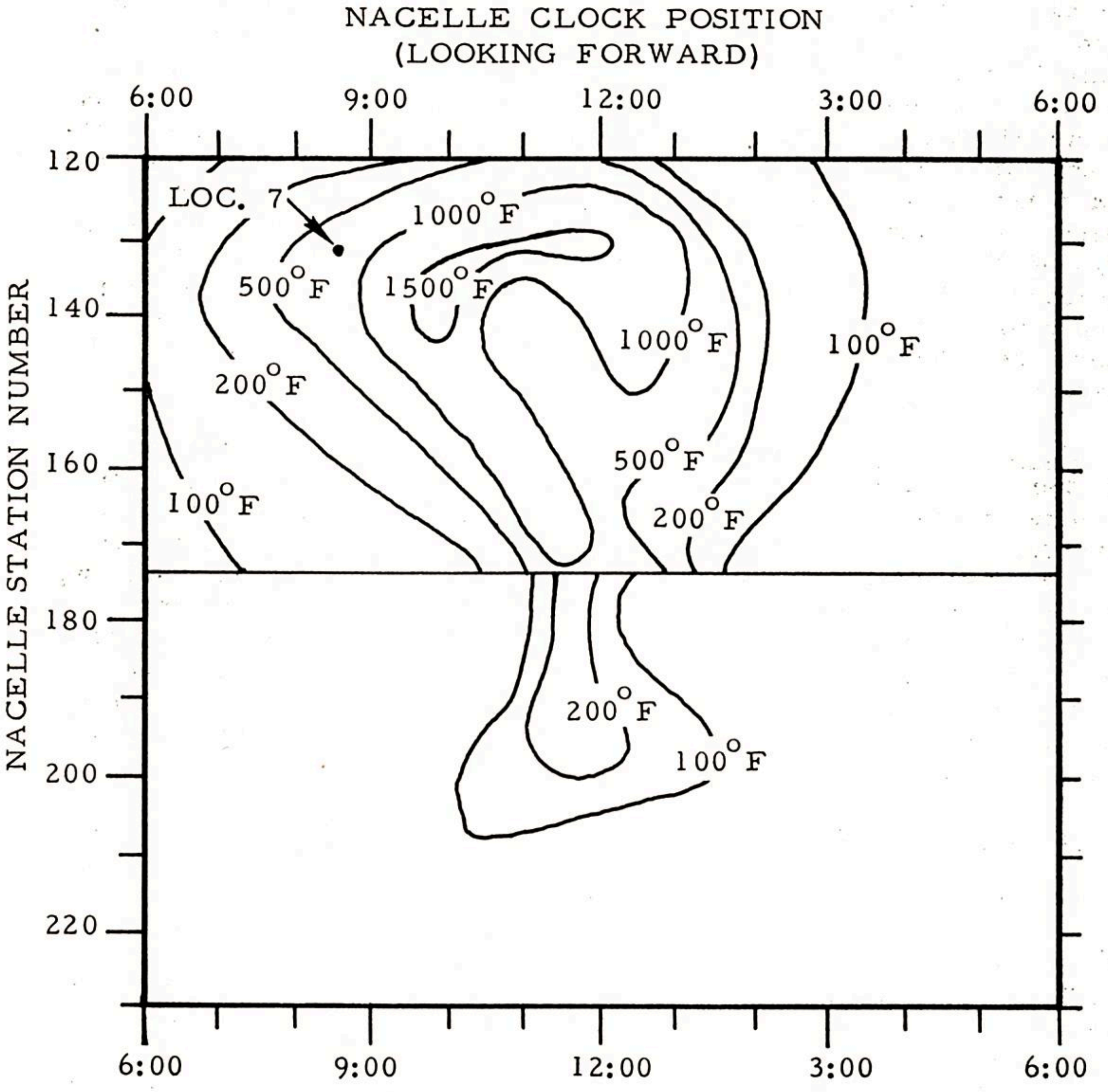
NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 25 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 5



NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 26 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 6



NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NO. = 0.62
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM
FUEL RELEASE DURATION 10 SECONDS

FIG. 27 - STABILIZED AIR TEMPERATURE RISE FOR A FIRE AT LOCATION 7

Fire Intensity: Approximately 100 of the test runs conducted under this phase were studied from the standpoint of the maximum recorded nacelle air temperature during the fire. The test conditions included a range of Facility Mach Numbers from 0.1 to 0.62, engine power settings to normal rated thrust, Type B jet fuel spray released at rates from 0.1 to 1.5 gpm, fuel release durations from 10 to 160 seconds, and release Locations 1 to 7. The arithmetic average of the maximum stabilized air temperature recorded during each of the 100 test fires was approximately 1500°F. Because of the spacing between thermocouples, the maximum temperature was not always recorded and therefore the true average maximum was higher than 1500°F. The maximum stabilized air temperature measured during any one run varied from a low of 900°F to a high of 2100°F. The volume of the nacelle with stabilized air temperatures above 1700°F was relatively small (no more than two air thermocouples measured temperatures above 1700°F at the same time). Temperatures above 1800°F were not measured by more than one thermocouple at any time during any one run in this test series.

Effect of the Type of Jet Fuel on Nacelle Fires: Comparative tests were conducted to determine the relative effects of Type A and Type B jet fuels on the size and intensity of the fire. A comparison of the resulting air temperature patterns and levels was made between identical test runs with each fuel. The test conditions and resulting temperatures are summarized in Table IV. The isothermal patterns produced by the two fuels were similar for each of the three release rates tested. The temperature measurements indicate that the size and intensity of the Type A jet fuel fire was somewhat greater at the higher release rates. However, this difference was relatively small and is considered to be of little significance.

Nacelle Radiation Environment During Engine Fires: The results of measurements taken of the relative amount of radiation produced by nacelle fires are summarized in Table V with typical values shown in Figures 28 and 29. The radiation measurement at each of the four sensor locations under the fan air duct is presented as equivalent to the TSO pan fire at a given distance from the flame sensor (zero degree surveillance angle). As discussed in Appendix V, the sensors are affected by both the intensity and the wave length of the radiation. The sensor output signal can be increased and the equivalent pan fire distance decreased by either of the following:

1. Increasing the fuel to air ratio to produce more radiation with wave lengths in the high visible range (producing a rich orange-color flame).

2. Decreasing the distance between the sensor and the fire (increased intensity at the sensor).

TABLE IV

EFFECTS OF JET FUEL TYPE ON NACELLE FIRES

0.5 Facility Mach Number
Test Engine @ Maximum Cruise Power
Fuel Release Duration 10 seconds

Nozzle Location Number 5
Nozzle Type A (see Appendix IV, Table XIV)

	Nacelle Air Temperature Measurements					
	Test Condition I Fuel Release Rate 0.3 gpm		Test Condition II Fuel Release Rate 0.7 gpm		Test Condition III Fuel Release Rate 1.5 gpm	
	Jet Fuel		Jet Fuel		Jet Fuel	
Thermocouple	Type A (°F)	Type B (°F)	Type A (°F)	Type B (°F)	Type A (°F)	Type B (°F)
1	410	390	720	600	750	570
2	205	205	215	230	565	345
3	1790	1790	1120	780	410	380
4	970	940	630	550	470	410
5	140	135	140	180	170	210
6	990	915	1470	1380	1360	1080
7	150	140	140	160	160	160
8	620	600	1400	1300	650	560
9	670	620	505	380	535	520
10	670	590	920	900	1240	1000
11	345	305	315	355	710	740
12	460	430	595	680	460	460
13	755	860	880	680	840	900
14	1180	1080	1505	1550	1400	1160
15	300	290	490	600	365	370
16	1060	1020	960	760	430	380
17	1190	1200	1055	880	1290	1030
18	150	145	140	165	190	200
19	1150	1300	1270	1080	1455	1420
20	730	720	985	760	460	360
21	420	365	630	1075	---	---
22	500	590	600	540	620	600
23	230	215	220	260	260	280
24	760	800	600	535	490	455
25	210	210	200	375	230	410
26	265	260	370	455	895	1390
Average	628	620	695	622	656	616

TABLE V

NACELLE RADIATION ENVIRONMENT DURING ENGINE FIRES

Nozzle Location Number	Number Test Runs	Range of Sensor Radiation Measurements (Equivalent Distance of Five-Inch Pan Fire from Sensor)			
		Sensor Number 1 (ft)	Sensor Number 2 (ft)	Sensor Number 3 (ft)	Sensor Number 4 (ft)
1	12	2.3 to 4.7	12.0 to ∞	∞	∞
2	4	∞	∞	7.5 to 11.4	∞
3	21	∞	∞	10.0 to ∞	∞
4	4	∞	∞	∞	2.0 to 4.1
5	58	3.4 to ∞	13.2 to ∞	0.0 to 11.9	2.7 to ∞
6	5	∞	∞	∞	∞
7	5	6.3 to ∞	∞	0.0 to 3.4	∞

Note: Sensors at Nacelle Station Number 127 and 1:00, 4:00, 11:00, and 7:30 o'clock positions for Numbers 1, 2, 3, and 4 sensors respectively.

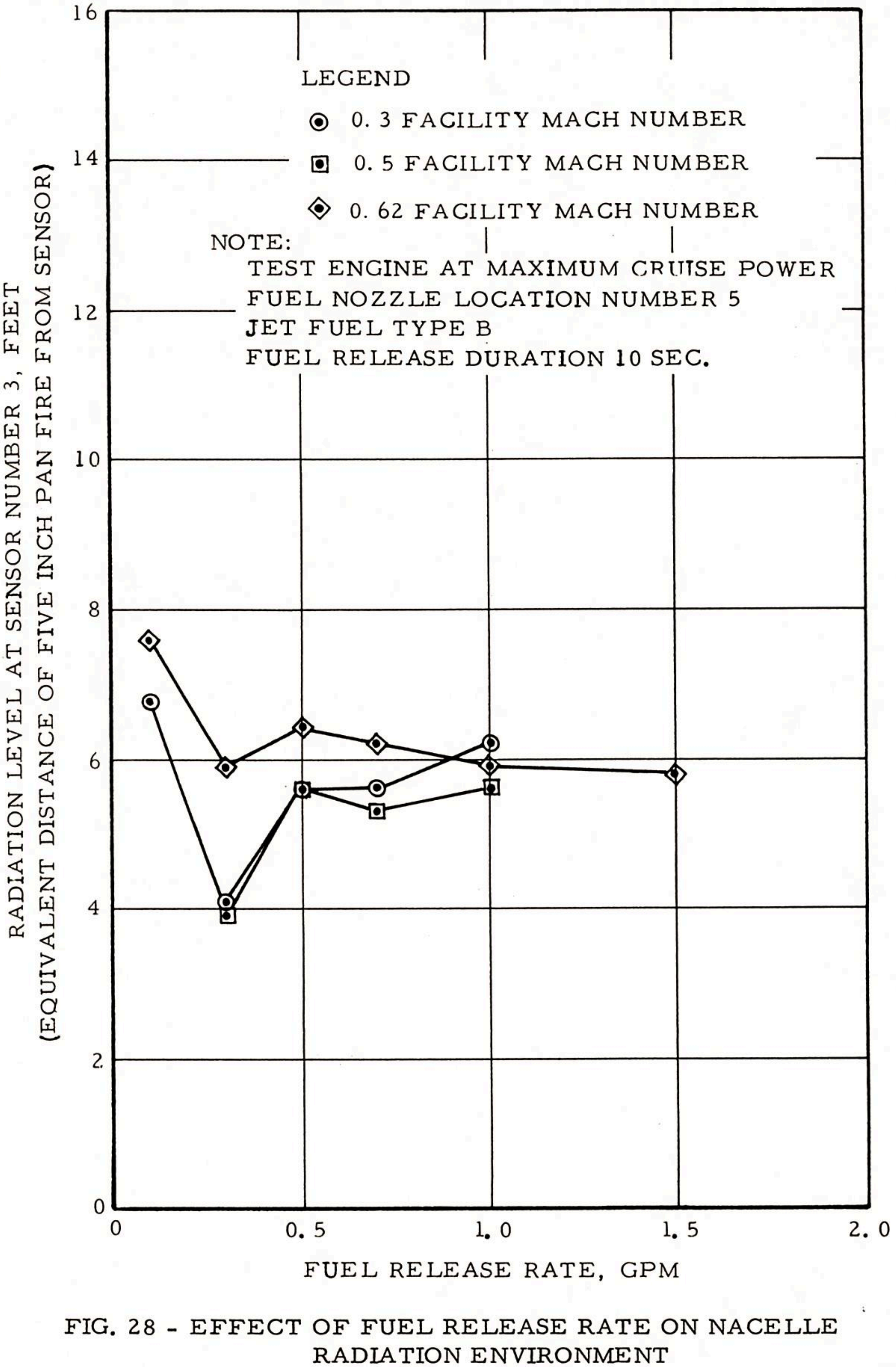


FIG. 28 - EFFECT OF FUEL RELEASE RATE ON NACELLE RADIATION ENVIRONMENT

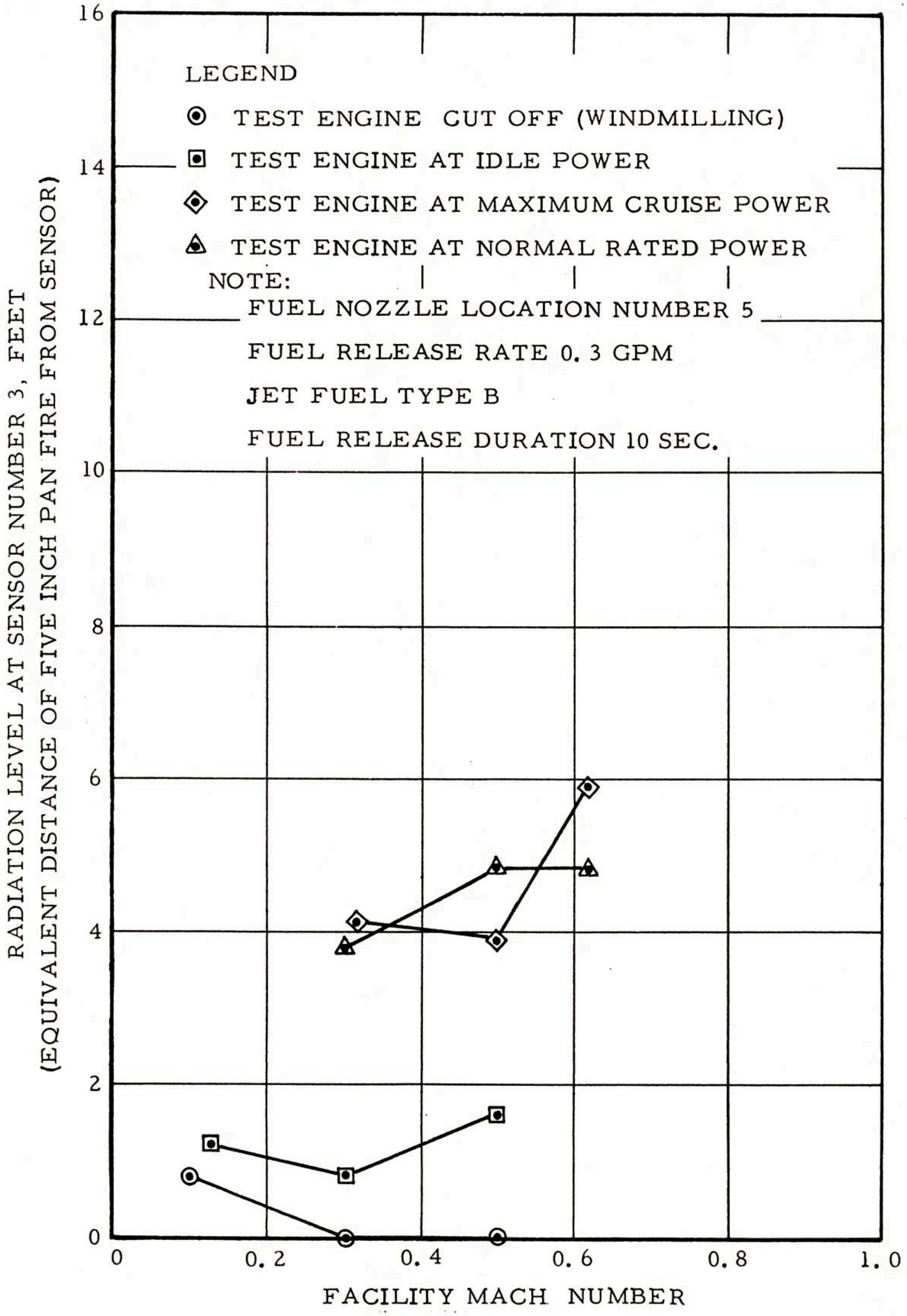


FIG. 29 - EFFECT OF SIMULATED FLIGHT CONDITIONS ON NACELLE RADIATION ENVIRONMENT

When a change in test conditions caused a change in the sensor output, a determination could not be made whether this was primarily due to a change in flame coloration or intensity level. However, since all the test fires in this phase resulted from igniting a spray of jet fuel, the flame coloration would not be expected to vary substantially. Therefore, it is reasoned that the sensor measurements are primarily relative indications of the intensity of radiation produced by fires over a range of test conditions.

Table V lists the measured output range of each sensor during the tests at each of the seven fuel release locations used in this phase. The surveillance area for Sensor Number 2 was severely blocked by the engine oil tank. As a result of this blockage, the radiation level at this sensor was extremely low for fires at all seven fuel release locations. The radiation levels at the four sensors during all but one of the Location 3 fires were below that measurable with the sensors used due to the distance to the flame and to the relatively small flame existing within the nacelle.

As shown in Figures 28 and 29 for a typical sensor, the radiation level was not affected by varying the fuel release rate over the range from 0.1 to 1.5 gpm and the Facility Mach Number over a range from 0.1 to 0.62. An increase in engine power settings, however, tended to increase the radiation level (Figure 29).

Fire and Overheat Detection

Introduction: Means for sensing fire and overheat conditions in aircraft engine nacelles are provided by monitoring the temperature and radiation environment in the nacelles and by direct visual monitoring of the engine installations and engine instruments. In commercial transport aircraft, the most common method of fire detection is provided by temperature sensitive sensors located in potential fire and critical structural areas of the nacelle.

To successfully detect an engine nacelle fire, the detector sensor must be capable of responding immediately to the fire-related nacelle environmental changes or at least before the damage becomes hazardous or the fire extinguisher system or other methods of fire control become ineffective. The maximum time available for detecting a fire is then a function not only of such factors as the fire size and intensity, the flight conditions under which the fire occurs, and the design of the engine installation, but also of an interpretation as to the conditions which constitute a hazard to the safety flight. A definition of the maximum allowable time for detection based on this interpretation was not an intended purpose of this full-scale test program. Therefore, it has been assumed for test purposes that variations in aircraft engine installations may range from a design in which prompt fire detection is required or desired to a design in which a relatively long period of time is available before conditions become hazardous or fire control provisions become inadequate. However, the damage and effects of fires of various durations on the fire control requirements for the test engine installation are presented in the following sections of this report as a relative indication of the time available for detection.

Operational experience by the airlines with detector systems has been such that false fire warnings have become a more prominent problem than in-flight fires without warnings. In an attempt to eliminate some of the false warning problems, fault discrimination provisions have been designed into the systems; parallel, redundant, and abbreviated systems have been put into service; protective housings and mounting supports for the sensing elements have been developed; and the installation of detectors in remote locations has been proposed. An investigation of the reliability of these new system approaches in detecting fires was considered beyond the scope of this test program. However, an investigation of the feasibility of detecting fires by sensors located in areas remote to potential fire locations and the requirements for such systems was considered to be within the scope of the program.

Another objective of the Fire and Overheat Detection Investigation was to provide design criteria and engineering data on the following:

1. Performance and installation requirements for heat and radiation-sensitive-type detectors.

2. Performance characteristics of current detector systems.

3. Indication of fire provided by means other than fire and overheat detector systems.

The Fire and Overheat Detection Investigation was limited to the environmental conditions and engine monitoring systems on the test engine installation and to the wind tunnel simulated flight capabilities except for tests in which the installation was modified to direct the nacelle airflow and provide a single exit for the air. The investigation was further limited to simulated spray-type Jet B fuel leaks and to simulated failures external to the engine case in which the engine installation was intact at ignition.

Test Equipment and Procedures: The Fire and Overheat Detection Investigation was conducted concurrently with the Fire Characteristics Investigation previously discussed, and the majority of information in this phase of the program was obtained during the Fire Characteristic tests. The fuel release and ignition systems, the fuel release locations, and the basic test procedures used throughout this investigation were the same as described in the Fire Characteristics Section of this report.

The performance of fire and overheat detector systems was based on the ability of the systems to provide an alarm signal in response to the various fire situations. The systems consisted of unmodified detector manufacturers' hardware with alarm setting selected by the detector and/or airframe manufacturers. In reviewing the performance of the various systems, care should be taken not to compare systems since no attempt was made to test each system under identical conditions and since the alarm set points for each system were not necessarily at an equivalent level.

In all, there were nine detector systems tested with only one of six heat sensitive continuous-type detector systems installed on the engine at any one time. A radiation sensing detection system and a unit fire detection system were installed and operating during the majority of the Fire and Overheat Detection tests. A second type radiation sensing detection system was operational for 12 of approximately 115 test runs under this phase with the test installation in a production configuration.

One of each of the two types of radiation detection sensors was installed at four locations under the fan air duct viewing horizontally from fore to aft. One of the systems utilized photoconductive cells sensitive to flame coloration and intensity of radiation produced in the visible wave length range. The second system consisted of photoconductive cells sensitive to near infrared radiation and a control unit which responded only to the radiation produced at frequencies corresponding to the flickering characteristics of flames.

Sensing elements of the six continuous-type fire detection systems were located between the engine and the horizontal firewall and extended through the vertical engine fireseal to provide coverage of both the compressor and accessory section and the combustor and turbine section. The sensing elements of five of the systems had the same configuration and were supplied, mounted in perforated tubes, by the detector manufacturers. The sensing element of a sixth system was supplied wrapped around a support tube and positioned above the engine at a different location.

The ninth system consisted of 13 unit-type fire detectors located to provide full coverage of the compressor and accessory section, the combustor and turbine section, and the strut cavity. This system was installed as original equipment on the test powerplant.

All engine systems and sensors installed on the powerplant (up to the normal strut/wing connection point) for monitoring the operation of the engine consisted of hardware supplied by engine and airframe manufacturers as standard equipment for the test powerplant installation. The connection to the control room and the read-out and recording instruments were provided as test hardware.

Appendix VI of this report contains detailed information on the detection systems, detector installations, engine monitoring systems, modifications to the test engine installations, and the individual test procedures and conditions.

Detector System Performance and Installation Requirements: As previously discussed, the heat produced by a fire followed the existing airflow paths and tended to leave the nacelle with the air. Fires originating in the vicinity of a nacelle air exit produced a slow rate of temperature rise throughout the nacelle due to the large amount of heat escaping with the air out the exit.

The fires resulting from releasing and igniting fuel at six locations in the nacelle compressor and accessory section were studied to determine minimum performance and installation requirements for several types of detector systems. The first phase of this study involved detection of the 10-second fires shown in Figures 21 to 25, inclusive, and 27 by continuous-type detector systems which respond to the average temperature over the entire length of the sensing element. The alarm settings required for detection of these six fires were calculated from isothermal plots and are listed in Table VI. These alarm temperatures represent the arithmetic average of the portions of the free air volume in the compressor and accessory compartment with temperatures below 150°F; between 150°F and 200°F, 200°F and 300°F, 300°F and 400°F, 400°F and 500°F, 500°F and 1000°F, 1000°F and 1500°F, and over 1500°F. The average temperature under the same engine power and simulated flight conditions and prior to the fires was approximately 275°F. The alarm temperature of this type detector system could not be set sufficiently low to detect the fires at Locations 1 and 3 because other normal operating conditions gave higher average temperatures.

TABLE VI

AVERAGE AIR TEMPERATURE IN NACELLE COMPRESSOR AND ACCESSORY SECTION FOR SHORT DURATION FIRES

0.62 Facility Mach Number — Fuel Release Duration 10 Seconds
Test Engine at Maximum Cruise Power — Fuel Release Rate 0.3 gpm

Nozzle Location Number	Average Zone II Temperature (°F)
1	330
2	470
3	300
4	415
5	450
7	665

The requirements for continuous-type detector systems (discrete) which respond when a short length of the element is heated to a set point were also studied for the short duration fires at each of the six locations. The minimum necessary coverage for alarm settings of 500°F and 1000°F are tabulated in Table VII for two detector element installations. A length of element run axially along the right side of the engine and a length of element run above the engine forward to the chimney would most likely be necessary to provide full coverage with Detector Installation Numbers 1 and 2, respectively.

TABLE VII

LOCAL AIR TEMPERATURES IN NACELLE COMPRESSOR AND ACCESSORY SECTION FOR SHORT DURATION FIRES (CONTINUOUS DISCRETE DETECTORS)

0.62 Facility Mach Number	Fuel Release Duration 10 seconds
Test Engine @ Maximum Cruise Power	Fuel Release Rate 0.3 gpm

Nozzle Location Number	Clock Positions with Air Temperatures above 1000°F	Clock Positions with Air Temperatures above 500°F	Nacelle Station Numbers with Air Temperatures above 1000°F	Nacelle Station Numbers with Air Temperatures above 500°F
1	12:00 to 2:00	11:00 to 3:00	155 to 170	145 to 175
2	7:00 to 9:00	7:00 to 11:00	135 to 155	130 to 175
3	5:00 to 6:00	4:00 to 7:00	165 to 175	160 to 175
4	5:00 to 7:00	3:00 to 10:00	150 to 175	140 to 175
5	11:00 to 1:00	8:00 to 2:00	135 to 160	135 to 175
7	8:00 to 12:00	8:00 to 1:00	125 to 175	125 to 175

Continuous Detector Locations Required for Coverage of Above Fires

Detector Installation 1 Elements Positioned Axially @ Clock Positions for Discrete Alarm Settings of 1000°F	Detector Installation 1 Elements Positioned Axially @ Clock Positions for Discrete Alarm Settings of 500°F	Detector Installation 2 Elements Positioned Radially Nacelle Station Numbers for Discrete Alarm Settings of 1000°F	Detector Installation 2 Elements Positioned Radially Nacelle Station Numbers for Discrete Alarm Settings of 500°F
6:00	7:00	140	165
9:00	12:00	170	
12:00			

Note: Clock Positions looking forward and moving clockwise.

This was considered necessary to provide coverage of fire originating at locations other than tested (near entrance to chimney and lower right forward area of the compartment). An estimated 10 to 15 feet of this type of element would be required to provide full coverage of the nacelle compressor and accessory section with either of the two detector installations.

Table VIII summarizes the location requirements for unit-type detection systems in responding to the same six short duration fires. These locations were determined for detectors which respond when one or more of the sensors is heated above the set points of 500°F or 1000°F. On the basis of the limited number of fire locations tested, unit detectors at (1) Nacelle Station Number 145 and a 3:00 o'clock position for a system with a 1000°F alarm set point, and (2) at Nacelle Station Number 130 and a 12:00 o'clock position for a system with either a 1000°F or a 500°F alarm set point are considered necessary. The system with a 500°F alarm set point then requires three sensors, one at each of the three cooling air exits.
With the exception of the fire resulting from releasing and igniting fuel at Location 2, the fires at each of the six locations in the forward compartment show a temperature rise in less than 10 seconds greater than 500°F at one or more on the three cooling air exits.

Fires resulting from releasing and igniting fuel at the six locations in the compressor and accessory section were also studied to determine the performance and installation requirements for flame detectors. In Reference 2, the radiation-sensing-type fire detectors are required to respond in a time not exceeding 5 seconds to a pan fire positioned in line with the sensor at a distance of 4 feet. This minimum allowable sensitivity was measured for each sensor and used to determine the coverage provided by the radiation-type detector installation with four sensors sensitive to radiation intensity and coloration. Ten of the 12 Location 1 fires listed in Table V produced radiation at a level above the minimum required for detection. The 4 fires at Location 2 and the 21 at Location 3 did not result in sufficient radiation reaching any one of the 4 sensors to enable detection. Three of the Location 4 fires, 13 of the Location 5 fires, and all 5 of the Location 7 fires resulted in a signal output from at least one of the sensors above the minimum required for detection. To provide coverage of the forward compartment of the test installation, the sensitivity and/or the number of these sensors would have to be increased. The additional coverage provided by increasing the sensitivity of the sensors is shown in Table IX. Increasing the sensitivity to the equivalent of the pan fire at a 6-foot distance extended detection to all Locations 1, 4, and 7 fires. Full coverage on Locations 2 and 5 fires would have required a 12-foot sensitivity. Since, at the 12-foot sensitivity level, only 1 of 21 fires at Location 3 produced sufficient radiation for detection, an additional sensor is considered

TABLE VIII

LOCAL AIR TEMPERATURES IN NACELLE COMPRESSOR AND ACCESSORY SECTION FOR SHORT DURATION FIRES (UNIT DETECTORS)

0.62 Facility Mach Number	Fuel Release Duration 10 seconds
Test Engine @ Maximum Cruise Power	Fuel Release Rate 0.3 gpm

Nozzle Location Number	Nacelle Locations with Air Temperatures above 1000°F		Nacelle Locations with Air Temperatures above 500°F	
	Clock Positions	Nacelle Station Nos.	Clock Positions	Nacelle Station Nos.
1	12:00 to 2:00	155 to 170	11:00 to 3:00	145 to 175
2	7:00 to 9:00	135 to 155	7:00 to 11:00	130 to 175
3	5:00 to 6:00	165 to 175	4:00 to 7:00	160 to 175
4	5:00 to 7:00	150 to 175	3:00 to 10:00	140 to 175
5	11:00 to 1:00	135 to 160	8:00 to 2:00	135 to 175
7	8:00 to 12:00	125 to 175	8:00 to 1:00	125 to 175

Unit Detector Locations Required for Coverage of above Fires

1000°F Alarm Setting Unit Detectors Located at			500°F Alarm Setting Unit Detectors Located at		
Clock Positions		Nacelle Station Nos.	Clock Positions		Nacelle Station Nos.
6:00	and	170	7:00	and	170
12:00	and	165	12:00	and	170
12:00	and	150			
9:00	and	145			

Note: Clock Positions looking forward and moving clockwise.

TABLE IX

EFFECT OF SENSITIVITY OF RADIATION TYPE SENSORS ON FIRE DETECTION

Nozzle Location Number	Number of Test Runs	Sensor Number	Number of Fires Detected with Sensitivity Settings of (Equivalent Distance of Five Inch Pan Fire from Sensor)				
			4 ft.	6 ft.	8 ft.	10 ft.	12 ft.
1	12	1	10	12	12	12	12
		2	0	0	0	0	1
		3	0	0	0	0	0
		4	0	0	0	0	0
		1 to 4	10	12	12	12	12
2	4	1	0	0	0	0	0
		2	0	0	0	0	0
		3	0	0	1	3	4
		4	0	0	0	0	0
		1 to 4	0	0	1	3	4
3	21	1	0	0	0	0	0
		2	0	0	0	0	0
		3	0	0	0	1	1
		4	0	0	0	0	0
		1 to 4	0	0	0	1	1
4	4	1	0	0	0	0	0
		2	0	0	0	0	0
		3	0	0	0	0	0
		4	3	4	4	4	4
		1 to 4	3	4	4	4	4
5	58	1	6	11	17	29	35
		2	0	0	0	0	0
		3	10	21	50	56	58
		4	2	2	3	4	8
		1 to 4	13	36	54	57	58
7	5	1	0	0	2	3	3
		2	0	0	0	0	0
		3	5	5	5	5	5
		4	0	0	0	0	0
		1 to 4	5	5	5	5	5

necessary for coverage on Location 3 fires. Full coverage of Locations 1, 2, 4, and 7 fires was provided by three of the four sensors. Since Sensor Number 2 at the 4:00 o'clock position did not respond to any of the fires at a level greater than one of the other three sensors, the same coverage was provided by three sensors. Due to the relatively high sensitivity requirement for detection of Locations 2 and 5 fires and the relative location of these fires to Location 3 fires, at least one sensor in addition to the three under the fan fairing and the one covering the drain vent area is considered necessary for full coverage by this type system. The limited coverage provided by each sensor was considered due primarily to the tightness of the nacelle cowling and the blockage provided by engine components. The small gap between the engine case and the cowl door and amount of blockage in this annular gap limited the frontal flame area viewed by each sensor.

Test results also indicated that these flame detectors neither alarmed nor responed to nacelle fires which were not in the viewing area of the sensor. Measurable sensor outputs were obtained only when the isothermal patterns showed the fire was located in the viewing area of the sensors.

The results of a limited number of tests with the radiation-sensing detection system sensitive to flickering near infrared radiation produced by a fire were generally the same as for the flame detector discussed above. Since the output signal from the four sensors in this system could not be measured without affecting the operation of the system, data on the performance and installation requirements for this system were limited to those obtained by monitoring the alarm signal. Some difficulty was experienced in detecting Location 5 fires with the four sensors installed under the fan fairing. One of four fires at this location was not detected. The remaining three fires produced alarms 30 to 53 seconds after ignition. Neither of the two Location 3 fires were detected by this detector system.

All of the tests conducted under the Fire and Overheat Detection Phase, with the test engine installation in a production configuration, were studied to determine if an area existed within the forward nacelle compartment where a temperature sensitive detector could be expected to promptly respond to all compartment fires. It was immediately apparent that due to the limited heating outside of the local fire area, detection of the 10-second Location 3 fires, such as shown in Figure 23, by temperature-sensing-type detectors positioned at locations remote from the drain vent area was highly improbable. Since a single sensor at Location 3 was not considered capable of providing a full coverage for Locations 1, 2, 5, and 7 fires, the study was extended on the basis that the drain vent area could be covered by a second detector or that a longer duration fire would provide sufficient heating to enable detection by a remotely located detector. The initial study involved a review of the air temperatures recorded at

27 locations in the nacelle compressor and accessory section to determine areas repeatedly showing a minimum temperature rise of 200°F during fires at Locations 1, 2, 4, 5, and 7. As a result of this study, it was found that (1) a thermocouple at Nacelle Station Number 170 and a 12:00 o'clock position normally responded by more than a 200°F temperature rise to Locations 1, 2, and 5 fires; (2) thermocouples below the horizontal firewall at Nacelle Station Number 150 and 11:40 and 12:30 o'clock positions responded to the majority of the Locations 1, 5, and 7 fires; (3) a thermocouple below the chimney at Nacelle Station Number 132 and a 12:00 o'clock position responded to Locations 4, 5, and 7 fires (Locations 1 and 2 fires were not conducted with this thermocouple installed); and (4) a thermocouple at Nacelle Station Number 150 and a 10:00 o'clock position responded to Locations 2, 4, 5, and 7 fires.

The first and third possible locations for a detector were eliminated since no apparent way to extend the coverage provided by a single detector at either of these locations could be found. Since the second and fourth thermocouple locations were relatively close and since this combination of thermocouples provided full coverage, prompt detection of all except Location 3 fires by a unit detector or a continuous detector positioned at Nacelle Station Number 150 and between 10:00 and 11:40 o'clock was considered possible. The recorded temperature measurements tabulated in Appendix VI showed that either or both of the thermocouples at 10:00 and 11:40 o'clock positions were exposed to a temperature rise greater than 200°F during 72 of the 78 fires at Locations 1, 2, 4, 5, and 7. The remaining six fires consisted of (1) one fire at Location 7 with the engine windmilling; (2) one Location 5 fire with the engine operating at idle; (3) two 10-second Location 1 fires with maximum recorded temperatures of 372°F and 383°F; and (4) two 10-second Location 5 fires with maximum recorded temperatures of 412°F and 445°F.

Since, under normal conditions with the test engine operating at takeoff thrust and with a compressor inlet total temperature of 78°F, the thermocouples at 10:00 and 11:40 o'clock positions were reading 290°F and 200°F, respectively, a minimum allowable temperature setting of 400°F was assumed for a detector in the area. With this set point, a unit or short continuous-type detector at Nacelle Station Number 150 between 10:00 and 11:40 o'clock positions could have been expected to promptly detect all of the test fires originating in the compressor and accessory section except for the two fires at low engine power settings, three of the Location 1 fires, and all of the Location 3 fires. With the length of continuous element extended to either the right side of the engine or aft to a location at Nacelle Station Number 170 and a 12:00 o'clock position, the coverage of all Location 1 fires would have been expected.

A comparison of Figures 21 to 25, inclusive, and 27 showed that a point at Nacelle Station Number 152 and 11:00 o'clock was the only location where the air temperature rise was a minimum of 200°F during fires at all five locations in the forward compartment (Location 3 excluded). These figures also showed that temperature rises above 100°F during all five fires occurred within a distance of approximately 10 inches from this point.

The longer duration fires at Location 3 were studied to determine the possibility of eventual detection of fire originating near an area where air exits the nacelle by remotely located temperature sensitive detectors. Figures 30a to 30d illustrate the gradual temperature rise for a long duration Location 3 fire. Thermocouples at Nacelle Station Number 150 (10:00 and 11:40 o'clock positions) were not exposed to a 200°F temperature rise until a time approaching 40 seconds after ignition. At this time, the thermocouples at 10:00 and 11:40 o'clock positions had measured a rise from 153°F to 445°F and from 149°F to 547°F, respectively.

After the next 10 seconds, the two thermocouples were reading temperatures of 384°F and 562°F. A comparison of the temperature rise at 50 seconds after ignition with that at 40 seconds after ignition shows that the fire intensity in the nacelle had decreased during this 10-second period. This decrease was attributed to changes in the nacelle airflow resulting from the deterioration of the drain vent area and the increased cooling air exit area.

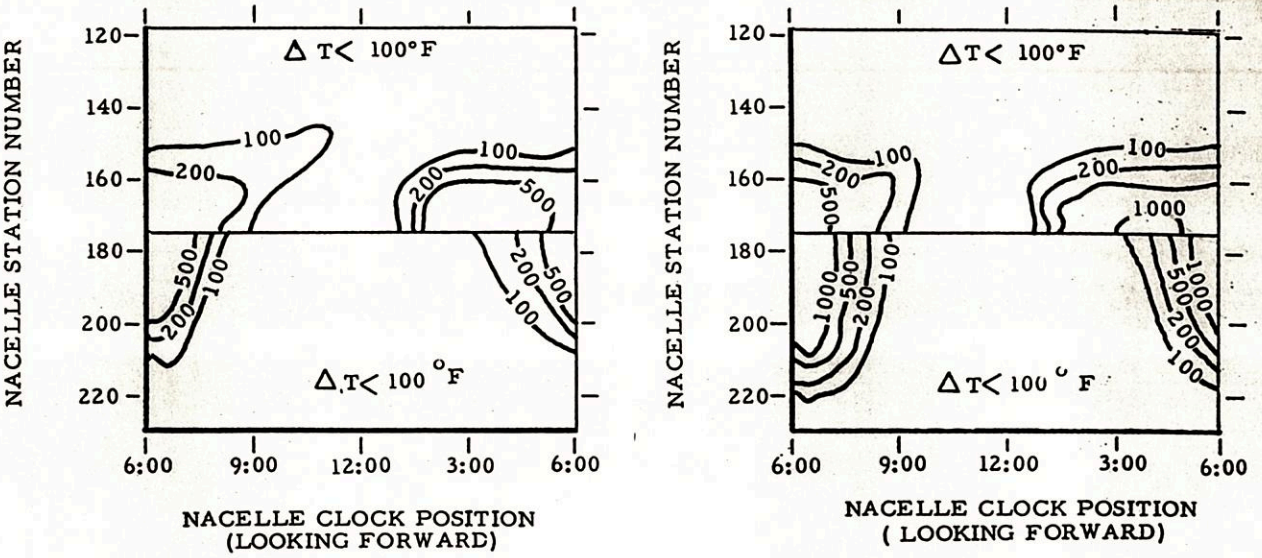
Increases in airflow and the amount of heat leaving the nacelle through openings enlarged by the fire present an additional problem in detecting fire with a remotely located sensor. In such a case, the temperature at the sensor would be expected to increase at a slower rate and to stabilize at a lower level.

Since the overall compartment temperature level was affected by fires originating within the compressor and accessory section of the test installation (including the fires near cooling air exits), detection by a single temperature sensitive unit or a short length continuous detector is considered possible if the alarm set point above normal operating temperatures is minimized. However, the adequacy of a system which would not provide prompt detection on all potential fires is considered to depend on such factors as:

1. The capability of the nacelle to withstand high temperatures in areas not covered by the detector for the length of time required for heat to reach the sensor.

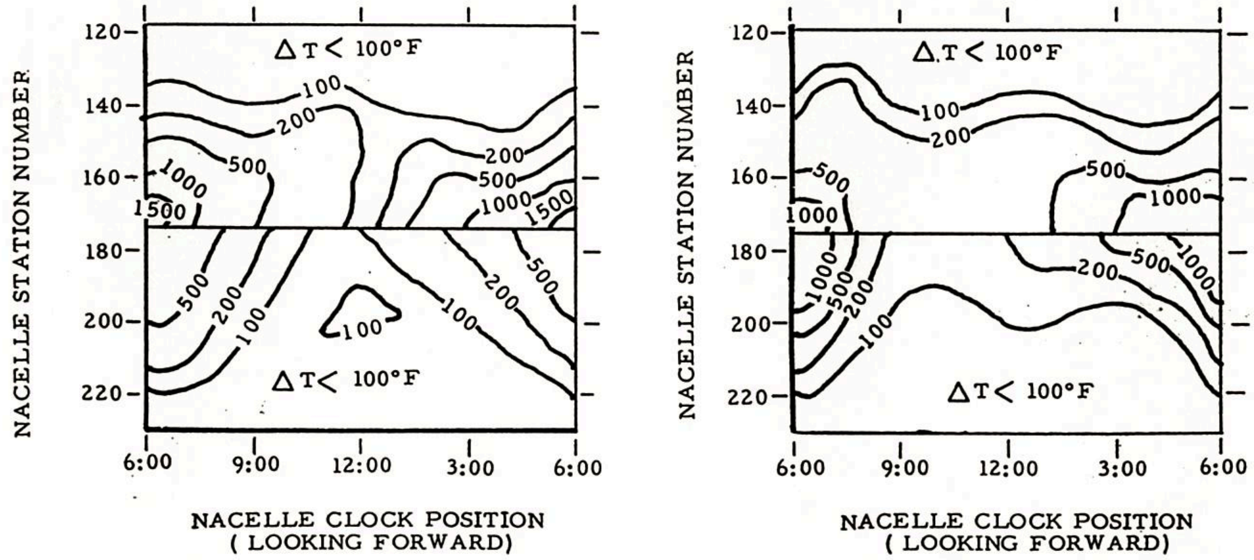
2. The capabilities of the fire extinguisher system and/or other fire control provisions in controlling the fire following detection.

NOTE:
TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NUMBER=0.5
JET FUEL TYPE B
FUEL RELEASE RATE 0.3 GPM



(a) 14 SEC. AFTER IGNITION

(b) 32 SEC. AFTER IGNITION



(c) 40 SEC. AFTER IGNITION

(d) 50 SEC. AFTER IGNITION

FIG. 30 - AIR TEMPERATURE RISE FOR A LONG DURATION FIRE AT LOCATION 3

3. The susceptibility of such a system to alarm to nonhazardous minor overheat conditions.

The merits of such a system are questionable since a possible elimination of some of the false alarm problems may have been gained by reducing the system performance as a fire detector and may create additional problems as a result of the requirements for lower alarm temperature settings.

Installation Design Considerations for Abbreviated Detector Systems: As previously discussed, the major problems of prompt fire detection in the forward compartment of the test installation with an abbreviated system were associated with the unpredictable airflow paths and the multiple cooling air exits. A series of tests was conducted with the nacelle modified in an attempt to develop a simplified fire detector installation without sacrificing existing fire protection provisions. These modifications are shown in Figure 31 and consisted of the following:

1. Ram air inlet installed in the forward strut fairing.

2. Sealed vertical engine fireseal.

3. Enlarged drain vent and flame arrestor installed.

4. Boundary-layer air duct installed to provide a layer of air over the nacelle skin downstream of the drain vent.

5. Cowl door seams sealed.

6. A unit detector installed above the new drain vent.

These modifications were intended to provide direction to the nacelle cooling airflow and a single exit for the air; to prevent fires from burning outside the air exits; and to provide prompt detection with a single unit detector. The location below the engine was selected for the single air exit to keep the heat away from the horizontal firewall and critical structure above the engine.

Four air thermocouples were positioned above and within 1-1/2 inches of the new drain vent frame. A unit fire detector with a 450°F alarm setting was positioned axially along the forward left side of the drain vent. Short duration fires originating at Locations 3, 4, 5, and 7 were conducted with this modified nacelle configuration. Fires at three of the locations were selected as being the most difficult to detect. The fourth location (Location 3) was above the new drain vent and was selected to evaluate the flame arrestor and boundary-layer air systems.

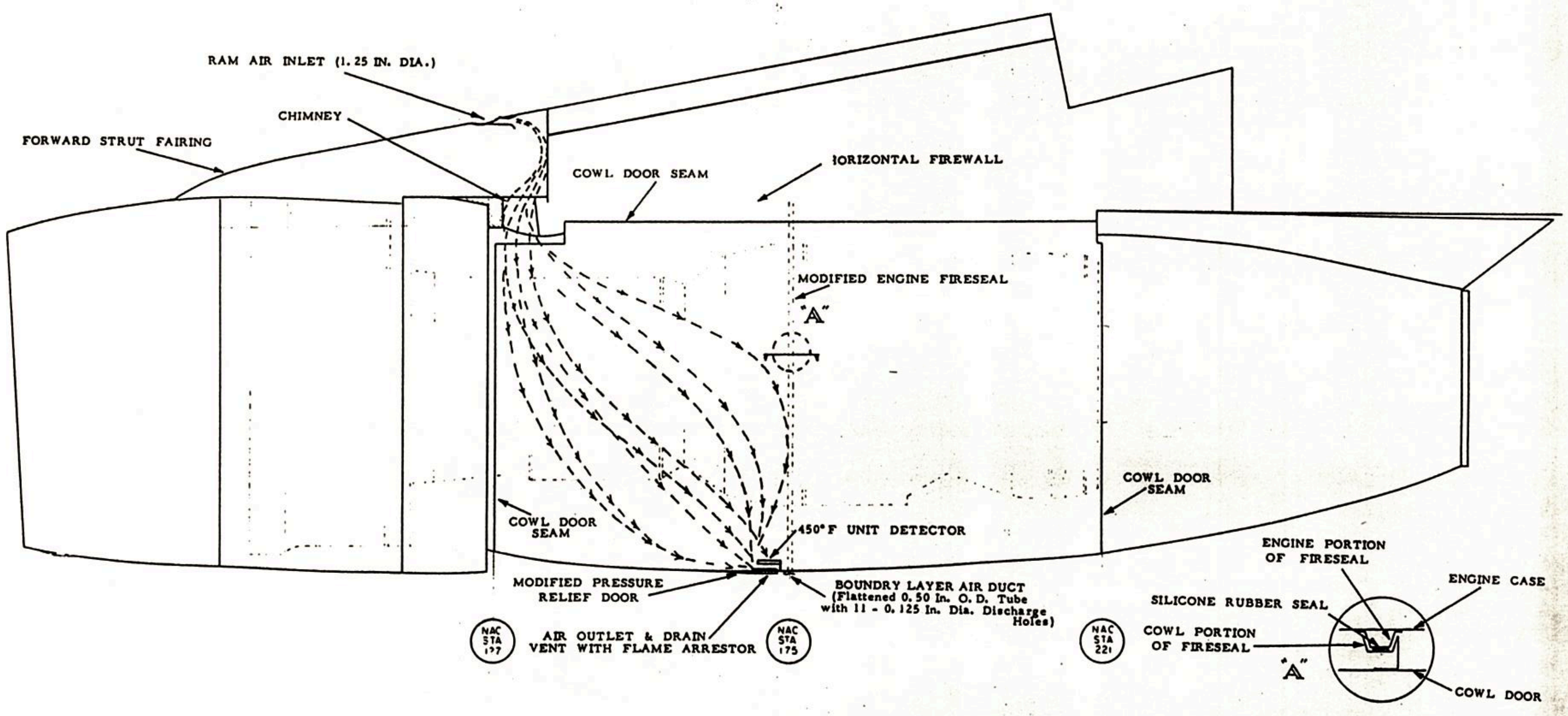


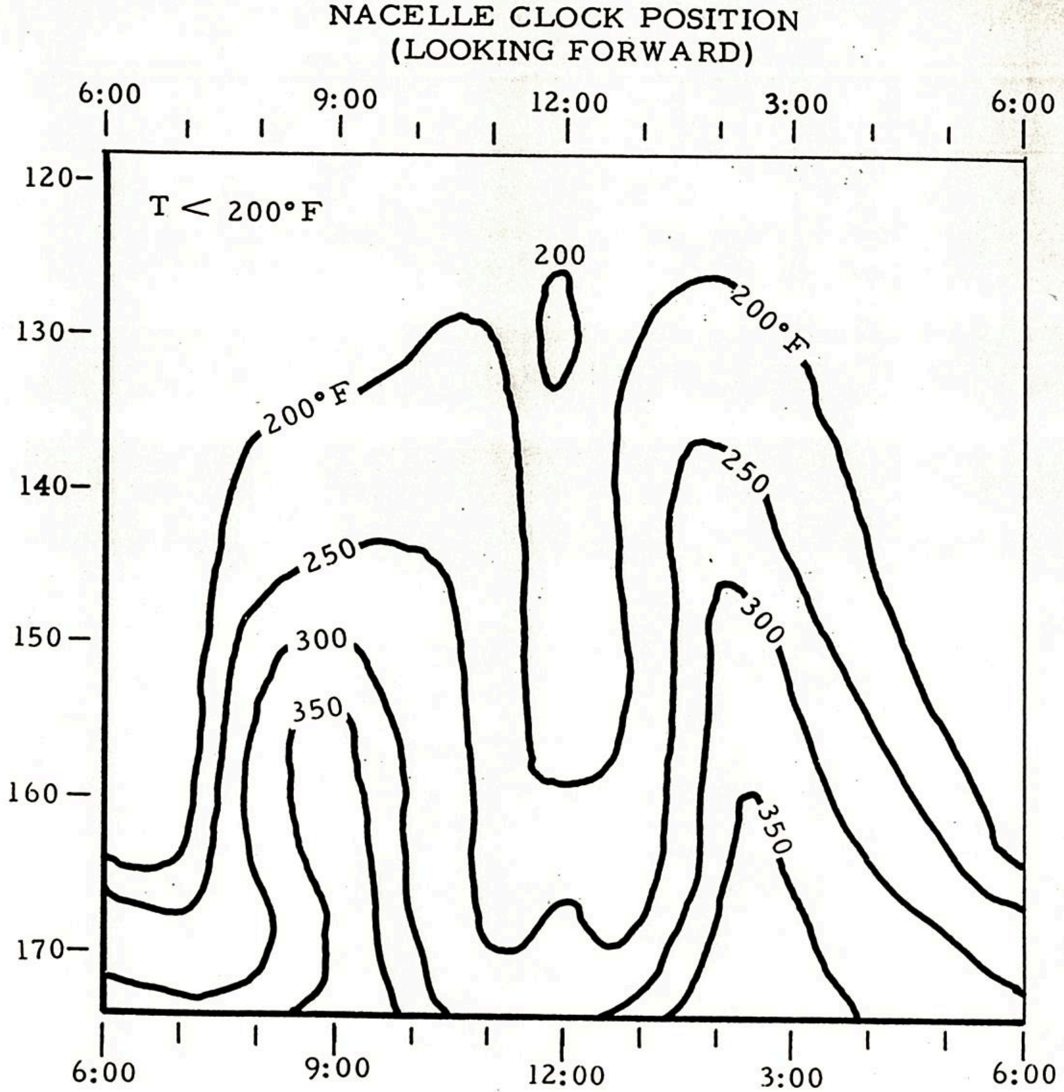
FIG. 31 - FORCED VENTILATION AND SINGLE AIR OUTLET NACELLE CONFIGURATION

The procedure for this test series included shutting the engine down and discharging the fire extinguisher. Following either a 10- or 15-second fire, the test engine was retarded to cutoff; the spark ignitor was deactivated; the extinguishant was discharged; the fuel release was discontinued; and the nacelle was inerted with carbon dioxide.

As shown in Figure 32, the air from the ram air inlet cooled the area above the engine, followed a path down both sides of the engine forward in the nacelle compressor and accessory section, and moved aft below the engine toward the modified drain vent. This resulted in a normal ambient air temperature of approximately 240°F at the drain vent for the test conditions.

The results of this series of tests are summarized in Table X. Since the fires resulting from releasing and igniting fuel at Location 5 were small low-intensity fires, the temperature rises at the drain vent were relatively small. A detector at the drain vent was considered capable of detecting larger Location 5 fires since the heat produced by the test fires was directed toward the drain vent. The low-intensity fires resulting from simulated small leaks at Location 7 generally produced the same results. The temperature rise at the drain vent was relatively low and was not as high as the temperature rise near the location of the leak. The heat moved aft and down along the fireseal over the left side of the engine toward the drain vent. Air leakage into the nacelle combustor and turbine section was evident from the air temperature rise aft of the modified engine fireseal during these tests. When the size of the simulated leak at Location 7 was increased, the temperature rise at the drain vent was considered sufficient for detection even though heat losses through the fireseal were again evident.

Although five of the six Location 4 fires were detected by the unit detector, the heat patterns in the area of the drain vent indicated that detection was marginal. Heat losses through the fireseal were again evident during the Location 4 fires. The heat patterns also indicated that the rising hot gases interrupted the downward flow of cooling air from the ram air inlet. As a result of this, the air was forced aft toward the engine fireseal and down either one or both sides of the engine to the drain vent exit. This change in the airflow produced what was considered to be a stagnant area at Location 4 which resulted in intense fires with relatively small simulated fuel leaks. This further produced a condition under which a small but intense fire could exist without substantially affecting the air temperature at this cooling air exit.



NOTE: TEST ENGINE AT MAXIMUM CRUISE THRUST
FACILITY MACH NUMBER = 0.5

FIG. 32 - STABILIZED AIR TEMPERATURE FOR FORCED VENTILATION AND SINGLE AIR OUTLET NACELLE CONFIGURATION

TABLE X

ABBREVIATED FIRE DETECTOR AT COOLING AIR EXIT VENT - TEST RESULTS

Jet Fuel Type B	Engine Schedule: Maximum Cruise to Cut Off
0.5 Facility Mach Number	@ Shut Down Time Indicated

Nozzle Location Number	Fuel Release Rate	Time of Events (zero time @ fuel release initiated)						Stabilized Air Temperatures Drain Vent Location Number (1)			
		Ignition	Engine Shut Down	Extinguisher Discharged	Fuel Release Discontinued	Unit Detector Alarmed	Unit Detector Cleared	1	2	3	4
	(gpm)	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)	(°F)	(°F)	(°F)	(°F)
5	0.3	2.0	9.8	17.4	24.6	----	----	340	545	410	790
5	0.3	2.0	9.8	17.5	24.6	----	----	270	350	330	350
7	0.3	2.5	9.8	17.7	25.0	----	----	260	295	280	330
7	0.3	2.0	9.8	17.3	24.5	----	----	270	300	295	340
7	1.0	1.5	9.9	17.6	24.7	----	----	770	720	490	1380
7	1.0	1.5	9.8	17.4	24.5	8.2	20.8	940	---	420	1720
4	1.0	3.0	9.8	17.5	24.7	12.3	23.7	400	240	355	430
4	1.0	2.5	15.5	23.1	25.8	11.6	32.0	480	240	480	350
4	0.3	3.0	15.3	22.8	29.6	14.7	19.7	270	400	300	---
4	0.3	3.5	15.4	----	29.8	Undetected		275	325	250	---
4	1.0	3.0	15.2	----	29.7	9.5	39.2	780	465	370	---
4 (2)	1.0	2.5	15.3	22.8	29.6	14.9	24.6	440	250	660	310
7 (2)	2.0	1.5	15.4	23.1	29.7	Undetected		1220	250	305	1820
7 (2)	1.0	1.5	15.3	22.7	29.5	10.1	33.3	1340	265	480	1950
3 (2)	1.0	3.0	15.3	22.7	29.7	6.2	31.0	540	230	750	1350

Notes: (1) Number 1 Location at aft right corner of drain vent
Number 2 Location at forward left corner of drain vent
Number 3 Location at forward right corner of drain vent
Number 4 Location at aft left corner of drain vent
(2) Forward seams of cowl doors unsealed

During two of the four Location 4 fires with a 1.0-gpm simulated fuel leak, the fire tended to completely prevent the cooling air from moving down the left side of the engine. As shown in Figure 33 for one of these two fires, the heat was directed up the left side of the engine aft toward the engine fireseal, and the cooling air was directed from the ram air inlet down the right side of the engine to the drain vent.

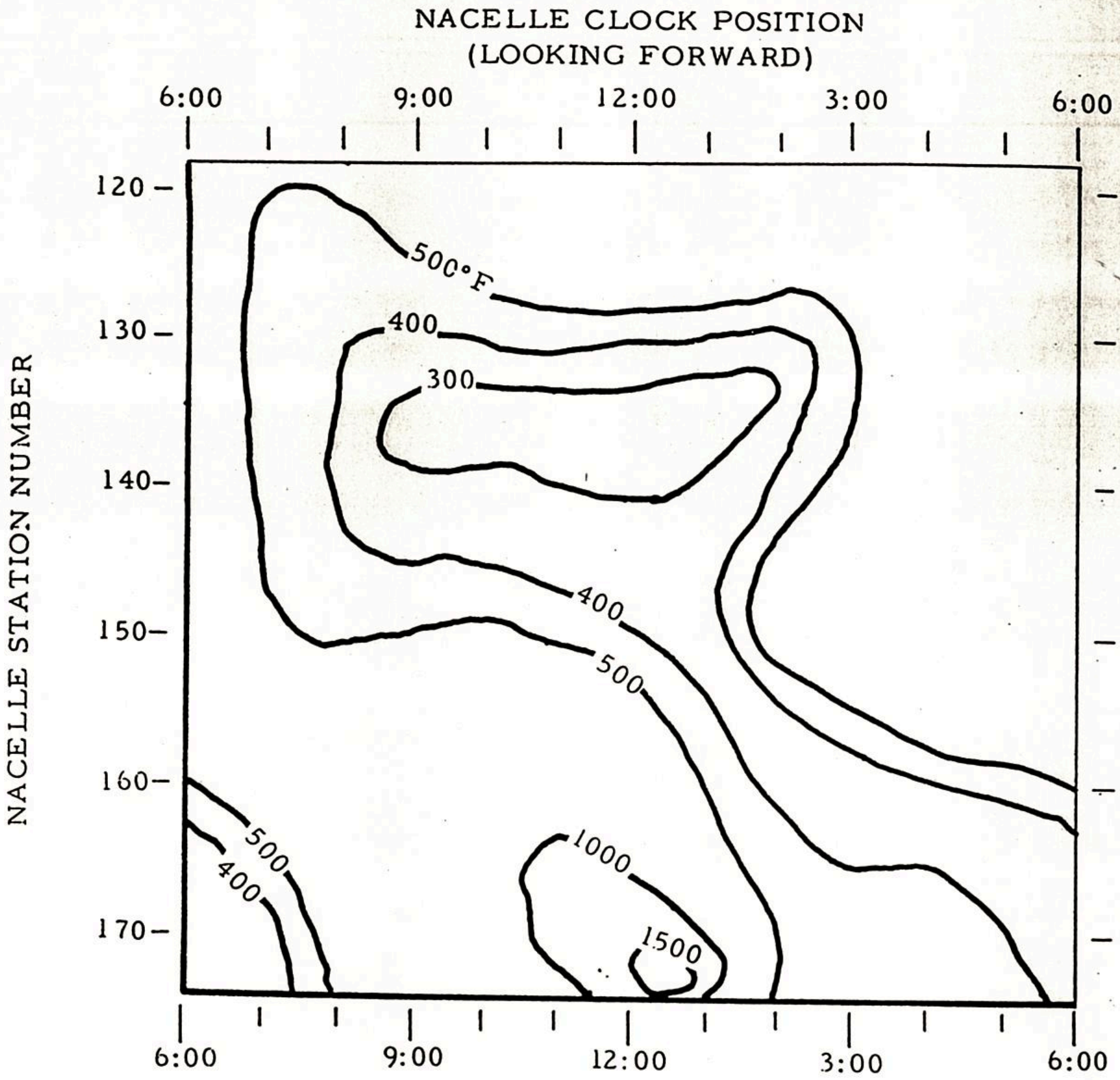
Although an airtight fireseal would be expected to produce a higher temperature rise at the drain vent, provisions to prevent the stagnant conditions at Location 4 are considered a requirement to assure prompt detection of Location 4 fires by the drain vent detector.

The Location 3 fire above the drain vent produced a substantial rise in the local temperatures and was rapidly detected by the unit fire detector. The motion picture coverage of the drain vent and an inspection of the test installation following this test indicated that the flame arrestor prevented this 20-second-duration fire from traveling through the drain vent and burning on the external surface of the cowling. This was also true of all the other fires under this test series.

These tests with the modified installation also indicated that a wide range of temperatures could exist at various locations in the vicinity of a cooling air exit during a fire. Because of this, a detector at an air exit should be located so as to provide coverage of all the air flowing through the opening.

Detector System Performance Characteristics: During tests under the Fire and Overheat Detection and other phases of the program, several types of detector systems currently in use were installed on the test engine to provide data on the response characteristics and coverage provided under actual fire and simulated flight conditions. The systems tested included one Unit Fire Detector (UFD) System, six Continuous Fire Detector (CFD) Systems, and two Surveillance Fire Detector (SFD) Systems. The description, sensor locations, and alarm settings of each detector are presented in Table XI and Appendix VI.

The detection coverage provided by each of the nine systems and the alarm response times are summarized in Table XII. The UFD System detected all fires resulting from releasing and igniting fuel at Locations 1 to 6, inclusive, within 13 seconds after ignition except a number of fires having a duration less than 8 seconds. Two of the test fires at Location 7 required relatively long periods of time for the UFD System to alarm.



NOTE: TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NUMBER = 0.5
JET FUEL TYPE B
FUEL RELEASE RATE 1.0 GPM
TIME AFTER IGNITION 6.8 SEC.

FIG. 33 - AIR TEMPERATURE FOR A FIRE AT LOCATION 4 WITH FORCED VENTILATION AND SINGLE AIR OUTLET NACELLE CONFIGURATION

TABLE XI

TEST FIRE DETECTION SYSTEMS

Detection System	Detector Location	Number of Sensors or Length of Element	Alarm Settings Average °F	Alarm Settings Discrete °F
UFD	Zone II	7 ea.	650	---
	Zone I	4 ea.	900	---
	Strut	2 ea.	450	---
CFD 1	Zones I & II	11 in. Zone II	710	---
		42 in. Zone I	Logarithmic	
CFD 2	Zones I & II	11 in. Zone II	600	1100
		42 in. Zone I	Arithmetic	
CFD 3	Zones I & II	11 in. Zone II	550	1100
		42 in. Zone I	Arithmetic	
CFD 4	Zones I & II	11 in. Zone II	---	765
		42 in. Zone I		
CFD 5	Zones I & II	11 in. Zone II	500	---
		42 in. Zone I	Logarithmic	
CFD 6	Zones I & II	30 in. Zone I	450	1100
		294 in. Zone II	Arithmetic	
SFD 1	Under Fan Air Duct	4 ea.	Flame Coloration & Radiation of Five in. Pan Fire @ Distance 4 ft.	
SFD 2	Under Fan Air Duct	4 ea.	Flickering Radiation of Five in. Pan Fire @ Distance 4 ft.	

Note: CFD 1 Through 6 Below Horizontal Strut Firewall and Extending Through Vertical Engine Fireseal

TABLE XII

PERFORMANCE OF FIRE DETECTOR SYSTEMS

System	Group (1)	Nozzle Location Number	Number Fires Detected	Detection Time (sec)	Number Fires Undetected	Undetected Fire Durations (sec)
UFD	---	1 thru 6	76	3.4 to 13.0	29	2.6 to 7.7
UFD	---	7	5	9.8 to 71.9	0	---
CFD 1	1	1, 2 & 5	8	8.1 to 20.0	19	4.9 to 8.5
CFD 1	2	3, 4 & 6	0	---	12	2.6 to 7.2
CFD 2	1	1 & 5	10	5.3 to 22.9	0	---
CFD 2	2	7	1	21.6	2	54.6 to 72.7
CFD 3	1	5	3	2.5 to 5.3	0	---
CFD 3	2	3 & 7	2	18.2 to 46.0	1	75.0
CFD 4	1	5	3	8.5 to 23.3	0	---
CFD 5	1	5 & 5A	59	4.0 to 16.1	1	13.0
CFD 5	2	4 & 4A	32	6.7 to 25.7	50	15.0 to 25.0
CFD 6	1	5	1	5.5	0	---
SFD 1		1, 2, 3, 4, 5 & 7	34	0.0 to 9.2	70	4.2 to 156.9
SFD 2		3, 5 & 7	9	0.5 to 53.2	3	41.5 to 72.4

Note: (1) Group 1 with nozzle locations in upper half of nacelle.
Group 2 with nozzle locations in lower half of nacelle.

The test results with the CFD Systems are presented in Table XII divided into two groupings according to fuel release locations in either the upper half or lower half of the nacelle. Generally, the CFD Systems detected fires resulting from simulated fuel leaks occurring in the upper half of the nacelle within 24 seconds after fuel ignited. Exceptions to this were a number of fires having a duration of less than 9 seconds and a 13-second 0.1-gpm fire at Location 5A.

Fires resulting from simulated fuel leaks occurring in the lower half of the nacelle were more difficult to detect with the CFD Systems. The CFD Systems detected 35 of the 100 fires originating in the lower half of the nacelle. Fourteen of the undetected fires were of a short duration (less than 8 seconds). Three of the remaining 51 undetected fires were long duration fires (55 to 75 seconds).

The SFD System Number 1, sensitive to flame coloration and the radiation level, alarmed within 3-1/2 seconds after ignition for 33 of the 34 fires detected. Eight of 12 fires at Location 1, the 4 Location 4 fires, 17 of 58 fires at Location 5, and the 5 Location 7 fires were detected by this system. The 4 fires at Location 2 and the 21 fires at Location 3 were not detected to the point of alarm by this system.

As previously discussed, the SFD System Number 2, sensitive to flickering radiation, provided full coverage of five Location 7 fires and four of five Location 5 fires. Neither of the Location 3 fires was detected by this system.

Fire Indications by Means Other Than Detector Systems: Tests under the Fire and Overheat Detection Phase indicated that the standard cockpit engine instruments and engine monitoring systems provided neither a reliable nor early indication of an abnormal condition during the engine fire nor a positive indication of a fire condition. Appendix VI contains detailed information of the engine instrumentation installed and operating for these tests. The nine failures listed in Table XIII occurred during the initial long duration fires. Prior to these long duration fires, eighty-three 10-second fires, three 15-second fires, and twelve 20-second fires had been conducted without an indication of fire by these systems. The engine instrumentation provided an indication of an abnormal condition during less than half of the initial long duration fires even though the failures were considered to have resulted from accumulative damage from the previous exposures to fire.

Visual indications of an engine fire were not always present in the artificially lighted environment and when present, the fire very often was spreading rapidly (Fire Resistance and Damage Section of this report). The only fires which normally produced an external flame were the fires resulting from releasing and igniting fuel above the drain vent at Location 3.

TABLE XIII

FIRE CAUSED ENGINE INSTRUMENTATION SYSTEM FAILURES

Incident	Engine Instrument	Cause of Failure	Fire Exposure Prior to Run Number Runs	Fire Exposure Prior to Run Total Time (min)	Fire Exposure During Run Time (sec)
1.	Oil Filter Differential Light	Shorted Wire	99	19.2	89
2.	Fuel Filter Differential Light	Shorted Wire	103	25.4	78
3.	Oil Filter Differential Light	Shorted Wire	106	28.6	54
4.	Oil Quantity Indicator - Sudden loss of oil	Shorted Wire	108	30.1	53
5.	Pressurizing and Dump Signal Pressure Indicator - Fluctuating Pressure	Burned Tubing (Leak)	108	30.1	53
6.	N_1 Indicator - Loss Signal	Shorted Wire	108	30.1	53
7.	N_2 Indicator - Loss Signal	Shorted Electrical Connector	109	31.0	77
8.	Oil Filter Differential Light	Shorted Wire	110	32.3	43
9.	Oil Pressure Indicator - Low Pressure	Shorted Wire	112	34.3	65

Fire Control and Extinguishment

Introduction: Commercial transport aircraft fire protection includes provisions for controlling and extinguishing in-flight powerplant fires. The investigations conducted under the Fire Control and Extinguishment Phase of the test program involved the use of high rate of discharge extinguisher systems of the types presently being used and anticipated for future use.

The test program was designed to provide information on the effects of the following items on the control and extinguishment of in-flight engine fires:

1. Fire conditions.

2. Flight conditions.

3. Nacelle ventilation and configuration.

4. Fire extinguishing agent and type container.

5. Oxygen and flammable fluid starvation.

6. Fuel and oil containment within a fire zone under fire emergency conditions.

The investigation was limited to determining fire control and extinguishment requirements for fires resulting from failures of systems external to the engine case in which the engine installation was intact at the time of ignition. The investigation was further limited to the normal environment of the test installation except for: (1) Tests in which the nacelle cooling air ventilation was increased beyond the normal range; (2) tests in which the installation was modified to provide a means of shutting off the cooling air; (3) the size and type of fire extinguishing agent container; and (4) the quantity and type of extinguishant.

The specific objective of the Fire Control and Extinguishment Investigation was to provide design criteria and engineering data on the following:

1. The quantity of agent required to extinguish engine nacelle fires and the effects of flight conditions and the type of fuel system failure on this quantity.

2. The effect of the duration of a fire on the extinguishing agent requirements.

3. The effects of low temperature exposure of extinguishants on minimum quantity requirements.

4. The effect of cooling air ventilation on the minimum quantity requirements of the extinguishing agents.

5. The relative effectiveness of fire extinguishing agents.

6. The effectiveness of recently developed fire extinguisher systems.

7. The effectiveness of fire emergency shutdown procedures, without utilizing the fire extinguisher system, in controlling and extinguishing fires.

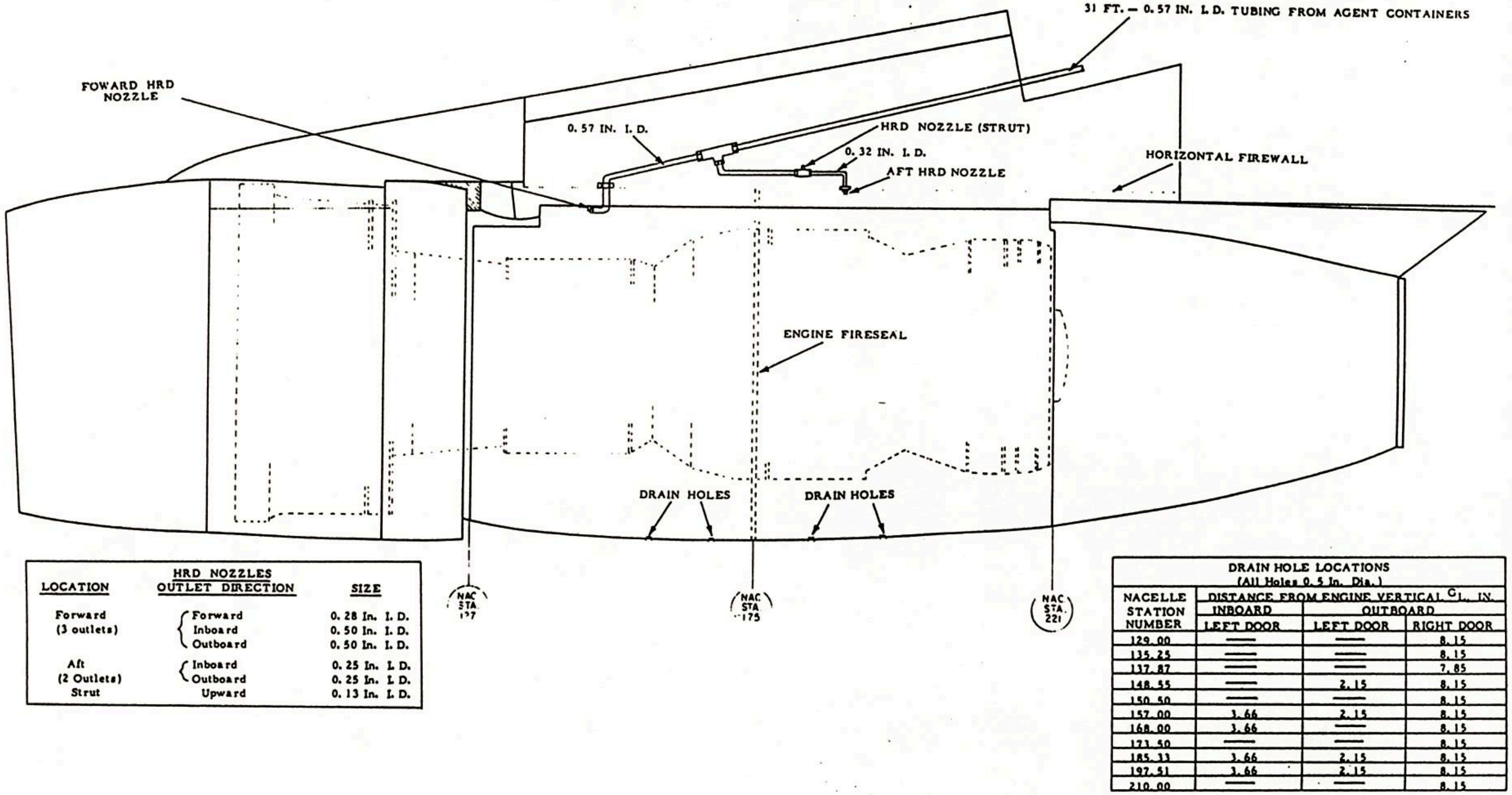
8. The effect of the fuel contained between the shutoff valve and the fuel control unit draining into the nacelle during a fire.

9. The need for a shutoff valve or other means of preventing oil from flowing into the nacelle during a fire.

Test Equipment and Procedures: The two-zone production-type fire extinguishing distribution system, as shown in Figure 34, from the strut/wing connection point to the nacelle discharge points was used throughout the Fire Control and Extinguishment Test Program. The spherical extinguishing agent containers were mounted at a location simulating the inboard strut and connected by tubing, sized according to the normal airplane distribution system, to the outboard engine installation. A backup extinguishing agent container, charged with 4-1/2 pounds of bromotrifluoromethane ($CBrF_3$) and pressurized to 600 psig with nitrogen, was also installed at the simulated inboard strut location. The second container was normally used in cases where the fire was not extinguished by 4-1/2 pounds or less of $CBrF_3$.

The production-type fire extinguisher containers were equipped with a cartridge and disc-type valve in the outlet. Extinguishing agent was forced out of the container by nitrogen pressure when the cartridge in the valve fired a slug rupturing the frangible disc in the outlet. During several tests, the cartridge and disc-type valve was replaced with a fast-acting pilot-operated solenoid valve (used only on test runs noted). The size of the fire extinguisher container was selected for each test so that the amount of nitrogen (at 400 psig) in the container was between 50 and 70 percent of the volume of the extinguishing system (total volume of container and distribution lines).

A fuel system independent of the engine fuel system was used throughout the tests to spray Type B jet fuel into the nacelle. A spray nozzle with a line pressure of approximately 150 psig was used to provide a relatively coarse full-cone 30° spray pattern. A spark discharge (transformer output rated at 10,000 volts and 23 milliamperes) was used to ignite the fuel spray.



LOCATION	HRD NOZZLES OUTLET DIRECTION	SIZE
Forward (3 outlets)	Forward	0.28 In. I. D.
	Inboard	0.50 In. I. D.
	Outboard	0.50 In. I. D.
Aft (2 Outlets)	Inboard	0.25 In. I. D.
	Outboard	0.25 In. I. D.
Strut	Upward	0.13 In. I. D.

DRAIN HOLE LOCATIONS
(All Holes 0.5 In. Dia.)

NACELLE STATION NUMBER	DISTANCE FROM ENGINE VERTICAL ℄, IN.		
	INBOARD	OUTBOARD	
	LEFT DOOR	LEFT DOOR	RIGHT DOOR
129.00	—	—	8.15
135.25	—	—	8.15
137.87	—	—	7.85
148.55	—	2.15	8.15
150.50	—	—	8.15
157.00	3.66	2.15	8.15
168.00	3.66	—	8.15
173.50	—	—	8.15
185.33	3.66	2.15	8.15
197.51	3.66	2.15	8.15
210.00	—	—	8.15

FIG. 34 - PRODUCTION NACELLE FIRE EXTINGUISHING DISTRIBUTION SYSTEM AND COWL DRAINAGE

Unless otherwise noted, the basic procedure used in these tests consisted of the following sequence of events:

1. Facility Mach number and engine power stabilized.
2. Spark ignitor activated.
3. Fuel spray release initiated.
4. Test engine retarded to cutoff.
5. Spark ignitor deactivated.
6. Fire extinguishant discharged.
7. Fuel spray release discontinued.

The time increments between each of the above events varied with the individual test requirements. However, the sequence of events normally followed one of three schedules identified as Schedules A, B, or C (Apprendix VII). The difference between schedules was in the length of time the test fire was allowed to burn before retarding the test engine (time increments of 10, 25, and 40 seconds for Schedule A, B, and C fires, respectively).

Although the fuel is normally shut off during a fire emergency prior to discharging the extinguisher, the procedure followed allowed the fuel release to continue until after the extinguisher was discharged. This procedure was followed in order to provide better test repeatability by establishing a stabilized fire condition with a constant fuel release rate and to assure that the fires were extinguished by the discharged agent and not by lack of fuel. This test procedure is considered to be valid since a positive control is not normally provided which prevents the fuel downstream of the shut-off valve or the lubricating and hydraulic fluids contained within the nacelle from continuing to leak during the agent discharge.

Tests under this phase were normally conducted with the test engine initially operating at maximum cruise rating and with tunnel airflow maintained constant throughout the run. At the higher simulated flight speeds, maintaining constant airflow was not possible due to tunnel limitations. In such cases, the flight speed decreased slightly to the maximum attainable value with the test engine retarded.

Appendix VII contains detailed information on the test installation configurations and the test procedures followed.

Effects of Fire Conditions on Extinguishment: The location, size and intensity, and duration of the fire had an effect on the requirements of the fire extinguisher system. The two fuel release locations tested and the nozzle position at each location were: (1) Location 4, forward of the main fuel filter at Nacelle Station Number 128 and 6:30 o'clock with the fuel spray directed down and slightly aft onto the cowl panel; and (2) Location 5, above the compressor bleed valve control at Nacelle Station Number 145 and 9:00 o'clock with the fuel spray directed aft onto the engine case.

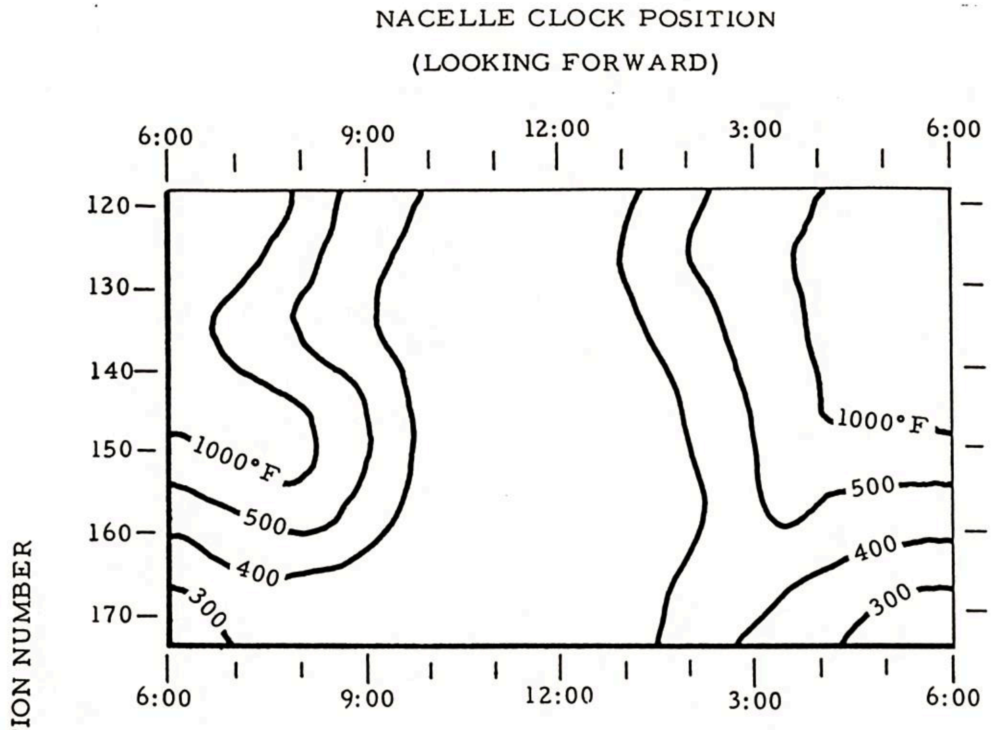
Schedule B fires at Location 4 required a minimum of 5 and 5-1/2 pounds of $CBrF_3$ extinguishant for a 1.0- and a 0.3-gpm simulated fuel leak, respectively. The fire resulting from the smaller leak required more extinguishant even though the 1.0-gpm fire affected a larger volume of the nacelle, as shown in the isothermal plots of these fires just prior to extinguishing agent discharge (Figure 35). Although not evident in these isothermal patterns, this was attributed to the 0.3-gpm fuel spray producing a more ideal fuel/air mixture and more intense fire, as indicated by other tests.

Tests conducted under the same conditions except with a fire resulting from releasing 0.3 gpm of Jet B fuel at Location 5 required 2-1/4 pounds of $CBrF_3$ extinguishant. Since the extinguishing agent weight requirements were 2-1/3 times as great to extinguish the Location 4 fire, fuel sprayed at a rate of 0.3 gpm at Location 4 was selected as the standard fire for the majority of the fire control and extinguishing tests.

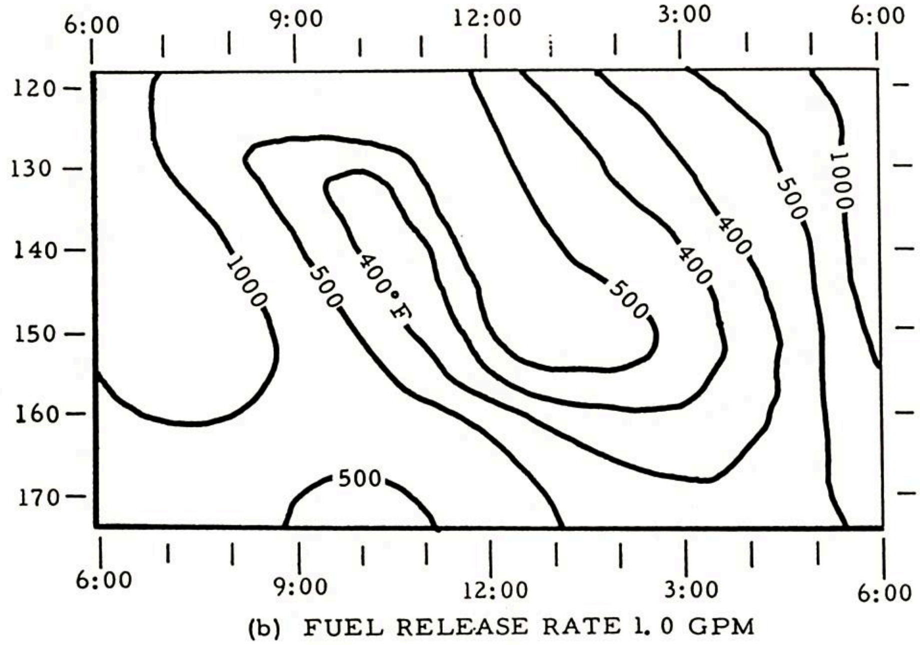
The quantity of agent required for extinguishment was substantially increased as the duration of fire prior to discharging the fire extinguisher system increased. For the 40-second Schedule C fire at a Facility Mach Number of 0.3, an agent quantity (10 pounds of $CBrF_3$) four times that required for a 10-second Schedule A fire was not effective. Likewise, a 40-second fire at a Facility Mach Number of 0.5 was not extinguished by 13-1/2 pounds of $CBrF_3$ extinguishant.

Inspection of the test installation after each of the Schedule C fires revealed that the nacelle internal airflow was changed as a result of the mating seams and joints being distorted and seals leaking. Apparently this change in the nacelle airflow substantially lowered the mixture concentration and changed the distribution of the extinguishant in the nacelle.

The longer duration fires also sufficiently heated components of the engine or nacelle cowling to reignite the fuel after the extinguishing agent dissipated. These reignitions were often in the form of an explosion. As shown in Figure 36, one of these explosive reignitions resulted in broken hinges and hinge supports and both side cowlings being buckled and sprung away from the strut. This reignition occurred



(a) FUEL RELEASE RATE 0. 3 GPM



(b) FUEL RELEASE RATE 1. 0 GPM

NOTE:
TEST ENGINE AT MAXIMUM CRUISE POWER
FACILITY MACH NUMBER = 0. 5
JET FUEL TYPE B

FIG. 35 - STABILIZED AIR TEMPERATURE FOR FIRES AT LOCATION 4

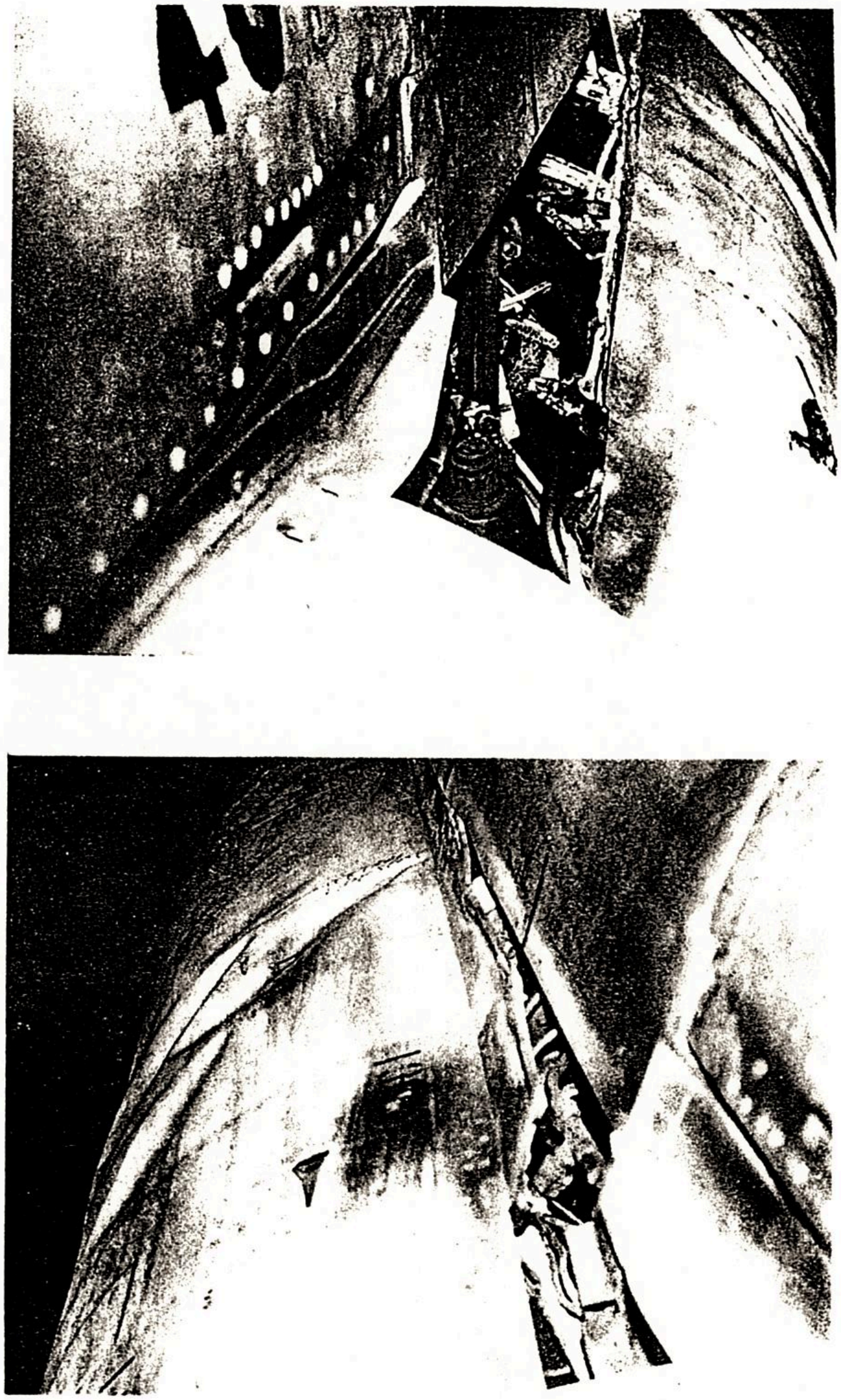


FIG. 36 - FAILURE OF COWL DOOR HINGE AND ATTACHMENT POINTS

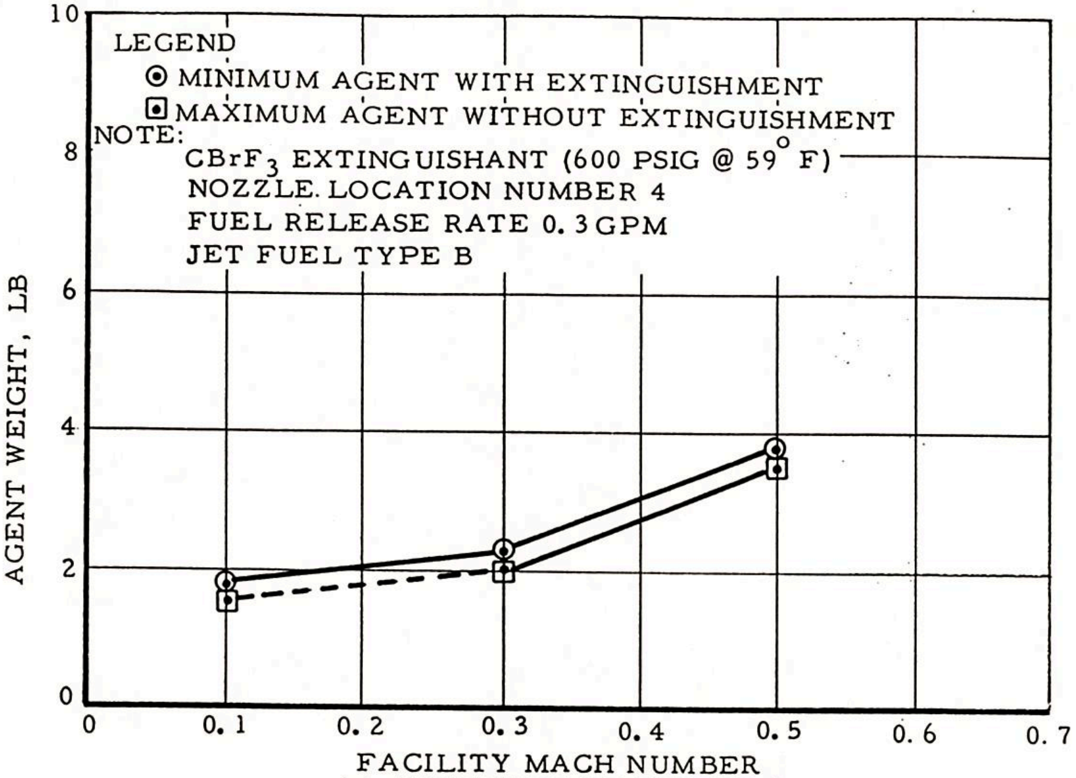
6.7 seconds after attempting to extinguish a Schedule C fire with 5 pounds of $CBrF_3$. Another test run in which a violent reignition occurred resulted in the left side cowling being completely blown off and the right side cowling being sprung open. The reignition of a Schedule B fire occurred 9.6 seconds after discharging 3-1/2 pounds of $CBrF_3$. This run was preceded by a run conducted under identical test conditions where 4 pounds of $CBrF_3$ extinguished the fire. Flame propagation rates as high as 75 and 95 fps and air temperature rises at rates of 4500°F per second were calculated for these two reignitions.

Effects of Flight Conditions on Extinguishment: Test results indicated that the required quantity of extinguishment generally increased with flight speed. As shown in Figure 37, more than 2-1/3 and 1-3/4 times as much extinguishing agent was needed at a 0.5 Facility Mach Number as compared to a 0.1 Facility Mach Number for Schedules A and B fires, respectively.

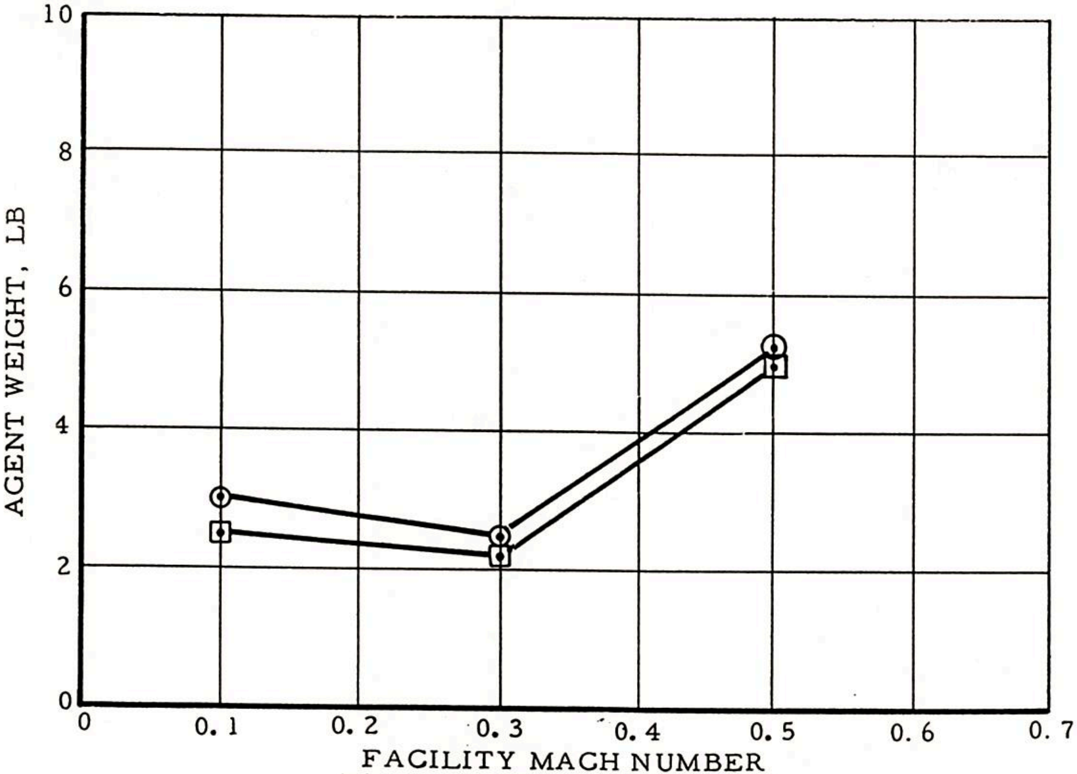
Test results also indicated that the fire extinguishing agent requirements substantially increased when the agent container was located in an area simulating the low temperatures of an unheated compartment at high flight altitudes. The minimum agent requirements at a simulated 30,000-foot altitude exposure to approximately -50°F temperature were determined and compared with requirements at sea level (59°F temperature). Table XIV lists the test conditions and results for each of the three extinguishants involved in this study. The results show comparative weight increases ranging from 25 to 57 percent for bromochlorodifluromethane ($CBrClF_2$) to between 56 and 73 percent for dibromodifluoromethane CBr_2F_2 when exposed to the low temperature. This increase is considered to result primarily from a decrease in the nitrogen pressure in the agent container and the effects of temperature on agent volatility.

To demonstrate the effects of increased nacelle ventilation on the fire extinguisher system requirements, modifications were made to the nacelle installation. The nacelle secondary cooling airflow was increased by installing additional blast tubes and removing the cowl door portion of the vertical fireseal. A detailed description of this opened engine compartment fireseal configuration is presented in Appendix III. It is estimated that these modifications more than doubled the nacelle ventilation rate. The results of comparative tests with and without the above modifications are summarized in Table XV for two fire situations. For the Schedule A and Schedule B fires, increases in the required agent weight for extinguishment were greater than 87 and 38 percent, respectively.

During the longer duration Schedule C fires, the formed rubber seals used in the Constant Speed Drive (CSD)/generator cooling air venturi were frequently damaged. When these seals were damaged, high



(a) SCHEDULE OF EVENTS A



(b) SCHEDULE OF EVENTS B

FIG. 37 - EFFECT OF FLIGHT SPEED ON FIRE EXTINGUISHMENT

TABLE XIV

FIRE EXTINGUISHING AGENT EFFECTIVENESS AT LOW TEMPERATURE

Jet Fuel Type B　　　　0.5 Facility Mach Number

Agent Formula Halon No.	Nozzle Location No. (1)	Schedule of Events	Fuel Release Rate (gpm)	Nitrogen Charge @ 59°F (psig)	Agent Weight				Agent Weight Increase (percent)
					Normal Temperature (59°F)		Low Temperature (-50°F)		
					Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	
Bromotrifluoromethane	4	A	0.3	600	3 3/4	3 ½	5 3/4	5 ½	>47,<64
$CBrF_3$ 1301	5A	B	1.0	400	1 ½	---	2 3/4	2 ½	>67
Dibromodifluoromethane CBr_2F_2 1201	4	A	0.3	400	4	3 3/4	6 ½	6 ½	>56,<73
Bromochlorodifluoromethane $CBrClF_2$ 1211	5A	B	1.0	400	2	1 3/4	2 3/4	2 ½	>25,<57

Note (1): Location 5A, above the compressor bleed valve control at Nacelle Station Number 145 and 10:30 o'clock with spray directed aft and slightly upward onto engine case.

TABLE XV

EFFECT OF COOLING AIRFLOW ON FIRE EXTINGUISHING REQUIREMENTS

Nozzle Location Number 4
Fuel Release Rate 0.3 gpm

Jet Fuel Type B
Extinguishing Agent CB_rF_3 (1301)
Nitrogen Charge 600psig @ 59°F

		Agent Weight				
		Production Configuration		Open Engine Fire Seal Configuration		
Schedule of Events	Facility Mach Number	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Agent Weight Increase (percent)
A	0.5	3 3/4	3 ½	7 ½	7	>87,<114
B	0.5	5 ¼	5	7 ½	7 ¼	>38,< 50
		Plugged CSD/Generator Cooling Duct (No Leakage)		Normal CSD/Generator Cooling Duct (Leakage)		
		Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	
C	0.3	4 ½	---	---	10	>122

velocity engine-fan discharge air entered into the lower forward nacelle area. To determine the degree to which this air leakage affected the performance of the fire extinguisher system, Schedule C tests were repeated with the fan air inlet completely blocked. As summarized in Table XV, less than one-half the amount of extinguishant was required during the tests with the blocked inlet.

Fire Extinguisher System and Agent Effectiveness: The results of tests conducted to determine the relative effectiveness of four different fire extinguishing agents are summarized in Table XVI for two different fire situations. The first fire was the standard 0.3-gpm fuel flow fire at Location 4 with the nacelle in the production configuration. Results on tests under this fire situation indicated that, on a weight basis, $CBrF_3$ and CBr_2F_2 were equally effective and approximately 50 percent more effective than $CBrClF_2$. The second fire resulted from a 1.0-gpm fuel spray at Location 5 with the nacelle in a production configuration except for increased nacelle ventilation due to a 1/2-inch-diameter horizontal hole through the cooling air venturi duct to the CSD/generator. Results of tests with the second fire situation showed that $CBrF_3$ was the most effective; CBr_2F_2 required 40 percent more; and chlorobromomethane (CH_2BrCl) was least effective with a weight requirement almost five times that of $CBrF_3$.

Comparative effectiveness between the conventional nitrogen pressurized fire extinguisher system and a pyrotechnic gas generator type system (Appendix VII) was determined through a series of fire tests. To maintain a consistent flame pattern within the nacelle during the comparative tests and to keep the required quantity of extinguishant within the acceptable limits of the 70-cubic-inch pyrotechnic pressurized container, the following modifications were made to the test installation:

1. The 1/2-inch-diameter hole through the CSD generator cooling air duct was opened to increase the nacelle ventilation.

2. All mating seams and joints of the side cowlings were sealed.

3. A blanking plate was installed on the interstage compressor bleed valve and the overboard discharge vent for this valve was closed and sealed.

The pyrotechnic gas generator container was connected to the two-zone fire extinguisher distribution system at the simulated inboard strut location. The amount of propellant was sized according to the type and quantity of extinguishant.

The test conditions and results of these comparative tests are summarized in Table XVII. A definite decrease in the minimum amount of

TABLE XVI

RELATIVE EFFECTIVENESS OF FIRE EXTINGUISHING AGENTS

	Test Condition I	Test Condition II
Nozzle Location Number	4	5
Fuel Release Rate	0.3gpm	1.0gpm
Type Extinguisher Valve	Cartridge	Solenoid
Schedule of Events	A	B
Nacelle Configuration	Production	Hole in Cooling Duct
Nitrogen Charge @ 59°F	400 psig	400 psig
Jet Fuel Type	B	B

Agent		Agent Weight			
		Test Condition I		Test Condition II	
Formula	Halon No.	Minimum with Extinguishment (1b)	Maximum without Extinguishment (1b)	Minimum with Extinguishment (1b)	Maximum without Extinguishment (1b)
Bromotrifluoromethane $CBrF_3$	1301	4	3 3/4	2 ½	2
Dibromodifluoromethane CBr_2F_2	1202	4	3 3/4	3 ½	3
Bromochlorodifluoromethane $CBrClF_2$	1211	5 3/4	5 ½	---	---
Chlorobromomethane CH_2BrCl	1011	---	---	12	9

TABLE XVII

EFFECTIVENESS OF PYROTECHNIC PRESSURIZED EXTINGUISHER AT NORMAL TEMPERATURE

Nozzle Location Number 4A — Jet Fuel Type B
Fuel Release Rate 1.0 gpm — Schedule of Events B

Agent Formula	Halon No.	Fire Type	Agent Weight				Agent Weight Comparison (percent change) (1)
			Pyrotechnic Pressurized		Nitrogen Pressurized (400 psig @ 70^{o}F)		
			Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	
Bromotrifluoro- methane $CBrF_3$	1301	I	2.2	---	4.0	3.5	>37 Decrease
Dibromodifluoro- methane CBr_2F_2	1202	II	4.0	3.0	2.0	---	>50 Increase
		III	2.5	---	2.5	2.0	< 25 Increase and possible reduction
Bromochlorodi- fluoromethane $CBrClF_2$	1211	I	---	4.2	4.5	---	< 7 Decrease and possible increase
		IV	3.0	2.5	3.5	3.0	< 29 Decrease
Chlorobromo- methane CH_2BrCl	1011	V	3.0	---	8.0	6.0	>50 Decrease

Note (1): Percent increase or decrease in the agent weight requirements for the pyrotechnic pressurized system as compared to the nitrogen pressurized system.

$CBrF_3$ and CH_2BrCl extinguishants required occurred with the pyrotechnic pressurized system. Results of tests with $CBrClF_2$ extinguishant were not as definite. In one case, a relatively small agent weight reduction was obtained with the pyrotechnic pressurized system while another case resulted in a probable increase. Test results with CBr_2F_2 extinguishant were similar to those obtained with $CBrClF_2$. The weight of CBr_2F_2 required to extinguish one of the two types of fires showed a substantial increase for the pyrotechnic pressurized system. The cause of the variation in system effectiveness with the type of extinguishant was not investigated. However, since the effects of such factors as (1) agent discharge temperature, (2) rate of discharge, (3) burst pressure of outlet disc, and (4) the size and type of propellant on the agents are not known and since these factors were not test variables, it is theorized that the conditions of test may have been more favorable for one agent than another.

The flame pattern, at the time of activating the fire extinguisher system, was studied for each test run in this series to assure that comparisons between the two systems were made for identical fire conditions. As listed in Table XVII, changes in the flame pattern occurred several times as testing progressed. Because of the different types of fires, a comparison of the effectiveness of the various types of fire extinguishing agents cannot be made in all cases.

The relative effectiveness of the pyrotechnic and nitrogen pressurized systems was also examined for a simulated 30,000-foot altitude exposure to approximately $-50^{o}F$ temperature environment. As shown in Table XVIII, the pyrotechnic pressurized system reduced the required weight of the three extinguishants tested ($CBrF_3$, CBr_2F_2, and CH_2BrCl) by more than 50 percent.

Since the hot propellant gases mix with and vaporize the liquid agent before leaving the container, it was not considered critical that the outlet fitting be positioned below the container as required for the conventional nitrogen pressurized system. To demonstrate this, a series of tests was conducted with a cold pyrotechnic container positioned with outlet fitting on top. Under these conditions, quantitites as low as 3.1 pounds of CBr_2F_2 agent extinguished Type II fires. This compares to tests under the same conditions in which 3 to 4 pounds of CBr_2F_2 (Table XVII) were required for a pyrotechnic discharge at room temperature with the outlet fitting at the bottom of the container. Under these limited test conditions, the cold pyrotechnic container with top discharge was as effective and probably more effective than a pyrotechnic container at room temperature with the outlet fitting on the bottom.

During the 41 test runs with the pyrotechnic pressurized system, three failures of the container occurred. Two were structural

TABLE XVIII

EFFECTIVENESS OF PYROTECHNIC PRESSURIZED EXTINGUISHER AT LOW TEMPERATURE (-50°F)

Nozzle Location Number 4A
Fuel Release Rate 1.0 gpm

Jet Fuel Type B
Schedule of Events B

Agent			Agent Weight				
			Pyrotechnic Pressurized (Low Temperature)		Nitrogen Pressurized (400 psig @ 70°F) (Normal Temperature)		
Formula	Halon No.	Fire Type	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Minimum with Extinguishment (lb)	Maximum without Extinguishment (lb)	Agent Weight Reduction (percent)
Bromotrifluoromethane $CBrF_3$	1301	VI	2.2	---	7.2	5.5	>60
Dibromodifluoromethane CBr_2F_2	1202	VI	2.5	---	8.0	5.0	>50
Chlorobromomethane CH_2BrCl	1011	VI	2.5	---	6.0	5.5	>55

failures of the outlet fitting during discharge with the resultant loss of extinguishant. The third was a failure of the propellant chamber burst disc without ignition of the propellant. The extinguishing agent was not discharged since the ignitor was expended without igniting the propellant and building up the pressure required to rupture the outlet burst disc.

Effectiveness of Oxygen and Fuel Starvation in Controlling Nacelle Fires: A series of tests was conducted to investigate the effectiveness of cooling air and fuel shutoff as means of controlling a nacelle fire without the use of a fire extinguisher system.

Prior to conducting the cooling air shutoff test runs, the cowling bast tubes were sealed and an auxiliary air supply with a shutoff valve was routed into the nacelle compressor and accessory section and manifolded to each of the blast tube outlet locations. To minimize air leakage, all joints, seams, and the interstage compressor overboard vent were sealed and the CSD/generator cooling duct removed and blanketed off. This provided a nearly airtight seals at all the known locations where air entered the nacelle. The openings in the vertical engine fireseal, the drain vent, and the drain holes were not sealed. Three test runs were conducted with the test engine operating at maximum cruise thrust and with a 0.5 Facility Mach Number. Under these conditions, 0.3 gpm of Jet B fuel was releasted and ignited at Location 4 with auxiliary cooling air flowing into the nacelle at rated from one-half to three-fourths of a pound per second. After 25 seconds of fire and with the spark ignitor deactivated, and fuel continuing to flow, the cooling air was shut off, with and without the test engine being retarded to cutoff. In all three cases, the fire relocated and continued to burn for an additional 25 seconds at which time it was extinguished by a secondary carbon dioxide system. To successfully control the fire by oxygen starvation, it was considered necessary to detect and extinguish the fire before fire related air leakage occurred. Since previous testing had indicated that a 40-second fire substantially increases the amount of air leakage, it was considered necessary to detect and extinguish the fire prior to this time.

These tests were repeated under the same conditions except for the following:

1. The cooling air manifold was replaced by tubing which directed air down both sides of the engine forward of the front mounts from the passage into the forward strut fairing.

2. Jet B fuel at 1.0 gpm was leased at Location 4A, forward of the main fuel filter at Nacelle Station Number 128 and 6:30 o'clock, with the spray directed horizontally inboard and slightly aft onto the side cowling.

The results for each run were essentially the same as the previous test series; the fire relocated and continued to burn. The fire was extinguished by the secondary carbon dioxide system approximately 20 seconds after shutting off the air supply.

The test conditions and results of the tests conducted to investigate the effectiveness of a fuel shutoff valve as a means of controlling a nacelle fire without a fire extinguisher system are summarized in Table XIX. In most cases, the fire diminished in size and frequently in intensity when fuel was shut off. Whether or not the fire continued depended on the location and size and duration of the simulated leak. A long duration (47 seconds) 0.3 gpm fuel leak near the nacelle drain holes burnt out shortly after fuel was shut off. When the size of this leak was increased (1.5 gpm for 17 seconds), the fire continued to burn after the fuel was shut off. Likewise, even a short duration (14 seconds) 0.13 gpm fuel leak near the top of the engine in an area where fuel could accumulate continued to burn after the fuel was shut off.

<u>Flammable Fluid Shutoff Requirements</u>: The need for minimizing the quantities of fuel and oil which could flow into and within a designated fire zone was investigated.

The tests involving the fuel system concerned determining hazards associated with having the fuel shutoff valve at a location away from the fire zone. In such an installation, the quantity of fuel trapped between the shutoff valve and the fuel control could leak into the fire zone after closing the fuel shutoff valve. As previously discussed in this report, the fire continues as long as fuel continues to leak and may continue after the fuel is shut off. Additional testing to demonstrate the need for a system to extinguish the fire being fed by fuel trapped between the shutoff valve and fuel control were considered unnecessary. However, consideration was given to hazards associated with suddenly releasing the trapped quantity of fuel into an existing fire. Three tests were conducted in which 1-1/2 gallons of Jet B fuel were released into a fire at rates of 9 and 40 gpm. A fire resulting from releasing and igniting 1.0 gpm of Jet B fuel at Location 4 had been burning for 15 seconds when the simulated trapped fuel was released at 2:00 o'clock above the fuel oil cooler onto the side cowling. In each of the three test runs, the fire relocated but did not show a substantial change in size and intensity. Since other tests have indicated that the 1.0-gpm fuel fire burned rich, it was theorized that had the initial leak been relatively small, the additional fuel would have increased the size of the fire.

The tests conducted to evaluate the need for a shutoff valve in the engine lubricating system were designed to simulate a failure of an oil line or the rupture of the oil tank during a nacelle fire.

TABLE XIX

EFFECTIVENESS OF FUEL STARVATION IN CONTROLLING NACELLE FIRES

Jet Fuel Type B
0.5 Facility Mach Number

Engine Schedule: Maximum cruise to cut off @ shut down time indicated

Nozzle Location Number	Fuel Release Rate (gpm)	Time of Events (Zero Time @ Fuel Release Initiated) Engine Shut Down (sec.)	Time of Events (Zero Time @ Fuel Release Initiated) Fuel Release Discontinued (sec.)	Time of Events (Zero Time @ Fuel Release Initiated) Fire Extinct (sec.)	Factor Causing Extinguishment
4	0.3	10.5	17.1	23	Fuel Starvation
4	0.3	41.4	46.9	53	Fuel Starvation
4	1.5	10.4	17.1	31.4	Carbon Dioxide Extinguisher
5A	1.0	5.9	8.6	42.6	Carbon Dioxide Extinguisher
5A	1.0	11.6	12.5	61.5	Carbon Dioxide Extinguisher
5A	1.0	11.2	12.4	35.7	Carbon Dioxide Extinguisher
5A	0.3	12.6	12.6	42.7	Carbon Dioxide Extinguisher
5A	0.3	6.5	14.7	37.6	Carbon Dioxide Extinguisher
5A	0.13	6.6	13.7	31.0	Carbon Dioxide Extinguisher
5A	2.5	11.2	13.9	50.7	Carbon Dioxide Extinguisher

The test conditions and results are presented in Table XX. The results indicated that when the initial leak was relatively small, the addition of oil tended to increase the size and intensity of the fire and when the initial leak was relatively large, the addition of oil tended either to not substantially change or to decrease the size and intensity of the fire.

TABLE XX

RESULTS OF LUBRICATING SYSTEM SHUTOFF REQUIREMENT TESTS

0.5 Facility Mach Number
Test Engine @ Maximum Cruise Power

Jet Fuel Type B
Lubricating Oil MIL-L-7808
Oil Release Location - 2:00 o'clock above the Fuel Oil Cooler onto Side Cowl Door

			Time of Events (Zero Time @ Fuel Release Initiated)			
Fuel Nozzle Location	Fuel Release Rate (gpm)	Oil Release Rate (gpm)	Oil Release Initiated (sec.)	Oil Release Discontinued (sec.)	Fuel Release Discontinued (sec.)	Remarks
4	0.3	13.5	10	30	50	Fire moved toward bottom of nacelle during oil release without substantially increasing fire size and intensity.
4A	0.3	13.5	10	30	45	Fire increased in size and intensity during oil release.
4A	1.0	13.5	15	35	50	Fire decreased in size and intensity during oil release.
4A	1.0	4.5	15	75	92	Fire decreased in size and intensity during oil release.

Fire Resistance and Damage

Introduction: Commercial transport aircraft fire protection includes provisions for preventing the spread of fire from one engine compartment to another and to other areas of the aircraft, and for preventing the failure of vital equipment and structural components before the fire can be brought under control.

The fire resistance characteristics of the test installation were studied in an attempt to show areas of weakness and strength as design considerations for future aircraft. The specific objectives of this study were to provide information on the following:

1. The effects of fires and explosions on the cowling, structural components, accessories, combustible fluid systems, and electrical systems of the nacelle and strut.

2. The effectiveness of the engine fireseal and strut firewalls in preventing the spread of fire.

3. The amount and type of damage sustained as a function of the length of time nacelle fires burn uncontrolled.

The Fire Resistance and Damage Investigation was limited to the environmental conditions, the structural design, and the system components of the test engine installation and to the wind tunnel simulated flight capabilities. The investigation was further limited to fuel fires having durations less than 2-1/4 minutes and to simulated failures external to the engine case in which the installation was intact at ignition.

Test Equipment and Procedures: The majority of the fire resistance and damage reported herein was obtained during the initial testing and at the same time fire characteristics and detection were investigated. The fuel release and ignition systems, the fuel release locations and the basic test procedures are described in the Fire Characteristics Section of this report. A limited amount of the reported damage was obtained during the Fire Control and Extinguishment Investigation.

The results were based on damage which occurred with the nacelle in a production configuration. In this configuration, the compressor and accessory section was separated from the combustor and turbine section by the engine fireseal. As mentioned previously, this fireseal had an annular opening around the engine and several holes above the engine which allowed air to move between the forward compartment and the compressor and turbine section. The strut was separated from the engine compartments by a horizontal firewall above the engine and a vertical firewall at the forward strut fairing seam line. The cowl door skin was 0.040-inch-thick aluminum. The skin above the engine, extending approximately 45° on both sides of the vertical centerline of the engine, was internally backed with 0.010-inch thick steel. The external skin surface was painted to facilitate photography and television monitoring.

The engine installation was inspected for damage after the completion of each fire test. If damaged, the cowl doors and forward strut fairing were replaced or repaired before the next test. If damaged to the point of failure, internal nacelle structure and components were also either repaired or replaced prior to the next test in an attempt to return the installation to near original condition. Once an item proved to be highly susceptible to damage by fire, means were taken to protect it or to replace it with a material having better fire-resistance characteristics. Once an item was protected or replaced, the durability under fire conditions was generally increased and subsequent damage is not reported.

Appendix VIII and Reference 3 contains detailed information on the condition of the test engine, nacelle, and strut at the completion of the fire test program.

Cowl Doors and Forward Strut Fairing: The nacelle skin with high velocity airflow over the external surface was highly resistant to damage from internal nacelle fires. An internal fire did not burn through the skin into the external airstream throughout the entire test program. Buckling of the skin and the occasional loss of rivets were the only evidence of fire on the external skin surface although, in many cases, internal bracing and stiffeners were melted or burned out. The painted surface of the nacelle skin seldom discolored due to the internal fires even in areas where there was evidence of high heat concentrations internally.

Cowl door and forward strut fairing internal aluminum brackets, bracing, stiffeners, flanges, and air blast tubes were frequently melted, cracked, and buckled as a result of the nacelle fires. An example of this type of damage is shown in Figure 38. Supports and components of the cowl door and forward strut fairing latches and aligning pins were also frequently damaged by fire. During one test, the left side of the forward strut fairing was partially opended as a result of damage to a latch (Figures 39 and 40).

The drain vent and pressure relief door located on the bottom of the left cowl door forward of the engine fireseal were highly susceptible to damage. The aluminum louvers in the drain vent opening and

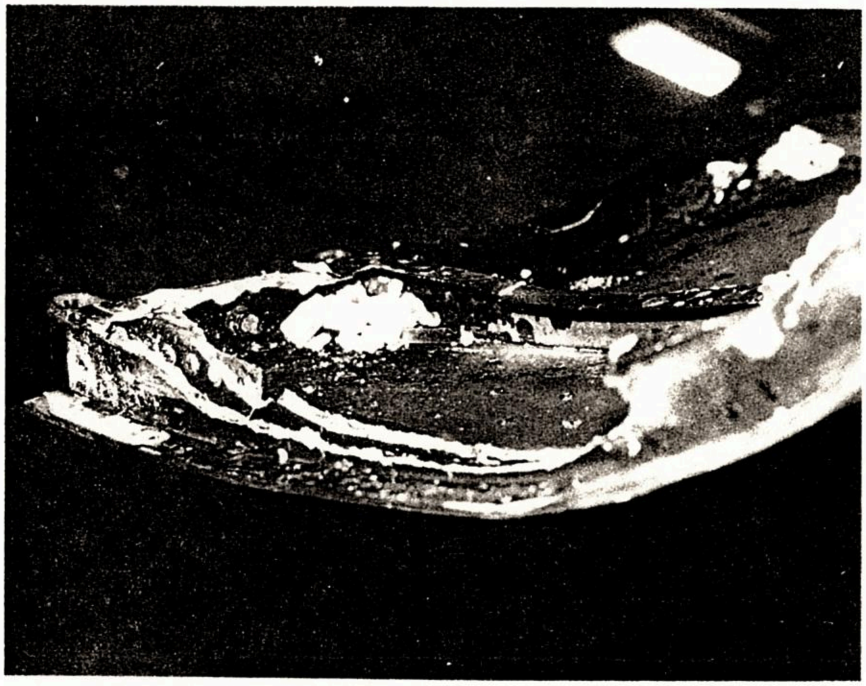


FIG. 38 - DAMAGED INTERNAL BRACING AT BOTTOM FORWARD END OF LEFT COWL DOOR

FIG. 39 - DAMAGED LATCH AND SEAM OF FORWARD STRUT FAIRING, EXTERNAL LEFT SIDE VIEW

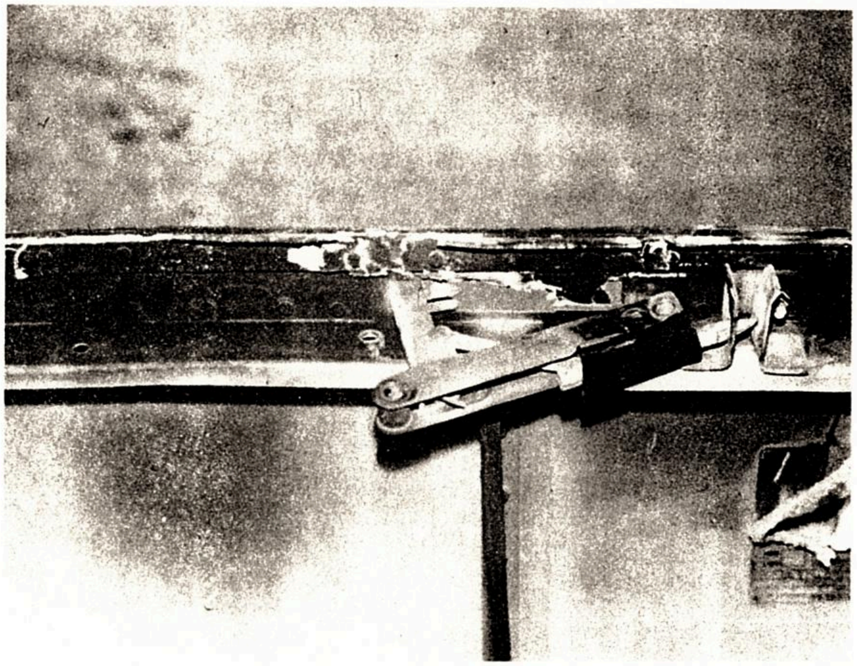


FIG. 40 - DAMAGED LATCH AND SEAM OF FORWARD STRUT FAIRING, INTERNAL LEFT SIDE VIEW

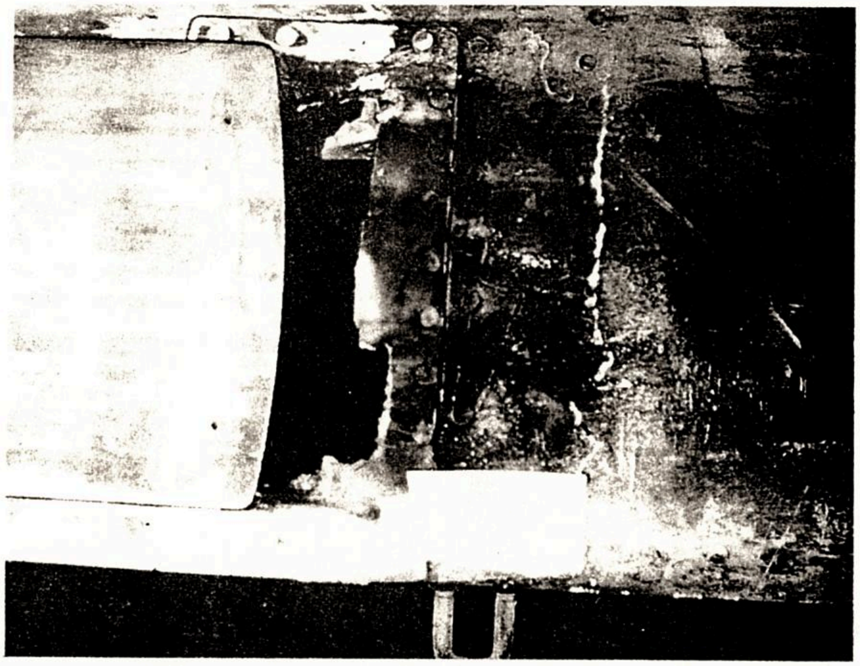


FIG. 41 - DAMAGED DRAIN VENT, LOUVERS AND SKIN, EXTERNAL VIEW

the surrounding structural framing were readily burned out and the size of the opening increased. Examples of damage in the area of the drain vent and pressure relief door are shown in Figures 41 and 42. The retainer springs shown in Figure 42 for the pressure relief door frequently would lose temper and allow the door to partially open. Fires which egressed from these openings burned with high intensity on the external surface of the skin downstream of the drain vent. The fire then frequently melted the aluminum skin and stiffeners and re-entered the nacelle aft of the engine fireseal (Figure 43).

Fires originating in the upper half of the nacelle damaged the area along the horizontal hinge lines which formed the mating seam between the cowl doors and strut. As shown in Figure 44, the fire opened external surface. The damage consisted of buckling and cracking the mating surfaces, and burning out the phenolic rub strip, the aluminum filler strip, and the aluminum skin. The 0.01-inch steel backing prevented the gap from increasing beyond that which occurred as a result of buckling and the burned out skin and rub strip.

Fire egress from the mating butt seam between the cowl doors at the bottom of the nacelle was common when fires were started below the engine. As shown in Figure 45, the fire buckled and burned out the internal structure and skin along the seam leaving a sizable gap. Frequently, this seam was damaged downstream of the drain vent as a result of the fires which egressed from the drain vent. Figure 46 shows damage to the butt seam resulting from the drain vent fire.

The area surrounding the drain holes in the bottom of the cowl doors was not damaged during any of the fire test runs. Motion picture coverage of this area of the nacelle frequently recorded fires as viewed through these 1/2-inch-diameter holes. This film coverage and the lack of apparent damage at the holes into the external airstream.

The rubber seal between the intercompressor bleed valve and the surge bleed door in the left cowl door was susceptible to damage from fire. Once this seal failed, the fire egressed through the surge bleed door and burning occurred in the airstream on the external surface of the skin. Fires also entered the airstream in a similar manner at the engine breather port. In both cases, the fire on the external surface often melted the skin and stiffeners and opened the nacelle. An example of this is shown in Figures 47 and 48 for a fire which burned through the surge bleed door.

Fire also egressed at the mating seams between the forward strut fairing and (1) the fan cowl and fan thrust reverser sleeve, and (2) the vertical strut firewall (Figures 49 and 50). Fires originating in the forward compartment frequently followed the cooling airflow

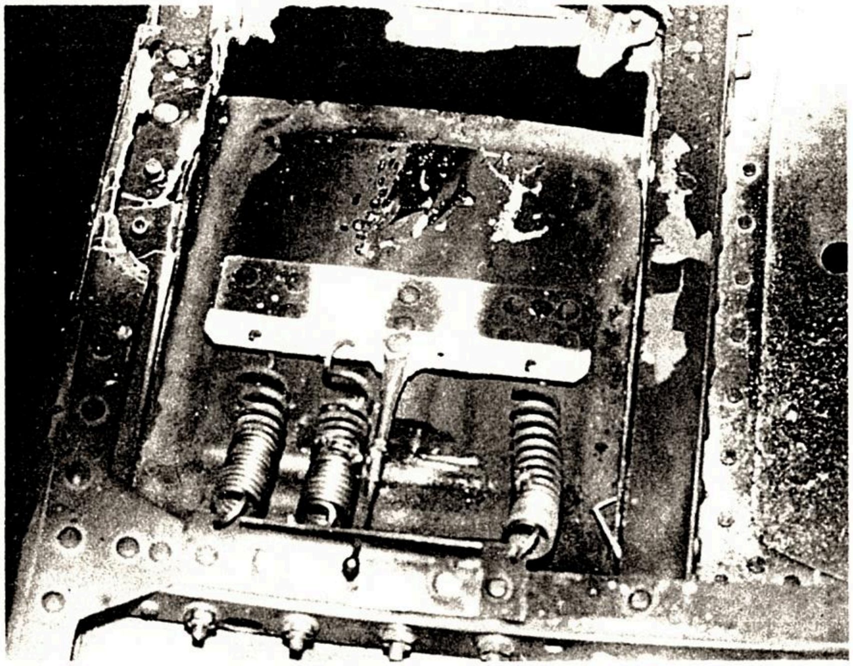


FIG. 42 - DAMAGED DRAIN VENT AND PRESSURE RELIEF DOOR SPRINGS, INTERNAL VIEW

FIG. 43 - DAMAGED DRAIN VENT (ZONE II) AND AREA OF FLAME RE-ENTRY (ZONE I)

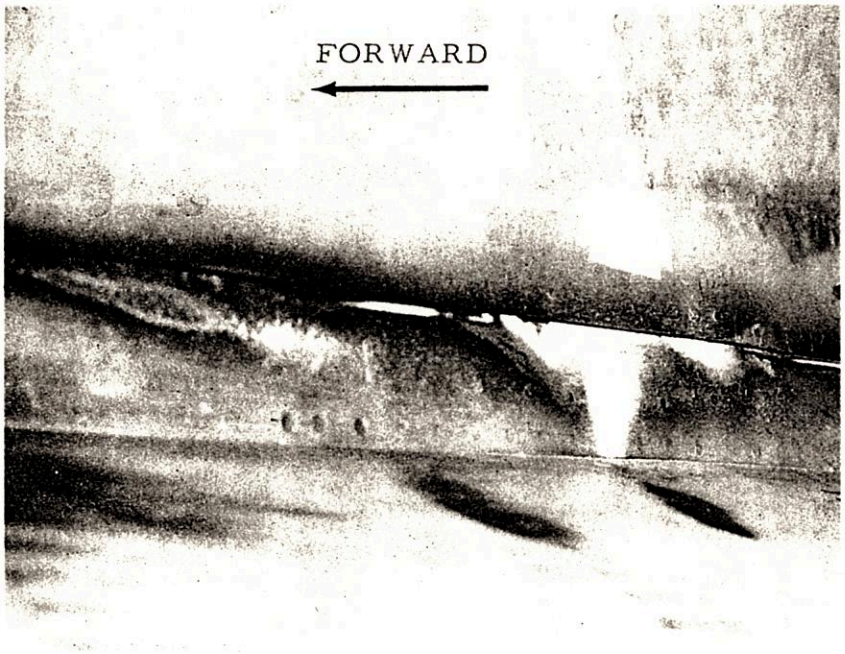


FIG. 44 - DAMAGED HORIZONTAL HINGE LINE, LEFT SIDE VIEW

FIG. 45 - DAMAGED COWL DOOR BUTT JOINT, BOTTOM VIEW

FIG. 46 - DAMAGED DRAIN VENT AND COWL DOOR BUTT, JOINT, BOTTOM VIEW

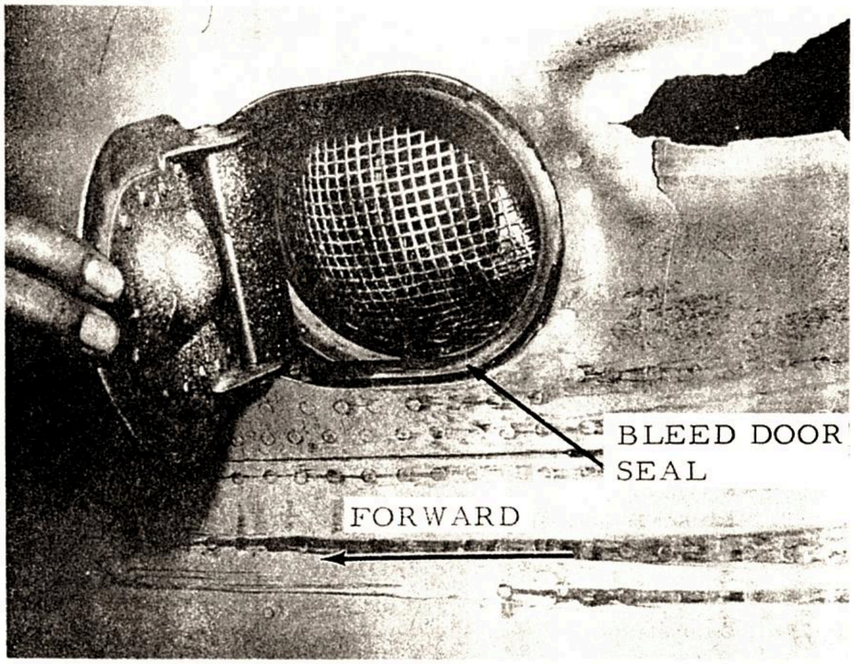


FIG. 47 - DAMAGED SURGE BLEED SEAL AND COWL DOOR, EXTERNAL VIEW

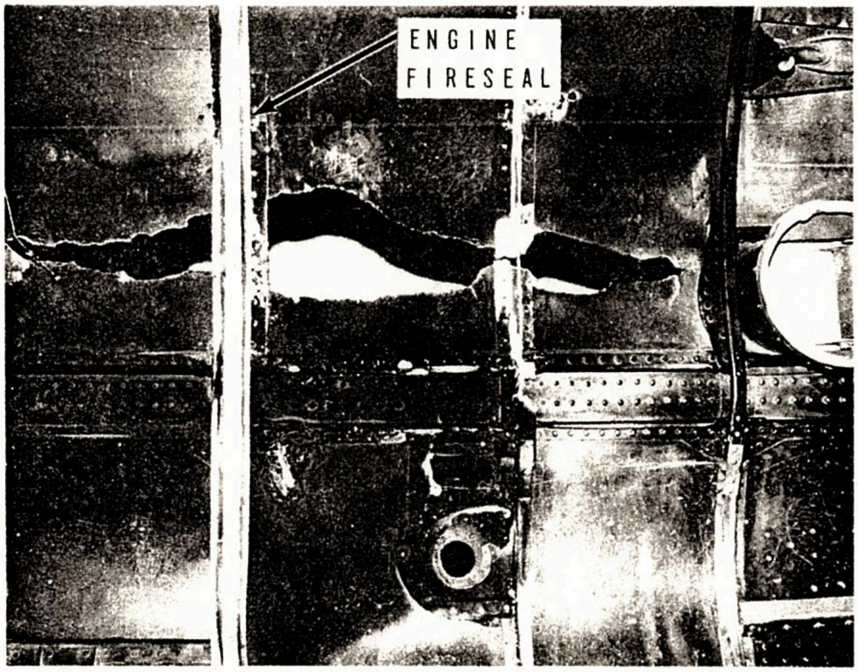


FIG. 48 - DAMAGED SURGE BLEED SEAL AND RESULTING COWL DOOR DAMAGE, INTERNAL VIEW

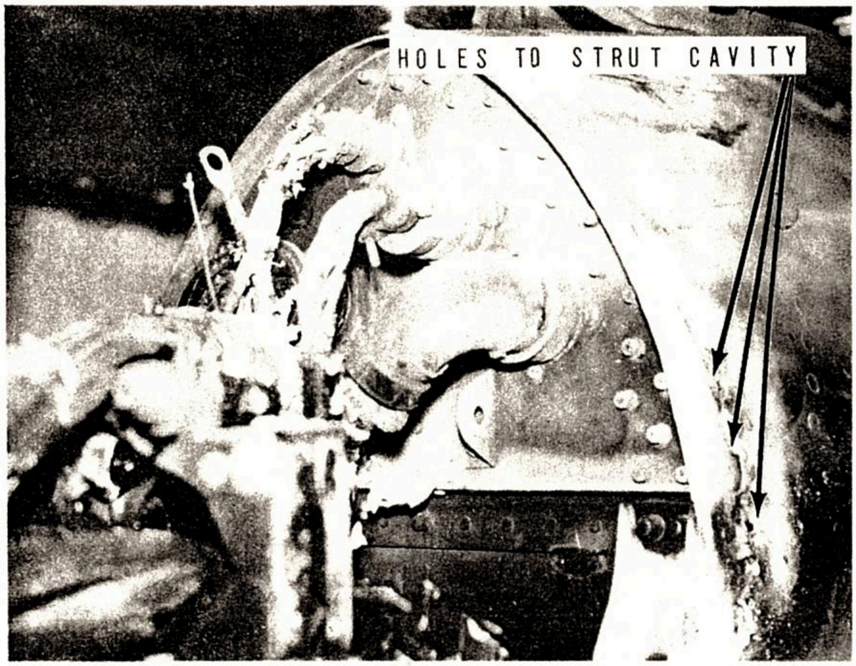


FIG. 49 - DAMAGED STRUT DOWNSTREAM OF FORWARD STRUT FAIRING

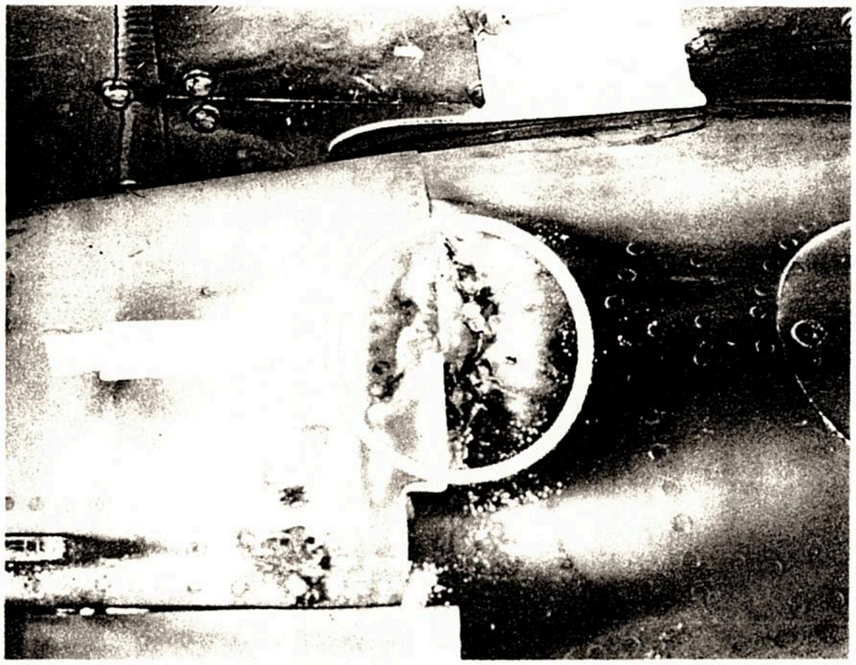


FIG. 50 - DAMAGED FORWARD STRUT FAIRING AND STRUT MATING SEAM

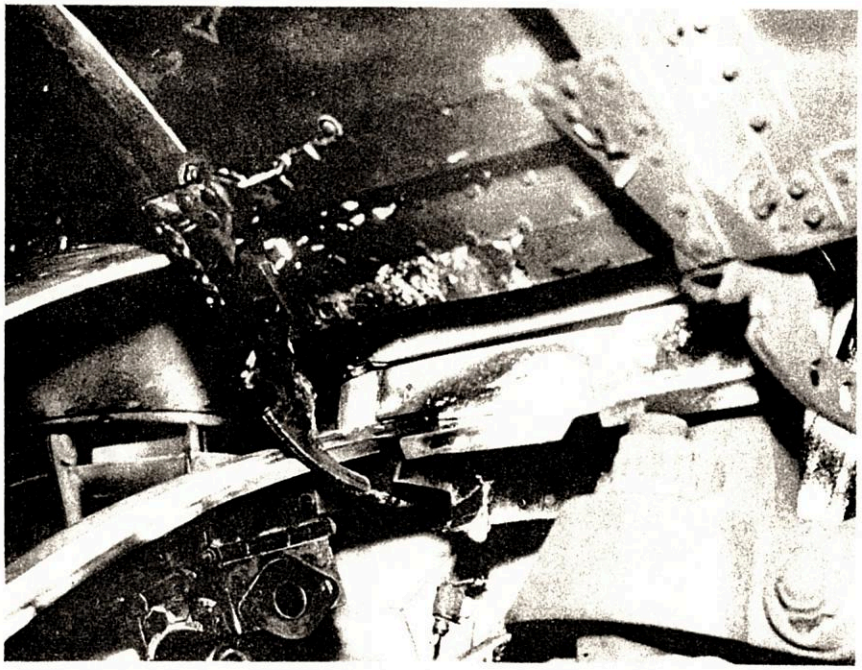


FIG. 51 - DAMAGED FORWARD HINGE AND UPPER ATTACHMENT POINTS ON LEFT COWL DOOR

through the chimney into this fairing and out the mating seams. The fires which egressed from the overlapping-type seam at the vertical strut firewall melted the strut skin. The damage shown in Figures 49 and 50 resulted from a fire which was allowed to burn for approximately 1 minute before discharging extinguishing agent. After approximately 20 seconds, the fire broke through the seam and burning could be seen on the surface of the strut. Inspection following this fire revealed three pencil-size holes in the aluminum strut skin.

Firewalls and Fireseals: The horizontal firewall separating the strut from the engine compartments was not penetrated by any of the test fires. Various brackets and stiffeners attached to the underside of this firewall were occasionally damaged and, in several cases, destroyed.

The vertical firewall under the forward strut fairing, separating the forward engine compartment from the strut also was not penetrated by any of the test fires. However, as previously discussed, fires tended to travel around this firewall into the strut cavity.

The engine fireseal separating the compressor and accessory section from the combustor and turbine section did not prevent fire from propagating from one section to the other. Fires originating in the compressor and accessory section produced air temperatures over 1500°F in the aft compartment without either damaging or burning externally around the fireseal. In addition, as previously discussed, fires tended to travel out the drain vent and around the engine fireseal into the aft compartment. In the section of the report covering Ignition Hazards, several cases of fire were reported in which fluids released in the compressor and accessory section ignited at locations aft of the fireseal and propagated into the forward compartment.

Internal Nacelle Structure and Components: The hinge and upper attachment points for the cowl doors were frequently damaged by fire. As shown in Figure 51, the extent of damage in several cases was such that the cowl door was no longer secured at the damaged attachment point. Sufficient restraint was provided by the remaining attachment points and the overlapping hinge line seams to prevent a noticeable gap at the cowl door seams.

The internal nacelle fires also cracked, buckled, and burned out sections of stiffeners and brackets below the horizontal strut firewall and support bracing for the fan air duct.

One nacelle component extremely susceptible to fire damage was the duct assembly which provided fan-discharge air to cool the CSD/generator. The aluminum duct was sealed on both ends by formed rubber gaskets (Figure 52). Fire in this region of the nacelle

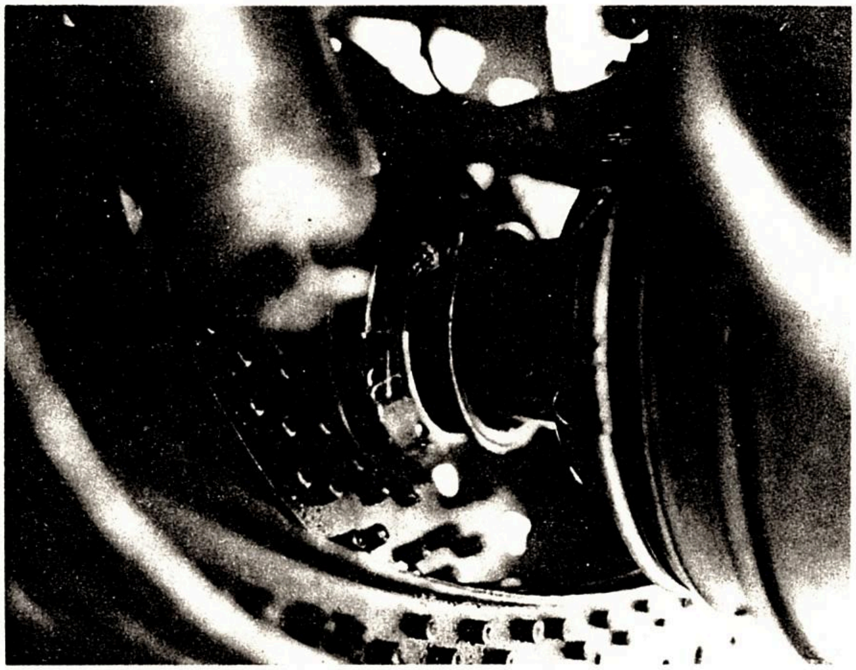


FIG. 52 - CSD/GENERATOR COOLING AIR DUCT ASSEMBLY

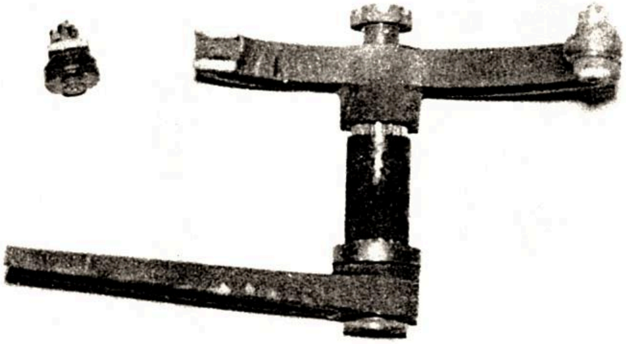


FIG. 53 - FAILED THRUST REVERSER BELL CRANK

consistently burned out the rubber gaskets and the aluminum tube allowing high velocity fan-discharge air to be directed to the fire region. When this occurred, a fire of moderate size and intensity was substantially intensified. As reported in the Fire Control and Extinguishing Section, this failure also produced a fire condition which was difficult to extinguish.

The thrust reverser bell cranks and actuator tubes located beneath the horizontal strut firewall in the forward compartment were destroyed during the initial fires having a duration exceeding 20 seconds. The melted and failed bell crank is shown in Figure 53. The failed actuating tubes appeared to have exploded as a result of the heat expanding trapped gas in the hollow sealed tube (Figure 54).

The engine mount fittings were not damaged by fire and were found to be structurally sound at the completion of the test program. The test engine had accumulated approximately 330 hours of operating time and had been subjected to an estimated 700 fires ranging in duration from 10 seconds to over 2 minutes during the test program. Although the engine was in a deteriorated condition at the end of the program, it did not fail when operated at settings up to the maximum allowable limits set by the manufacturer.

The following items were also damaged by fire to varying degrees of severity during the test program:

1. Start lever safety spring.
2. Drain lines.
3. Engine fireseal (cracked and buckled).
4. Oil pressure transmitter.
5. Oil pressure differential switch housing.
6. Electrical connectors and grommets.
7. Electrical wiring and cabling.
8. Engine thermocouple harness.
9. Clamps and brackets.

Effect of Fire Duration on Damage: The initial 98 fire tests were short duration fires consisting of eighty-three 10-second fires, three 15-second fires, and twelve 20-second fires. During these fires, damage was limited to heat discoloration, carbon deposits, burned drain

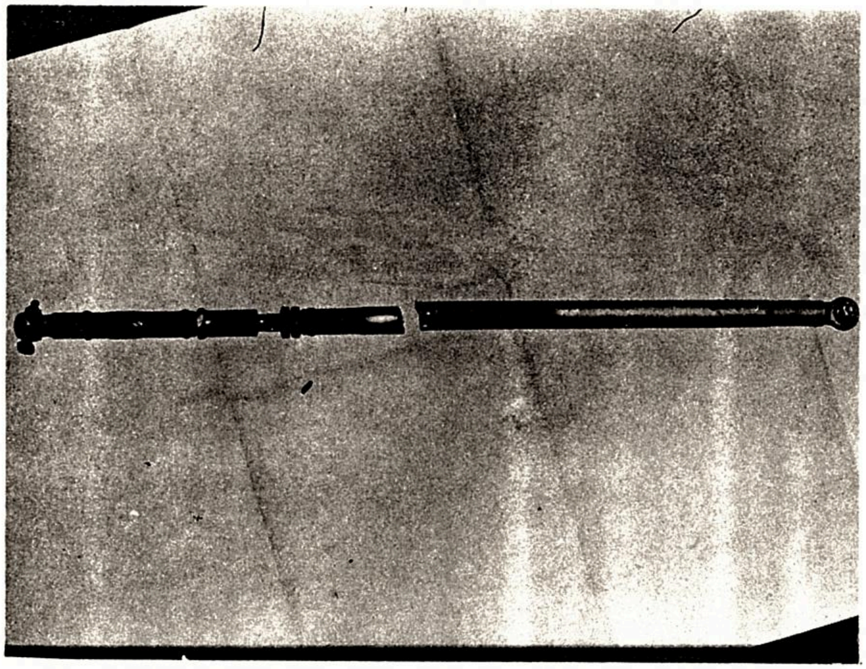


FIG. 54 - FAILED THRUST REVERSER ACTUATOR TUBE

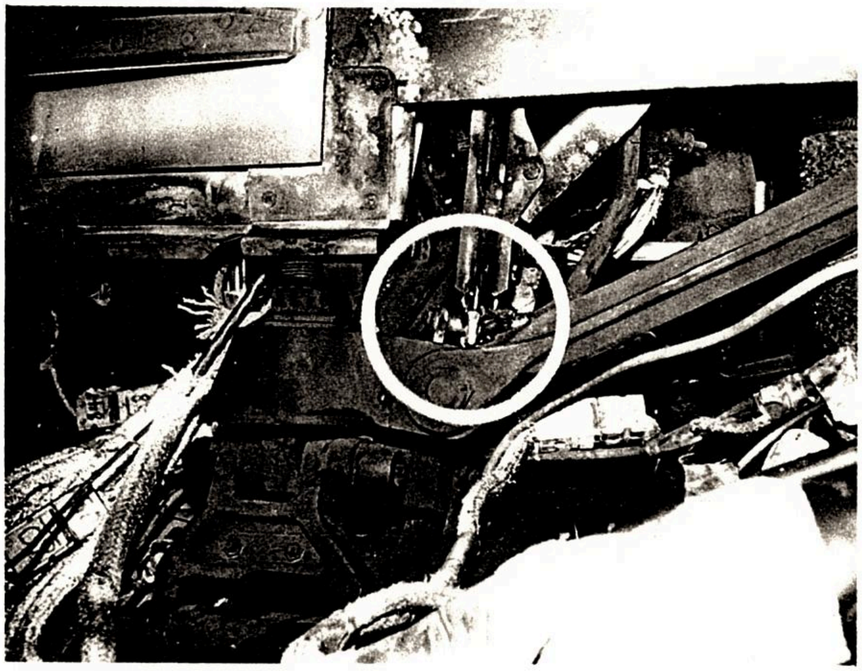


FIG. 55 - FAILED HINGE ATTACHMENT POINT

tubes, and minor buckling and cracking of internal cowl door framing.

The tests generally indicated that damage resulting from fires having a total duration less than 1 minute was limited to failures of drain tubes, springs, wiring, seals, clamps, electrical connectors, brackets, mating seams, the cooling air exit vent, and miscellaneous small components. The tests further indicated that damage from fires having a total duration greater than 1 minute and less than 2-1/4 minutes included failures of stiffeners, hinge supports, bell cranks, actuating tubes, portions of the cowl door and strut skin and ribs, blast tubes, and cooling air ducts.

Damage from Explosions: Explosions occurred as a result of (1) fuel vapors reigniting following extinguishing system discharge and agent dissipation and (2) fuel vapor buildup prior to ignition. The explosive reignitions occurred after a fire had burned for a period of time and after engine shutdown. The first explosion of this type resulted in the following damage to the nacelle:

1. All hinge and attachment points and support bracing for the cowl doors were either broken, bent, or pulled out (Figure 55).

2. The aft thrust reverser sleeve was forced partially open producing a 1/2-inch gap at the cowl door mating seam.

3. The cowl doors were opened along the hinge line (Figure 36).

4. The cowl door skin and stiffeners were buckled.

The damage from the second severe explosive reignition was similar except the left cowl door was completely blown off and the right cowl door was opened at the bottom. The aft thrust reverser sleeve was also punctured by the left cowl door as it was carried down the tunnel with the airstream.

The second type explosion occurred with the engine operating and with the high velocity fan air flowing over the cowl doors. The most severe delayed ignition-type explosion resulted in the following damage to the nacelle:

1. The left cowl door was blown off.

2. The right cowl door was opened and the skin peeled off by the fan air.

3. The main fuel line to the fuel pump was ruptured by the left cowl door.

4. All hinge and attachment points and support bracing were either torn or bent.

5. The oil tank and the retaining strap received minor damage.

6. The power lever controls and throttle linkage were bent.

7. The fireseal above the engine was buckled.

The failed fuel line resulted in a large quantity of fuel being released into the tunnel airstream. The fire was apparently extinguished by the explosion and the released fuel did not ignite.

The explosion forced the left cowl door out away from the engine and the forward edge struck the test section wall at Nacelle Station Number 142. This indicated that the cowl door moved out 3 feet through an airstream ranging from transonic to 0.5 in Mach Number while moving aft a distance of only 15 inches. This demonstrates the potenial danger to an adjacent wing or fuselage structure.

SUMMARY OF RESULTS

Ignition Hazards

The significant findings obtained as a result of the Ignition Hazards Investigation are as follows:

1. Hot surface thermal ignition of flammable fluids with the test installation in a production configuration:

   a. Occurred infrequently under steady-state simulated flight conditions when the simulated leak was located in the combustor and turbine section.

   b. Did not occur under steady-state simulated flight conditions when the simulated leak was located in the compressor and accessory section.

   c. Occurred frequently in the combustor and turbine section only under transient simulated flight conditions with the simulated leak located in either engine compartment.

2. Hot surface thermal ignition of flammable fluids did not occur with the test installation modified to increase the cooling airflow and to provide relatively unrestricted air movement between the two engine compartments. These tests were limited to steady-state simulated flight conditions with the simulated leak located in the compressor and accessory section.

3. Hot surface thermal ignition of flammable fluids frequently occurred at low airflows with the test installation modified to control the cooling airflow over the engine combustor and turbine case. These ignitions occurred under both stady-state and transient simulated flight conditions.

4. As determined by the lowest environmental temperature level under which ignition occurred under comparable test conditions, the relative order in which the fluids tested were ignited by hot surfaces generally was (a) jet-aircraft-type, commercial fire-resistant hydraulic fluid, no ignitions, (b) Type B jet fuel, (c) Mil-L-23699 lubricating oil, (d) Mil-L-7808 lubricating oil, (e) Type A jet fuel, and (f) Mil-H-5606 hydraulic fluid, most easily ignited.

5. Hot surface thermal ignition of Jet Type A fuel occurred at lower steady-state engine power settings and at higher ventilation rates when spray released as compared to an unpressurized solid-stream-type release.

6. Hot surface thermal ignition of Jet Type B fuel did not occur when spray released under steady-state environmental temperature conditions approaching those which resulted in ignition of unpressurized solid-stream-type releases.

7. The period of time which was necessary for fuel to be released prior to a hot surface thermal ignition decreased as the engine case temperature level was increased.

8. The engine case temperatures necessary for ignition were lowered when (a) the simulated flight conditions were transient as compared to steady-state, (b) the transition from high engine power to idle was at a maximum rate, (c) the nacelle was tightly sealed and ventilation was minimum, and (d) the simulated flight speed was minimum.

9. As the nacelle cooling airflow was increased, the low hot surface ignition limit, as defined by the engine power setting and corresponding case temperature level, also increased.

10. All delayed thermal ignitions of simulated flammable fluid leaks were in the form of explosions, as evidenced by over-pressures, with varying degrees of severity.

11. The longer the time period flammable fluids were released prior to being thermally ignited by the hot engine surfaces the more violent the explosion.

12. Increasing the nacelle cooling airflow in the stagnant-through-low ventilation range (to 41 compartmental air changes per minute) did not prevent the occurrence of severe explosive ignition. However, the severe explosive ignitions occurred only when the increase in airflow was accompanied by an increase in the size of the simulated fuel leak.

13. All three hot surface thermal ignitions involving pressurized spray releases of Type A jet fuel were in the form of relatively violent explosions. These ignitions occurred when the fuel was released under steady-state simulated flight conditions with cooling air ventilation rates ranging from 21 to 40 compartmental changes per minute.

14. The separation of an ignition source from a simulated fuel leak without airtight isolation resulted in explosive-type ignitions. The explosions occurred with both restricted and relatively unrestricted airflow between the simulated leak and the ignition source.

Fire Characteristics

The significant findings obtained as a result of the Fire Characteristics Investigation are as follows:

1. The maximum intensity fires occurred at (a) lower fuel release rates than rates producing the maximum size fires, and (b) fuel spray release rates of or less than 1.0 gallon per minute. The relative size and intensity of the fires were determined by the nacelle volumes where temperatures were above 500°F and 1500°F, respectively.

2. The size and intensity of the fires were significantly greater at maximum cruise engine power than at any other power setting tested. Variation of simulated flight speed had little or no effect on the fire except for runs at maximum cruise power where the size and intensity decreased with increasing flight speed.

3. Temperature measurements indicated that the size and intensity of the Type A jet fuel fires were slightly greater than Type B jet fuel when the leakage rates were compared on a volumetric basis.

4. Fires resulting from leaks near a discharge location for nacelle cooling air at the bottom of the nacelle affected a relatively small portion of the engine compartment environment and produced a slow rate of temperature rise throughout the compartment.

5. The air temperatures aft of the engine fireseal continued to increase significantly as the rate which fuel was released and ignited in the compressor and accessory section was increased (testing limited to a maximum rate of 1.5 gpm of Type B jet fuel).

6. The spray-type fuel fires normally resulted in rapid stabilization of the air temperature environment in the compartment where fuel was released and ignited except when (a) the fire burned through seals or seams, and (b) the fuel release location was near an area where the cooling air exited the nacelle.

7. The fires originating in the nacelle compressor and accessory section spread with the airflow toward one or more of three cooling air exits.

8. The maximum stabilized flame temperature in the nacelle measured during the Fire Characteristics Investigation was 2100°F.

9. The level of visible radiation produced by nacelle fires was not substantially affected by either fuel spray release rate or simulated flight speed. However, the radiation level substantially increased when the engine was operated at the high power settings as compared to idle operation and being shut down and windmilling.

Fire and Overheat Detection

The significant findings obtained as a result of the Fire and Overheat Detection Investigation are as follows:

1. The temperature rise measured in the compressor and accessory section during 10-second-duration fires at two of the fuel release locations tested was considered to be too low for detection by long continuous-type systems, installed to cover the entire section, which respond to the average temperature over the length of sensing element.

2. Temperature measurements indicated that 10 to 15 feet of element would have been necessary for coverage of the 10-second-duration test fires in the nacelle compressor and accessory section by continuous-type detector systems which required heating of only a short length of the element.

3. Temperature measurements indicated that three sensors, one at each cooling air exit, would have been necessary for coverage of the 10-second fires in the nacelle compressor and accessory section by unit- or spot-type detection systems.

4. Temperature measurements indicated that detection by a single temperature-sensitive unit or a short length continuous detector was feasible but would require the alarm set point be minimized and a nacelle design capable of resisting the fire for the time period required for heat to reach the detector.

5. All the intense short duration fires conducted with the nacelle modified to provide a single cooling air exit vent were considered capable of being detected by a sensor at the vent except for fires which interrupted the airflow and produced a stagnant area.

6. The abbreviated continuous fire detection systems located above the engine detected fires occurring in the upper half of the nacelle within one-half minute following ignition.

7. The majority of the fires occurring in the lower half of the nacelle were not detected by the abbreviated continuous-type fire detection systems located above the engine.

8. Flame radiation measurements indicated that a minimum of five sensors at specific locations would have been necessary for coverage of the 10-second-duration fires in the nacelle compressor and accessory section by surveillance fire detector systems.

9. The ability of surveillance fire detectors to respond to fires was limited by the tightness of the nacelle cowling, the blockage provided by engine components, and the lack of reflective radiation. The two surveillance fire detection systems tested with sensors located under the fan-air duct, did not provide alarm signals to many of the fires originating within the compressor and accessory section.

10. The level of radiation at a sensor not in direct line of sight with nacelle fires was too low to be measured by the surveillance fire detector.

11. The surveillance fire detector system sensitive to flame coloration and radiation level normally alarmed within 3-1/2 seconds after ignition for the fires detected.

12. Standard cockpit engine instruments and engine monitoring systems neither provided a reliable nor an early indication of the existence of an abnormal condition during the nacelle fires.

13. Visual indications of engine fires were not always present, and when present, the fire very often was spreading rapidly.

Fire Control and Extinguishment

The significant findings obtained as a result of the Fire Control and Extinguishment Investigation are as follows:

1. The minimum required quantity of fire extinguishing agent was affected substantially by (a) the location of the simulated fuel leak, (b) the fire duration, (c) the simulated flight speed, (d) the temperature of the agent in the container, (e) the nacelle ventilation rate and the amount of air leakage, (f) the type of agent, and (g) the type of fire extinguisher system.

2. The effect of the size of the leak and the size and intensity of the resulting fire on the minimum required quantity of fire extinguishing agent was not substantial.

3. The quantity of agent required for extinguishment was increased by more than 250 percent as the fire duration increased from 10 to 40 seconds.

4. The required quantity of fire extinguishing agent was substantially affected by the flight speed simulated. The minimum required quantity of extinguishant generally increased with flight speed.

5. Fire extinguishing agent requirements increased substantially when the agent container was located in a low temperature area simulating an unheated compartment at high altitude. Increases in the range of 25 to 75 percent were experienced.

6. Increases in the nacelle ventilation rate and the amount of air leakage substantially increased quantity of agent required for extinguishment.

7. On a weight basis, bromotrifluoromethane ($CBrF_3$) was generally the most effective extinguishing agent followed in a decreasing order of effectiveness by dibromodifluoromethane (CBr_2F_2), bromochlorodifluoromethane ($CBrClF_2$), and chlorobromomethane (CH_2BrCl).

8. Comparative effectiveness of the pyrotechnic gas-generator-type fire extinguisher system to the conventional nitgrogen pressurized system showed variations with the type extinguishment from a substantial agent weight reduction to a sizable increase. However, under low temperature conditions, the pyrotechnic pressurized system reduced the required weight of all three agents tested by more than 50 percent compared to the nitrogen pressurized sytem.

9. Explosive reignitions occurred following discharge of the fire extinguisher system when the quantity of agent was sufficient to momentarily extinguish a long duration fire, but insufficient to prevent reignition. The long duration fires apparently heated small exposed metal components of the engine and nacelle sufficiently to reignite the fuel spray after the extinguishing agent dissipated.

10. Shutting off all designed cooling air as a means of controlling a nacelle fire resulted in the fire relocating and continuing to burn.

11. Tests conducted to investigate the effectiveness of a fuel shutoff valve as a means of controlling a nacelle fire showed that the fire in most cases diminished in size and frequently in intensity. Whether or not the fire continued for at least 15 seconds depended on the location, size, and duration of the simulated fuel leak.

12. The sudden release of quantities of fuel or oil into an existing fire did not substantially change the size and intensity of the fire

providing the initial fire was burning rich. When the initial leak was relatively small, the addition of oil tended to increase the size and intensity of the fire.

Fire Resistance and Damage

The significant findings obtained as a result of the Fire Resistance and Damage Investigation are as follows:

1. The nacelle aluminum skin with high velocity airflow over the external surface was highly resistant to damage from internal nacelle fires.

2. Internal aluminum brackets, bracing, stiffeners, flanges, air-blast tubes, the drain vent, and pressure relief door were frequently damaged as a result of the nacelle fires.

3. Burning occurred on the external nacelle surfaces as a result of fires damaging and egressing from the following mating surfaces and seals:

   a. Horizontal hinge lines between cowl doors and the strut.

   b. The butt seam between the cowl doors.

   c. The seal between intercompressor bleed valve and the surge bleed door in the left cowl door.

   d. Seal at the engine breather port.

   e. Forward strut fairing seams.

4. The horizontal firewall separating the strut from the engine compartments was not penetrated by any of the test fires.

5. The vertical firewall at the forward strut fairing seam was not penetrated by any of the test fires. However, fires traveled out this seam into the external airstream, around the firewall, and burned into the strut cavity.

6. The engine fireseal separating the compressor and accessory section from the combustor and turbine section did not prevent fire from propagating from one section to the other.

7. Fires which egressed the nacelle burned with high intensity on the external surface melting the downstream skin and stiffeners.

8. The hinge and upper attachment points for the cowl doors, the CSD/generator cooling air duct assembly, and the thrust reverser bell cranks and actuator tubes were destroyed by fire.

9. The engine mount fittings were not damaged by fire and were found to be structurally sound at the completion of the test program.

10. Although the test engine was in a deteriorated condtion at the end of the program, it was operable. However, testing did not involve long duration uncontrolled fires.

11. Damage resulting from fires having a duration less than 1 minute generally was limited to failures of drain tubes, springs, wiring, seals, clamps, electrical connectors, brackets, mating seams, the cooling air exit vent, and miscellaneous small components.

12. Damage from fires having a total duration greater than 1 minute included failures of stiffeners, hinge supports, bell cranks, actuating tubes, strut skin, blast tubes, and cooling air ducts.

13. Explosions from fuel vapor reigniting following extinguishing system discharge or fuel vapor buildup prior to ignition extensively damaged the engine installation.

14. Portions of the nacelle cowl doors and, in several cases, entire doors were failed by explosions and propelled into areas adjacent to and downstream of the engine installation.

CONCLUSIONS

Based on the results of full-scale fire tests with the turbofan engine installation used, it is concluded that:

1. Explosive hot surface thermal ignitions of flammable fluid leaks can occur when high compartment environmental temperatures (including elevated air temperatures and on the order of 900°F or greater surface temperatures) exist on engine installations.

2. Violent explosive ignitions or reignitions of flammable fluid leaks can occur on engine installations when:

   a. The compartment environmental temperatures are just sufficient to cause a hot surface thermal ignition.

   b. The ignition occurs during an engine power change.

   c. The flammable fluid systems and potential ignition sources are not located in separate compartments with airtight isolation between.

   d. The fire burns for approximately 30 seconds or longer before discharging a quantity of agent sufficient for momentary extinguishment but insufficient to prevent reignition.

3. Hot surface thermal ignitions in an engine compartment without cooling airflow occur with substantially lower engine case temperatures than a ventilated compartment. The ventilation rate necessary to prevent ignition increases as the environmental temperature level of the compartment increases.

4. Type B (JP-4) jet fuel is a less in-flight powerplant fire hazard than Type A (kerosene) jet fuel since (a) higher environmental temperatures were required for hot surface thermal ignition of Type B, and (b) the size and intensity of the Type B fires were slightly less.

5. The size and intensity of a nacelle fire are functions of both the size of the fuel leak and the amount of cooling airflow and are limited by either. Ignition of a relatively small fuel leak, therefore, can produce a more intense fire than a large fuel leak in a nacelle with low ventilation.

6. Prompt detection of nacelle fires by temperature-sensitive-type systems located in remote areas is unfeasible unless all the cooling air is directed to the detector.

7. Fire detection by flame radiation sensors requires clear line of sight coverage to all potential fire locations with either highly sensitive sensors or short surveillance distances.

8. Visual observance of the nacelle and the monitoring of standard cockpit engine instruments cannot be relied on to provide an early and positive indication of an abnormal condition during a nacelle fire.

9. Flight conditions substantially affect the requirements of the fire extinguisher system on engine installations where the nacelle ventilation is influenced by flight speed or engine power setting or the agent container is located in an unheated compartment.

10. The longer the duration of a nacelle fire, the greater the fire extinguishing requirements and the more susceptible the installation to explosive reignitions.

11. A high rate of discharge extinguishing system with a marginal quantity of agent produces environmental conditions susceptible to an explosive reignition when used to extinguish a nacelle fire.

12. A pyrotechnic gas-generator-type extinguisher system offers the following performance improvements over the nitrogen pressurized-type system: (a) more effective low temperature operation; (b) more effective with less volatile extinguishing agents; and (c) eliminates problems associated with the attitude of the container and the intermixing action of the nitrogen and liquid agent.

13. Shutoff of all designed cooling air flowing into a nacelle without making the compartment airtight is not effective as a sole means of controlling a nacelle fire.

14. Shutoff of the fuel flowing into a low airflow nacelle is an effective means of reducing the size and intensity of a nacelle fire. However, it is not always an effective means of extinguishing the fire unless the drainage and nacelle design preclude large accumulations of fuel, and the installation is capable of resisting the fire for the time required to consume the accumulated fuel.

15. A properly designed fire extinguishing system is required for reliable fire protection on the installation tested.

16. To prevent a fire from rapidly spreading from one compartment to another (a) a airtight fireproof barrier must separate the compartments; and (b) provisions for preventing the fire from traveling externally around this barrier and entering another compartment must be incorporated. If the fireproof barrier is not airtight, the openings must be rigidly fixed and tests should be conducted to assure that flames cannot propagate through the openings.

17. Provisions for preventing a limited quantity of oil from flowing into, within, or through a fire zone are not essential on turbine engine installations with low ventilating airflow, where a small fuel leak produces a rich fire. However, to minimize the duration of the fire, the need would increase for adequate drainage, detections, and extinguishment provisions in the zone and for prompt utilization of the extinguisher.

RECOMMENDATIONS

Based on the data obtained in this report, it is recommended that:

1. Ignition be prevented by (a) designing the flammable fluid systems for maximum protection against the occurrence of leaks, (b) providing a system to detect the presence of a combustible mixture, (c) providing airtight isolation between flammable fluid systems and potential ignition sources, and (d) providing a diaphram with all openings sealed to isolate the combustion, turbine, and tailpipe sections from the compressor and accessory sections.

2. Explosive ignitions be prevented by (a) providing sufficient drainage and ventilation to minimize fuel vapor buildup within the nacelle, (b) eliminating or isolating potential ignition sources at locations remote from the flammable fluid systems, and (c) eliminating or isolating areas having environmental temperatures approaching the minimum required for ignition.

3. Explosive reignitions be prevented by (a) prompt shutoff of the fuel flowing into the nacelle to minimize fuel accumulation and vapor buildup, (b) minimizing fuel leakage after fuel shutoff, and (c) promptly extinguishing the fire with a quantity of agent sufficient to inert the nacelle for the time required to dissipate the fuel vapors and for metal components to cool.

4. Powerplant installations with potential explosive ignition and reignition hazards include provisions for a system to suppress and a design to withstand or dissipate the explosive forces.

5. Fire detector installations include coverage at all locations where cooling air exits the nacelle compartment.

6. Nacelle fires be promptly detected and extinguished to prevent (a) damage which renders the extinguishing system ineffective due to increased air leakage, and (b) explosive reignitions following extinguishing system discharge.

7. The adequacy of the fire extinguishing system be determined either in-flight or under simulated flight conditions with the environmental temperature extremes of the compartment where the agent container is located on the aircraft simulated.

8. Fire extinguisher systems be designed (a) to allow for any additional air leakage that could occur as a result of a fire, and (b) to prevent explosive reignitions.

9. Components of cooling air and other pressurized air systems located within the nacelle be capable of resisting fire without leaking for a time sufficient for detection and extinguishment.

10. When seams or openings are located in the nacelle forward of the firewalls, design provisions be made to prevent the propagation of fire in the external airstream around the firewall.

11. Critical areas downstream and adjacent to nacelle cooling air exit vents in the fire zones be protected against fire burning outside of the vent.

12. The susceptibility of nacelle seams and seals to fire damage and the resulting effects on the ability to control a fire be considered in the overall fire protection design of an engine installation.

13. The possibility of flammable fluids leaking out of seals, seams, or drain ports in a fire zone, flowing on the external surface, and entering other compartments of the nacelle or aircraft and any resulting hazard be considered in the design of an engine installation.

14. Fire zone ventilation be sufficient to provide direction to the airflow and prevent stagnant areas in an attempt to minimize the possibility of ignition and to reduce fuel vapor buildup.

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Appreciation is expressed for the cooperation of the personnel of the Naval Air Propulsion Test Center at Trenton, New Jersey, and for the support provided by the aviation industry and fire detector and extinguisher equipment manufacturers.

The authors also wish to acknowledge the personal interest and contribution of the many FAA personnel who supported this effort.

APPENDIX I

FACILITY AND SUPPORT EQUIPMENT

Facilities for conducting the full-scale fire test program were located in a test wing at the U. S. Naval Air Propulsion Test Center, Trenton, New Jersey. The wing consisted of a test chamber, control room, shop, and preparation areas as shown in Figure 1.1.

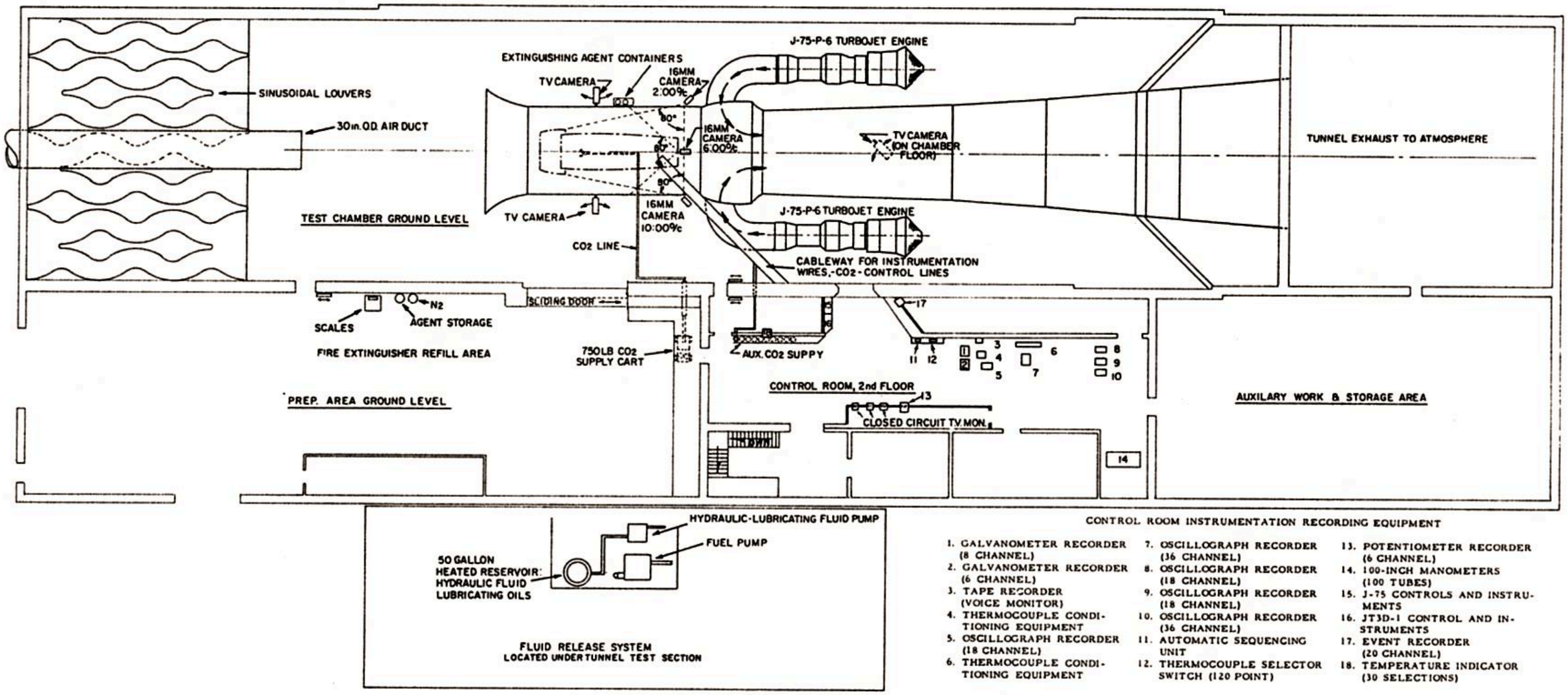
The test chamber was a rectangular room, approximately 33-feet square and 200-feet long, housing an open-end induction wind tunnel. Exhaust gases from two J-75-P-6 turbojet engines were ducted to the energy section of the tunnel to lower the static pressure downstream of the test section and to induce high velocity airflow through the test section. Outside air was drawn into the test chamber, directed to the two turbojet engines and the test engine, through the tunnel, turned upward 90° and exhausted to atmosphere. The air was acoustically treated on entry and exiting.

The pod/pylon-turbofan engine test article was mounted in the test section and the strut faired to the test section wall, as shown in Figure 1.2. The axial locations of the various engine cases relating to the nacelle stations referenced throughout the report are presented in Table I. Several of the "systems," not deemed necessary for operation during the test program, were deactivated. The thrust reverser systems were pneumatically disconnected and secured in a stowed postion. The pneumatic starter was not used during the program for starting purposed, but was used occasionally for windmilling. The starter air supply line was utilized for routing instrumentation wires. The generator was mechanically disconnected to prevent rotation. The anti-ice system and fuel deicer were deactivated. The Constant Speed Drive in-line filter was bypassed after initial tests damaged the "O" rings.

Three spare sets of nacelle cowl doors were utilized during the test program in an attempt to maintain a high degree of integrity. A spare forward strut fairing cowl was also utilized during the program.

The test engine and the two engines used to power the tunnel were operated from the control room. Operational performance of these engines was monitored, and test data were manually recorded in the control room from direct reading indicators.

The test engine and drive engines operated on independent fuel systems. The fluid release systems used for the Ignition Hazards Studies and in producing test fires in the nacelle were independent of either of these systems and were capable of supplying fluids in quantities from 0.01 to 20.0 gpm at pressures from 10 to 2000 psig. Temperature range of the fluid used could be controlled from ambient to 600°F.



CONTROL ROOM INSTRUMENTATION RECORDING EQUIPMENT

1. GALVANOMETER RECORDER (8 CHANNEL)
2. GALVANOMETER RECORDER (6 CHANNEL)
3. TAPE RECORDER (VOICE MONITOR)
4. THERMOCOUPLE CONDITIONING EQUIPMENT
5. OSCILLOGRAPH RECORDER (18 CHANNEL)
6. THERMOCOUPLE CONDITIONING EQUIPMENT
7. OSCILLOGRAPH RECORDER (36 CHANNEL)
8. OSCILLOGRAPH RECORDER (18 CHANNEL)
9. OSCILLOGRAPH RECORDER (18 CHANNEL)
10. OSCILLOGRAPH RECORDER (36 CHANNEL)
11. AUTOMATIC SEQUENCING UNIT
12. THERMOCOUPLE SELECTOR SWITCH (120 POINT)
13. POTENTIOMETER RECORDER (6 CHANNEL)
14. 100-INCH MANOMETERS (100 TUBES)
15. J-75 CONTROLS AND INSTRUMENTS
16. JT3D-1 CONTROL AND INSTRUMENTS
17. EVENT RECORDER (20 CHANNEL)
18. TEMPERATURE INDICATOR (30 SELECTIONS)

FIG. 1.1 - TEST FACILITY AND SUPPORT EQUIPMENT

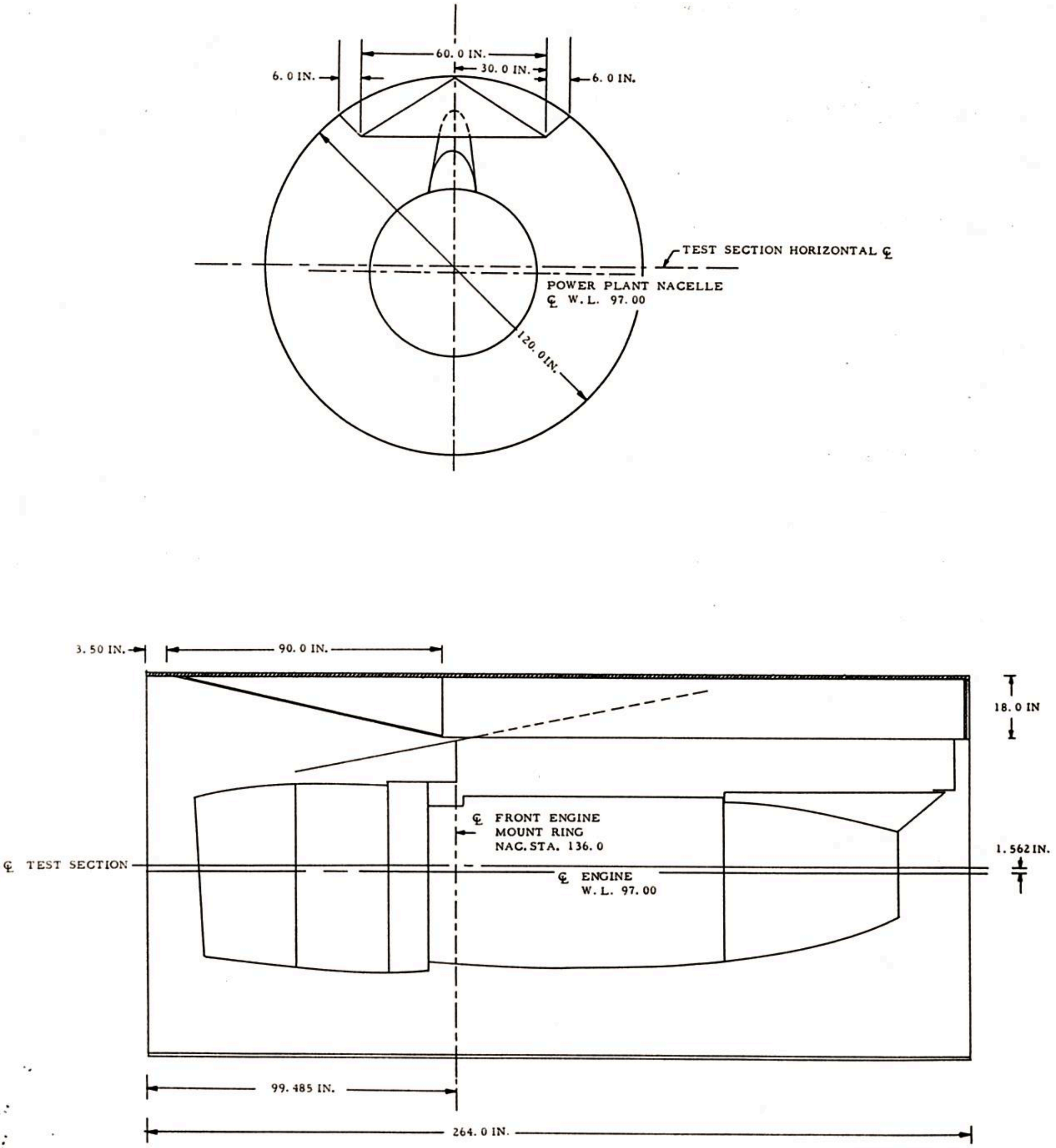


FIG. 1.2 - TEST SECTION INSTALLATION OF TURBOFAN ENGINE

TABLE I

NACELLE STATION IDENTIFICATION FOR ENGINE CASES

Engine Case (Listed in Order From Front To Rear)	Nacelle Station Number
Air Inlet Case, Front Flange	89.5
Front Compressor Front Case, Front Flange	115.8
Front Compressor Rear Case, Front Flange	122.9
Intermediate Case, Front Flange	133.9
Diffuser Case, Front Flange	153.2
Burner Case, Front Flange	170.1
Turbine Case, Front Flange	190.9
Exhaust Case, Front Flange	206.9
Exhaust Case, Rear Flange	218.6

The test facility fire protection consisted of a 33,000-gallon foam system and an 8,000-pound carbon dioxide (CO_2) system. The test article was protected by a 750-pound CO_2 system. Local test fires within the test article were controlled by 150 pounds of CO_2 in ten 15-pound bottles. All fire protection systems were controlled from the control room.

An environmental chamber was utilized to provide ambient temperatures from -50°F to +200°F for the aircraft-type extinguishing agent storage containers.

In addition to standard powerplant installation temperature measurements, chromel-alumel thermocouples were used to measure nacelle ambient air, engine case, and nacelle cowl skin temperatures.

The theromocouple output signals were recorded on high response oscillograph recorders and any six preselected thermocouples were paralleled to a potentiometer-type recorder for direct readout and test monitoring.

One hundred and five thermocouples were scanned and recorded on an eight-channel galvanometer-type recorder through a crossbar stepping switch having a 5-second cycling time.

Selected test parameters such as fuel-to-fire duration and flow rate, engine pressures, temperatures and rotor speed (N_2), nacelle static and explosive pressures, and agent discharge time were recorded on an oscillograph. Various wind tunnel and nacelle pressures were measured on a bank of fifty 100-inch manometers.

Motion picture coverage of the test article was accomplished by three 16mm movie cameras located as shown in Figure 1.1. Color film was used throughout the test program and exposed at 16 frames per second. Various special photographic coverage was accomplished by the use of 16mm gun cameras remotely located at various positions around the test article. One of these cameras was positioned to provide a closeup view of the drain holes.

The electrical output of the various fire detectors, installed in the test nacelle, was recorded on a high response galvanometer-type recorder. Five data recorders and six various test systems were related to a common base reference time through the use of a 20-channel event recorder. This instrument recorded relative on and off times for all recorders and systems.

A time-sequencing cam was used to control the ignitor, fuel release, emergency procedure signal, fire extinguishing agent discharge and to switch recorders on and off.

Remote control of closed circuit television cameras provided visual coverage of the right and left sides of the test article as well as both of the tunnel drive engines.

All recording equipment provided permanent records of the electro-mechanically produced raw data in the form of line deflections from a base reference line. These records were manually read and the necessary computations were made to convert the readings into engineering values.

APPENDIX II

FACILITY CALIBRATION AND FLIGHT SIMULATION

Facility Calibration

The test facility, as described in Appendix I, was initially calibrated over the full range of operating conditions of both the test engine and the tunnel drive engines.

Facility calibration was accomplished through extensive instrumentation of the right half of the test section with symmetry being assumed about a vertical centerplane.

Three axial instrumentation stations were located in the test section and designated Stations "B," "C," and "D." These stations were located at Nacelle Station Numbers 103.5, 168.5, and 264.5, respectively. Two six-probe total pressure rakes were installed at each of these stations; one at 45° and the other 135° from the top vertical centerline. The six probes on each rake were equally spaced between the tunnel wall and nacelle. The distance between the nacelle and the nearest probe provided sufficient clearance for the sideward motion of the test article during high engine power condition. The probe located approximately midway between the tunnel wall and the nacelle on each respective rake was pitot-static. A preliminary survey of the test section indicated that the cross-sectional static pressure gradient at each of three stations was negligible.

Pressure data recorded during the calibration phase are presented as radial Mach number profiles in Figures 2.1 through 2.12. The profiles at the 135° Station "D" location were not plotted in Figures 2.11 and 2.12 since the rake was not installed for the high engine power calibration test runs.

Axial Mach number gradients are shown in Figures 2.13 through 2.16 based on data obtained from the radial profile curves. The values are presented for a point 10-1/2 inches from the tunnel wall on the 135° radial for four engine power conditions.

The six instrumentation rakes were removed from the test section after completion of the calibration phase and a single pitot-static probe installed at Station "B," 45° from the top vertical centerline. This probe was connected to a Mach meter located on the J-75 operator's panel in the control room and referenced as the facility Mach number.

Power conditions for the JT3D-1 engine were set as defined by the thrust curve shown in Figure 2.17.

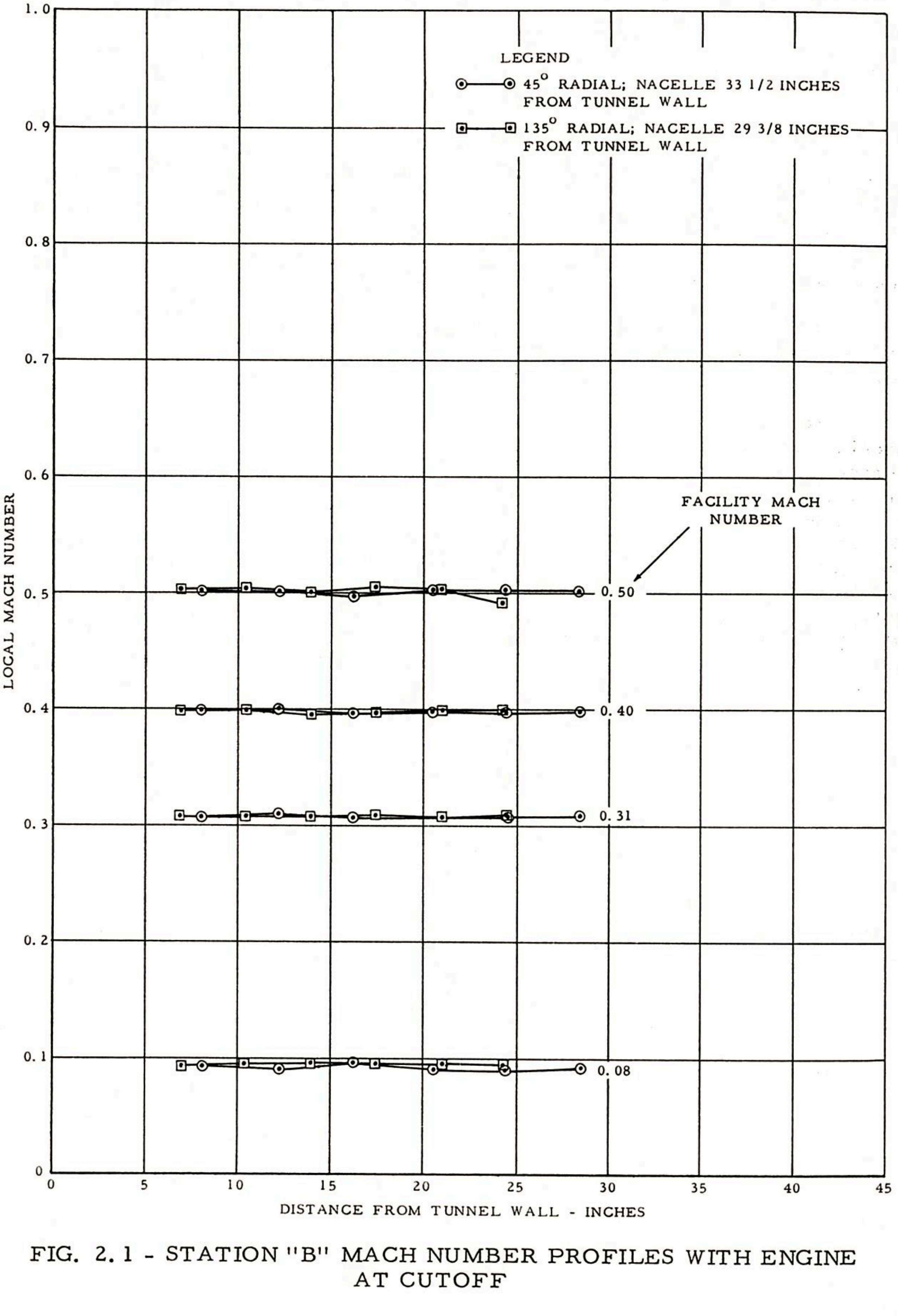


FIG. 2.1 - STATION "B" MACH NUMBER PROFILES WITH ENGINE AT CUTOFF

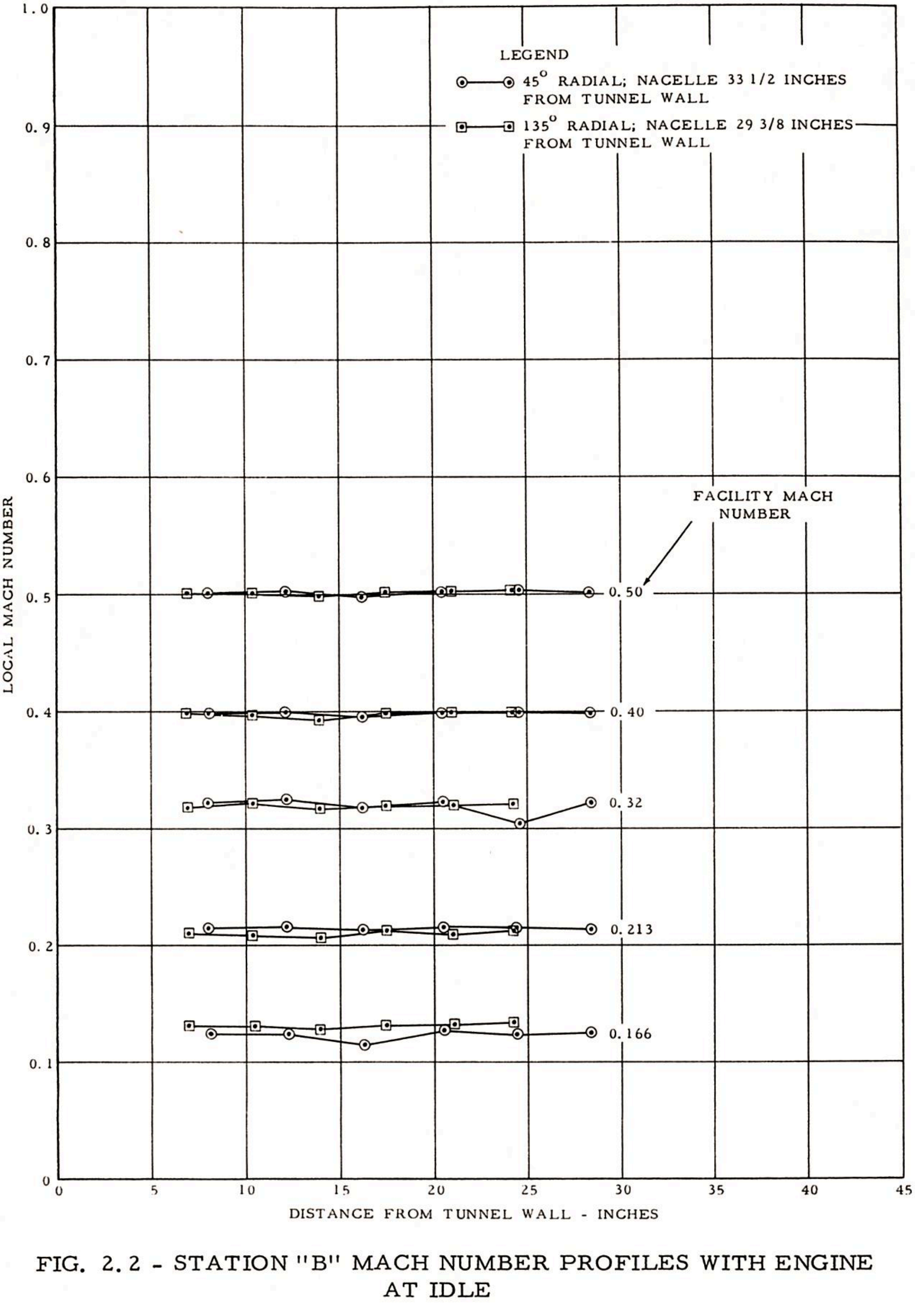


FIG. 2.2 - STATION "B" MACH NUMBER PROFILES WITH ENGINE AT IDLE

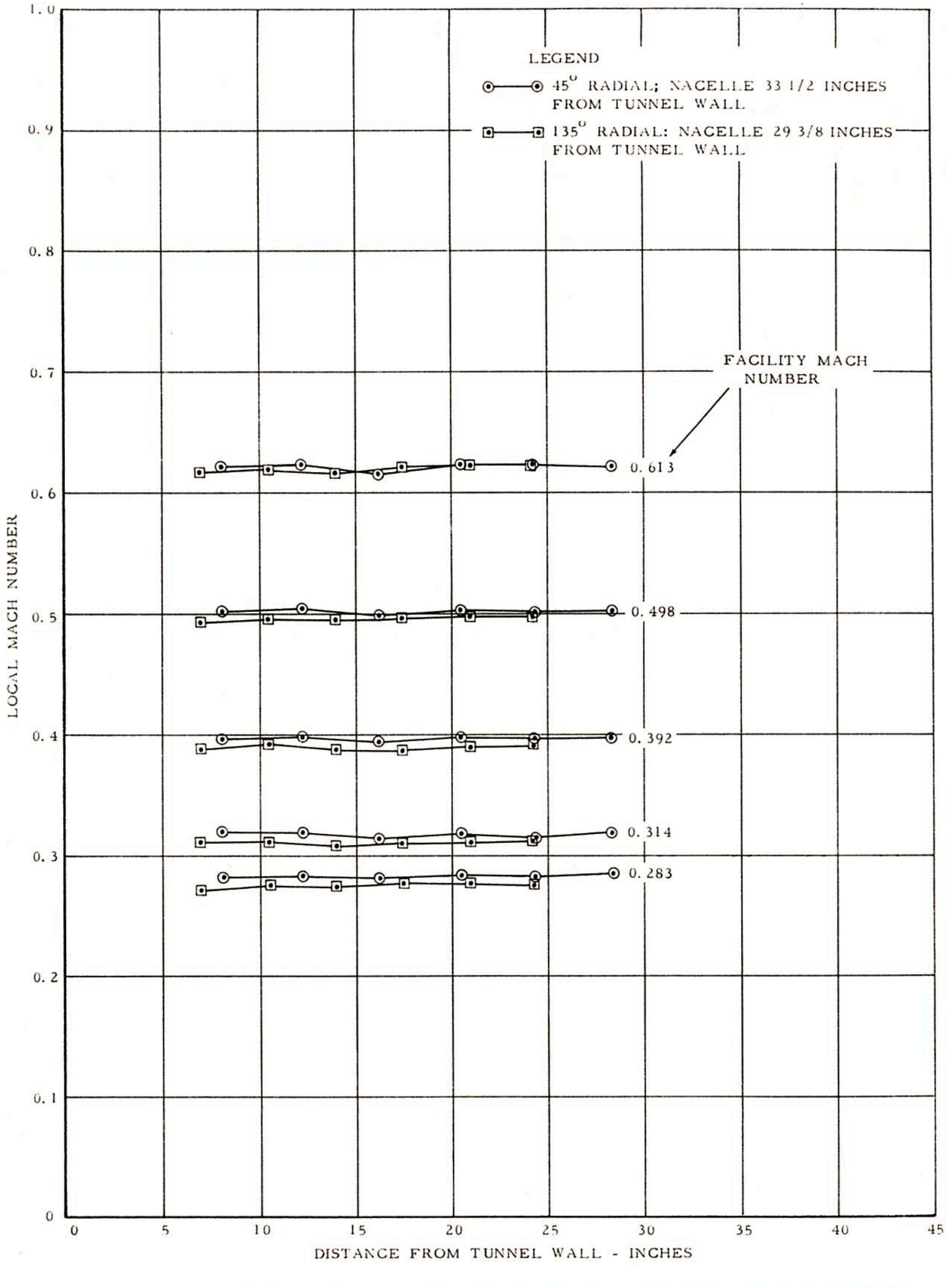


FIG. 2.3 - STATION "B" MACH NUMBER PROFILES WITH ENGINE AT 9000 RPM (N_2)

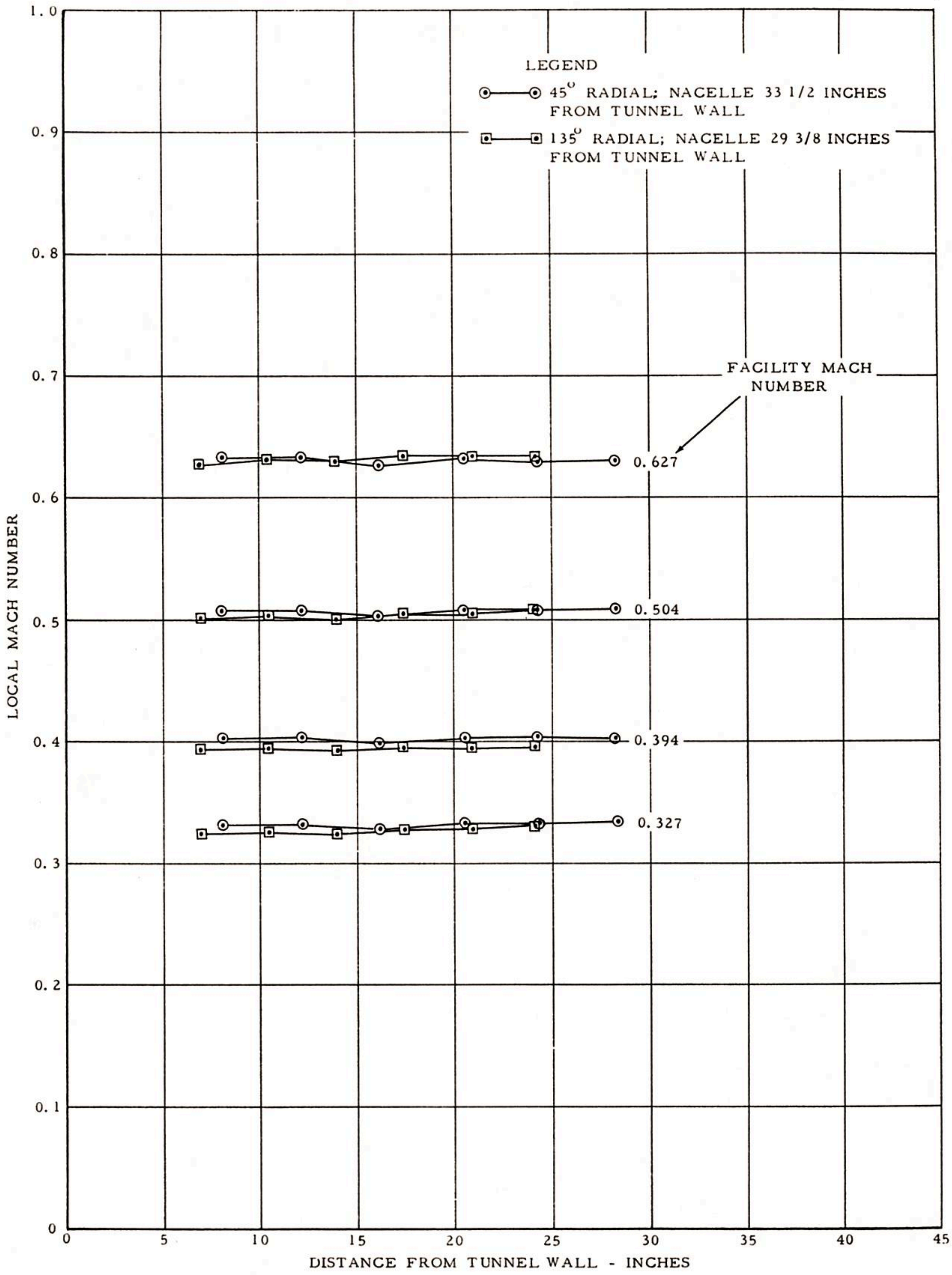


FIG. 2.4 - STATION "B" MACH NUMBER PROFILES WITH ENGINE AT 9600 RPM (N_2)

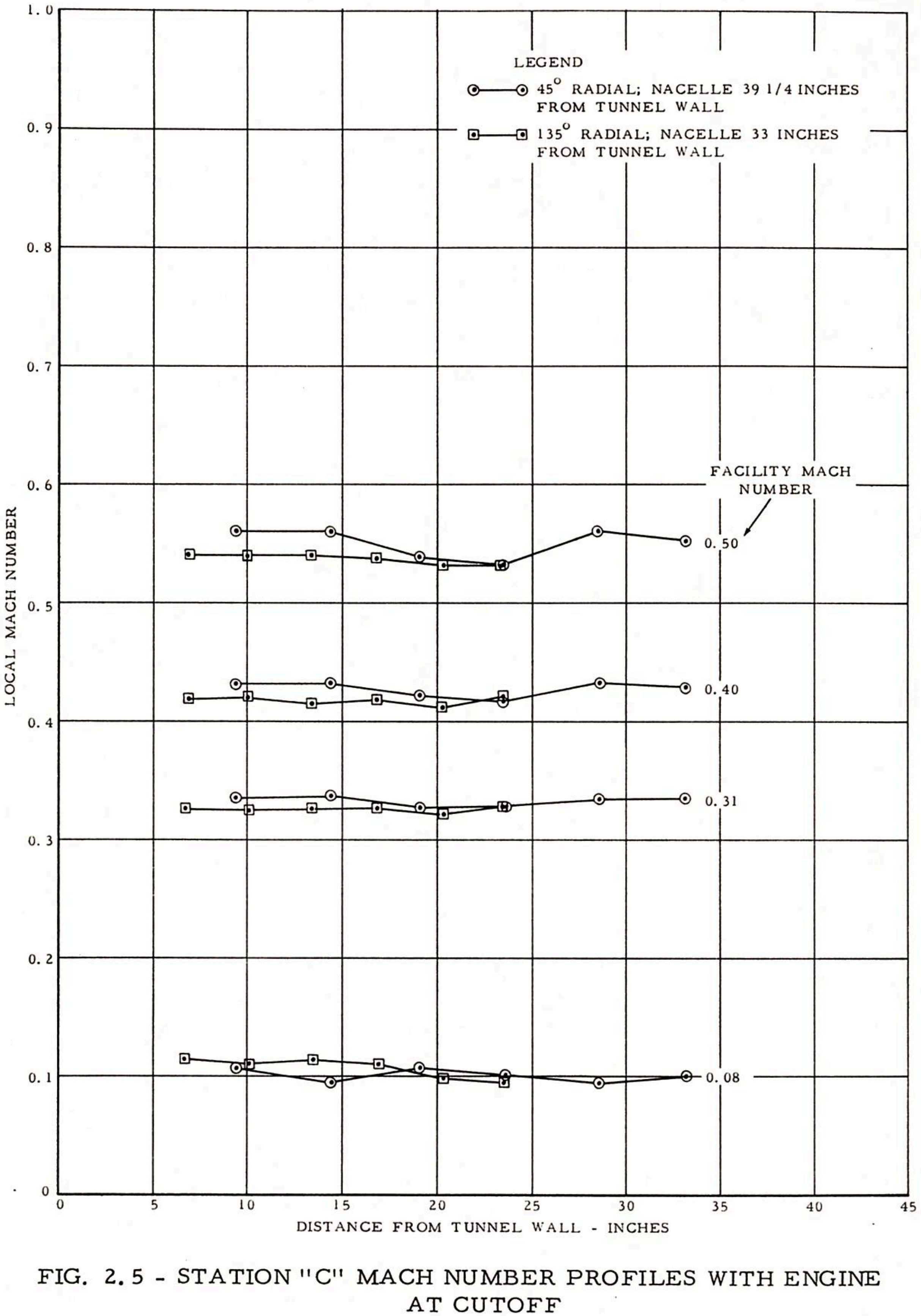


FIG. 2.5 - STATION "C" MACH NUMBER PROFILES WITH ENGINE AT CUTOFF

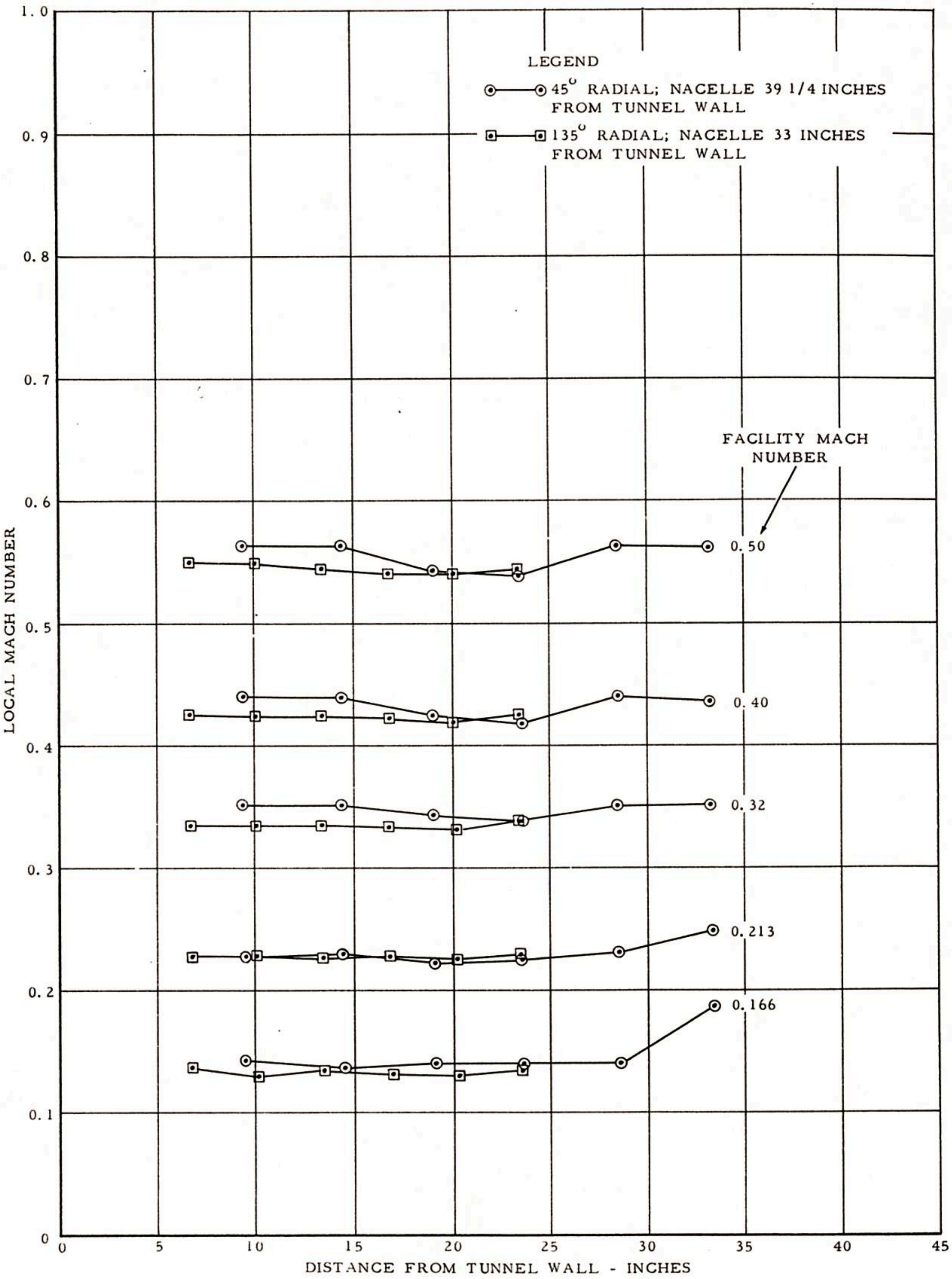


FIG. 2.6 - STATION "C" MACH NUMBER PROFILES WITH ENGINE AT IDLE

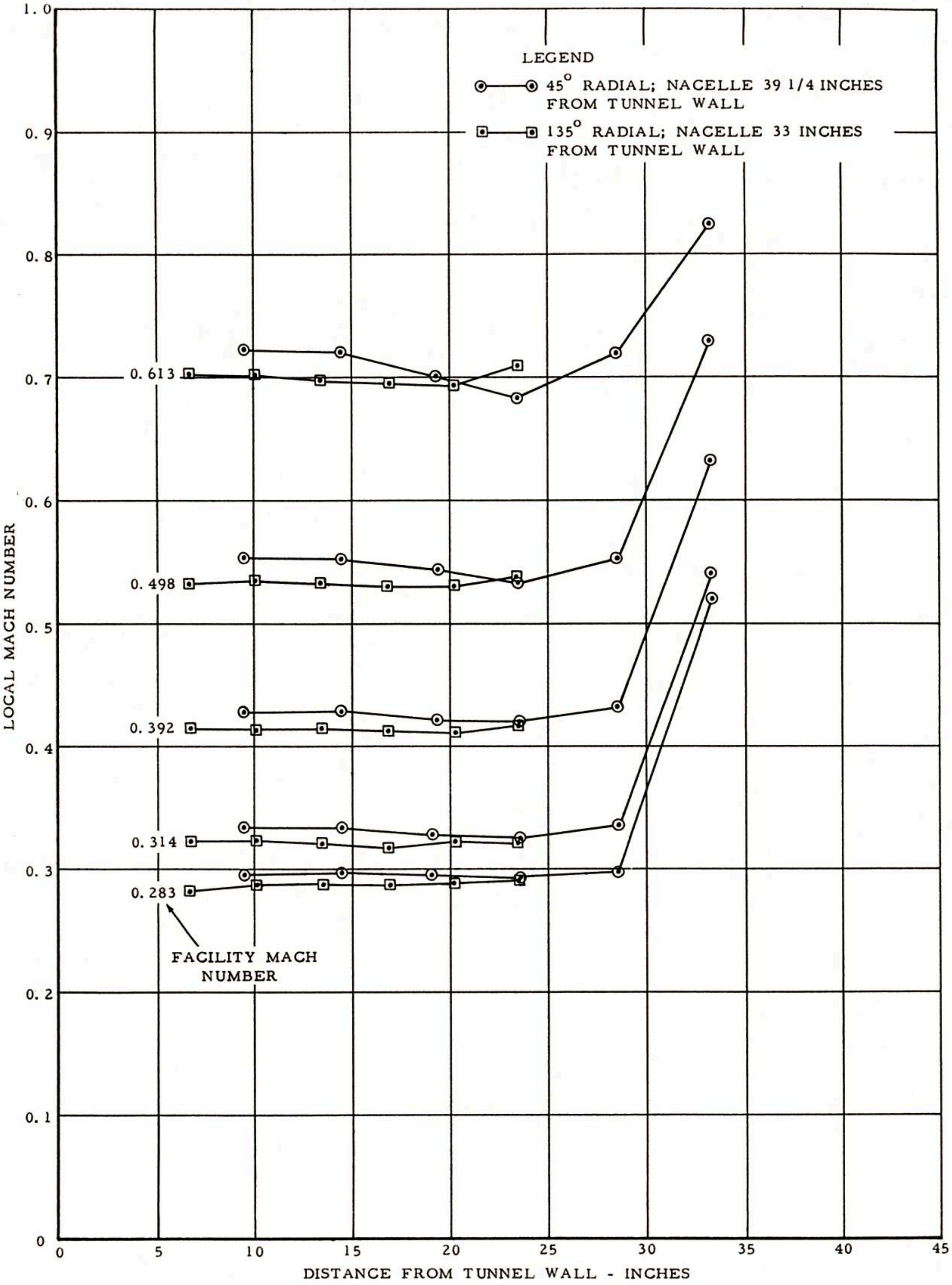


FIG. 2.7 - STATION "C" MACH NUMBER PROFILES WITH ENGINE AT 9000 RPM (N_2)

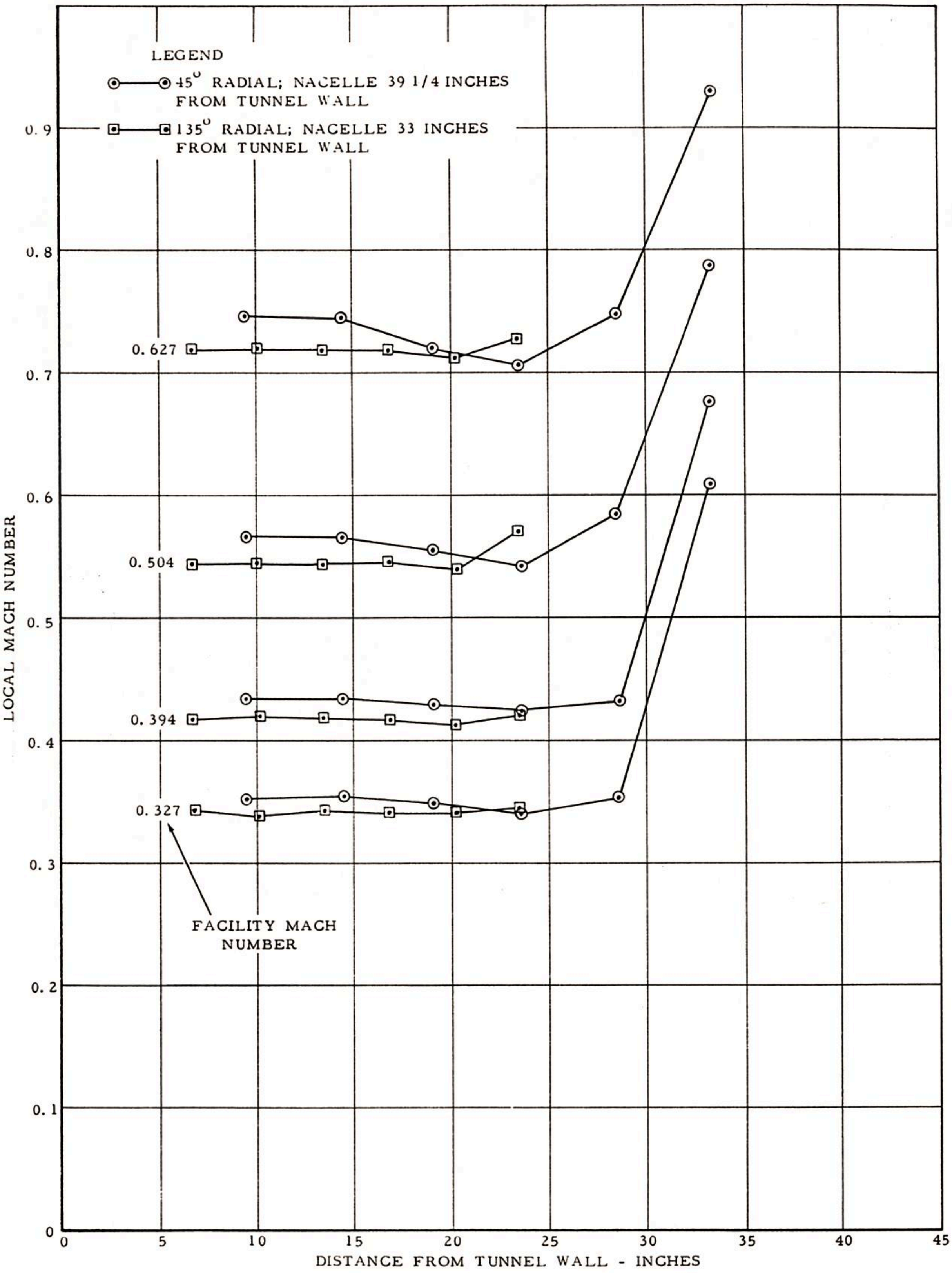


FIG. 2.8 - STATION "C" MACH NUMBER PROFILES WITH ENGINE AT 9600 RPM (N_2)

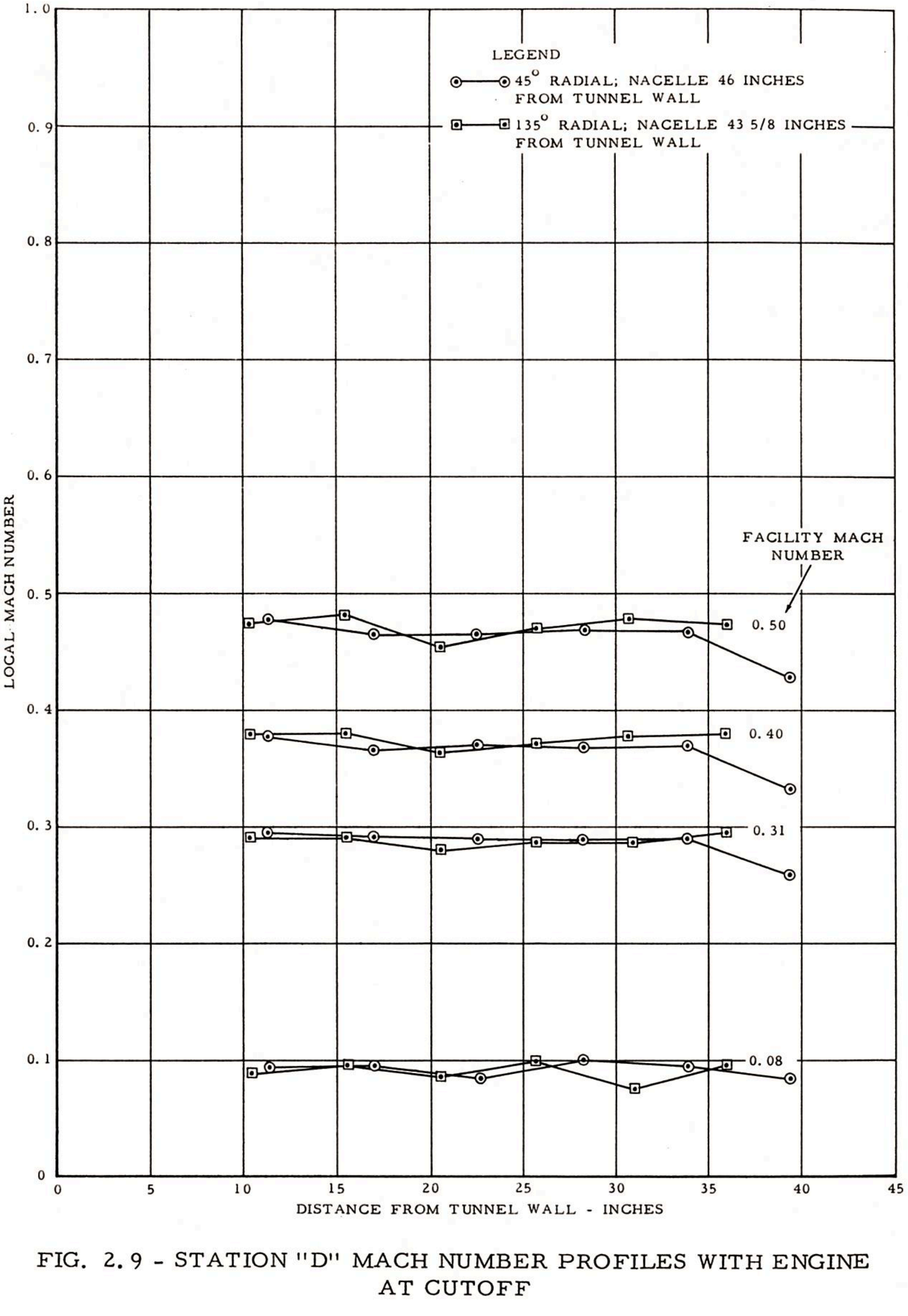


FIG. 2.9 - STATION "D" MACH NUMBER PROFILES WITH ENGINE AT CUTOFF

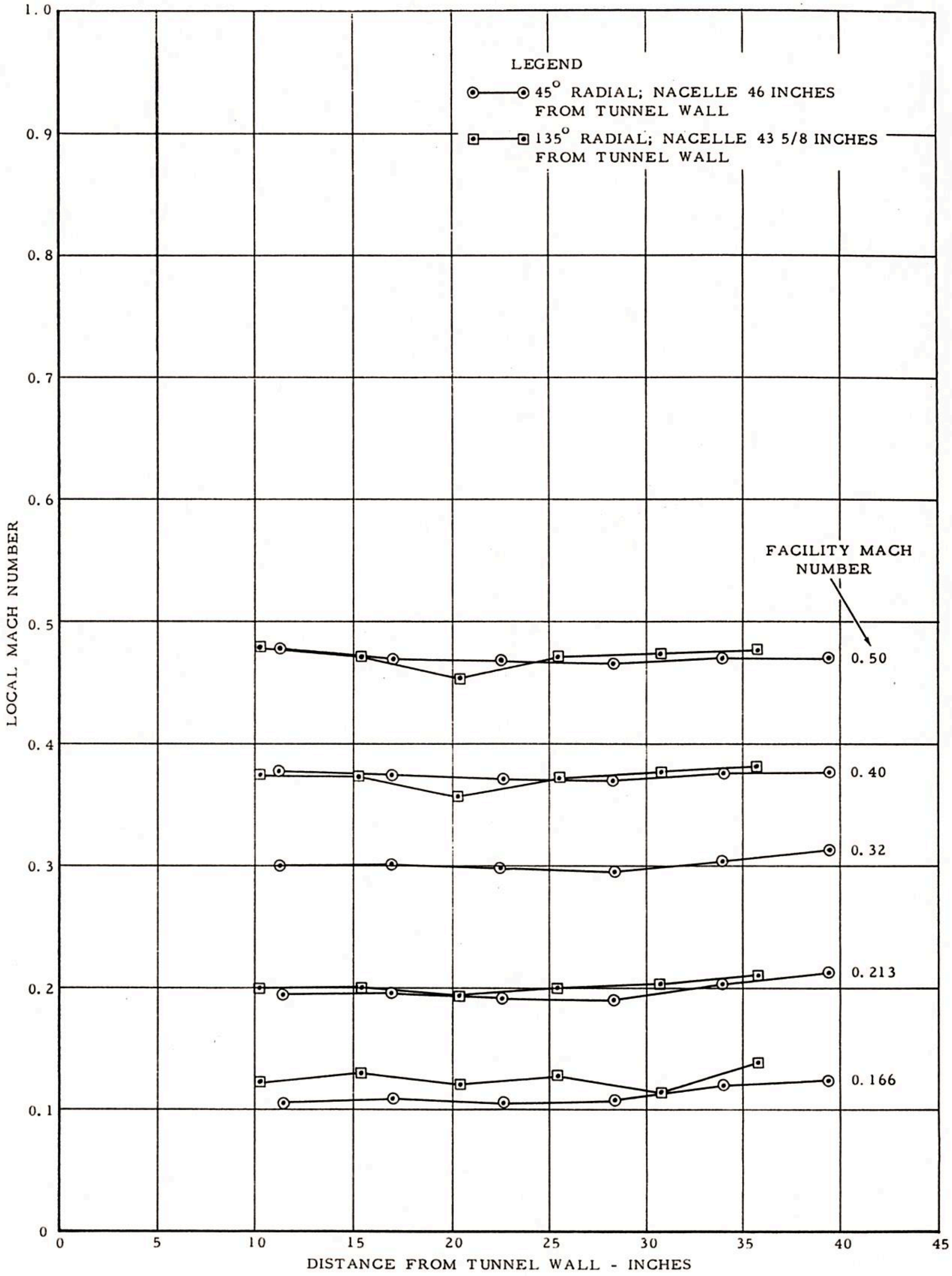


FIG. 2.10 - STATION "D" MACH NUMBER PROFILES WITH ENGINE AT IDLE

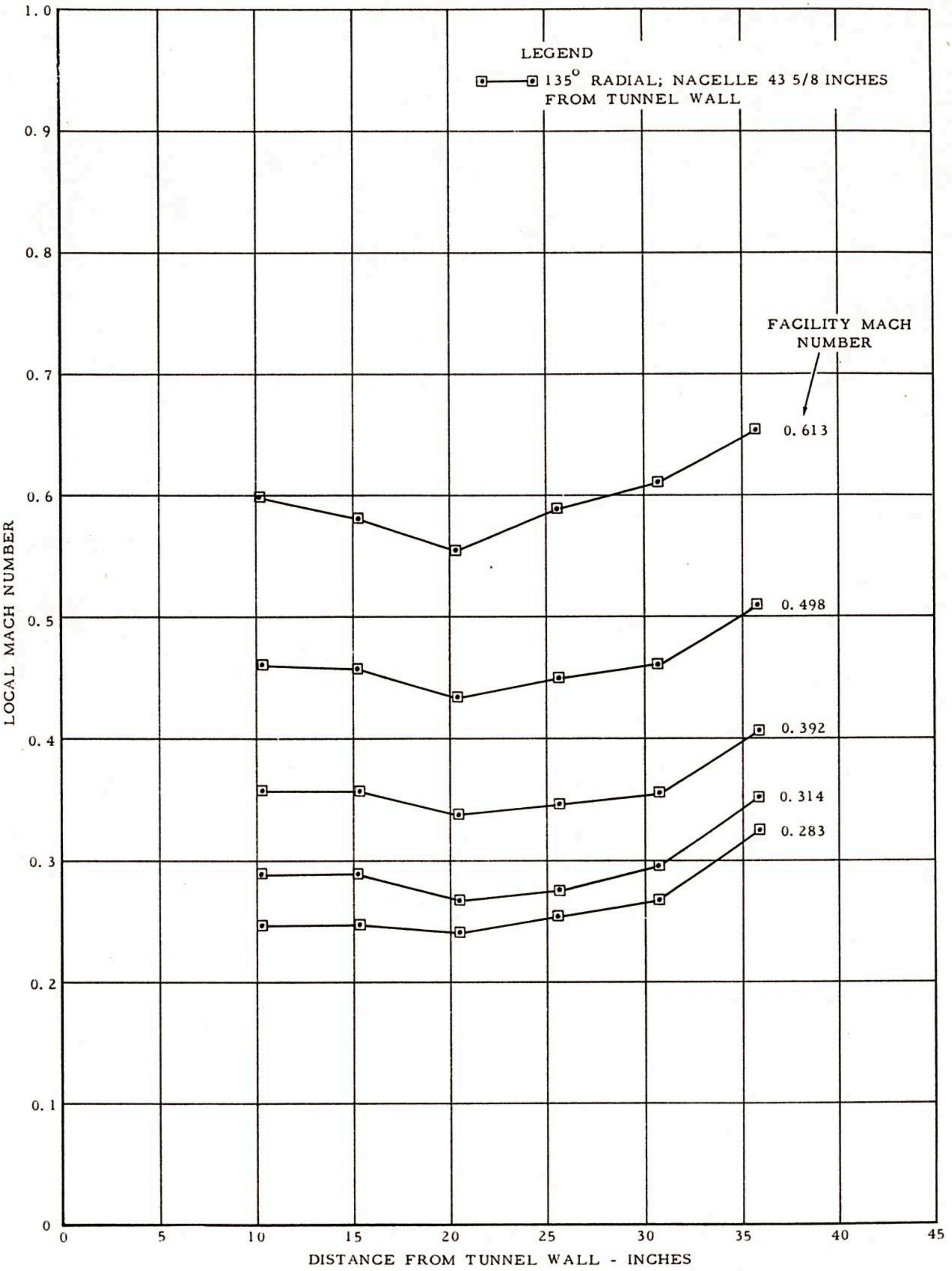


FIG. 2.11 - STATION "D" MACH NUMBER PROFILES WITH ENGINE AT 9000 RPM (N_2)

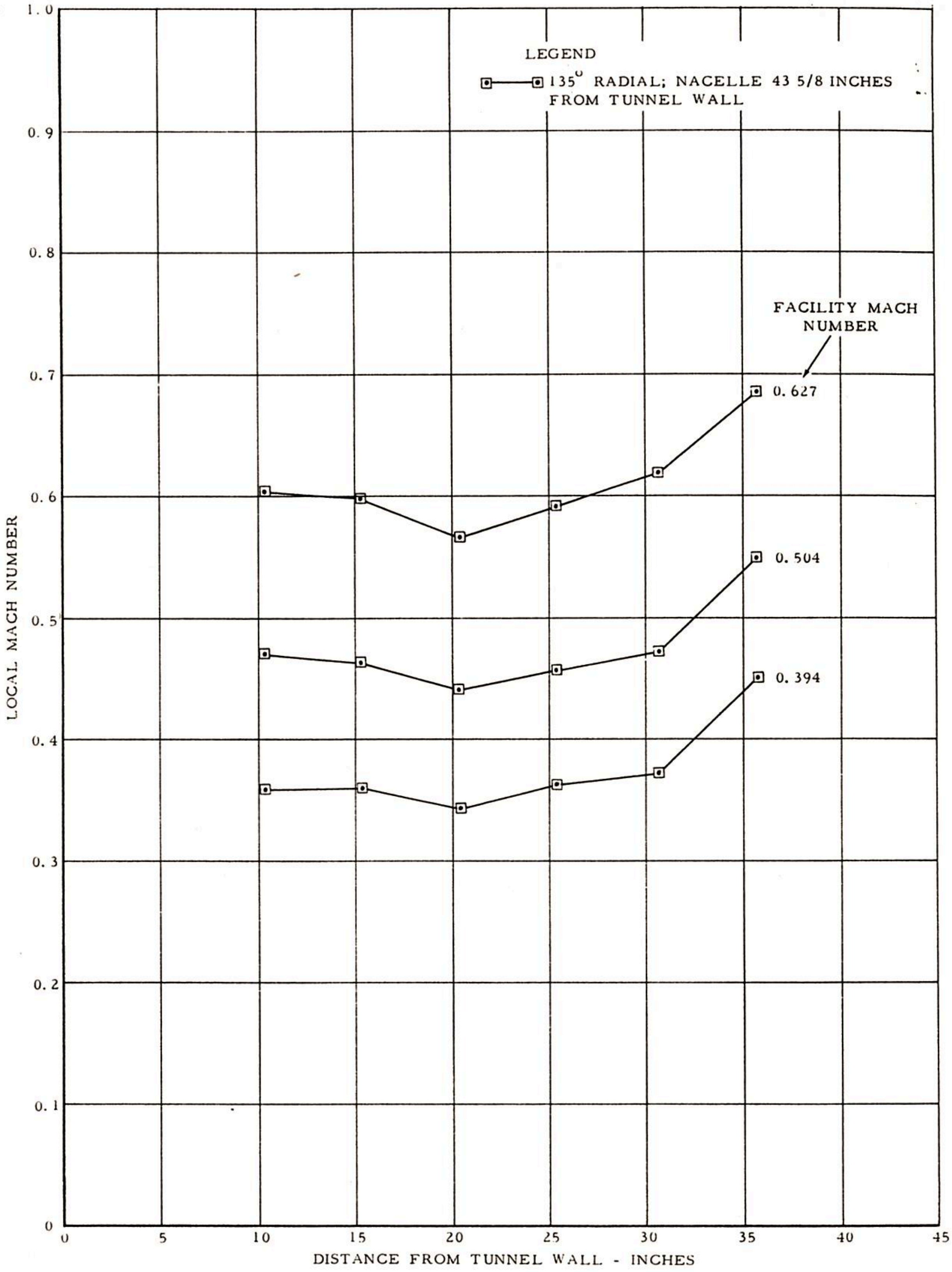


FIG. 2.12 - STATION "D" MACH NUMBER PROFILES WITH ENGINE AT 9600 RPM (N_2)

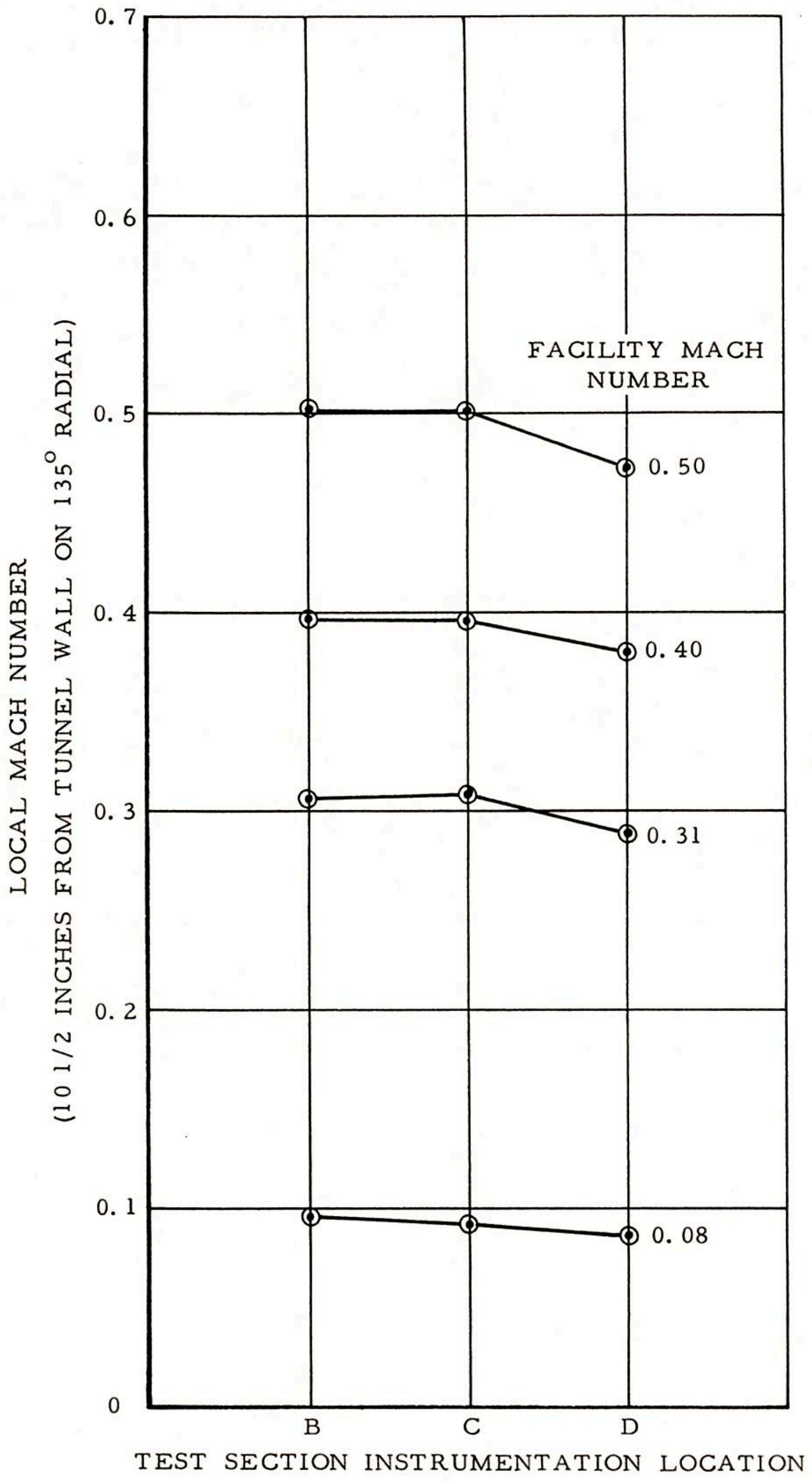


FIG. 2.13 - AIRSTREAM MACH NUMBER GRADIENT ALONG TEST SECTION WITH ENGINE AT CUTOFF

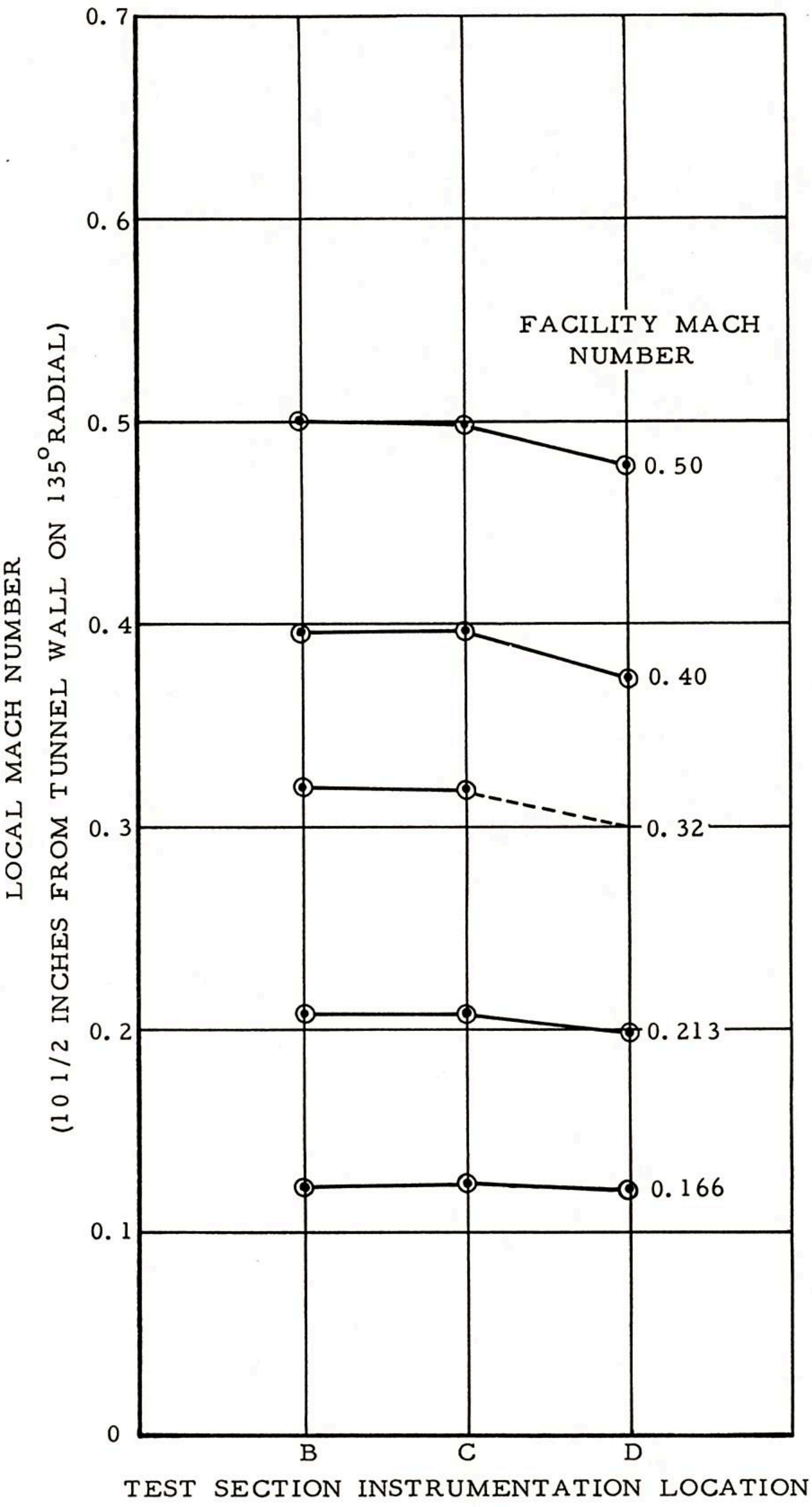


FIG. 2.14 - AIRSTREAM MACH NUMBER GRADIENT ALONG TEST SECTION WITH ENGINE AT IDLE

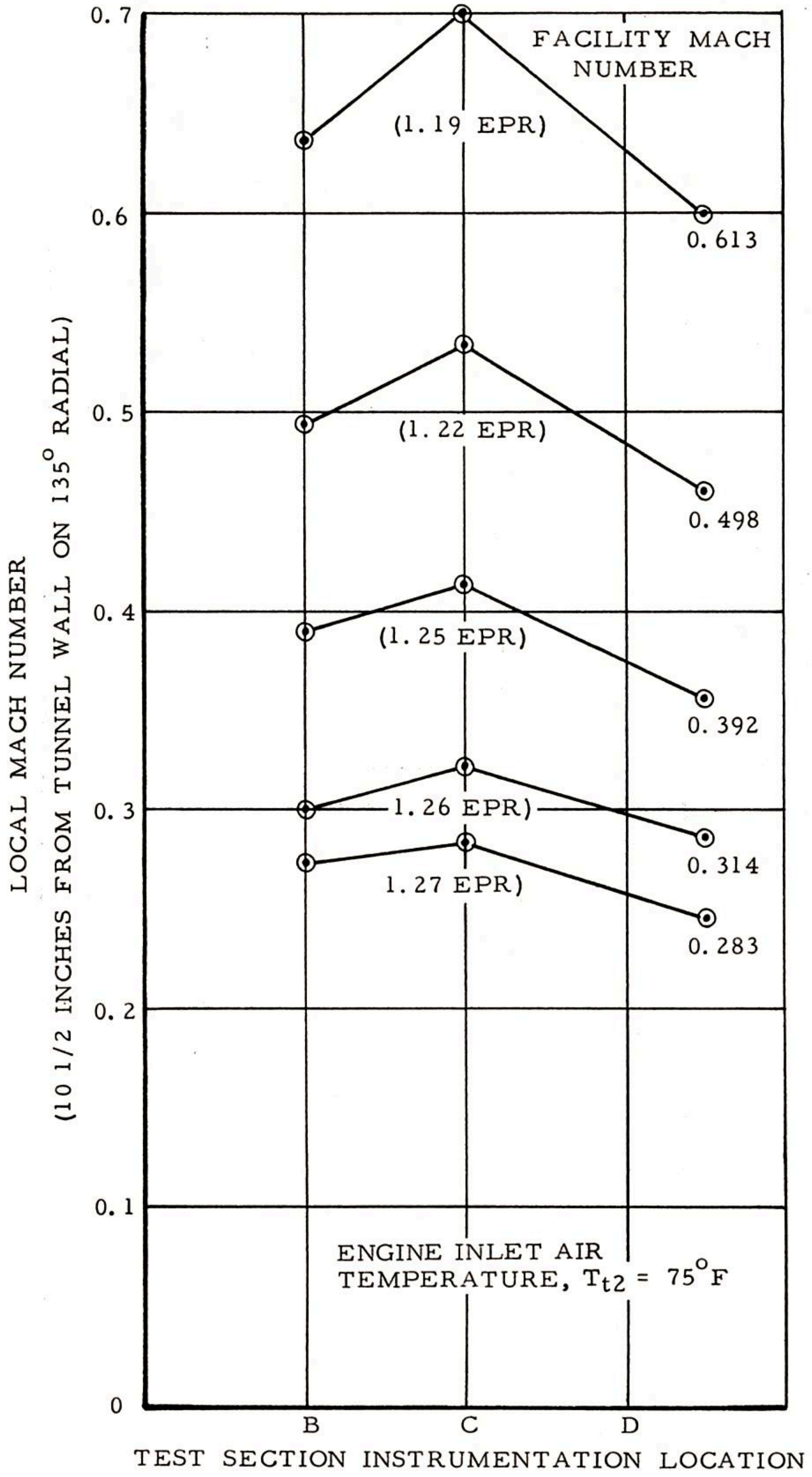


FIG. 2.15 - AIRSTREAM MACH NUMBER GRADIENT ALONG TEST SECTION WITH ENGINE AT 9000 RPM (N_2)

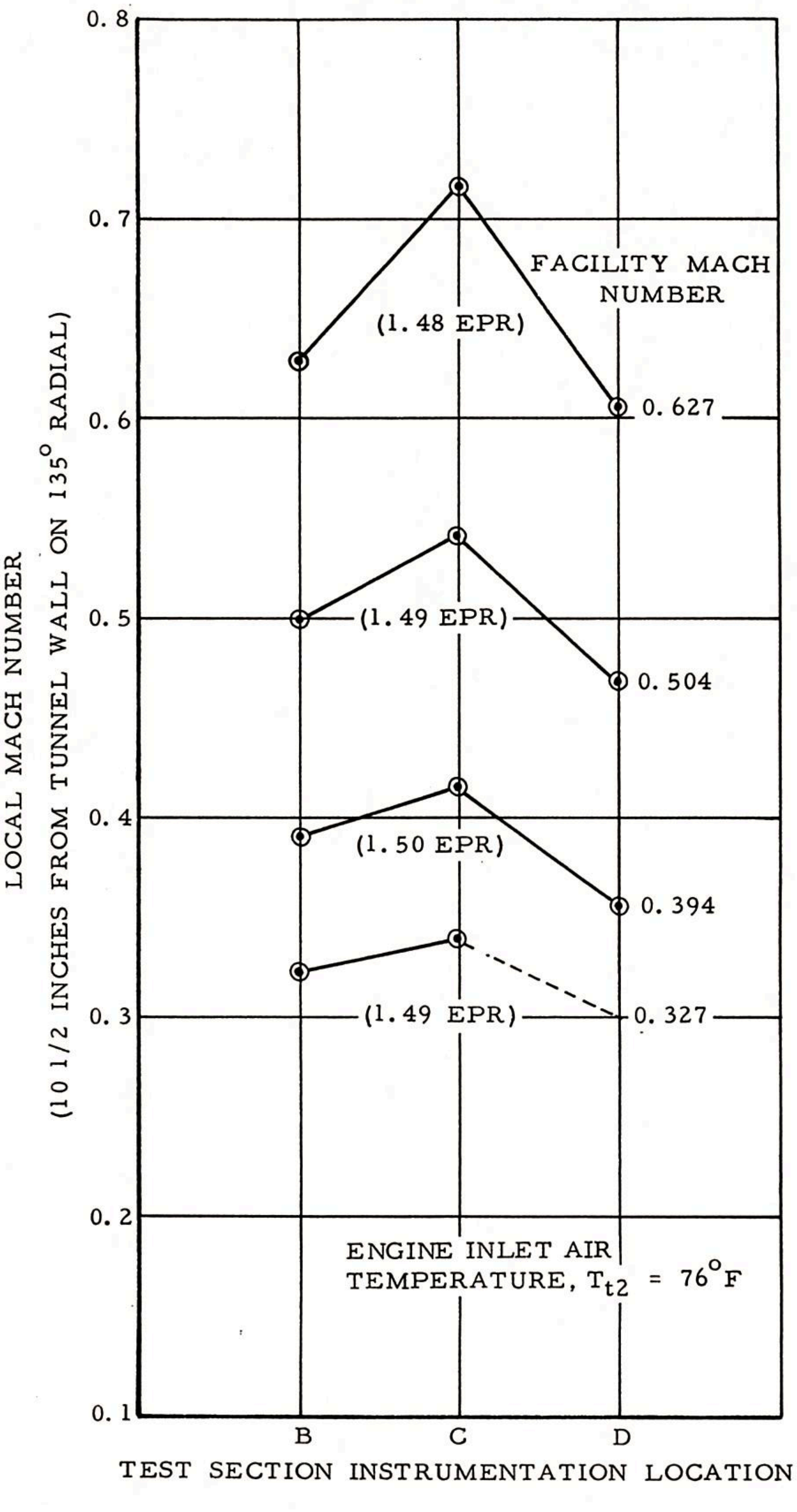


FIG. 2.16 - AIRSTREAM MACH NUMBER GRADIENT ALONG TEST SECTION WITH ENGINE AT 9600 RPM (N_2)

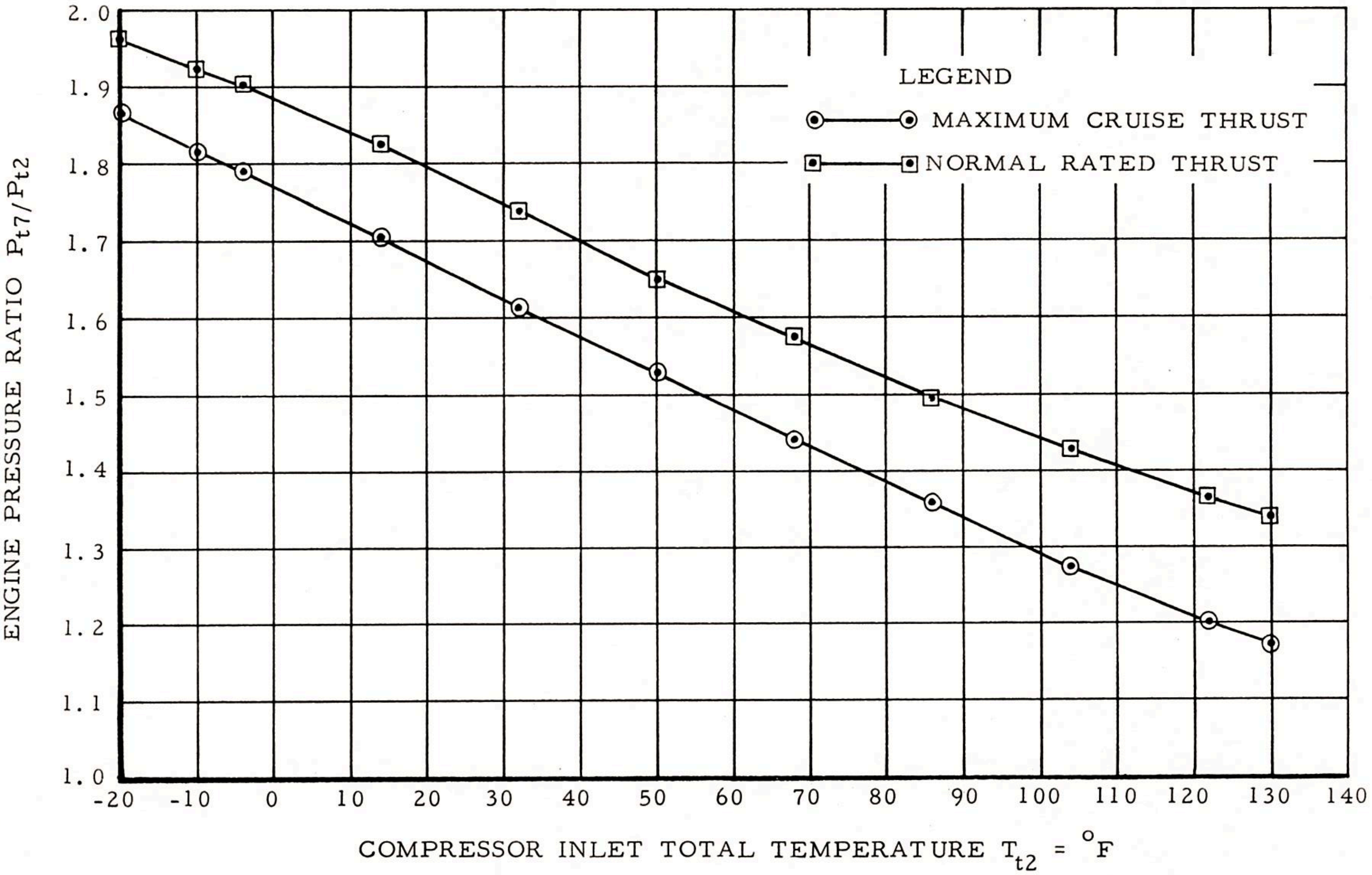


FIG. 2.17 - TEST ENGINE RATED THRUST SETTINGS

The correlation between local Mach number and pressure altitude in the test section is shown in Figure 2.18. This figure also defines the mismatch between local tunnel temperature and that of standard altitude temperature.

The radial profiles indicate that the induced air velocities through the test section at Station "B" were basically flat straight-line profiles. A constant Mach number from the tunnel wall to the nacelle skin is shown in Figures 2.1 to 2.4 for low through high engine power conditions. The Station "C" profile data shown in Figures 2.5 through 2.8 indicated a flat straight-line profile at the 135° radial. The profile at the 45° radial was also a flat straight-line with the exception of the probe near the nacelle. The profile at this location was influenced by the fan air which provided a relatively high velocity airstream over the nacelle surface. Data at the 135° radial did not reflect this increase in Mach number because the probe nearest the nacelle was outside of the effect of the fan airstream.

The profile curves for Station "D" are shown in Figures 2.9 through 2.13. The effects of the fan airstream are again noticeable.

The effects of variations in the amount of fan air and the free air cross-sectional area around the test article on the local air velocities are shown in Figures 2.9 through 2.12.

Flight Simulation

Estimates of nacelle ventilation rates and airflow rates for each of the primary exits in the compressor and accessory section (Zone II) are presented for the test engine installation. Airflow comparisons are also presented based on wind tunnel and flight nacelle pressure measurements. These estimates are based on appropriate assumptions and limited test data in lieu of a comprehensive test program.

All nacelle cooling air was assumed to be entering into Zone II through the five small blast tubes located in the cowl doors. Portions of this air passed through the chimney into the forward strut fairing and through the drain vent and drain holes and reentered the external airstream. The remaining cooling air passed through the engine fireseal into the combustor and turbine section (Zone I) and out around the exhaust nozzle. Three of the five blast tubes had flush circular ram inlets and two had diverging wall submerged ram inlets.

The amount of air entering the blast tubes is a function of the size and shape of the tube and the local conditions at the ends of the tube. Figure 2.19 is an estimated local Mach number distribution along this external surface of the cowl doors with the test engine at maximum cruise power. This curve was derived from the pressures measured at Stations "C" and "D" during the facility calibration at the probe locations nearest to the cowling and from an assumed choked condition at the fan discharge exit.

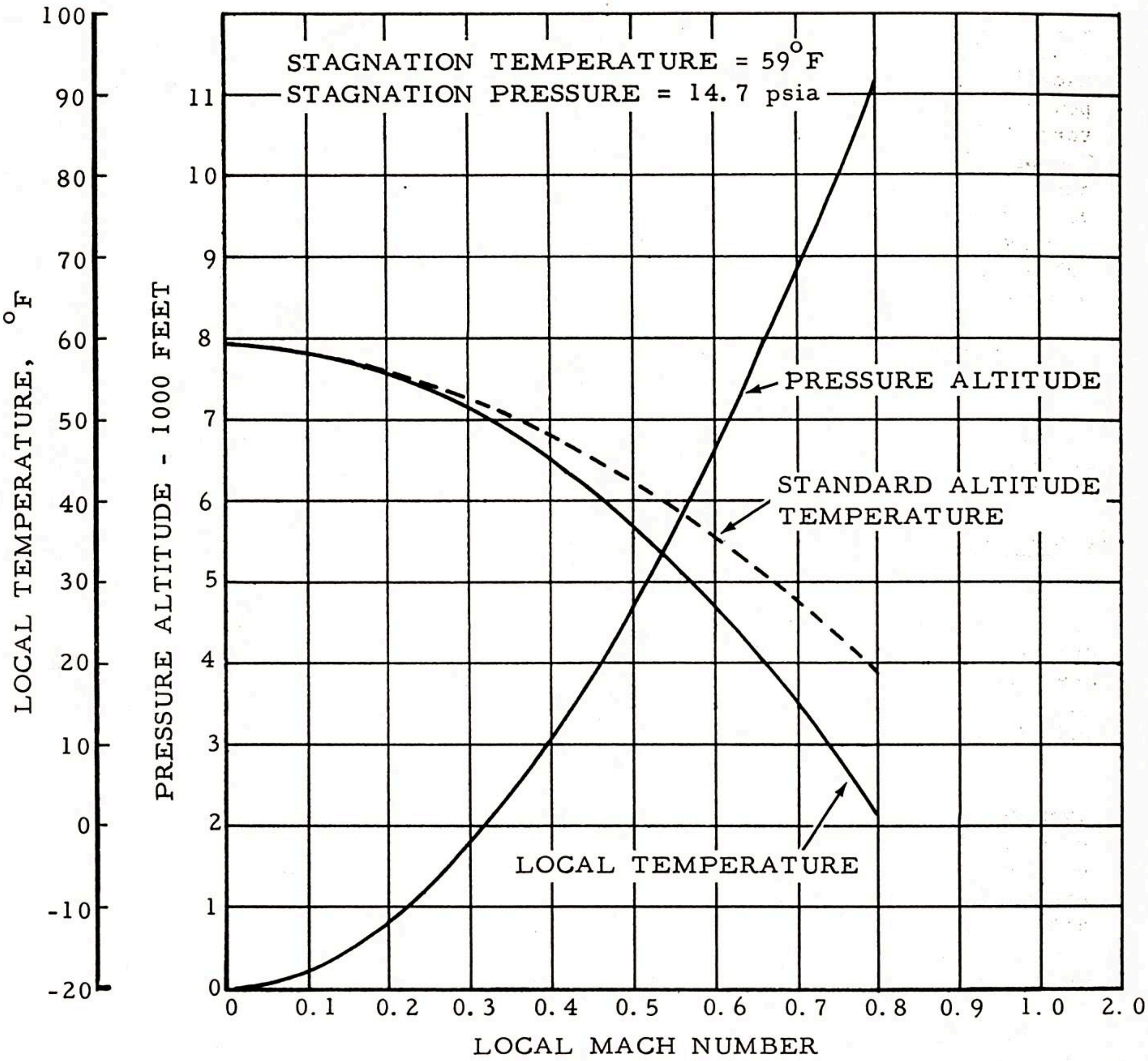


FIG. 2.18 - FREE STREAM TEST SECTION TEMPERATURE AND PRESSURE ALTITUDES

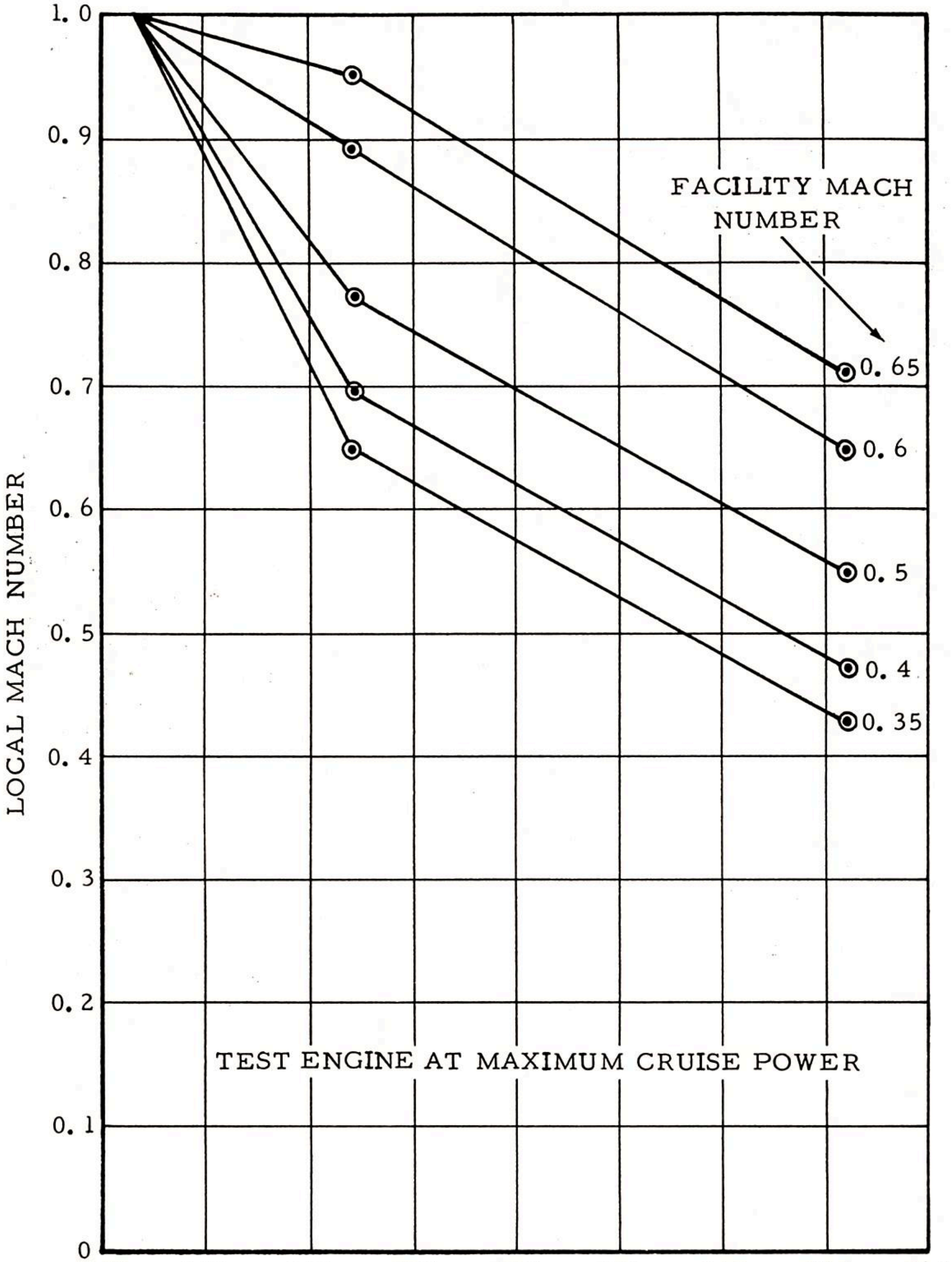


FIG. 2.19 - ESTIMATED LOCAL MACH NUMBER DISTRIBUTION ALONG EXTERNAL SURFACE OF COWL DOORS

Figure 2.20 is an estimate of the variation of mass flow ratio with local Mach number for diverging wall submerged and flush circular ram inlets. These curves were derived from empirical wind tunnel data (References 4 and 5) and under the assumption that the total pressure recovery for each blast tube was equal to the pressures measured in the tubes with the exit closed and without flow. The flow through each blast tube was calculated from Figures 2.19 and 2.20 and facility calibration measurements in the airstream around the test engine installation. The estimated ventilation rate in Zone II is shown in Figure 2.21 as the summation of the flows through each of the five blast tubes.

Static pressure measurements inside the nacelle cavity and on the external surfaces of the nacelle were taken with the test engine operating in the wind tunnel at maximum cruise power over a range of facility Mach numbers. These measurements are presented in Figures 2.22 to 2.25, inclusive. Figures 2.22 and 2.23 also show the aircraft company-furnished in-flight pressure measurements on a 707-320C nacelle at pressure altitude (Reference 6) and Mach numbers corresponding to the conditions at the wind tunnel reference probe. These flight data were also obtained for the engine operating at maximum cruise power. However, the aircraft used had a later model engine (JT3D-3) with a maximum cruise power rating higher than the test engine. The flight static pressure external to the forward strut fairing shown in Figure 2.24 was assumed equal to free stream altitude static. The flight external static pressure in the area of the drain vent shown in Figure 2.25 was estimated from company-furnished model test data (Reference 7). Both wind tunnel and flight measurements revealed that the static pressure in the forward strut fairing and throughout Zone II was essentially constant.

The percentage of total airflow out of each of the primary exits in Zone II was calculated for the test engine installation assuming: (1) That the leakage out the various exits was proportional to the parameter $A\sqrt{\rho \Delta P}$, where A is the area of the exit, ρ is the air density at the exit, and ΔP is the pressure differential across the exit; (2) that the density of the air at each exit was the same; and (3) that the loss coefficient for each exit was equal. With these assumptions, the percentage of the total flow out an exit is equal to

$$\frac{A_1 \Delta P_1^{\frac{1}{2}}}{A_1 \Delta P_1^{\frac{1}{2}} + A_2 \Delta P_2^{\frac{1}{2}} + A_3 \Delta P_3^{\frac{1}{2}}} \times 100$$

where the subscripts represent the three exits. These percentages were calculated from this equation and are presented in Figure 2.26 for the test engine installation. The calculations were based on the static pressures shown in Figures 2.22 to 2.24, inclusive, measured areas through the engine fireseal and drain vent and manufacturer's estimates of the forward strut fairing leakage area (Reference 8). The drain vent area was increased to include the Zone II drain hole area. Since the leakage out

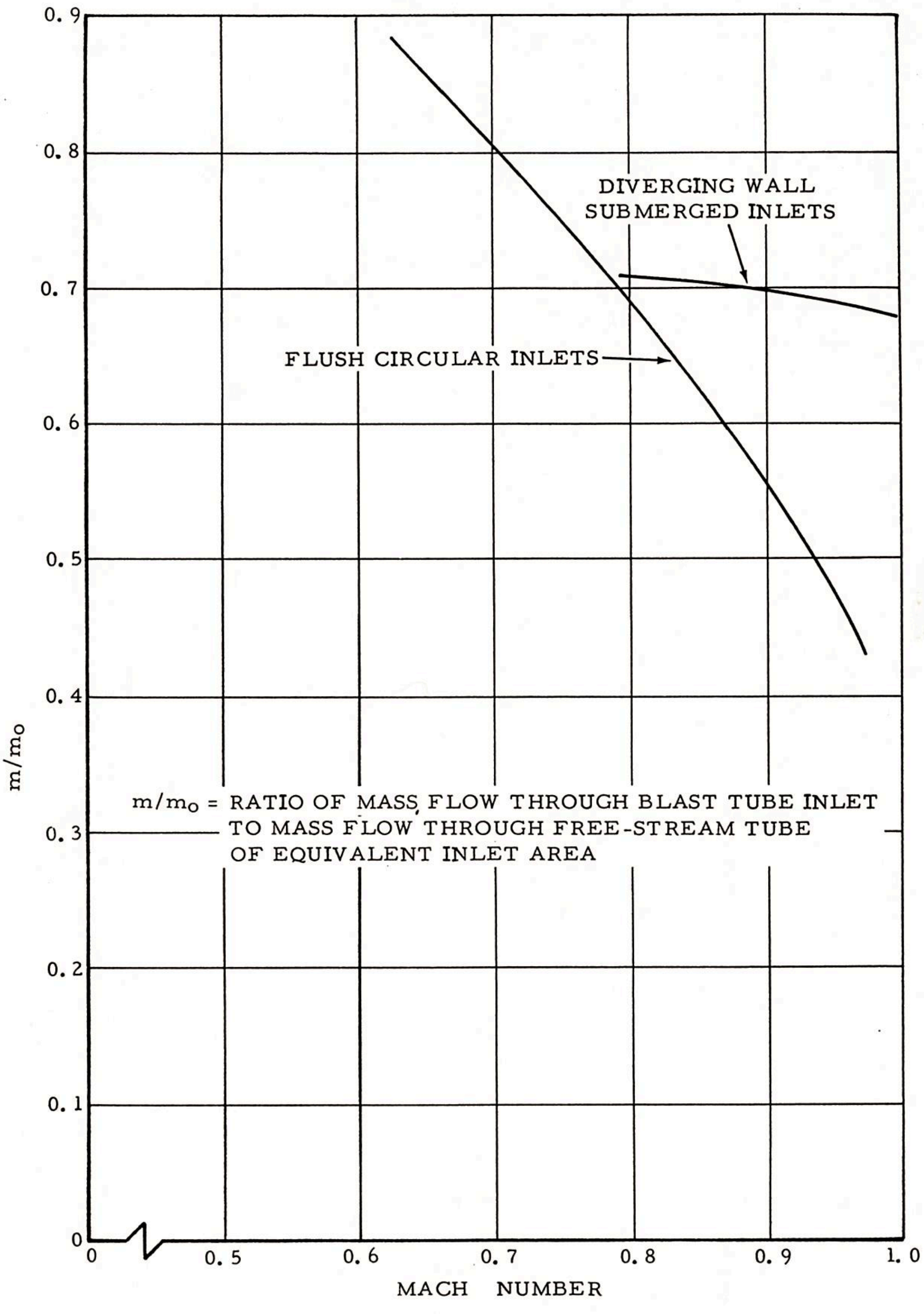


FIG. 2.20 - ESTIMATED MASS FLOW RATIO VARIATION WITH MACH NUMBER FOR BLAST TUBES

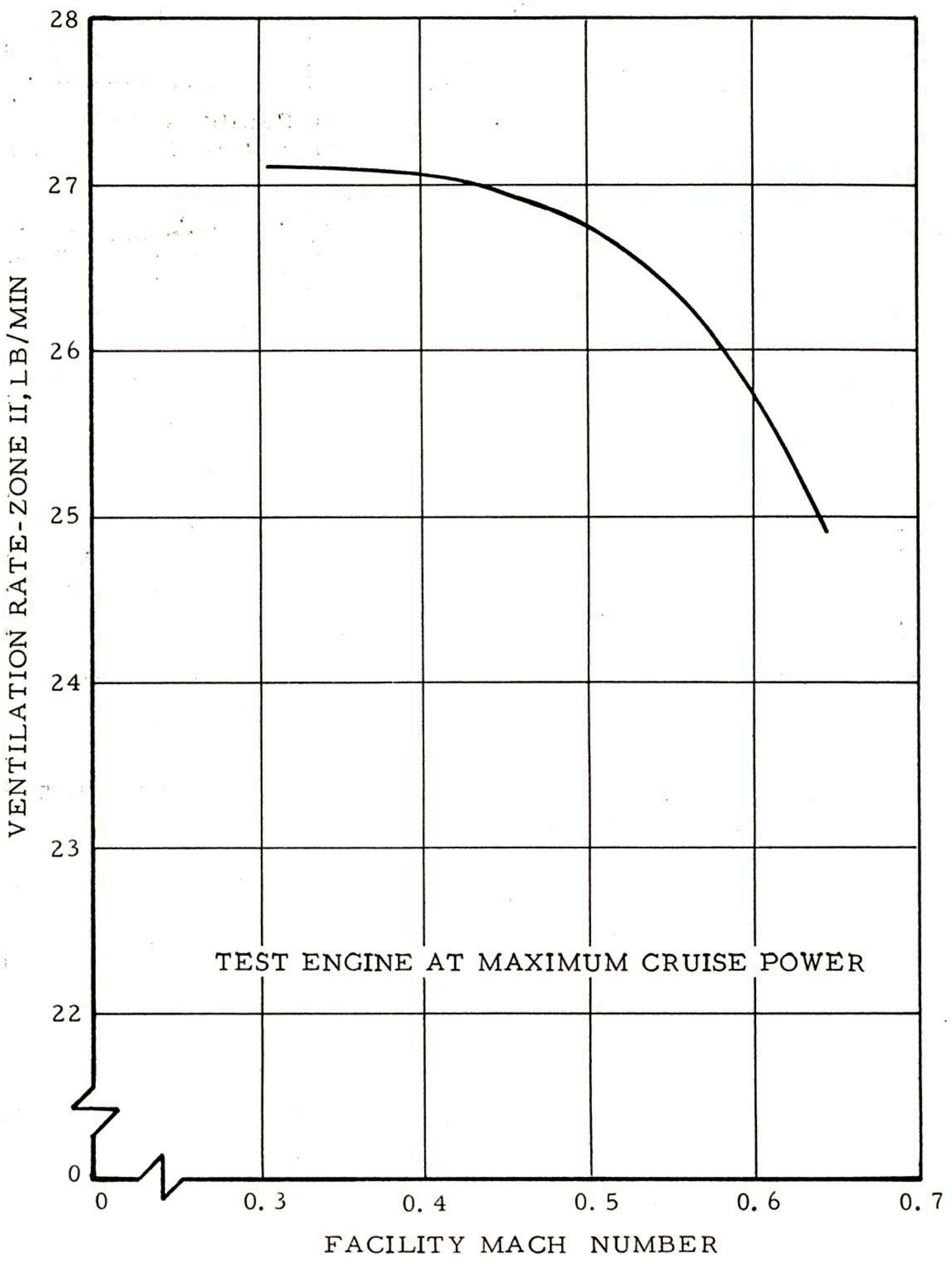


FIG. 2.21 - ESTIMATED NACELLE VENTILATION RATE VARIATION WITH MACH NUMBER

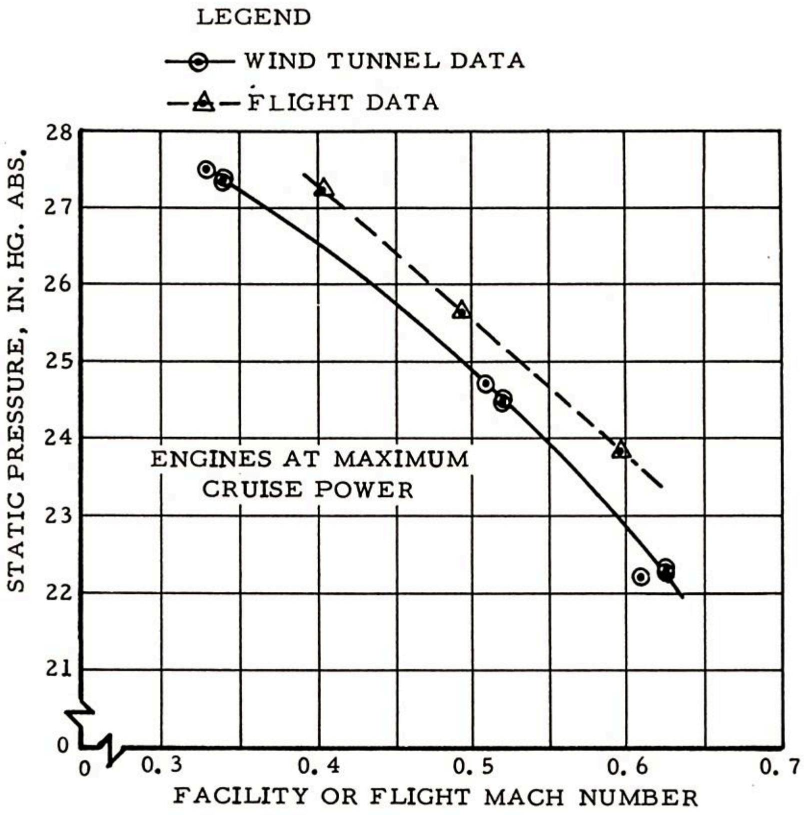


FIG. 2.22 - VARIATION OF ZONE II PRESSURE WITH MACH NUMBER

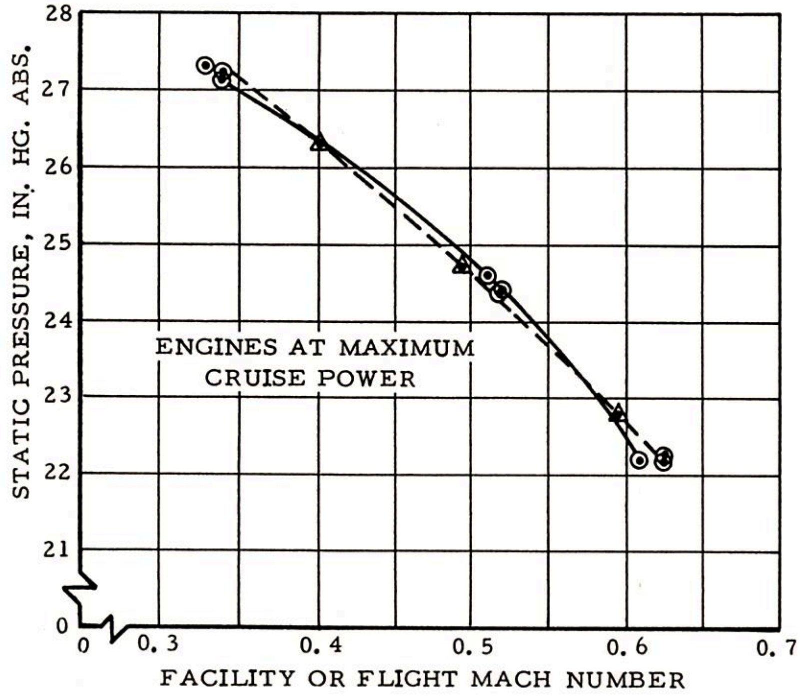


FIG. 2.23 - VARIATION OF ZONE I PRESSURE WITH MACH NUMBER

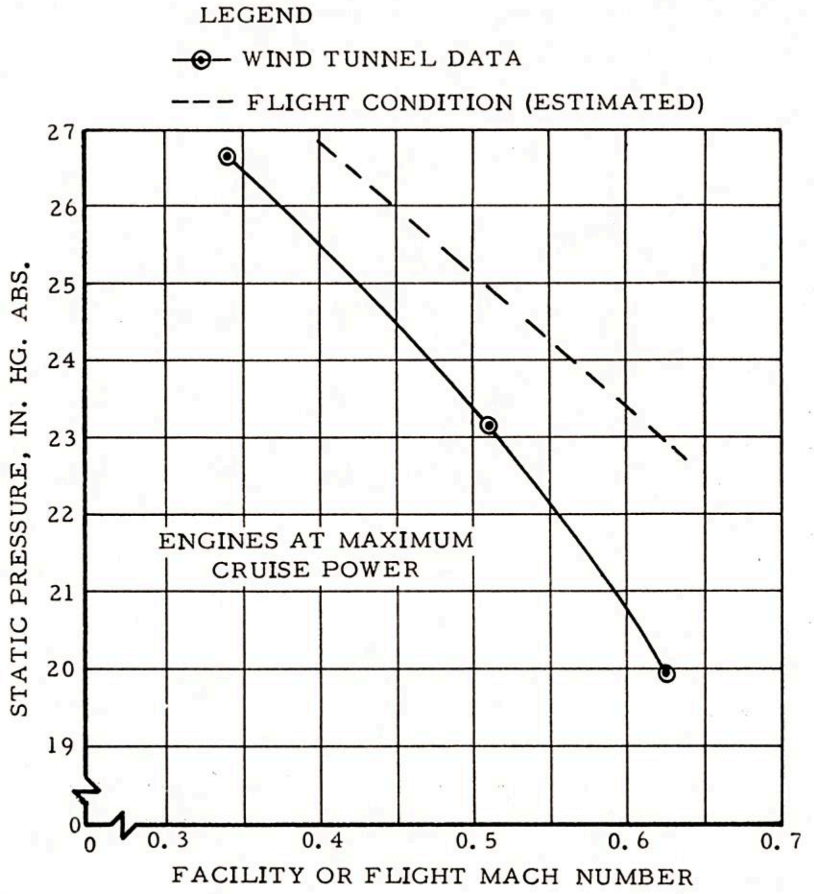


FIG. 2.24 - VARIATION OF FORWARD STRUT FAIRING EXTERNAL PRESSURE WITH MACH NUMBER

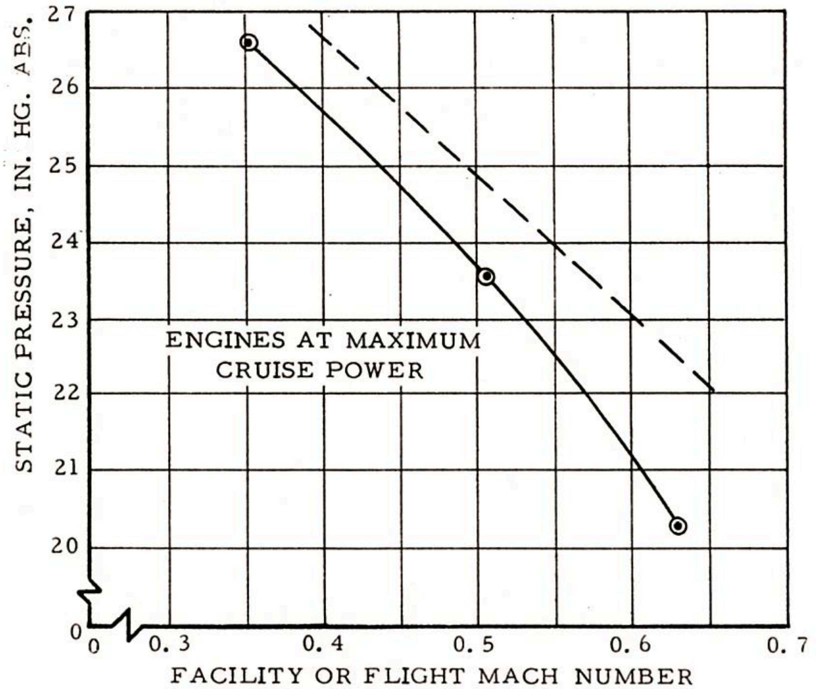


FIG. 2.25 - VARIATION OF DRAIN VENT EXTERNAL PRESSURE WITH MACH NUMBER

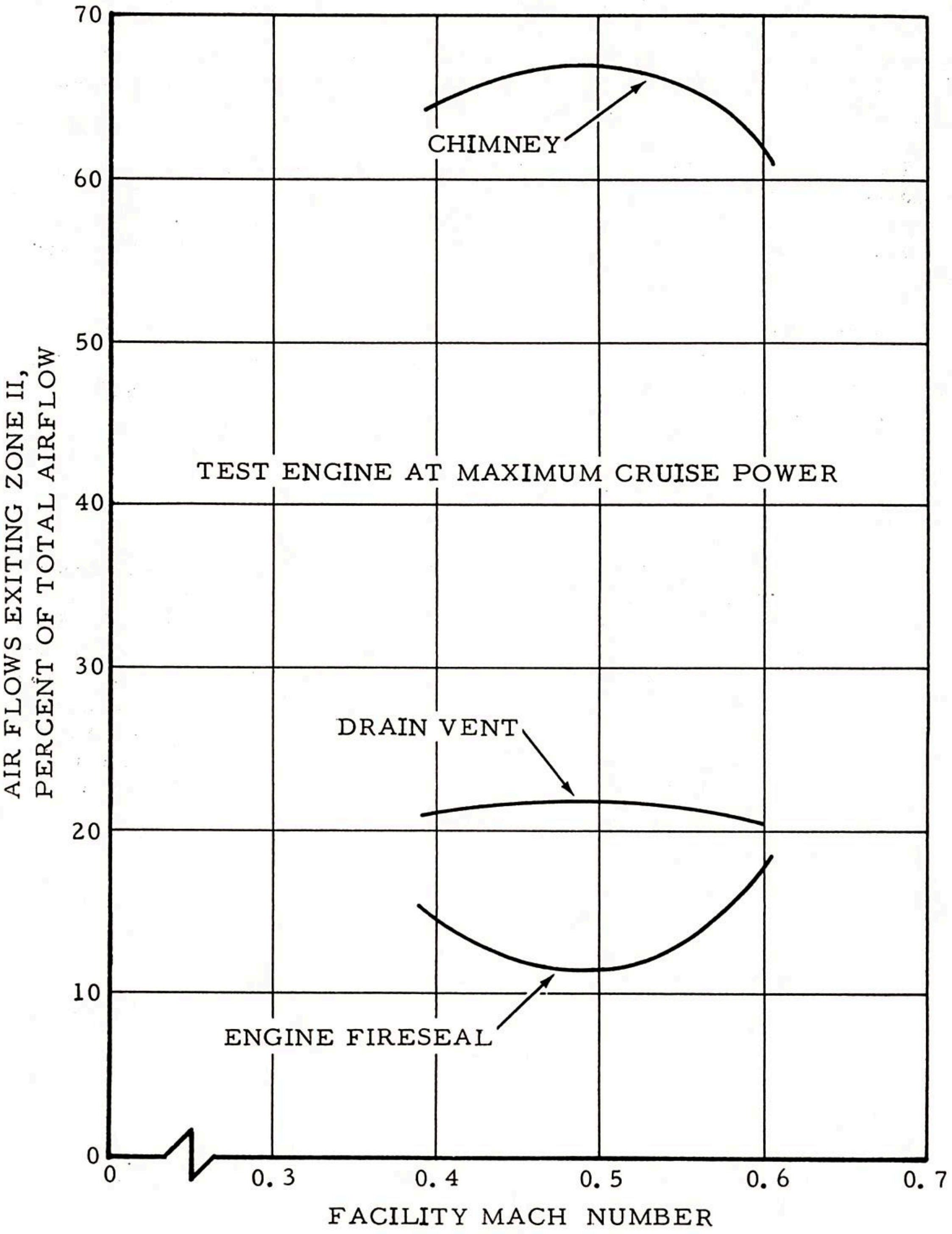


FIG. 2.26 - ESTIMATED PERCENTAGES OF COOLING AIR FLOWS THROUGH ZONE II EXITS

the forward strut fairing was through metal-to-metal seams while the fireseal and drain vent flows were through designed open areas, the percentage values for the chimney are considered to be high and the values for the fireseal and drain vent are considered to be low when loss coefficients are considered.

The amount of cooling air flowing out the three exits in Zone II was calculated from Figures 2.20 and 2.26 and is presented in Figure 2.27. Again, because of differences in loss coefficients between exits, the values shown in these figures are considered to be high for the chimney and low for the drain vent and fireseal.

The results of a comparison between flight and wind tunnel estimated airflows out the three Zone II exists are presented in Figure 2.28 for equal Zone II static pressures. This comparison was made using the following equation:

$$\frac{W_1 \text{ Flight}}{W_1 \text{ Wind Tunnel}} = \frac{\Delta P_1{}^{1/2} \text{ Flight}}{\Delta P_1{}^{1/2} \text{ Wind Tunnel}}$$

Where W is the weight flow rate through an exit. The equation assumes that the exit areas and loss coefficients were the same for both the wind tunnel and flight installations, but does not assume that the loss coefficients at each of the three exits were equal. The greatest difference shown in this figure between wind tunnel and flight Zone II airflows is across the engine fireseal. This difference is considered to be due to the greater influence of the ejector pumping action at the exhaust nozzle on Zone I static pressures in flight, with the higher maximum cruise engine power rating and the higher local Mach numbers around the exhaust nozzle.

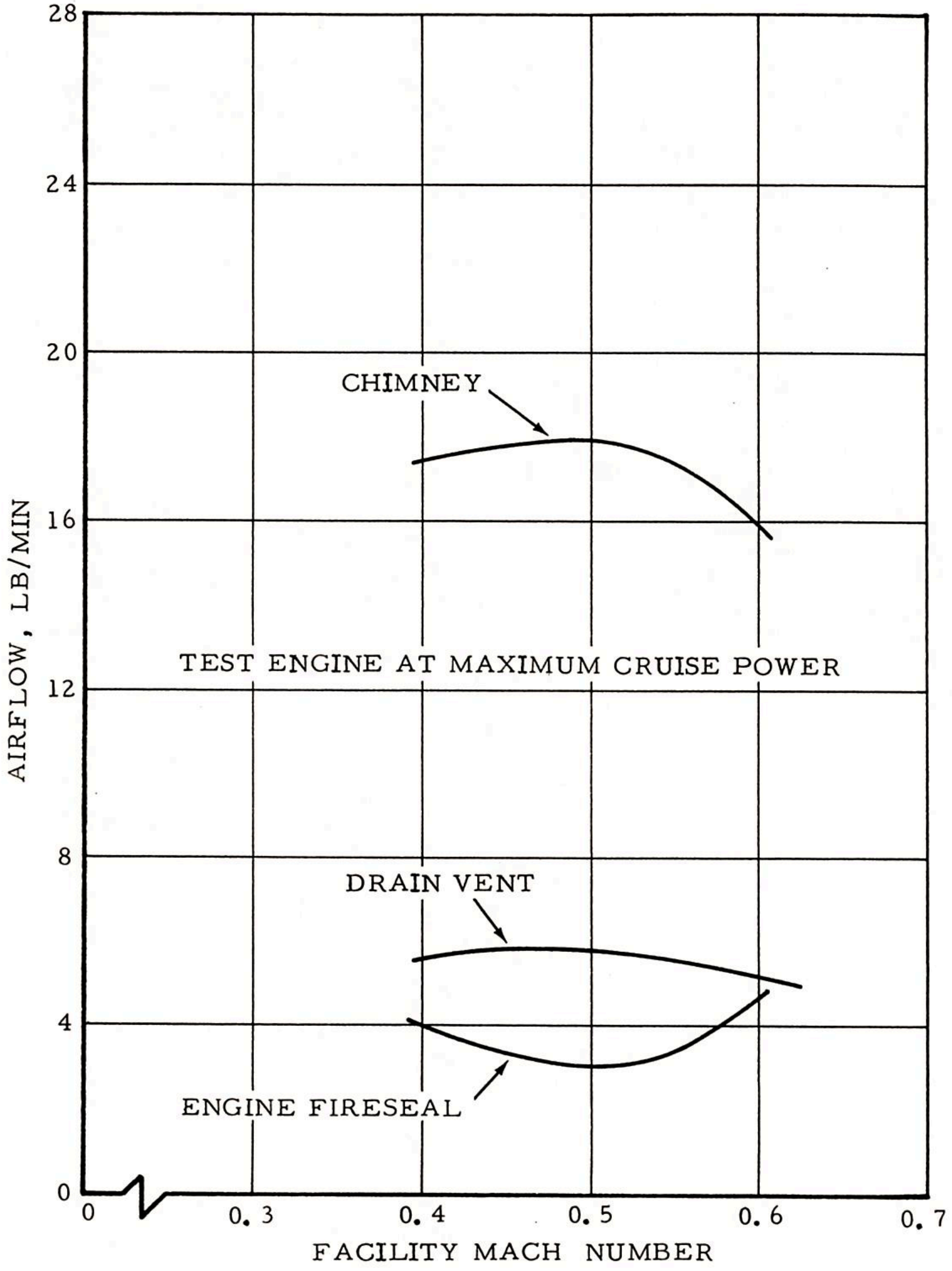


FIG. 2.27 - ESTIMATED COOLING AIR FLOWS THROUGH ZONE II EXITS

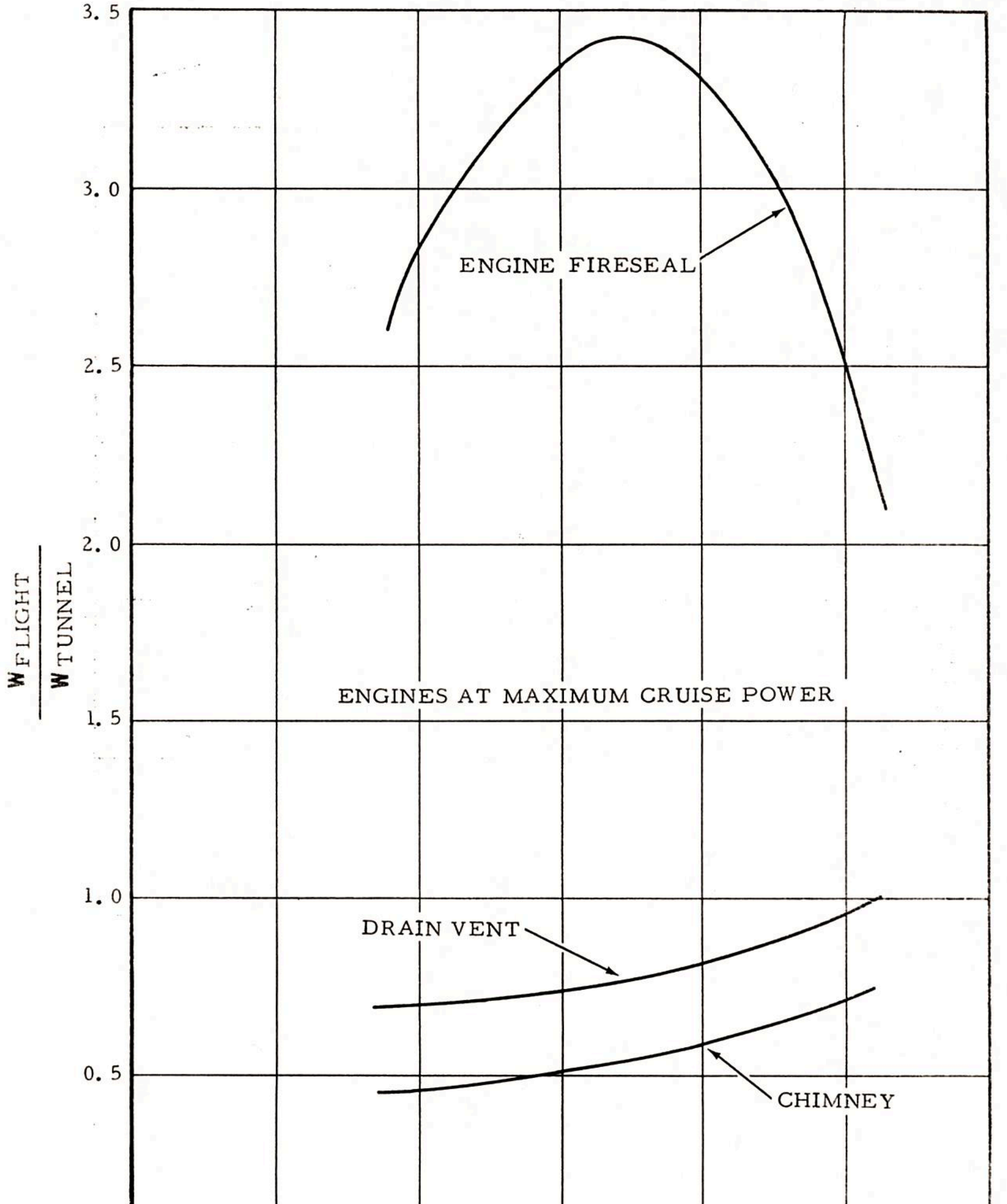


FIG. 2.28 - ESTIMATED RATIO OF FLIGHT TO WIND TUNNEL COOLING AIR FLOWS THROUGH ZONE II EXITS

APPENDIX III

NACELLE AIRFLOW AND TEMPERATURE SURVEY

Engine Nacelle Installation Configurations

The Nacelle Airflow and Temperature Survey was conducted with two test installation configurations. The production configuration was an unmodified nacelle/strut as manufactured for airline service. The general layout of this configuration is shown in Figures 2 and 34 of the report. Components located in the nacelle compressor and accessory section (Zone II) are cooled by five air blast tubes. The size and location of these tubes are shown in Figure 3.1. Ventilation in the nacelle combustor and turbine section (Zone I) was provided by air movement between zones through a 1/16-inch annular gap and four holes (1/2- to 1-inch diameter) in the engine fireseal. The designed air exits in the nacelle were through drain holes, the drain vent (Figure 3.1), and the annular opening between the exhaust nozzle and the aft thrust reverser sleeve.

The opened engine compartment fireseal configuration consisted of a modified production installation with increased cooling air and the flow restrictions eliminated between Zones II and I. This modification was accomplished by installing the additional cooling air blast tubes shown in Figure 3.2 and by removing the cowl door portion of the engine fireseal as shown in Figure 3.3.

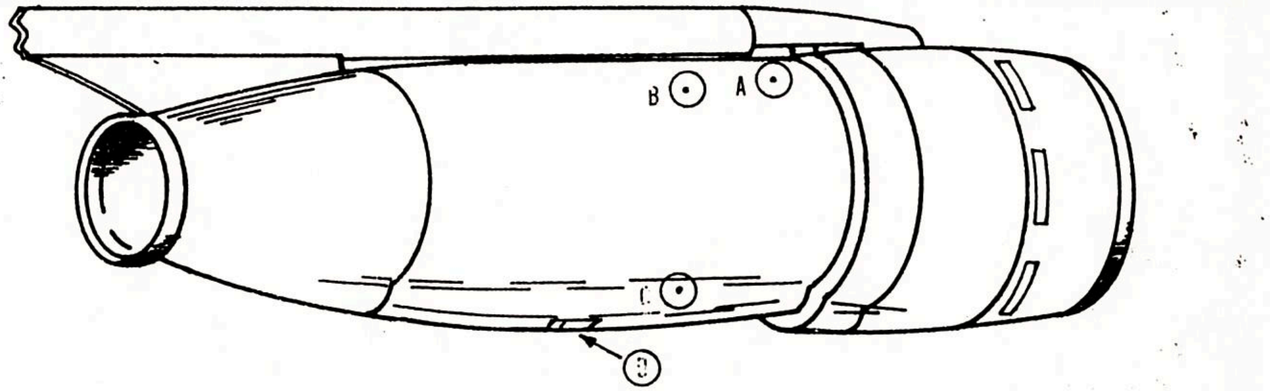
Test Equipment and Procedure

The various combinations of engine operation and flight simulation shown in Table I were selected to enable powerplant fire protection testing in the low altitude flight regimes.

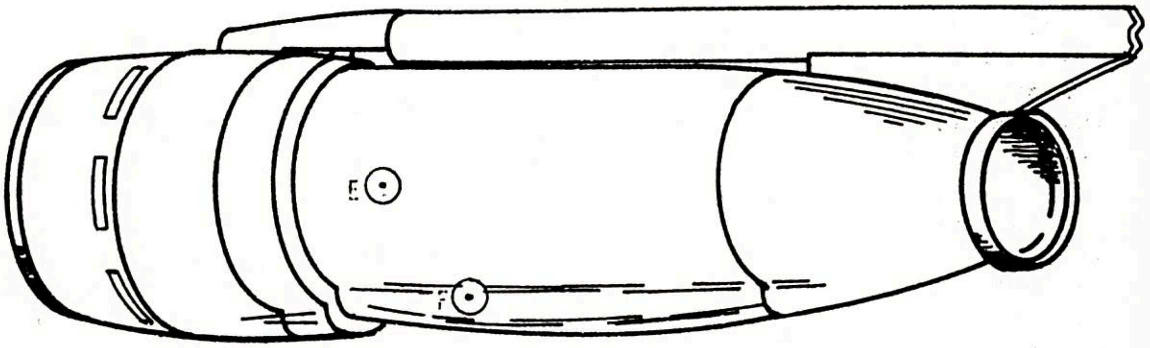
Airflow direction measurements were obtained by closed circuit television coverage of 16 directional indicators mounted on the nacelle and visible from the outside.

Airflow velocity measurements were made at each directional indicator position following the airflow direction measurements with pitot-static probes. All test conditions conducted during the airflow direction survey were repeated with the pitot-static probes aligned with the airflow direction.

The interior surface temperatures of the nacelle skin were measured by 24-gauge chromel-alumel thermocouples installed at the 19 locations listed in Table II. The engine case temperatures were measured by 20-gauge chromel-alumel thermocouples installed at the 32 locations tabulated in Table III. The secondary cooling air temperatures were measured by 30-gauge chromel-alumel thermocouples installed at the 34 locations tabulated in Table IV.



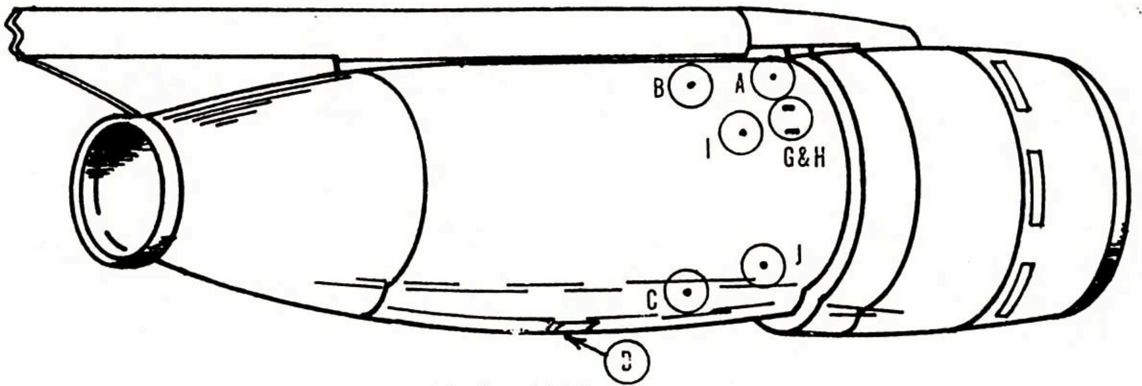
RIGHT SIDE



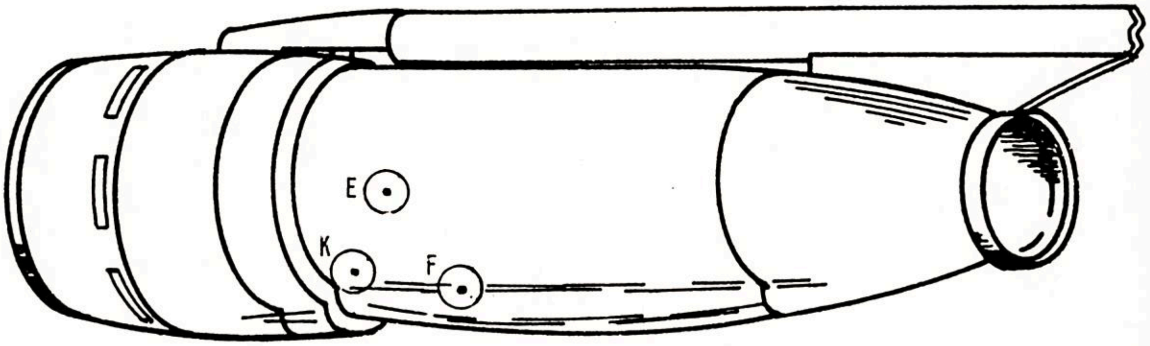
LEFT SIDE

	ITEM	SIZE	LOCATION
A	INLET AIRBLAST TUBE (DIVERGING INLET)	5/8" ID	STATION 143/12:45 O'CLOCK ZONE II
B	INLET AIRBLAST TUBE (CIRCULAR INLET)	5/16" ID	STATION 170/2 O'CLOCK ZONE II
C	INLET AIRBLAST TUBE (CIRCULAR INLET)	5/16" ID	STATION 164/5:15 O'CLOCK ZONE II
D	AIR OUTLET--DRAIN VENT	6" X 9/16"	STATION 170/6 O'CLOCK ZONE II
E	INLET AIRBLAST TUBE (DIVERGING INLET)	5/8" ID	STATION 149/9 O'CLOCK ZONE II
F	INLET AIRBLAST TUBE (CIRCULAR INLET)	3/8" ID	STATION 165/7:30 O'CLOCK ZONE II

FIG. 3.1 - COOLING AIR OPENINGS FOR PRODUCTION CONFIGURATION



RIGHT SIDE



LEFT SIDE

ITEM		SIZE	LOCATION
A, B, C, D, E, F	SAME AS IN FIGURE 3.1		
G	INLET AIRBLAST TUBE	1/2" OD	STATION 137/2:15 O'CLOCK ZONE II
H	INLET AIRBLAST TUBE	1/2" OD	STATION 137/2:45 O'CLOCK ZONE II
I	INLET AIRBLAST TUBE	1/2" OD	STATION 144/2:45 O'CLOCK ZONE II
J	INLET AIRBLAST TUBE	1/2" OD	STATION 145/4:30 O'CLOCK ZONE II
K	INLET AIRBLAST TUBE	1/2" OD	STATION 141/7:15 O'CLOCK ZONE II

FIG. 3.2 - COOLING AIR OPENINGS FOR MODIFIED CONFIGURATION

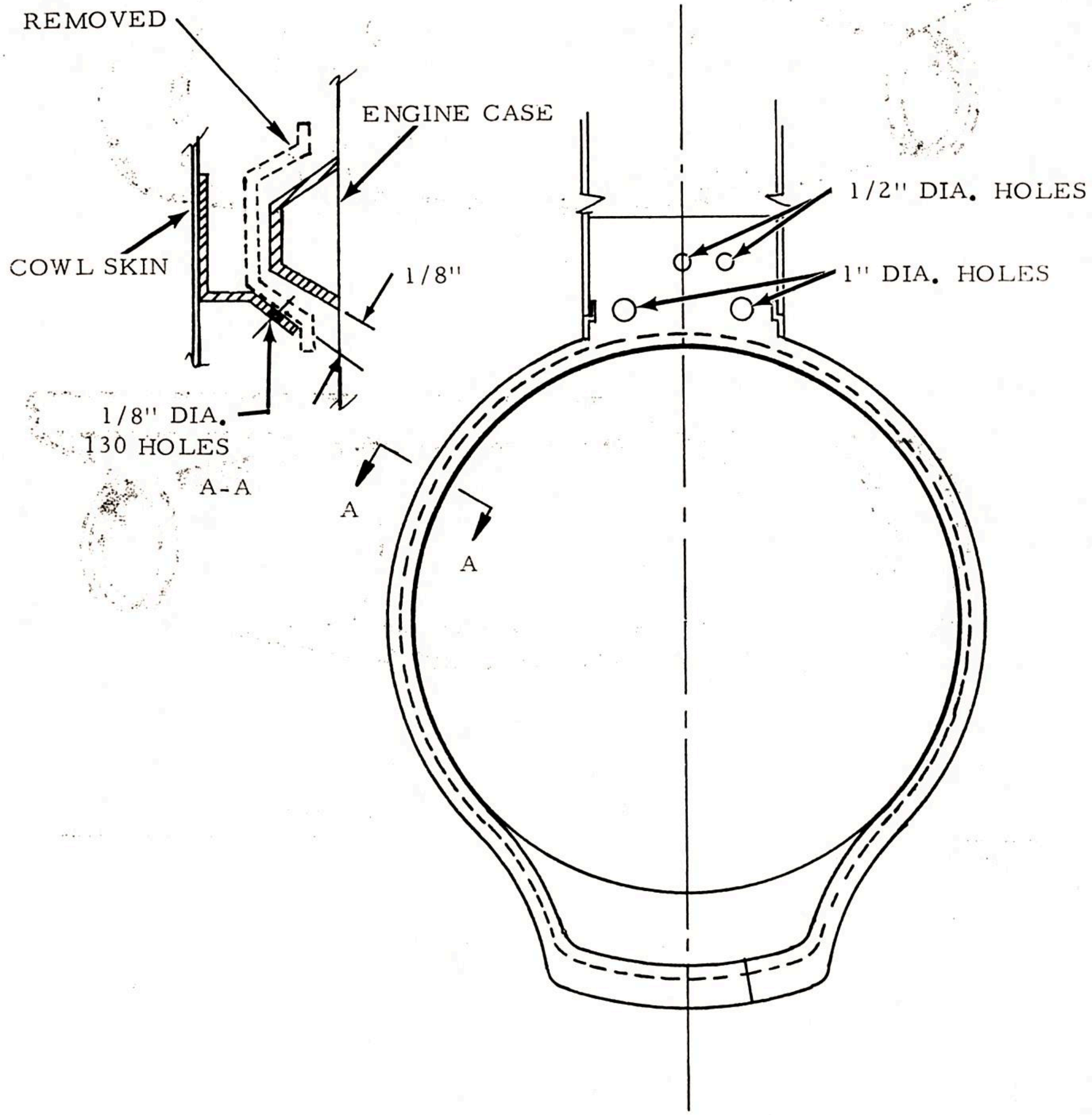


FIG. 3.3 - FIRESEAL MODIFICATION FOR OPEN ENGINE COMPARTMENT FIRESEAL CONFIGURATION

TABLE I

TEST CONDITIONS FOR NACELLE AIRFLOW AND TEMPERATURE SURVEY

AIRFLOW SURVEY

Engine Power Setting	Facility Mach No.	Nacelle Configuration
Cut Off (Windmilling)	0.1, 0.3 & 0.5	Production & Modified
Idle	0.1, 0.3 & 0.5	Production & Modified
N_2 = 9000 RPM	0.3, 0.5 & 0.6	Production
Maximum Cruise	0.3, 0.5 & 0.6	Modified
N_2 = 9500 RPM	0.3, 0.5 & 0.6	Production
Normal Rated	0.3, 0.5 & 0.6	Modified

TEMPERATURE SURVEY

Engine Power Setting	Facility Mach No.	Nacelle Configuration
Idle	0.2, 0.3, 0.4 & 0.5	Production & Modified
N_2 = 9000 RPM	0.3, 0.4, 0.5 & 0.6	Production
Maximum Cruise	0.3, 0.4, 0.5 & 0.6	Modified
N_2 = 9500 RPM	0.3, 0.4, 0.5 & 0.6	Production
Normal Rated	0.3, 0.4, 0.5 & 0.6	Modified

TABLE II

LOCATION OF NACELLE SKIN THERMOCOUPLES

	Thermocouple Location			Thermocouple Location	
Thermocouple Number	Clock Position	Nacelle Station No.	Thermocouple Number	Clock Position	Nacelle Station No.
1	9:00	158.5	11	4:00	138.3
2	6:00	169.0	12	5:30	143.0
3	7:00	158.5	13	2:00	153.0
4	9:30	170.0	14	2:00	165.0
5	6:00	182.7	15	3:30	169.0
6	8:00	183.7	16	5:30	166.5
7	10:30	178.5	17	5:00	180.0
8	6:00	213.5	18	1:00	204.5
9	8:00	217.4	19	3:30	205.0
10	10:30	216.5			

TABLE III

LOCATION OF ENGINE CASE THERMOCOUPLES

	Thermocouple Location			Thermocouple Location	
Thermocouple Number	Clock Position	Nacelle Station No.	Thermocouple Number	Clock Position	Nacelle Station No.
20	2:00	200.5	39	9:00	152.0
21	4:00	200.5	40	12:00	152.0
22	6:00	200.5	41	11:00	143.0
23	8:00	200.0	42	8:30	161.0
24	10:00	200.5	43	7:00	159.0
25	12:00	200.5		(Accessory Gear Case)	
26	2:00	189.0	44	7:00	186.0
27	4:00	189.5		(Drain Tank)	
28	6:00	190.0	45	1:00	153.5
29	8:00	189.0		(Bleed Air Duct)	
30	10:00	189.0	46	4:00	156.5
31	12:00	188.0		(Fuel-Oil Cooler)	
32	2:00	172.0	47	2:00	134.5
33	4:00	172.0	48	4:00	134.5
34	5:30	171.5	49	9:00	136.5
35	6:30	172.5	50	2:00	152.5
36	8:00	172.3		(Oil Tank)	
37	10:00	172.3	51	6:00	201.5
38	2:00	154.0		(Aft Thrust Reverser Actuator)	

TABLE IV

LOCATION OF COOLING AIR THERMOCOUPLES

	Thermocouple Location			Thermocouple Location	
Thermocouple Number	Clock Position	Nacelle Station No.	Thermocouple Number	Clock Position	Nacelle Station No.
52	2:00	209.0	69	12:00	170.0
53	4:30	209.0	70	1:00	151.0
54	6:30	209.0	71	3:15	151.0
55	8:00	209.0	72	8:30	150.0
56	10:00	209.5	73	10:00	150.0
57	12:00	209.0	74	12:00	150.5
58	2:00	192.5	75	2:00	133.0
59	4:00	192.5	76	3:15	135.5
60	6:00	192.0	77	8:30	137.0
61	7:30	191.7	78	10:00	136.5
62	10:00	191.0	79	10:30	135.5
63	12:00	192.0	80	12:00	121.5
64	2:00	171.5	81	2:30	120.5
65	4:00	170.5	82	7:00	124.5
66	6:00	171.5	83	10:00	124.0
67	9:00	171.5	84	12:00	122.5
68	10:00	170.5	85	8:00	159.0

Direction and Velocity of Nacelle Airflow

Airflow directional data indicated the movement of air within Zone II was toward three general locations (Figure 3.4): (1) the cavity in the forward strut fairing through the chimney, (2) the drain vent, and (3) the annular opening and holes in the engine fireseal.

The local airflow directions were somewhat random with large changes frequently occurring when the engine and/or facility Mach numbers were changed.

The pitot-static method of obtaining velocities was found to be inadequate because the secondary air velocities were below the measuring capability of the instrumentation (approximately 30 feet per second). Airflow velocity measurements were not taken with the nacelle in an opened engine compartment fireseal configuration.

Nacelle Skin, Engine Case, and Secondary Air Temperature

The nacelle skin temperatures on the inner surface of the cowl doors did not exceed 185°F at engine power settings to the maximum tested and decreased 5°F to 30°F as the Facility Mach Number increased from 0.3 to 0.6.

Engine case temperatures increased with an increase in engine power setting and did not significantly change with facility Mach number. The highest engine case temperatures were measured on the forward combustor case in Zone II and the turbine inlet case in Zone I. The engine case temperature measurements at each nacelle station were averaged and related to exhaust gas temperature. These average temperatures are tabulated in Tables V and VI for the production and modified engine nacelle installation, respectively.

The secondary air temperatures in both Zone II and Zone I increased with engine power when the facility Mach number was maintained constant. Variation of secondary air temperature in either zone with an increase in facility Mach number and at the high engine power settings was not significant. At idle power, an increase in temperature in Zone II was apparent as the facility Mach number was increased. This indicated a reduction of airflow from Zone II to I.

Figures 3.5 to 3.10, inclusive, are secondary air temperature profiles for each combination of engine power setting, facility Mach number and nacelle configuration. Maximum air temperatures obtained under the highest engine operating condition tested ranged from 150°F to 350°F in Zone II and 400°F to 500°F in Zone I.

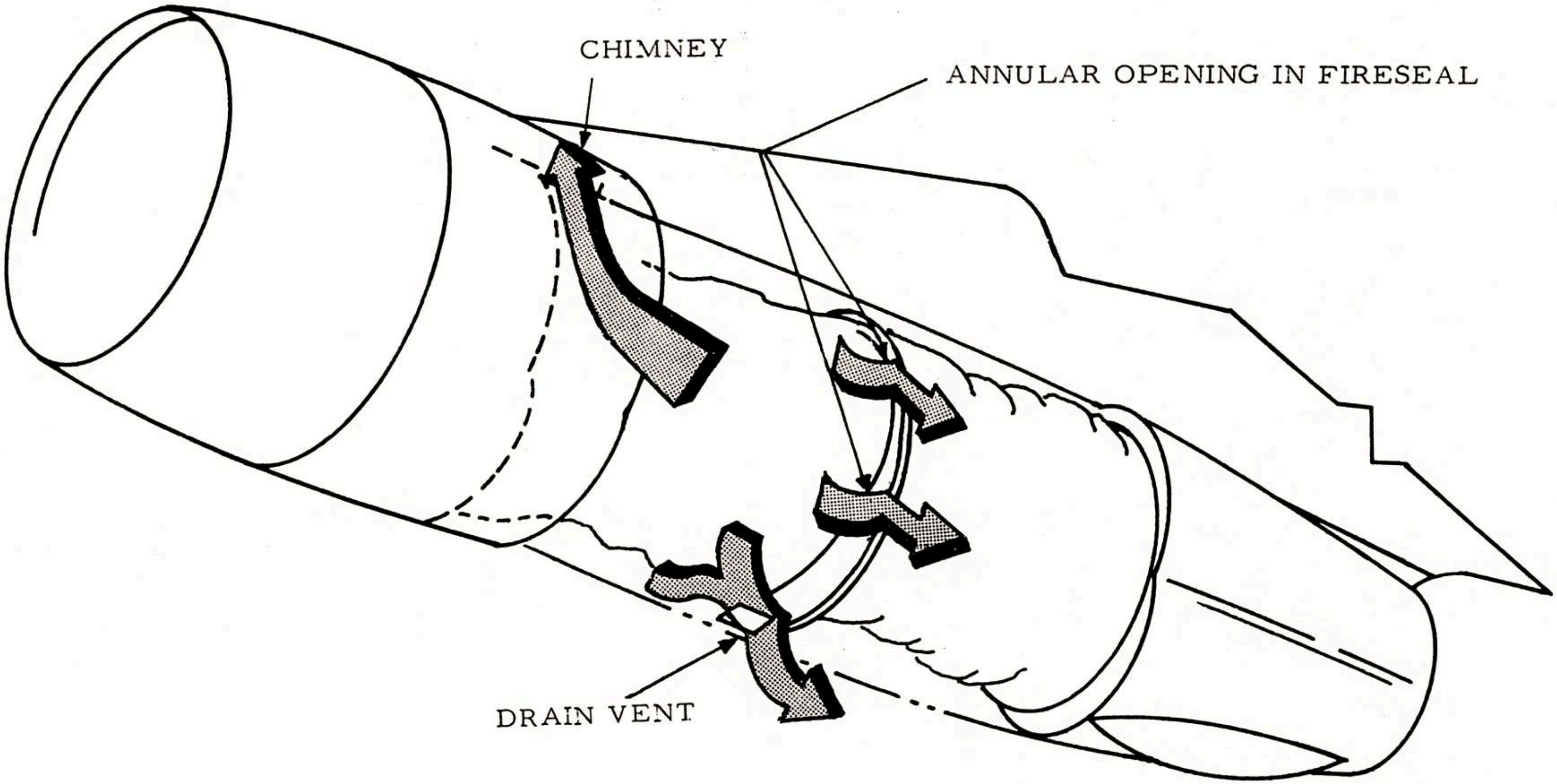


FIG. 3.4 - AIRFLOW EXITS IN ZONE II

TABLE V

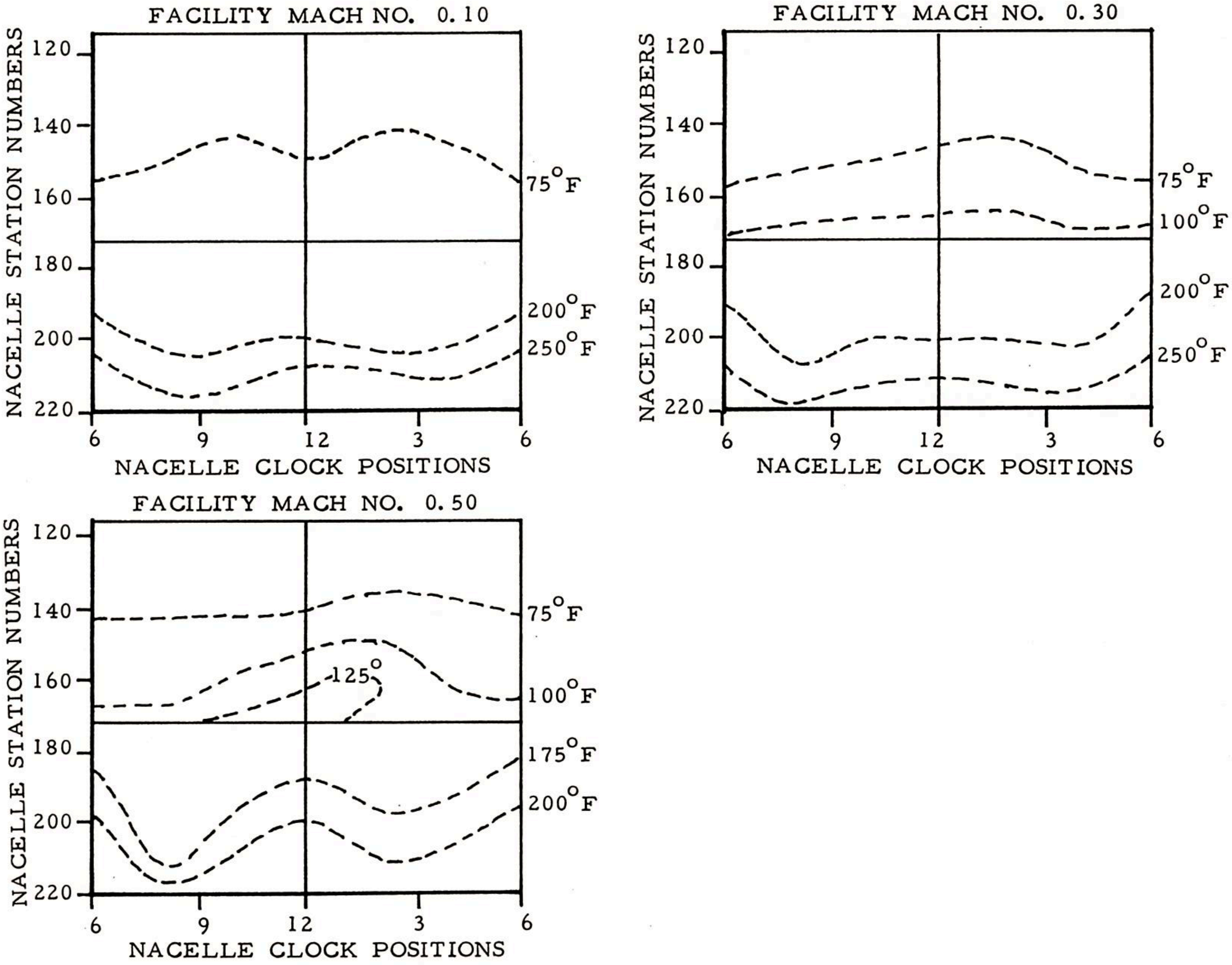
AVERAGE ENGINE CASE TEMPERATURE FOR PRODUCTION NACELLE INSTALLATION CONFIGURATION

Exhaust Gas Temperature (°F)	Facility Mach Number	Case Temperature at Nacelle Station Number							
		135.8 (°F)	143.6 (°F)	153.3 (°F)	161.6 (°F)	172.5 (°F)	189.6 (°F)	200.6 (°F)	201.1 (°F)
500	0.3	150	160	245	315	365	370	490	495
500	0.4	160	175	250	325	385	380	500	510
500	0.5	180	205	265	350	420	425	535	540
600	0.3	200	220	300	395	465	465	625	600
600	0.4	215	240	310	410	500	490	660	625
600	0.5	230	260	320	420	525	520	690	670
600	0.6	240	285	330	450	555	540	710	675
700	0.3	240	270	350	465	560	550	750	695
700	0.4	255	300	370	475	600	590	795	745
700	0.5	260	300	380	480	615	605	810	780
700	0.6	275	325	400	510	635	625	835	800
800	0.4	290	340	430	540	660	650	900	860
800	0.5	295	345	435	540	690	680	900	865
800	0.6	305	355	455	560	705	695	950	915
850	0.4	300	350	450	560	690	680	945	915
850	0.5	305	355	450	560	710	700	945	915

TABLE VI

AVERAGE ENGINE CASE TEMPERATURE FOR OPEN ENGINE COMPARTMENT FIRESEAL CONFIGURATION

Exhaust Gas Temperature (°F)	Facility Mach Number	Case Temperature at Nacelle Station Number							
		135.8 (°F)	143.6 (°F)	153.3 (°F)	161.6 (°F)	172.5 (°F)	189.6 (°F)	200.6 (°F)	201.1 (°F)
500	0.3	120	150	180	230	285	285	510	475
500	0.5	140	180	220	290	350	350	510	510
600	0.3	155	195	255	315	405	400	670	620
600	0.5	175	220	280	365	450	440	635	635
700	0.3	190	245	325	395	525	510	830	815
700	0.4	155	240	345	415	540	535	770	---
700	0.5	180	260	340	435	545	530	750	750
700	0.6	165	255	330	465	560	525	750	760
800	0.3	230	295	400	480	645	620	985	905
800	0.4	235	290	375	475	620	595	835	855
800	0.5	240	305	400	510	640	620	870	870
800	0.6	235	285	365	505	625	615	865	870
850	0.6	275	305	385	420	655	655	920	920


FACILITY MACH NO. 0.10

FACILITY MACH NO. 0.30

FACILITY MACH NO. 0.50

FIG. 3.5 - PRODUCTION NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT IDLE

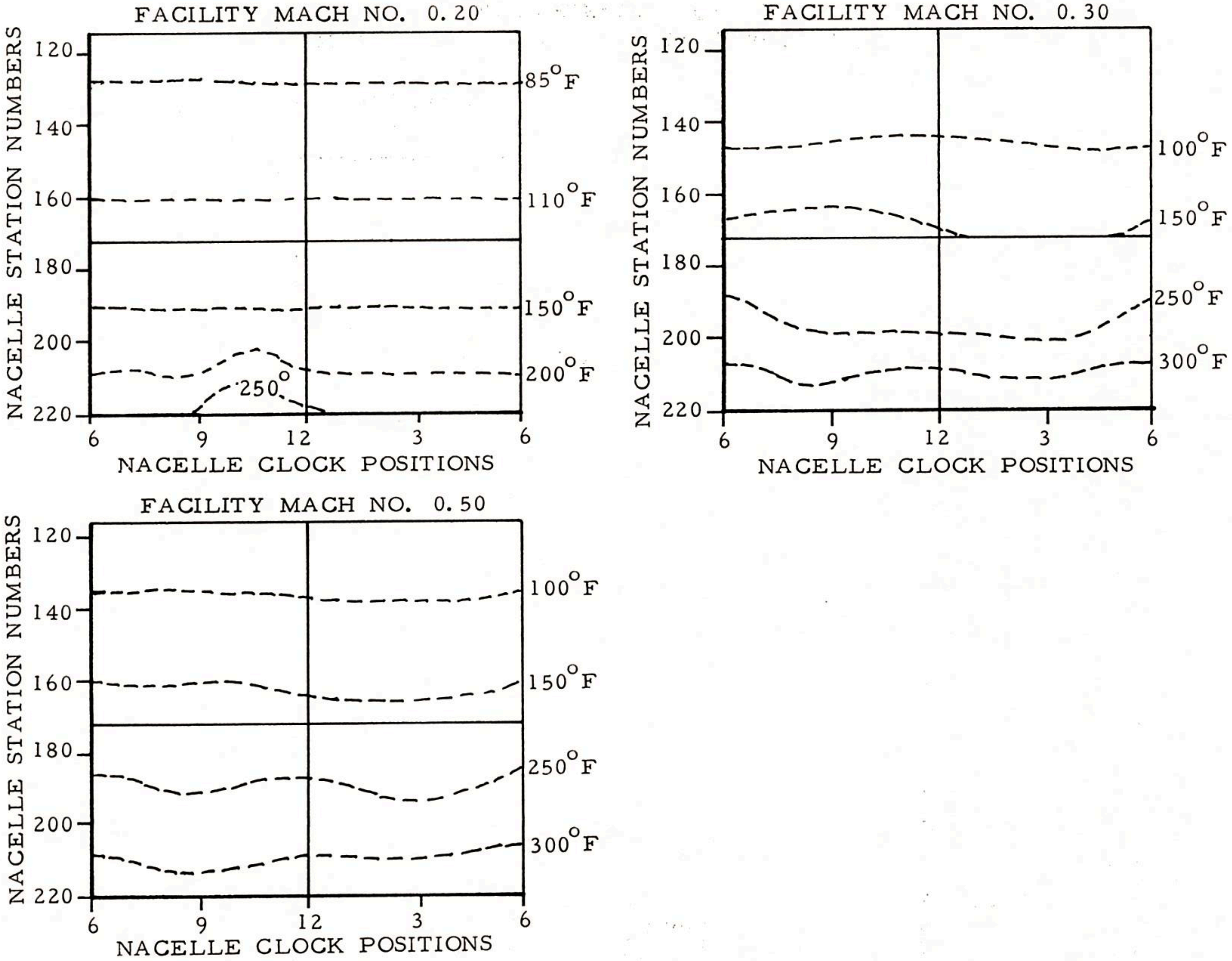
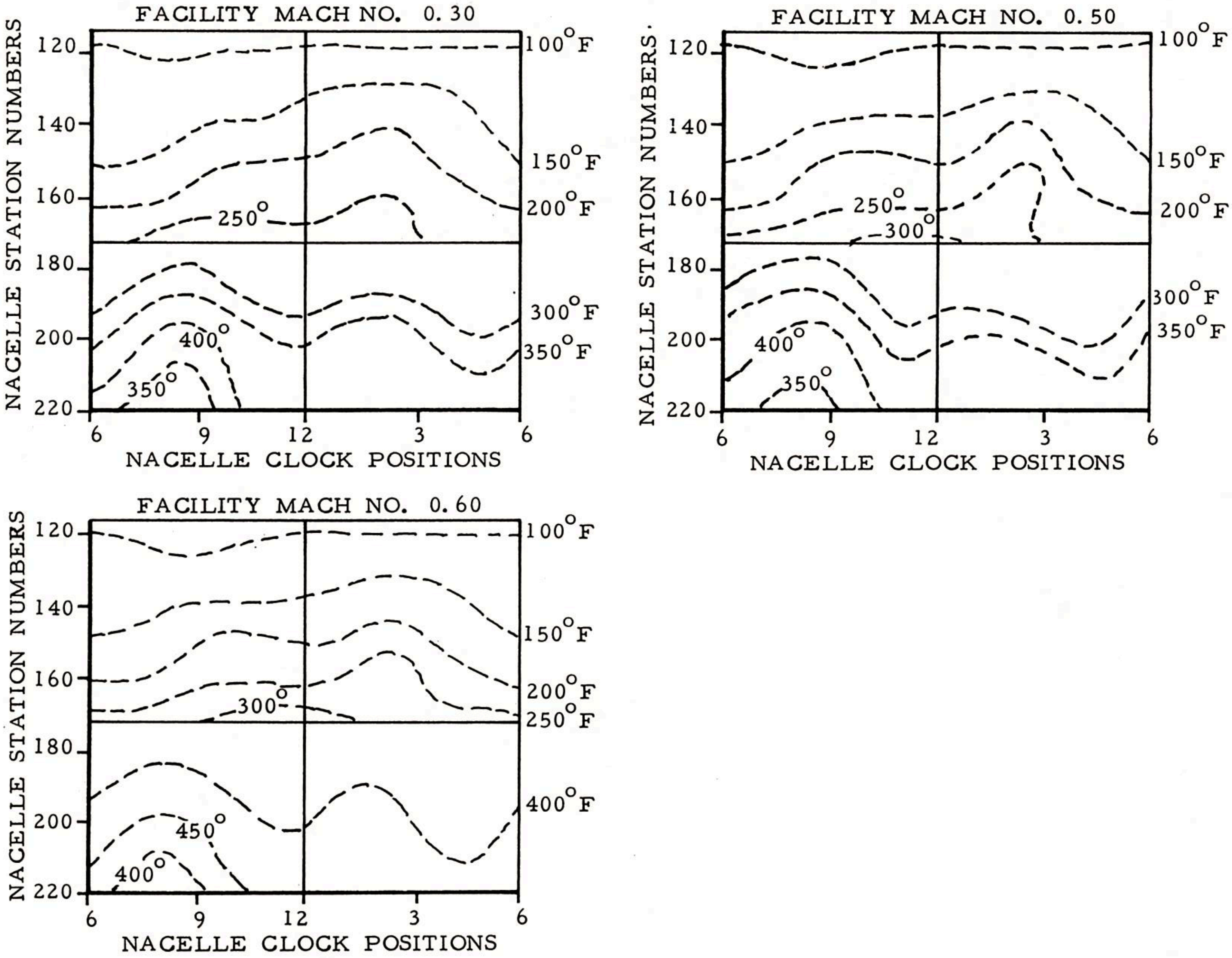


FIG. 3.6 - MODIFIED NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT IDLE



FACILITY MACH NO. 0.30

FACILITY MACH NO. 0.50

FACILITY MACH NO. 0.60

FIG. 3.7 - PRODUCTION NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT 9000 RPM (N_2)

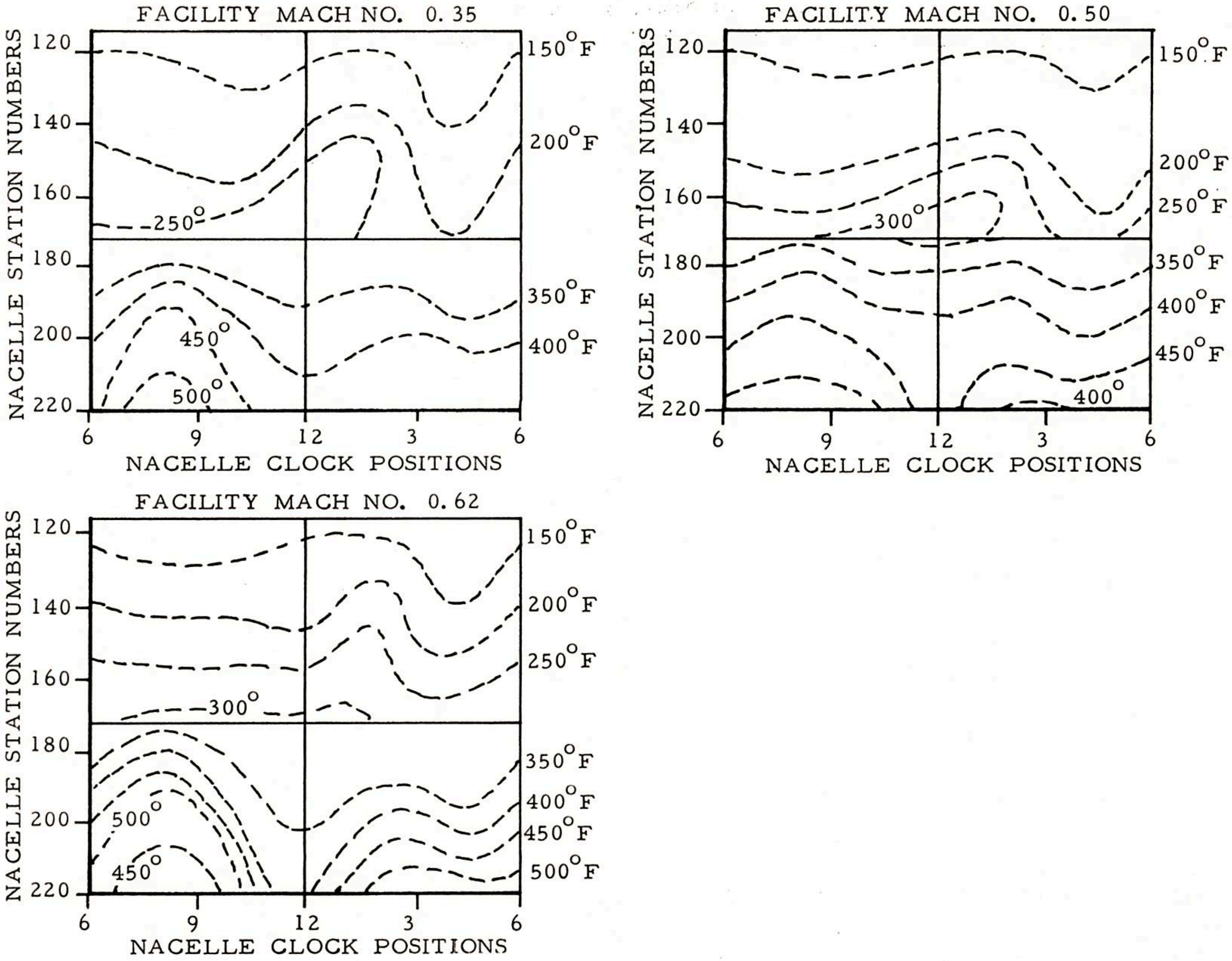
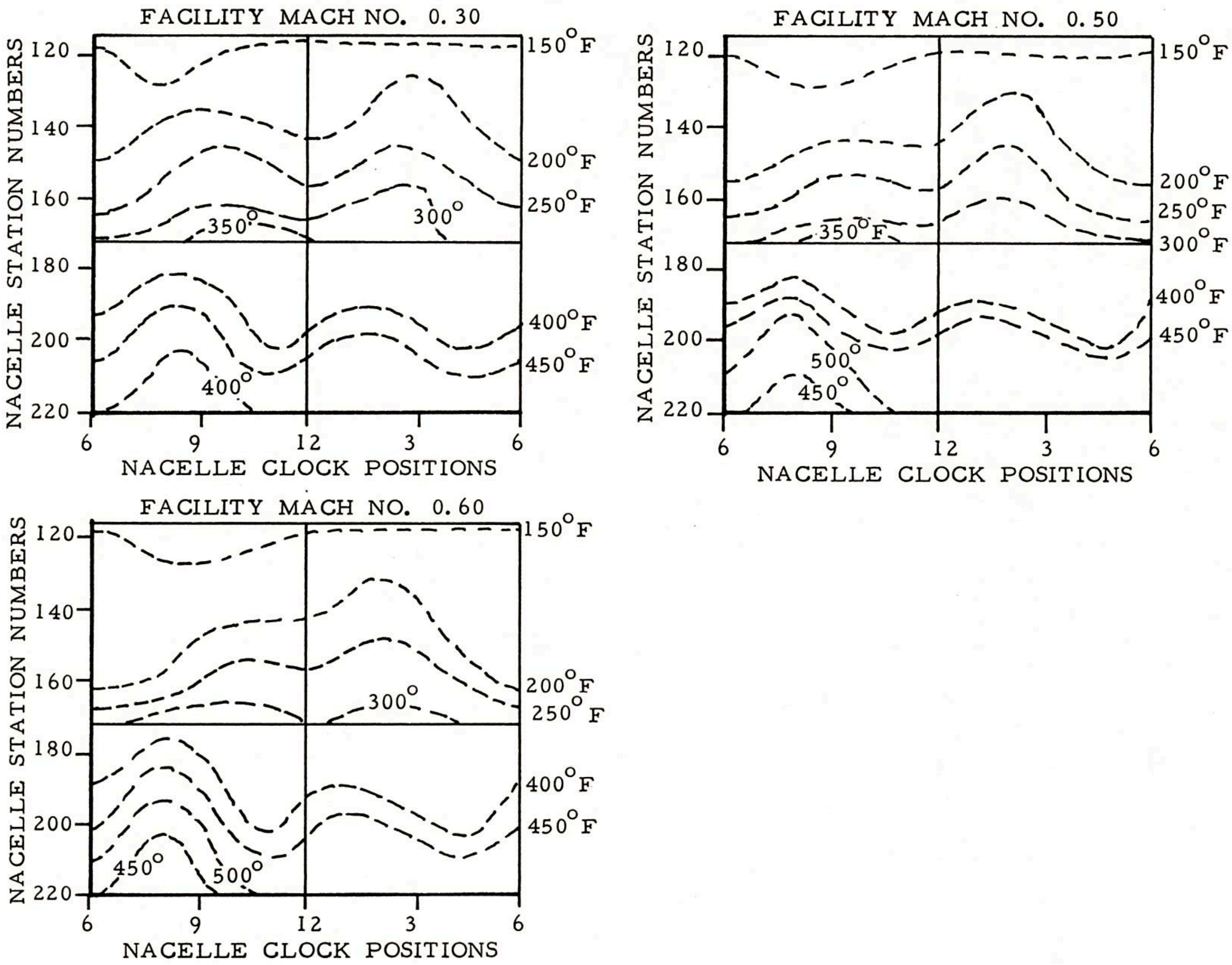


FIG. 3.8 - MODIFIED NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT MAXIMUM CRUISE

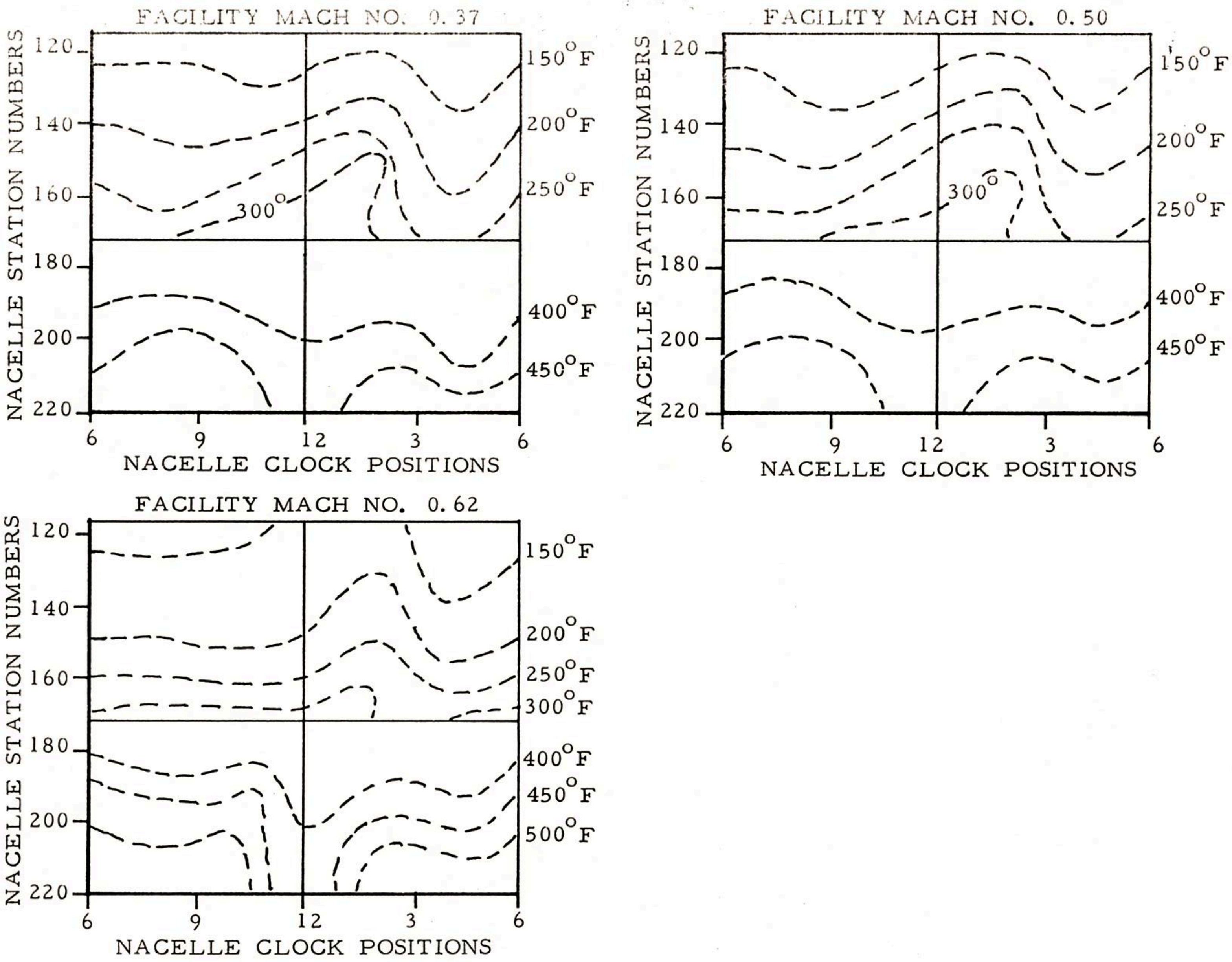


FACILITY MACH NO. 0.30

FACILITY MACH NO. 0.50

FACILITY MACH NO. 0.60

FIG. 3.9 - PRODUCTION NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT 9500 RPM (N_2)



FACILITY MACH NO. 0.37

FACILITY MACH NO. 0.50

FACILITY MACH NO. 0.62

FIG. 3.10 - MODIFIED NACELLE AIR TEMPERATURE PATTERN WITH ENGINE AT NORMAL RATED

Figures 3.11 and 3.12 show a comparison of average secondary air temperatures throughout each nacelle configuration for all test conditions as set forth in Table I.

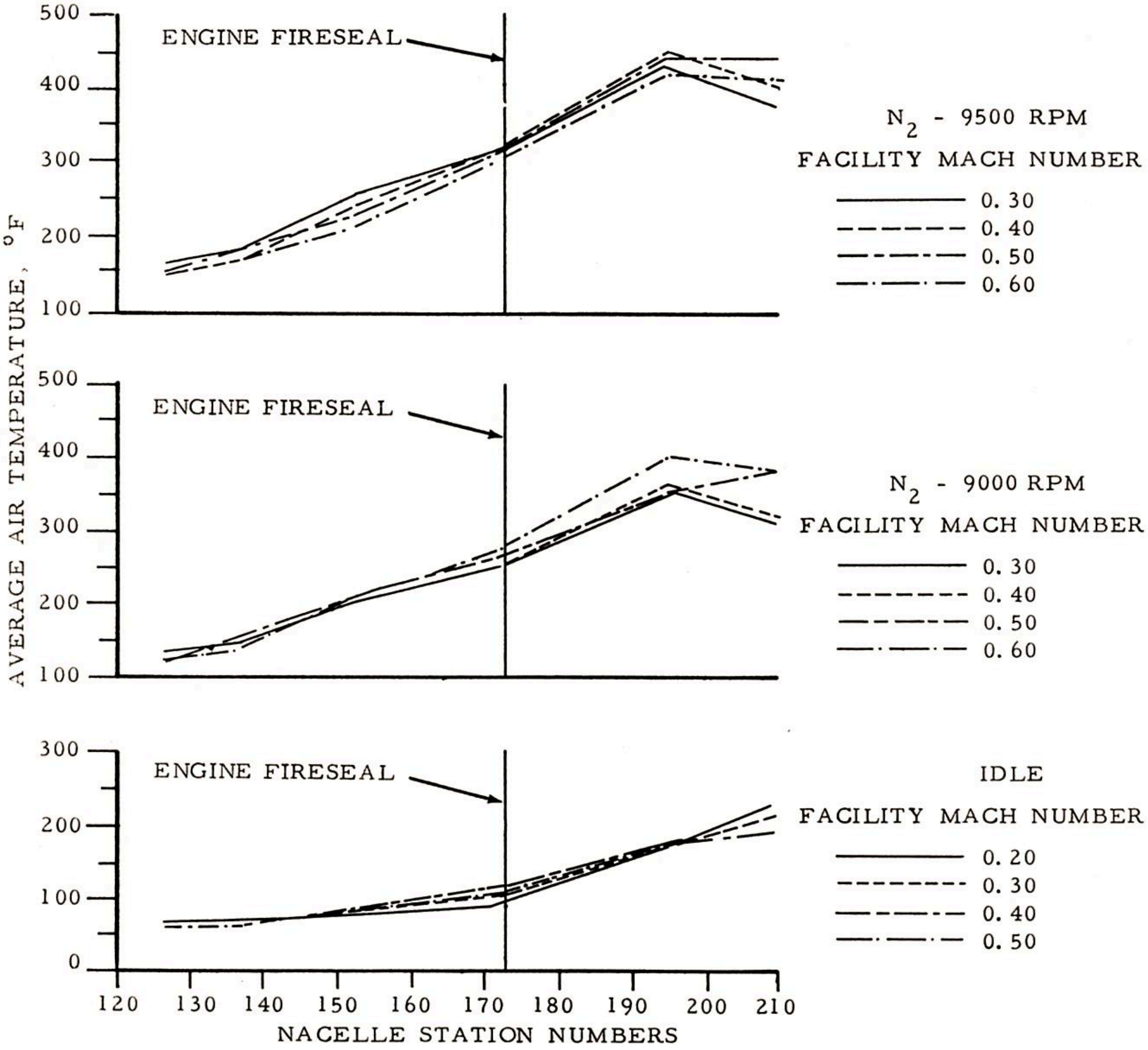


FIG. 3. 11 - VARIATION OF NACELLE AIR TEMPERATURE WITH MACH NUMBER AND ENGINE POWER SETTING - PRODUCTION CONFIGURATION

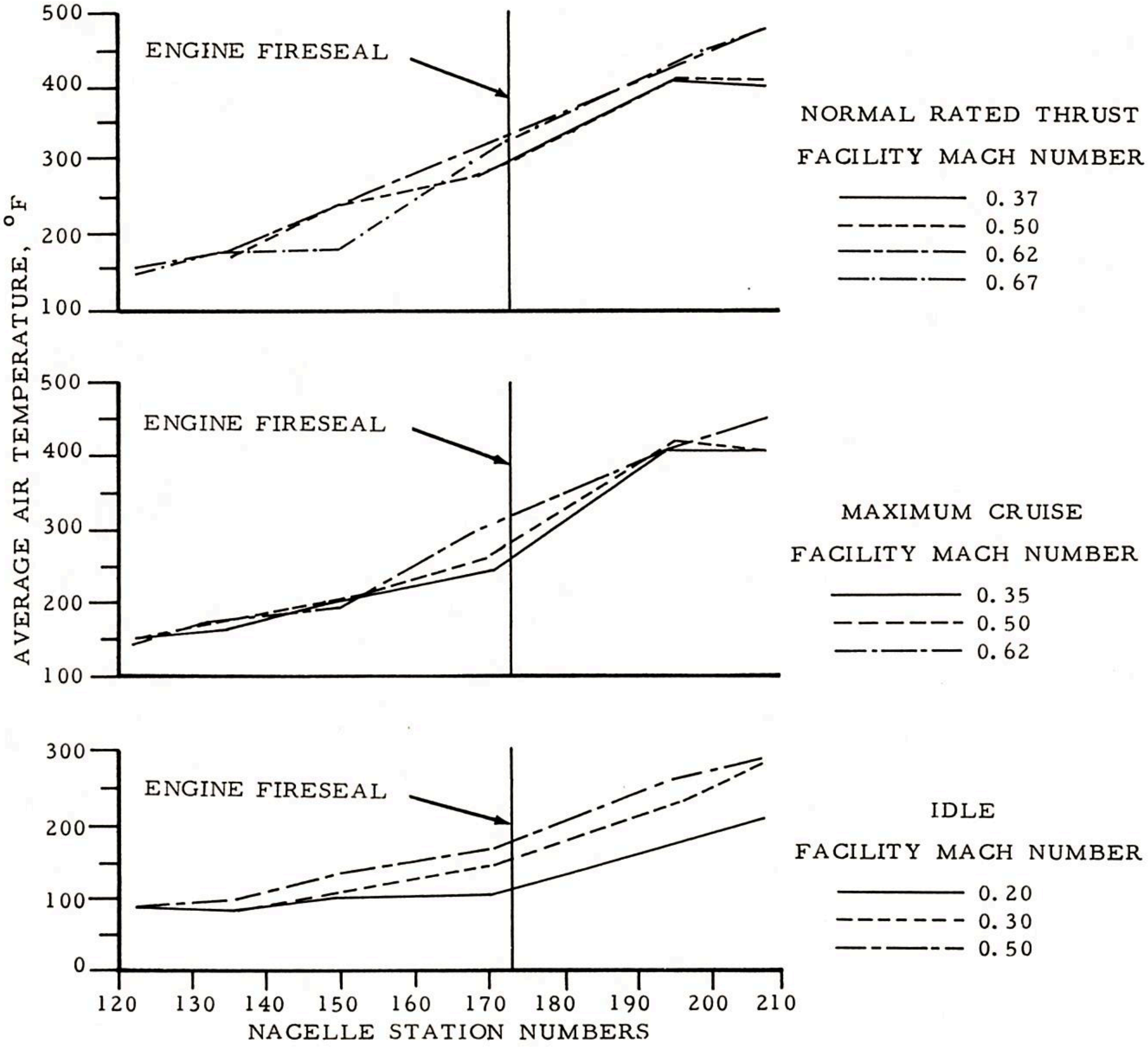


FIG. 3.12 - VARIATION OF NACELLE AIR TEMPERATURE WITH MACH NUMBER AND ENGINE POWER SETTING - MODIFIED CONFIGURATION

APPENDIX IV

IGNITION HAZARDS DATA SUPPLEMENT

Engine Nacelle Installation Configurations

The three installation configurations tested during the Ignition Hazards Study were as described below.

Production Configuration: The production configuration was an unmodified nacelle/strut installation as manufactured for airline service. See Appendix III for a detailed description of this configuration.

Opened Engine Compartment Fireseal Configuration: This configuration consisted of a modified production installation with increased cooling air and with the flow restrictions eliminated between the nacelle compressor and accessory section and the nacelle combustor and turbine section. This was accomplished by installing additional cooling air blast tubes and removing the cowl door portion of the engine fireseal. A detailed description of this configuration is also contained in Appendix III.

Controlled Cooling Airflow Configuration: The production installation was modified so that the cooling airflow in the area of the turbine case could be controlled over a range of conditions. These modifications consisted of the following items (Figure 4.1):

1. Sealing the nacelle combustor and turbine section (Zone I) by diaphragms to prevent air movement from the nacelle compressor and accessory section (Zone II) and into the aft thrust reverser sleeve. This provided a closed compartmental free air volume of 16 cubic feet.

2. Installing an annular plenum chamber connected to an external supply of compressed air in the forward end of the nacelle combustor section.

3. Providing seventeen 1/2-inch diameter vent holes in the aft turbine section nacelle skin at Nacelle Station Number 210.

4. Installing an obstruction at 2:00 o'clock position between Nacelle Station Numbers 192 and 203 to collect and puddle fluids running down the engine case.

These modifications provided controlled movement of air to the plenum through approximately 350 holes (7-1/4 square inches total flow area) in the plenum, into the sealed compartment, over the hot engine case and out the nacelle skin openings.

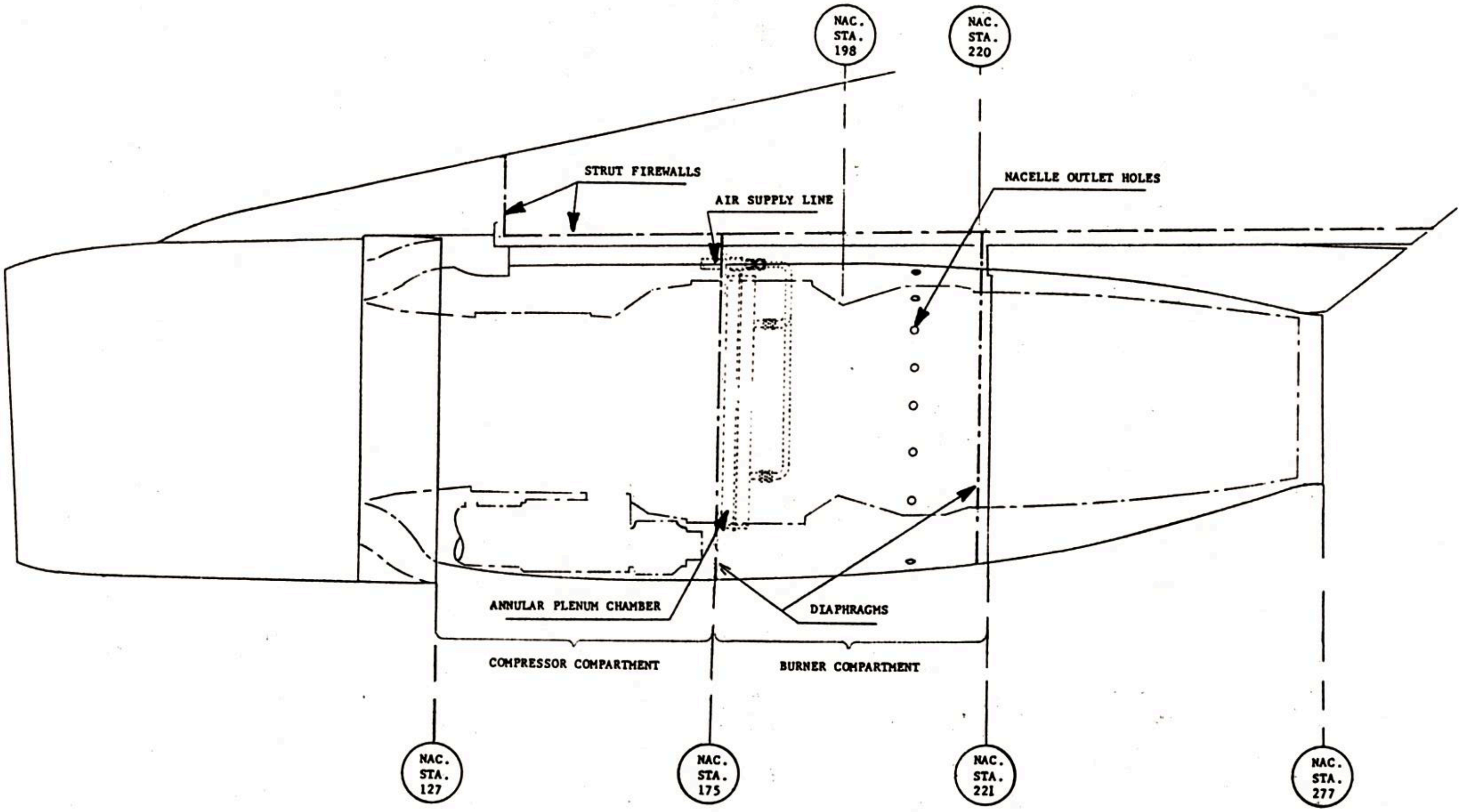


FIG. 4.1 - NACELLE CONFIGURATION WITH CONTROLLED COOLING AIRFLOW

Test Equipment and Procedure

The flammable fluid systems used were independent of the test engine systems and were capable of simulating failures over a wide range of line pressures, fluid temperatures, and flow rates. The systems recirculated the fluid so that the flow conditions could be established in the return line prior to releasing the fluid into the nacelle. All Ignition Hazard tests were conducted with constant fluid flow except for a number of runs under Categories IV, V, and VI (refer to Tables I to XII for category definitions) test conditions in Zone I. During these runs, the fluids were released at a gradually increasing rate for periods up to 77 seconds before reaching a constant flow.

The nacelle air temperatures were measured by 34 unshielded number 30-gauge chromel-alumel thermocouples installed at the locations used during the air temperature survey (Appendix III). In addition, for Categories II and III tests in Zone II and Categories II through VI tests in Zone I, 10 air thermocouples were installed just below the horizontal firewall between Nacelle Station Numbers 127 and 222. Another additional 10 air thermocouples were installed in the nacelle combustor and turbine section for Categories IV, V, and VI tests in Zone I.

In addition to the engine case temperature measurements made during the original survey (Appendix III), temperatures were recorded throughout the Ignition Hazard Study at several of the original 31 locations. During Categories IV, V, and VI tests in Zone I, from 9 to 11 additional measurements were made of the turbine inlet case temperature between Nacelle Station Numbers 195.6 and 204.8.

Unless otherwise noted, all nacelle and engine case temperatures listed under the Ignition Hazards portion of this report were measured just prior to releasing the flammable fluids into the nacelle.

The nacelle pressure measurements taken during Categories IV, V, and VI tests in Zone I were static pressure measurements in the nacelle cavity at a 12:00 o'clock position and Nacelle Station Number 181.

Pressure transducers were used to measure the transient over-pressures during explosive ignitions. The pickups were positioned at the following locations:

1. 12:00 o'clock position at Nacelle Station Number 130.

2. 6:00 o'clock position at Nacelle Station Number 130 near the constant speed drive unit.

3. 3:00 o'clock position at Nacelle Station Number 165 over the diffuser case.

TABLE I

IGNITION HAZARD TEST RESULTS - ZONE II - CATEGORY I

Category I - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Pressurized Spray
Simulated Flight Conditions - Steady

Facility Mach No.	Engine Power Setting (1)	Exhaust Gas Temperature (°F)	Fluid Release Location (2)	Nozzle Type (3)	Fuel Release Rate (gpm)	Fuel Line Pressure (psig)	Fuel Temperature (°F)	Fuel Release Duration (sec.)	Continued Engine Time (4) (sec.)	Engine Power Setting Reduction (5)	Ignition
JET FUEL TYPE A (KEROSENE)											
0.36	TOT	870	C	A	0.3	62	62	150	60	NRT	No
0.38	TOT	865	C	A	1.0	78	57	60	150	NRT	No
0.38	TOT	865	C	B	0.1	255	64	150	60	I	No
0.38	TOT	865	C	B	0.03	27	60	150	60	I	No
0.37	TOT	845	D	A	0.3	50	224	150	60	NRT	No
0.37	TOT	855	D	A	1.0	70	230	60	120	NRT	No
0.37	TOT	865	D	B	0.1	280	215	150	120	NRT	No
0.37	TOT	870	D	B	0.03	45	210	150	60	NRT	No
0.37	TOT	860	D	A	0.3	45	231	60	180	NRT	No
JET FUEL TYPE B (JP-4)											
0.62	NRT	805	A	A	0.4	265	62	60	30	I	No
0.50	NRT	803	A	A	0.4	280	58	60	0	I	No
0.38	NRT	790	A	A	0.4	269	48	180	0	I	No
0.62	NRT	795	A	A	1.0	350	51	60	0	I	No
0.50	NRT	810	A	A	1.0	352	50	60	0	I	No
0.37	NRT	800	A	A	0.2	490	54	60	0	I	No
0.38	NRT	815	A	A	1.0	350	52	60	0	I	No
0.62	NRT	805	B	A	0.4	260	46	60	0	I	No
0.62	NRT	810	B	A	0.1	1050	62	60	60	I	No
0.62	NRT	810	B	A	0.2	1050	68	35	0	CO	No
0.62	NRT	795	B	A	0.7	955	57	60	180	I	No
0.38	NRT	800	B	A	0.7	960	65	60	120	I	No
0.38	NRT	805	B	A	0.4	265	45	60	60	I	No
0.38	NRT	805	B	A	1.0	770	76	60	120	I	No
0.38	NRT	805	B	A	1.1	-	76	60	120	I	No
0.62	NRT	795	B	A	1.1	950	72	60	90	I	No
0.50	NRT	817	C	A	0.4	100	51	180	120	I	No
0.50	NRT	812	C	A	0.8	200	53	120	60	I	No
0.50	NRT	807	C	A	1.3	150	46	60	60	I	No
0.50	NRT	807	C	A	2.2	365	46	15	60	I	No
0.50	NRT	816	D	B	0.1	210	35	180	60	I	No
0.50	NRT	813	D	B	0.1	99	35	300	60	I	No
0.50	NRT	810	D	B	0.1	50	28	420	60	I	No
0.38	TOT	875	D	B	0.1	200	41	150	90	NRT	No
0.38	TOT	870	D	B	0.05	50	40	150	60	NRT	No
0.38	TOT	865	D	A	0.3	55	54	150	90	NRT	No
0.37	TOT	870	D	A	1.0	80	60	60	90	NRT	No
0.38	TOT	865	D	B	0.03	37	44	150	60	NRT	No
0.38	TOT	867	E	B	0.03	37	45	150	60	NRT	No
0.37	TOT	867	E	B	0.03	37	45	150	135	I	No

NOTES:
(1) CO - Cutoff (windmilling)
I - Idle
NRT - Normal Rated Thrust
TOT - Take-off Thrust
(2) See Table XIII
(3) See Table XIV
(4) Time period test engine at test power following fluid shut off.
(5) Test engine power setting following continued engine time.

TABLE II

IGNITION HAZARDS TEST RESULTS - ZONE II - CATEGORIES II & III

Category II - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

Category III - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Transient

				CATEGORY II				CATEGORY III				
Fluid (1) Release Location	Fluid Release Rate (gpm)	Fluid Line Pressure (psig)	Fluid Temperature (°F)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Duration (sec.)	Ignition	Facility Mach No.	Engine Power Setting Reduction (2)	Fluid Release Duration (3) (sec.)	Ignition	Ignition Time (3) (sec.)
					JET FUEL TYPE B (JP-4)							
171	0.3	10	250	0.35	847	30	No	Steady	I	30	No	-
171	0.3	24	250	0.35	860	30	No	Decreasing	I	30	No	-
171	0.3	16	261	0.40	855	30	No	Decreasing	I	5+	Yes	4.8
171	0.3	14	268	0.40	850	30+	No	Decreasing	I	5+	Yes	4.3
171	0.3	13	265	0.40	800	30	No	Decreasing	I	30	No	-
171	0.3	12	270	0.40	825	30	No	Decreasing	I	30	No	-
171	0.3	14	262	0.50	800	30	No	Decreasing	I	30	No	-
171	0.3	12	-	0.50	825	30	No	Decreasing	I	30	No	-
171	0.3	13	-	0.50	850	30	No	Decreasing	I	30	No	-
171	0.3	-	252	0.50	865	30	No	Decreasing	I	5+	Yes	4.6
171	0.3	13	261	0.50	870	30	No	Decreasing	I	30	No	-
171	0.3	34	267	0.40	850	30	No	Decreasing	I	30	No	-
171	0.3	32	267	0.40	855	30	No	Decreasing	I	30	No	-
171	0.3	33	264	0.40	875	30	No	Decreasing	I	7+	Yes	6.1
171	0.3	30	258	0.45	875	30	No	Decreasing	I	30	No	-
171	0.3	32	275	0.45	850	30	No	Decreasing	I	7+	Yes	4.9
171	0.3	32	280	0.45	850	30	No	Decreasing	I	30	No	-
171	0.3	34	260	0.45	875	30	No	Decreasing	I	30	No	-
171	0.3	34	260	0.35	880	30	No	Decreasing	I	30	No	-
					MIL-H-5606 HYDRAULIC FLUID							
171	0.3	36	250	0.35	875	30	No	Decreasing	I	30	No	-
171	0.3	35	250	0.40	875	30	No	Decreasing	I	6+	Yes	5.7
171	0.3	35	255	0.40	875	30	No	Decreasing	I	6+	Yes	5.4
171	0.3	34	258	0.40	800	30	No	Decreasing	I	30	No	-
171	0.3	33	260	0.40	825	30	No	Decreasing	I	10+	Yes	9.9

NOTES: (1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) Test engine power setting reduced to Idle.
(3) Referenced to zero time at start of Category III portion of run.

TABLE III

IGNITION HAZARD TEST RESULTS - ZONE II - CATEGORY IV

Category IV - Test Conditions:
Installation Configuration - Opened Engine Compartment Fireseal
Simulated System Failure - Pressurized Spray
Simulated Flight Condition - Steady

Facility Mach No.	Engine Power Setting (1)	Exhaust Gas Temperature (°F)	Fuel Release Location (2)	Nozzle Type (3)	Fuel Release Rate (gpm)	Fuel Line Pressure (psig)	Fuel Temperature (°F)	Fuel Release Duration (sec.)	Continued Engine Time (4) (sec.)	Engine Power Setting Reduction (5)	Ignition
JET FUEL TYPE A											
0.37	TOT	870	B	A	0.3	85	231	150	0	NRT	No
0.35	TOT	870	B	A	1.0	70	235	180	0	I	No
0.37	TOT	865	B	A	1.0	70	233	180	0	NRT	No
0.37	TOT	865	B	A	1.0	60	232	180	0	NRT	No

NOTES: (1) CO - Cutoff (windmilling)
I - Idle
NRT - Normal Rated Thrust
TOT - Take-off Thrust
(2) See Table XIII
(3) See Table XIV
(4) Time period test engine at test power following fluid shut off.
(5) Test engine power setting following continued engine time.

TABLE IV

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORY I - LUBRICATING OILS

Category I - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Pressurized Spray
Simulated Flight Condition - Steady

Facility Mach No.	Engine Power Setting (1)	Exhaust Gas Temperature (°F)	Fluid Release Location (2)	Nozzle Type (3)	Fluid Release Rate (gpm)	Fluid Line Pressure (psig)	Fluid Temperature (°F)	Fluid Release Duration (sec.)	Continued Engine Time (4) (sec.)	Engine Power Setting Reduction (5)	Ignition	Ignition Time (sec.)
					LUBRICATING OIL MIL-L-7808							
0.50	NRT	795	F	C	0.5	15	160	120	60	I	No	-
0.36	NRT	807	G	C	0.5	8	325	120	90	I	No	-
0.50	NRT	800	G	C	0.5	7	225	120	120	I	No	-
0.62	NRT	800	G	C	0.5	6	205	120	60	I	No	-
0.62	NRT	780	G	C	0.5	5	198	120	120	CO	No	-
0.35	NRT	800	G	C	0.5	8	253	120	120	I	No	-
0.62	NRT	795	G	C	0.5	5	251	120	60	I	No	-
0.50	NRT	810	G	C	0.5	6	262	120	60	I	No	-
0.50	NRT	800	G	C	0.5	-	262	120	60	I	No	-
0.50	NRT	805	G	C	0.01	43	332	120	60	I	No	-
0.50	NRT	807	G	C	1.0	12	262	60	180	I	No	-
0.50	NRT	810	G	C	0.3	22	255	180	120	I	No	-
0.50	NRT	797	G	C	0.2	3	245	180	0	I	No	-
0.50	NRT	800	G	D	0.5	7	266	120	60	I	No	-
0.50	NRT	805	G	D	1.0	36	250	60	60	I	No	-
0.50	NRT	800	G	C	0.5	6	352	120	120	I	No	-
0.62	TOT	860	G	D	0.6	8	608	150	0	NRT	No	-
0.62	TOT	865	G	D	0.5	3	610	240	0	NRT	No	-
0.62	TOT	855	G	D	0.6	7	608	240	0	NRT	No	-
0.62	TOT	855	G	D	0.6	6	600	85+	0	NRT	Yes	84
					LUBRICATING OIL MIL-L-23699							
0.62	TOT	845	G	D	0.6	8	615	240	0	NRT	No	-
0.62	TOT	855	G	D	0.6	7	616	240	0	NRT	No	-
0.62	TOT	850	G	D	0.6	7	700	240	0	NRT	No	-

NOTES: (1) CO - Cutoff (windmilling)
I - Idle
NRT - Normal Rated Thrust
TOT - Take-off Thrust
(2) See Table XIII
(3) See Table XIV
(4) Time period test engine at test power following fluid shut off.
(5) Test engine power setting following continued engine time.

TABLE V

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORY I - HYDRAULIC FLUID

Category I - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Pressurized Spray
Simulated Flight Condition - Steady

Facility Mach No.	Engine Power Setting (1)	Exhaust Gas Temperature (°F)	Fluid Release Location (2)	Nozzle Type (3)	Fluid Release Rate (gpm)	Fluid Line Pressure (psig)	Fluid Temperature (°F)	Fluid Release Duration (sec.)	Continued Engine Time (4) (sec.)	Engine Power Reduction Setting (5)	Ignition	Ignition Time (sec.)
					HYDRAULIC FLUID MIL-H-5606							
0.50	NRT	790	H	E	0.3	1630	69	240	180	I	No	-
0.62	TOT	850	H	E	0.3	1300	-	150	30	NRT	No	-
0.62	TOT	860	H	E	0.3	1400	58	97	0	CO	Yes	75.8
0.62	TOT	860	H	E	0.3	1390	44	150	0	NRT	No	-
0.62	TOT	860	H	E	0.7	950	84	150	0	NRT	No	-
0.62	TOT	845	H	E	0.1	220	-	240	0	NRT	No	-
0.62	TOT	860	H	E	0.2	1220	-	75	72	NRT	No	-
0.62	TOT	855	H	E	0.4	1740	-	180	0	NRT	No	-

NOTES: (1) CO - Cutoff (windmilling)
I - Idle
NRT - Normal Rated Thrust
TOT - Take-off Thrust
(2) See Table XIII
(3) See Table XIV
(4) Time period test engine at test power following fluid shut off.
(5) Test engine power setting following continued engine time.

TABLE VI

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORIES II & III JET FUELS

Category II - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

Category III - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Transient

			CATEGORY II				CATEGORY III				
Fluid Release Location (1)	Fluid Release Rate (gpm)	Fluid Temperature (°F)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Duration (sec.)	Ignition	Facility Mach No.	Engine Power Setting Reduction (2)	Fluid Release Duration (3) (sec.)	Ignition	Ignition Time (3) (sec.)
JET FUEL TYPE A - KEROSENE											
195.6	0.03	139	0.50	855	120	No	Decreasing	I	60	No	-
195.6	0.3	260	0.50	855	120	No	Decreasing	I	6+	Yes	5.5
195.6	0.3	280	0.50	855	120	No	Decreasing	I	8+	Yes	7.4
195.6	0.3	255	0.50	855	120	No	Decreasing	I	6+	Yes	5.0
195.6	0.3	259	0.50	865	60	No	Decreasing	I	5+	Yes	4.3
195.6	0.3	253	0.50	845	60	No	Decreasing	I	7+	Yes	6.0
195.6	0.3	272	0.50	855	45	No	Decreasing	I	6+	Yes	5.0
195.6	0.3	250	0.50	830	30	No	Decreasing	I	6+	Yes	5.0
195.6	0.3	246	0.50	800	30	No	Decreasing	I	6+	Yes	5.0
195.6	0.3	262	0.50	755	30	No	Decreasing	I	30	No	-
195.6	0.3	262	0.50	800	30	No	Decreasing	(4)	52	No	-
195.6	0.3	255	0.50	840	30	No	Decreasing	(4)	33	No	-
195.6	0.3	248	0.50	825	30	No	Steady	I	90	No	-
195.6	0.3	240	0.40	825	30	No	Decreasing	I	11+	Yes	10.0
195.6	0.3	246	0.60	825	30	No	Decreasing	I	90	No	-
195.6	0.3	256	0.50	825	30	No	Decreasing	I	6+	Yes	5.0
195.6	0.3	258	0.50	825	30	No	Decreasing	I (5)	90	No	-
195.6	0.3	254	0.55	825	30	No	Decreasing	I	90	No	-
195.6	0.3	260	0.50	825	30	No	Decreasing	I	90	No	-
195.6	0.3	255	0.50	860	30	No	Decreasing	I	90	No	-
195.6	0.3	247	0.52	857	30	No	Decreasing	I	5+	Yes	4.0
195.6	0.3	262	0.50	825	30	No	Decreasing	I	90	No	- (6)
195.6	0.3	266	0.50	860	30	No	Decreasing	I	90	No	- (6)
195.6	0.3	278	0.50	820	30	No	Decreasing	I	8+	Yes	7.0
195.6	0.3	278	0.50	820	30	No	Decreasing	I	90	No	- (6)
195.6	0.3	279	0.50	820	30	No	Decreasing	I	90	No	- (6)
195.6	0.3	283	0.50	825	30	No	Decreasing	I	8+	Yes	7.0
195.6	0.3	271	0.52	825	30	No	Decreasing	I	90	No	-
195.6	0.3	258	0.52	825	30	No	Decreasing	I	90	No	-
195.6	0.3	258	0.52	850	30	No	Decreasing	I (5)	9+	Yes	8.0
195.6	0.3	255	0.52	850	30	No	Decreasing	I (5)	90	No	-
195.6	0.3	252	0.52	850	30	No	Decreasing	I	7+	Yes	6.0
195.6	0.3	251	0.50	825	30.5	No	Decreasing	I	89.5	No	-
195.6	0.3	254	0.52	862	27.5	No	Decreasing	I	92.5	No	-
195.6	0.3	248	0.52	825	31.5	No	Decreasing	I	88.5	No	-
195.6	0.3	250	0.52	825	10.5	No	Decreasing	I	109.5	No	-
195.6	0.3	252	0.40	800	29.5	No	Decreasing	I	16+	Yes	15.5
195.6	0.3	253	0.50	825	29.3	No	Decreasing	I	90.7	No	-
195.6	0.3	262	0.40	840	39.0	No	Decreasing	I	15+	Yes	14.0
195.6	0.3	297	0.50	825	46.0	No	Decreasing	I	74.0	No	-
195.6	0.3	290	0.40	825	31.5	No	Decreasing	I	20+	Yes	19.0
195.6	0.3	283	0.40	800	30.5	No	Decreasing	I	19+	Yes	18.5
195.6	0.3	275	0.40	775	31.0	No	Decreasing	I	15+	Yes	14.0
195.6	0.3	277	0.40	750	31.0	No	Decreasing	I	16+	Yes	15.0
195.6	0.3	295	0.40	700	32.0	No	Decreasing	I	88.0	No	-
JET FUEL TYPE B											
195.6	.01, 0.05, 1.0	Amb.	0.50	855	180	No	-	-	-	-	-
195.6	0.3	Amb.	0.50	855	180	No	-	-	-	-	-
195.6	1.0	Amb.	0.50	855	180	No	-	-	-	-	-
195.6	1.0	253	0.50	855	180	No	-	-	-	-	-
195.6	1.0	282	0.35	855	120	No	Decreasing	I	60	No	-
195.6	0.3	218	0.35	855	120	No	Decreasing	I	60	No	-
195.6	0.03	144	0.35	855	120	No	Decreasing	I	60	No	-
195.6	>0.3	265	0.39	865	30.4	No	Decreasing	I	19+	Yes	18.0
195.6	0.3	267	0.39	865	30.4	No	Decreasing	I	89.6	No	-
195.6	0.3	260	0.40	860	29.9	No	Decreasing	I	13+	Yes	12.8
195.6	0.3	273	0.40	800	31.5	No	Decreasing	I	88.5	No	-
195.6	0.3	274	0.40	825	31.0	No	Decreasing	I	18+	Yes	17.5
195.6	0.3	265	0.42	825	31.0	No	Decreasing	I	14+	Yes	13.0
195.6	0.3	267	0.42	800	-	-	-	-	-	-	-
195.6	0.3	260	0.44	800	31.5	No	Decreasing	I	88.5	No	-
195.6	0.3	253	0.44	825	31.0	No	Decreasing	I	10+	Yes	9.0
195.6	0.3	253	0.46	825	31.5	No	Decreasing	I	88.5	No	-
195.6	0.3	274	0.46	840	31.5	No	Decreasing	I	88.5	No	-
195.6	0.3	265	0.46	865	30.5	No	Decreasing	I	10+	Yes	9.5
195.6	0.3	263	0.48	860	30.5	No	Decreasing	I	89.5	No	-
195.6	0.3	266	0.38	825	29.6	No	Decreasing	I	90.4	No	-
195.6	0.3	264	0.43	850	30.5	No	Decreasing	I	89.5	No	-
195.6	0.3	280	0.42	870	31.0	No	Decreasing	I	89.0	No	-

NOTES:
(1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) Test engine power setting reduced to Idle.
(3) Referenced to zero time at start of Category III portion of run.
(4) Test engine power maintained at Category II condition and tunnel drive power reduced.
(5) Engine power transition to Idle at a below maximum rate.
(6) Side cowl door seams leaking and nacelle ventilation above normal.

TABLE VII

IGNITION HAZARD RESULTS - ZONE I - CATEGORIES II & III - LUBRICATING OILS

Category II - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized running
Simulated Flight Condition - Steady

Category III - Test Conditions:
Installation Configuration - Production
Simulated System Failure - Unpressurized running
Simulated Flight Condition - Transient

			CATEGORY II					CATEGORY III				
Fluid Release Location (1)	Fluid Release Rate (gpm)	Fluid Temperature (°F)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Duration (sec.)	Ignition	Ignition Time (sec.)	Facility Mach No.	Engine Power Setting Reduction (2)	Fluid Release Duration (3) (sec.)	Ignition	Ignition Time (3) (sec.)
					LUBRICATING OIL MIL-L-7808							
195.6	0.30	268	0.51	850	29.4	No	-	Decreasing	I	90.6	No	-
195.6	0.30	255	0.40	842	29.0	No	-	Decreasing	I	8+	Yes	7.0
195.6	0.30	253	0.40	837	29.0	No	-	Decreasing	I	3+	Yes	2.5
195.6	0.30	260	0.40	825	30.0	No	-	Decreasing	I	4+	Yes	3.0
195.6	0.30	270	0.35	700	30.3	No	-	Decreasing	I	89.7	No	-
195.6	0.30	270	0.35	700	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	262	0.40	800	31.0	No	-	Decreasing	I	9+	Yes	8.0
195.6	0.30	262	0.40	775	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	264	0.40	780	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	264	0.40	785	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	257	0.40	790	30.5	No	-	Decreasing	I	5+	Yes	4.0
195.6	-	220	0.36	862	31.5	No	-	Decreasing	I	8+	Yes	5.0
195.6	-	248	0.36	825	30.5	No	-	Decreasing	I	4+	Yes	3.5
195.6	0.30	258	0.36	800	30.5	No	-	Decreasing	I	4+	Yes	3.5
195.6	0.30	267	0.36	775	30.5	No	-	Decreasing	I	6+	Yes	5.0
195.6	0.30	266	0.36	750	-	No	-	Decreasing	I	-	Yes	-
195.6	0.30	266	0.36	725	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	260	0.36	735	29.5	No	-	Decreasing	I	90.5	No	-
195.6	0.30	261	0.36	740	30.0	No	-	Decreasing	I	90.0	No	-
195.6	0.30	251	0.33	750	30.5	No	-	Decreasing	I	4+	Yes	3.0
195.6	0.30	253	0.50	870	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	250	0.48	865	31.5	No	-	Decreasing	I	88.5	No	-
195.6	0.30	260	0.46	870	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	252	0.44	870	31.0	No	-	Decreasing	I	6+	Yes	5.0
195.6	0.30	242	0.45	870	30.5	No	-	Decreasing	I	6+	Yes	5.0
195.6	0.30	260	0.45	825	30.5	No	-	Decreasing	I	7+	Yes	6.5
195.6	0.30	263	0.45	775	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	252	0.45	800	30.0	No	-	Decreasing	I	6+	Yes	5.5
195.6	0.30	254	0.45	785	30.5	No	-	Decreasing	I	89.5	No	-
					LUBRICATING OIL MIL-L-23699							
195.6	0.30	255	0.40	860	31.5	No	-	Decreasing	I	8+	Yes	7.5
195.6	0.30	259	0.36	865	7+	Yes	6.8	Decreasing	I	-	-	-
195.6	0.30	253	0.40	825	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	254	0.40	850	31.0	No	-	Decreasing	I	4+	Yes	3.5
195.6	0.30	247	0.40	835	31.0	No	-	Decreasing	I	9+	Yes	8.5
195.6	0.30	253	0.40	825	30.0	No	-	Decreasing	I	5+	Yes	4.5
195.6	0.30	255	0.40	800	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	250	0.36	865	7+	Yes	6.5	Decreasing	I	-	-	-
195.6	0.30	262	0.50	870	29.5	No	-	Decreasing	I	90.5	No	-
195.6	0.30	255	0.48	870	29.0	No	-	Decreasing	I	91.0	No	-
195.6	0.30	246	0.46	870	27.0	No	-	Decreasing	I	5+	Yes	4.0
195.6	0.30	250	0.47	870	30.0	No	-	Decreasing	I	90.0	No	-
195.6	0.30	261	0.46	825	30.4	No	-	Decreasing	I	89.6	No	-
195.6	0.30	259	0.46	850	29.5	No	-	Decreasing	I	90.5	No	-
195.6	0.30	252	0.46	875	33.0	No	-	Decreasing	I	87.0	No	-
195.6	0.30	265	0.46	865	27.0	No	-	Decreasing	I	93.0	No	-
195.6	0.30	256	0.42	867	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	250	0.40	865	30.0	No	-	Decreasing	I	11+	Yes	10.0
195.6	0.30	252	0.35	820	30.5	No	-	Decreasing	I	5+	Yes	4.0
195.6	0.30	263	0.35	820	27.0	No	-	Decreasing	I	2+	Yes	1.5
195.6	0.30	271	0.35	800	31.0	No	-	Decreasing	I	89.0	No	-
195.6	0.30	264	0.36	840	30.5	No	-	Decreasing	I	6+	Yes	5.5
195.6	0.30	266	0.36	860	29.0	No	-	Decreasing	I	12+	Yes	11.5
195.6	0.30	260	0.37	880	6+	Yes	5.0	Decreasing	I	-	-	-

NOTES:
(1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) Test engine power setting reduced to Idle.
(3) Referenced to zero time at start of Category III portion of run.

TABLE VIII

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORIES II & III - HYDRAULIC FLUIDS

Category II - Test Conditions
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

Category III - Test Conditions
Installation Configuration - Production
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Transient

			CATEGORY II					CATEGORY III				
Fluid Release Location (1)	Fluid Release Rate (gpm)	Fluid Temperature (°F)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Duration (sec.)	Ignition	Ignition Time (sec.)	Facility Mach No.	Engine Power Setting Reduction (2)	Fluid Release Duration (3) (sec.)	Ignition	Ignition Time (3) (sec.)
					HYDRAULIC FLUID MIL-H-5606							
195.6	0.30	246	0.40	860	31.5	No	-	Decreasing	I	3+	Yes	2.5
195.6	0.30	248	0.37	860	9+	Yes	8.4	-	-	-	-	-
195.6	0.30	240	0.35	825	30.5	No	-	Decreasing	I	2+	Yes	2.0
195.6	0.30	267	0.34	750	30.5	No	-	Decreasing	I	4+	Yes	4.0
195.6	0.30	278	0.33	700	30.5	No	-	Decreasing	I	19+	Yes	18.7
195.6	0.30	262	0.35	800	30.0	No	-	Decreasing	I	3+	Yes	2.5
195.6	0.30	266	0.34	750	30.5	No	-	Decreasing	I	4+	Yes	4.0
195.6	0.30	262	0.33	700	31.0	No	-	Decreasing	I	21+	Yes	20.5
195.6	0.30	283	0.29	650	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	261	0.50	860	31.0	No	-	Decreasing	I	2+	Yes	1.5
195.6	0.30	263	0.55	870	31.5	No	-	Decreasing	I	7+	Yes	6.5
195.6	0.30	269	0.64	870	30.5	No	-	Decreasing	I	5+	Yes	4.5
195.6	0.30	258	0.50	750	29.6	No	-	Decreasing	I	-	Yes	-
195.6	0.30	266	0.55	870	30.3	No	-	Decreasing	I	89.7	No	-
195.6	0.30	268	0.50	700	30.5	No	-	Decreasing	I	89.5	No	-
195.6	0.30	270	0.50	725	30.2	No	-	Decreasing	I	89.8	No	-
195.6	0.30	253	0.50	875	30.6	No	-	Decreasing	I	3+	Yes	2.6
195.6	0.30	-	0.50	700	30.2	No	-	Decreasing	I	89.8	No	-
195.6	0.30	254	0.55	755	30.4	No	-	Decreasing	I	89.6	No	-
195.6	0.30	-	0.55	800	29.9	No	-	Decreasing	I	3+	Yes	2.7
195.6	0.30	256	0.55	750	29.7	No	-	Decreasing	I	90.3	No	-
195.6	0.30	257	0.55	800	30.8	No	-	Decreasing	I	4+	Yes	3.6
195.6	0.30	257	0.40	700	30.6	No	-	Decreasing	I	8+	Yes	7.2
195.6	0.30	260	0.40	650	30.7	No	-	Decreasing	I	89.3	No	-
195.6	0.30	248	0.50	750	30.5	No	-	Decreasing	I	11+	Yes	10.3
195.6	0.30	277	0.40	725	30.2	No	-	Decreasing	I	89.8	No	-
195.6	0.30	274	0.40	675	29.9	No	-	Decreasing	I	90.1	No	-
195.6	0.30	262	0.55	775	30.9	No	-	Decreasing	I	6+	Yes	5.1
195.6	0.30	257	0.40	650	30.4	No	-	Decreasing	I	89.6	No	-
195.6	0.30	282	0.32	675	30.6	No	-	Decreasing	I	11+	Yes	10.7
195.6	0.30	268	0.35	873	57	No	-	Decreasing	MC	15.5	No	-
195.6	0.30	262	0.35	890	74	No	-	-	-	-	-	-
				JET AIRCRAFT COMMERCIAL FIRE-RESISTANT HYDRAULIC FLUID								
195.6	0.30	76	0.40	865	30.9	No	-	Decreasing	I	89.1	No	-
195.6	0.30	76	0.52	865	30.8	No	-	Decreasing	I	89.2	No	-
195.6	0.30	76	0.39	865	31.4	No	-	Decreasing	I	88.6	No	-

NOTES: (1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) Test engine power setting reduced to Idle or Maximum Cruise.
(3) Referenced to zero time at start of Category III portion of run.

TABLE IX

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORIES IV & V - JET FUELS

Category IV - Test Conditions:
Installation Configuration - Controlled Cooling Airflow
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

Category V - Test Conditions:
Installation Configuration - Controlled Cooling Airflow
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Transient

					CATEGORY IV							CATEGORY V					Case (6) Temperature		Cooling Air Temperature (7)		Temperature at Ignition (8)		Location Of Ignition (9)		
Fluid Release Location (1)	Fluid Temperature (°F)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.)	Nacelle Pressure (psia)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Rate (2) (gpm)	Fluid Release Duration (sec.)	Constant Fluid Flow Time (3) (sec.)	Ignition	Ignition Time (sec.)	Facility Mach No.	Engine Power Reduction Setting (4)	Fluid Release Duration (5) (sec.)	Ignition	Ignition Time (5) (sec.)	Max. (°F)	Min. (°F)	Max. (°F)	Min. (°F)	Case (°F)	Cooling Air (°F)	Sta.	O/C	Ignition Type (10)
											JET FUEL TYPE A														
201.6	115	0.04	4	12.8	0.4	950	0(0.04)	112.4	20.2	No	-	-	-	-	-	-	1037	976	610	290	-	-	-	-	-
201.6	145	0.06	6	-	0.4	950	0(0.1)	130.2	22.6	No	-	-	-	-	-	-	1039	976	615	295	-	-	-	-	-
201.6	165	0.04	4	-	0.4	950	0(0.3)	137.6	23.6	No	-	-	-	-	-	-	1033	937	605	200	-	-	-	-	-
201.6	178	0.06	6	-	0.4	950	0(1.0)	47.9	27.5	Yes	46.0	-	-	-	-	-	1029	971	625	275	910	520	196	4:15	2
201.6	197	0.65	59	13.3	0.4	950	0(0.9)	138.5	40.0	No	-	-	-	-	-	-	1000	917	540	345	-	-	-	-	-
201.6	195	0.49	45	-	0.4	950	0(0.9)	139.0	34.6	No	-	-	-	-	-	-	1036	950	540	420	-	-	-	-	-
201.6	190	0.34	32	-	0.4	950	0(0.9)	137.4	40.3	No	-	-	-	-	-	-	1036	917	535	350	-	-	-	-	-
201.6	167	0.23	22	-	0.4	950	0(1.0)	27.0	-	Yes	24.7	-	-	-	-	-	1030	926	535	345	900	600	210	11:00	3
197	222	0.22	21	13.0	0.4	800	0(1.0)	136.2	57.0	No	-	-	-	-	-	-	922 (954)	851	570	355	-	-	-	-	-
197	224	0.22	21	-	0.4	850	0(1.0)	142.0	61.9	No	-	-	-	-	-	-	969 (994)	900	600	375	-	-	-	-	-
											JET FUEL TYPE B														
195.6	200	Min.	Min.	-	0.4	950	0.3	18.5	0	Yes	15.5	-	-	-	-	-	1072	1000	650	495	1060	510	201	1:00	6
195.6	200	Min.	Min.	-	0.4	900	0.3	14.3	0	Yes	13.0	-	-	-	-	-	1030	950	700	350	1015	390	202	2:00	5
195.6	200	Min.	Min.	-	0.4	850	0.3	74.4	0	No	-	Decreasing	I	5.5	Yes	2.9	965	895	620	280	895	600	204	10:00	1
195.6	173	Min.	Min.	-	0.4	850	0.1	75.0	0	No	-	Decreasing	I	3.0	Yes	1.5	1017	845	620	395	800	600	195	10:00	1
195.6	220	0.48	44	13.3	0.4	850	0.3	87.6	0	No	-	-	-	-	-	-	1003	889	510	390	-	-	-	-	-
195.6	210	0.49	45	13.3	0.4	900	0.3	92.3	0	No	-	-	-	-	-	-	1044	905	510	380	-	-	-	-	-
195.6	215	0.48	44	13.3	0.4	950	0.3	90.0	0	No	-	-	-	-	-	-	1062	951	590	375	-	-	-	-	-
195.6	217	0.29	28	13.2	0.4	900	0.3	88.2	0	No	-	-	-	-	-	-	1033	924	580	380	-	-	-	-	-
195.6	224	0.29	28	13.2	0.4	950	0.3	89.6	0	No	-	-	-	-	-	-	1083	971	600	440	-	-	-	-	-
195.6	226	0.08	8	13.1	0.4	900	0.3	88.3	0	No	-	-	-	-	-	-	1025	929	630	400	-	-	-	-	-
195.6	226	0.08	8	13.0	0.4	950	0.3	87.8	0	No	-	-	-	-	-	-	1076	985	650	380	-	-	-	-	-
195.6	226	Min.	Min.	13.1	0.4	860	0.3	87.4	0	No	-	-	-	-	-	-	991	886	660	410	-	-	-	-	-
195.6	178	Min.	Min.	13.1	0.4	870	0.3	29.1	0	Yes	26.1	-	-	-	-	-	1014	921	675	425	940	475	201	12:15	4
195.6	224	0.00 (11)	0 (11)	12.8	0.4	950	0.3	87.6	0	No	-	-	-	-	-	-	1046	977	680	350	-	-	-	-	-
195.6	220	0.06	6	12.8	0.4	950	0.3	88.3	0	No	-	-	-	-	-	-	1042	985	625	350	-	-	-	-	-
195.6	221	0.07	7	12.8	0.4	950	0.6	88.6	0	No	-	-	-	-	-	-	1031	985	640	350	-	-	-	-	-
195.6	223	0.03	3	12.8	0.4	950	0.6	88.3	0	No	-	-	-	-	-	-	1060	981	630	390	-	-	-	-	-
195.6	-	0.04	4	13.1	0.4	950	0(0.2)	74.7	74.8	No	-	-	-	-	-	-	1053	944	625	390	-	-	-	-	-
195.6	145	0.04	4	13.1	0.4	950	0(0.1)	126.8	43.0	No	-	-	-	-	-	-	1025	907	660	325	-	-	-	-	-
195.6	134	0.04	4	-	0.4	950	-	-	-	No	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
195.6	134	0.07	7	-	0.4	950	0.04	144.3	2.8	No	-	-	-	-	-	-	1029	979	640	350	-	-	-	-	-
195.6	160	0.04	4	-	0.4	950	0.1	147.6	15.1	No	-	-	-	-	-	-	1031	974	670	355	-	-	-	-	-
195.6	183	0.04	4	-	0.4	950	0.3	148.6	12.8	No	-	-	-	-	-	-	1000	907	675	290	-	-	-	-	-
195.6	203	0.04	4	-	0.4	950	1.0	147.7	3.0	No	-	-	-	-	-	-	1037	979	685	395	-	-	-	-	-
195.6	246	0.04	4	-	0.4	950	0.2	99.0	0.0	No	-	-	-	-	-	-	1029	956	645	300	-	-	-	-	-
201.6	190	0.44	41	-	0.4	950	0(0.3)	135.8	39.5	No	-	-	-	-	-	-	1013	936	540	400	-	-	-	-	-
201.6	210	0.44	41	-	0.4	950	0(1.0)	148.4	75.2	No	-	-	-	-	-	-	1017	932	535	410	-	-	-	-	-
201.6	186	0.23	22	-	0.4	950	0(0.3)	130.7	33.8	No	-	-	-	-	-	-	1007	929	540	350	-	-	-	-	-
201.6	202	0.23	22	-	0.4	950	0(1.0)	129.4	68.7	No	-	-	-	-	-	-	1013	925	570	350	-	-	-	-	-
201.6	-	0.23	22	-	0.4	985	0(1.0)	78.7	72.6	No	-	-	-	-	-	-	1047	958	590	400	-	-	-	-	-
201.6	186	0.22	21	-	0.4	985	0(0.8)	59.0	-	Yes	56.8	-	-	-	-	-	1031	987	626	350	995	550	201	4:30	2

NOTES:
(1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) x.xx indicates constant fluid flow; 0(x.xx) indicates increasing fluid flow from 0 gpm to x.xx gpm and then constant flow.
(3) Time at which constant fluid flow was obtained.
(4) Test engine power setting reduced to Idle.
(5) Referenced to zero time at start of Category V portion of run.
(6) Case temperature range between nacelle stations 200.8 and 201.8, (xxxx) maximum value includes thermocouples numbers 20, 230, and 231.
(7) Estimated temperature range at nacelle station 200 based on isothermal data.
(8) Estimated temperatures at ignition location based on isothermal and isochronal thermocouple measurements.
(9) Estimated location of ignition based on isochronal thermocouple response data.
(10) Severity of ignition ranging from a mild explosion (7) to a violent explosion (1).
(11) Zero controlled cooling airflow with exit vent holes unplugged.

TABLE X

IGNITION HAZARD TEST RESULTS ZONE I CATEGORY IV LUBRICATING OILS

Category IV - Test Conditions:
Installation Configuration - Controlled Cooling Airflow
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

CATEGORY IV

Fluid (1) Release Location	Fluid Temperature (°F)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.)	Nacelle Pressure (psia)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Rate (2) (gpm)	Fluid Release Duration (sec.)	Constant Fluid Flow Time (3) (sec.)	Ignition	Case (4) Temperature		Cooling Air Temperature(5)	
											Min. (°F)	Max. (°F)	Min. (°F)	Max. (°F)
						LUBRICATING OIL MIL-L-7808								
201.6	206	0.44	41	13.3	0.4	950	0(0.3)	142.0	3.8	No	932	974	375	535
201.6	218	0.29	28	-	0.4	950	0(0.3)	136.1	15.8	No	947	1026	355	540
201.6	218	0.06	6	-	0.4	950	0(0.3)	134.8	4.7	No	961	1009	345	590
201.6	232	0.07	7	-	0.4	950	0(1.0)	137.9	69.5	No	959	1007	395	610

Notes:
(1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) x.xx indicated constant fluid flow; 0(x.xx) indicates increasing fluid flow from 0 gpm to x.xx gpm and then constant flow.
(3) Time at which constant fluid flow was obtained.
(4) Case temperature range between nacelle stations 200.8 and 201.8.
(5) Estimated air temperature range at nacelle station 200 based on isothermal data.

TABLE XI

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORY IV - HYDRAULIC FLUID

Category IV - Test Conditions:
Installation Configuration - Controlled Cooling Airflow
Simulated System Failure - Unpressurized Running
Simulated Flight Condition - Steady

Fluid Release Location (1)	Fluid Temperature (°F)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.)	Nacelle Pressure (psia)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Rate (2) (gpm)	Fluid Release Duration (sec.) MIL-H-5606	Constant Fluid Flow Time (3) (sec.)	Ignition	Ignition Time (sec.)	Case (4) Temperature		Cooling Air Temperature(5)		Temperature at Ignition(6)		Location of Ignition (7)		Ignition Type (8)
												Max. (°F)	Min. (°F)	Max. (°F)	Min. (°F)	Case (°F)	Cooling Air (°F)	Sta.	O/C	
195.6	180	0.03	3	13.1	0.4	950	0(0.03)	121.3	11.5	No	-	1042	983	655	295	-	-	-	-	-
195.6	182	0.03	3	-	0.4	950	0(0.1)	97.8	42.1	Yes	90.6	1035	979	650	375	950	510	200	11:00	1
195.6	-	0.03(9)	3(9)	-	0.4	950	0(0.1)	140.0	49.3	No	-	1027	968	620	375	-	-	-	-	-
201.6	102	0.03	3	13.0	0.4	950	0(0.1)	16.1	14.7	Yes	12.0	1029	950	635	380	975	600	200	10:30	6
201.6	120	0.25	24	-	0.4	950	0(0.1)	20.2	17.6	Yes	17.1	1019	960	605	395	975	600	201	10:00	7
201.6	122	0.85	77	-	0.4	950	0(0.1)	139.5	17.2	No	-	1033	945	520	420	-	-	-	-	-
201.6	191	0.63	58	13.4	0.4	950	0(0.1)	127.9	25.9	No	-	1054	950	600	380	-	-	-	-	-
201.6	166	0.60	55	-	0.4	950	0(0.1)	124.7	24.3	No	-	1054	945	575	365	-	-	-	-	-
201.6	180	0.24	23	-	0.4	900	0(0.1)	135.5	19.5	No	-	981	932	590	355	-	-	-	-	-
201.6	154	0.24	23	-	0.4	925	0(0.1)	45.7	39.3	Yes	42.7	993	921	595	325	935	500	201	11:00	6
201.6	176	0.39	37	-	0.4	925	0(0.1)	129.6	25.5	No	-	1005	943	605	395	-	-	-	-	-
201.6	173	0.38	35	-	0.4	950	0(0.1)	138.9	9.2	No	-	1025	964	600	350	-	-	-	-	-
201.6	220	0.38	35	-	0.4	950	0(0.3)	140.4	6.4	No	-	1029	962	595	350	-	-	-	-	-
201.6	196	0.39	37	-	0.4	950	0(0.3)	68.1	24.2	Yes	65.2	1019	937	615	355	950	500	203	3:30	5
201.6	216	0.45	41	-	0.4	950	0(0.3)	85.3	15.9	Yes	82.9	1037	941	600	395	950	425	199	2:30	2
201.6	224	0.59	54	-	0.4	950	0(0.3)	141.4	16.5	No	-	997	937	525	270	-	-	-	-	-

NOTES:
(1) Nacelle station number for an open end 3/8 inch AN tee fitting positioned above engine so as to run fluid down both sides of engine.
(2) x.xx indicates constant fluid flow; 0(x.xx) indicates increasing fluid flow from 0 gpm to x.xx gpm and then constant flow.
(3) Time at which constant fluid flow was obtained.
(4) Case temperature range between nacelle stations 200.8 and 201.6.
(5) Estimated air temperature range at nacelle station 200 based on isothermal data.
(6) Estimated temperatures at ignition location based on isothermal and isochronal thermocouple measurements.
(7) Estimated location of ignition based on isochronal thermocouple response data.
(8) Severity of ignition ranging from mild (7) to a violent explosion (1).
(9) Side cowl door seams leaking and nacelle ventilation above normal.

TABLE XII

IGNITION HAZARD TEST RESULTS - ZONE I - CATEGORY VI

Category VI - Test Conditions:
Installation Configuration - Controlled Cooling Airflow
Simulated System Failure - Pressurized Spray
Simulated Flight Condition - Steady

Fluid Release Location (1)	Fluid Temperature (°F)	Nozzle Type (2)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.)	Nacelle Pressure (psia)	Facility Mach No.	Exhaust Gas Temperature (°F)	Fluid Release Rate (3) (gpm)	Fluid Release Duration (sec.)	Constant Fluid Flow Time (4) (sec.)	Ignition	Ignition Time (sec.)	Case (5) Temperature		Cooling Air Temperature (6)		Temperature at Ignition (7)		Location of Ignition (8)		Ignition Type (9)
													Max. (°F)	Min. (°F)	Max. (°F)	Min. (°F)	Case (°F)	Cooling Air (°F)	Sta.	O/C	
									JET FUEL TYPE A												
197	-	D	0.22	21	-	0.4	900	0(0.8)	48.6	-	Yes	45.8	955	916	625	375	940	580	201	10:30	2
197	202	D	0.24	23	12.9	0.4	800	0(1.0)	135.2	77.4	No	-	919	834	535	325	-	-	-	-	-
197	186	D	0.23	22	-	0.4	850	0(0.9)	51.9	-	Yes	49.2	957	878	550	350	800	520	210	3:30	2
197	211	D	0.44	41	-	0.4	900	0(1.0)	140.8	61.3	No	-	1003 (1012)	916	580	420	-	-	-	-	-
197	168	D	0.43	40	-	0.4	925	0(0.7)	36.5	-	Yes	34.1	1038 (1099)	939	585	425	900	425	196	1:00	2
									JET FUEL TYPE B												
197	200	D	0.23	22	13.1	0.4	950	0(1.0)	121.9	70.3	No	-	987	942	605	400	-	-	-	-	-
197	218	D	0.23	22	-	0.4	975	0(1.0)	134.2	71.6	No	-	1012	963	625	460		-	-	-	-

NOTES:
(1) Nacelle station number for a spray nozzle positioned above the engine with the spray directed down and aft onto the engine case.
(2) See Table XIV.
(3) x.xx indicates constant fluid flow; 0(x.xx) indicates increasing fluid flow from 0 gpm to x.xx gpm and then constant flow.
(4) Time at which constant fluid flow was obtained.
(5) Case temperature range between nacelle stations 200.8 and 201.8, (xxxx) maximum value includes thermocouples numbers 20, 230 and 231.
(6) Estimated air temperature range at nacelle station 200 based on isothermal data.
(7) Estimated temperatures at ignition location based on isothermal and isochronal thermocouple measurements.
(8) Estimated location of ignition based on isochronal thermocouple response data.
(9) Severity of ignition ranging from mild (7) to a violent explosion (1).

4. 9:00 o'clock position at Nacelle Station Number 165 over the diffuser case.

The simulated flight condition to be tested was set up according to the facility Mach number and either the engine pressure ratio or the exhaust gas temperature of the test engine. The test runs under transient conditions were conducted at either a constant or a decreasing facility Mach number. During tests with constant Mach number, the tunnel drive engines were advanced in power to overcome the loss in ejector pumping as the power of the test engine was reduced. The tunnel drive engines remained at a constant power setting as the test engine was retarded to idle for transient test runs with decreasing Mach number.

The Ignition Hazard test runs were initiated by releasing the flammable or combustible fluid after the nacelle temperature environment stabilized. If ignition occurred, the flow of fluid was discontinued and carbon dioxide was immediately discharged into the nacelle to extinguish the fire and minimize fire damage.

Variation of Engine Case Temperature with Exhaust Gas Temperature

The engine case temperature as measured during the initial temperature survey is presented in Appendix III. As the engine accumulated test time under severe operating conditions, the exhaust gas temperature increased in relation to the engine pressure ratio (Figure 4.2). As shown in Figure 4.3, the onset of the turbine case temperature rise and the station with maximum temperatures are estimated to have moved aft approximately 6 inches during the course of the test program. At the same time, the heat pattern around the turbine case was significantly changed with the development of a localized hot area between 1:00 and 3:00 o'clock positions at Nacelle Station Number 201. Figure 4.4 shows the average turbine case temperatures at Nacelle Station Number 201 for both the initial and final temperature surveys. The average temperature of the localized hot air is shown to have been 75°F to 100°F higher than the average case temperature outside of the hot area.

Nacelle Compartmental Isothermal and Isochronal Ignition Patterns

The estimated location of ignition for Zone I, Categories IV, V, and VI test runs is based on the relative time each of the air thermocouples responded to the ignition. The thermocouple response data were used to plot the isochronal lines throughout the nacelle compartment. The area in which ignition originated could then readily be determined from the isochronal patterns. The thermocouple responses, isochronal lines, and estimated location of ignition for a typical test run are presented in Figure 4.5.

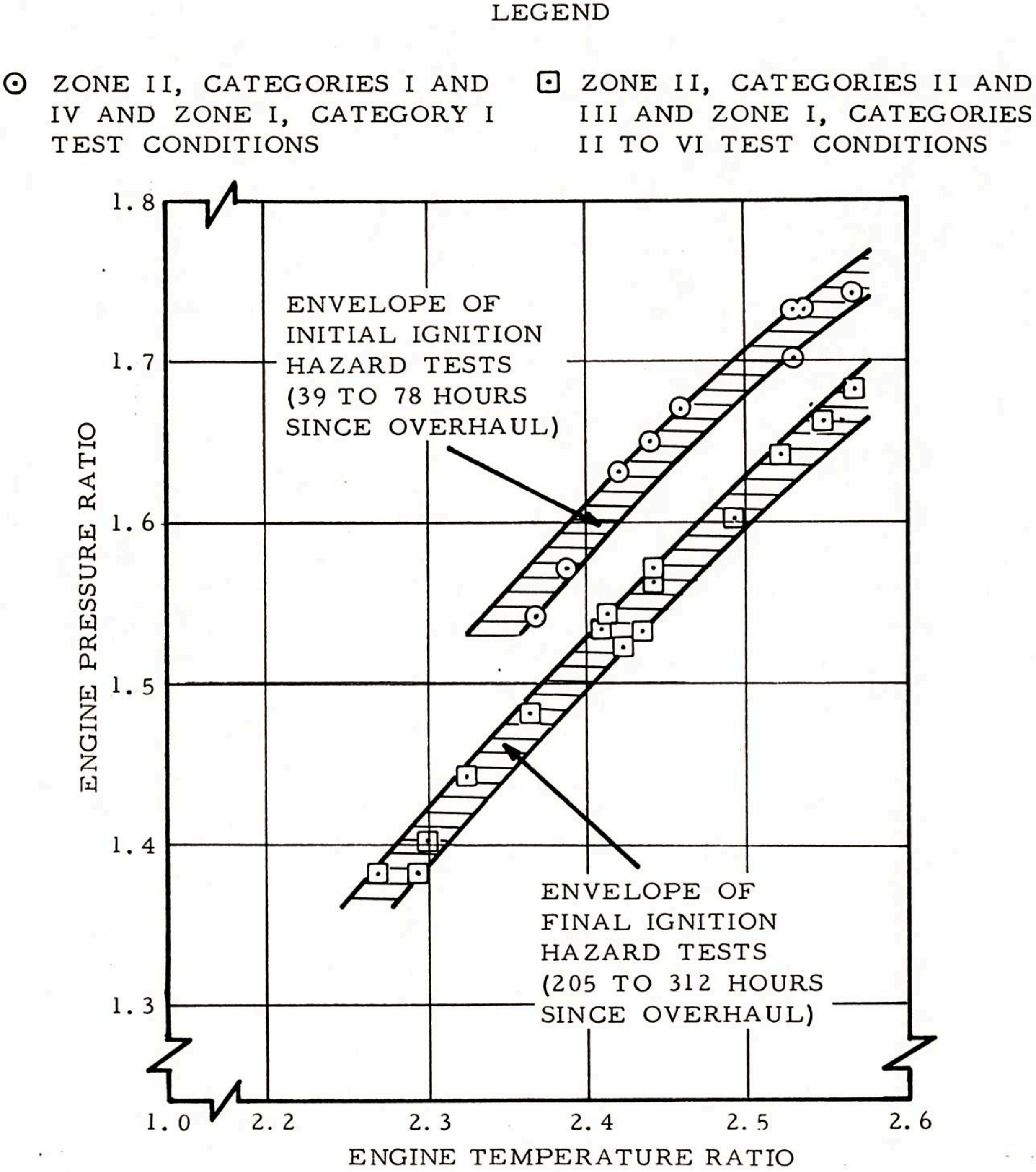


FIG. 4.2 - VARIATION OF ENGINE EXHAUST GAS TEMPERATURE WITH OPERATION TIME

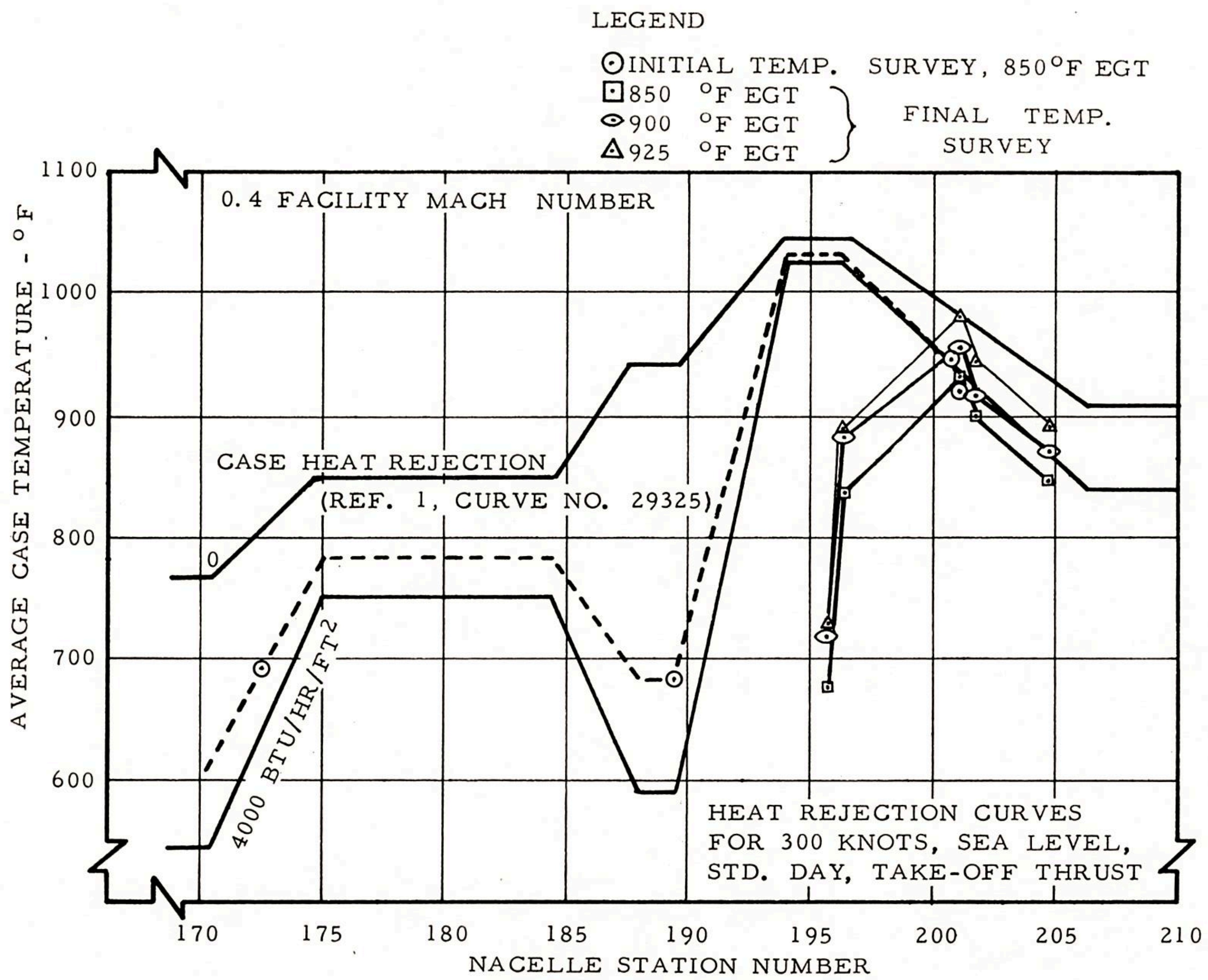


FIG. 4.3 - AVERAGE EXTERNAL ENGINE CASE TEMPERATURE IN ZONE I

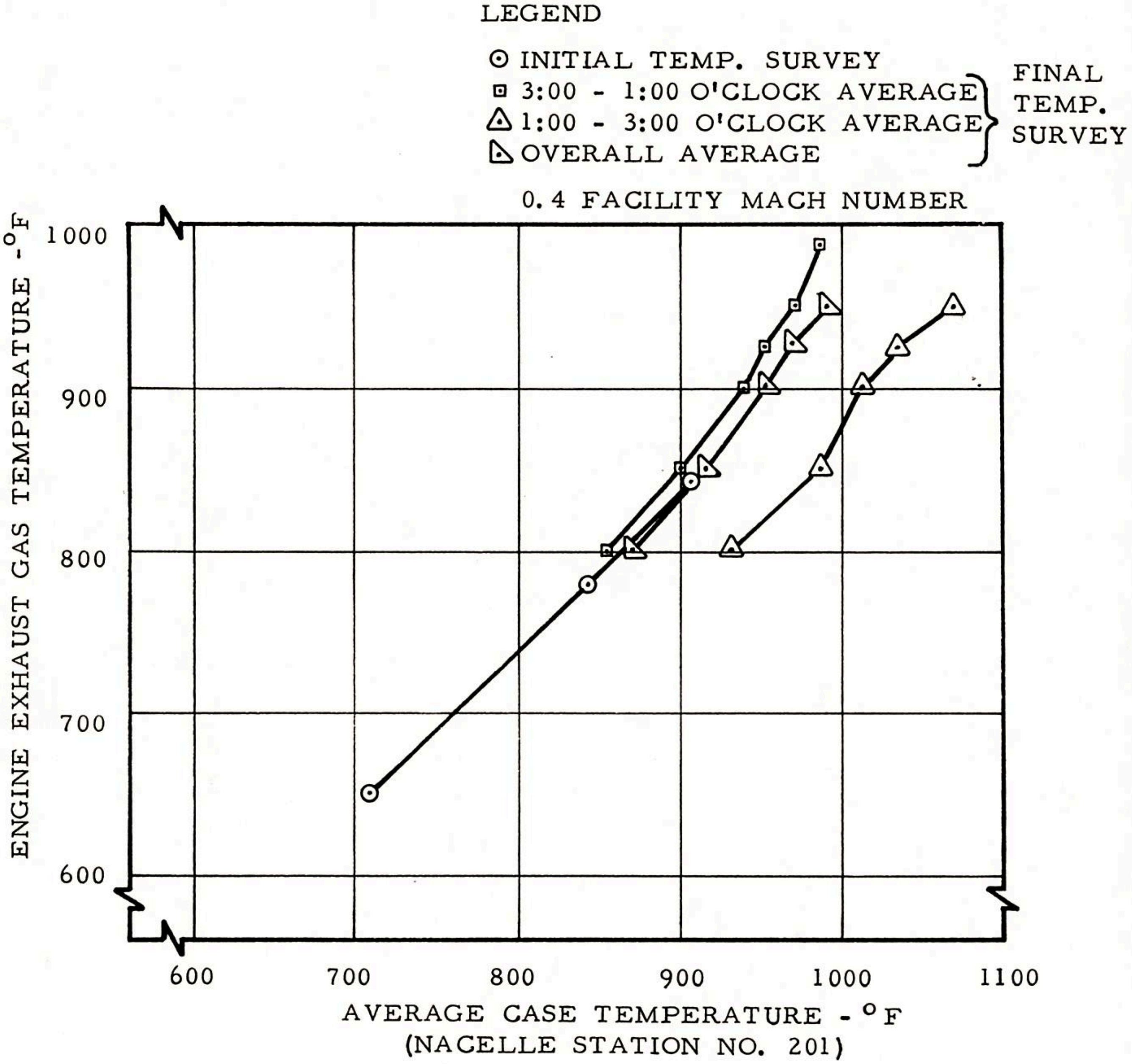
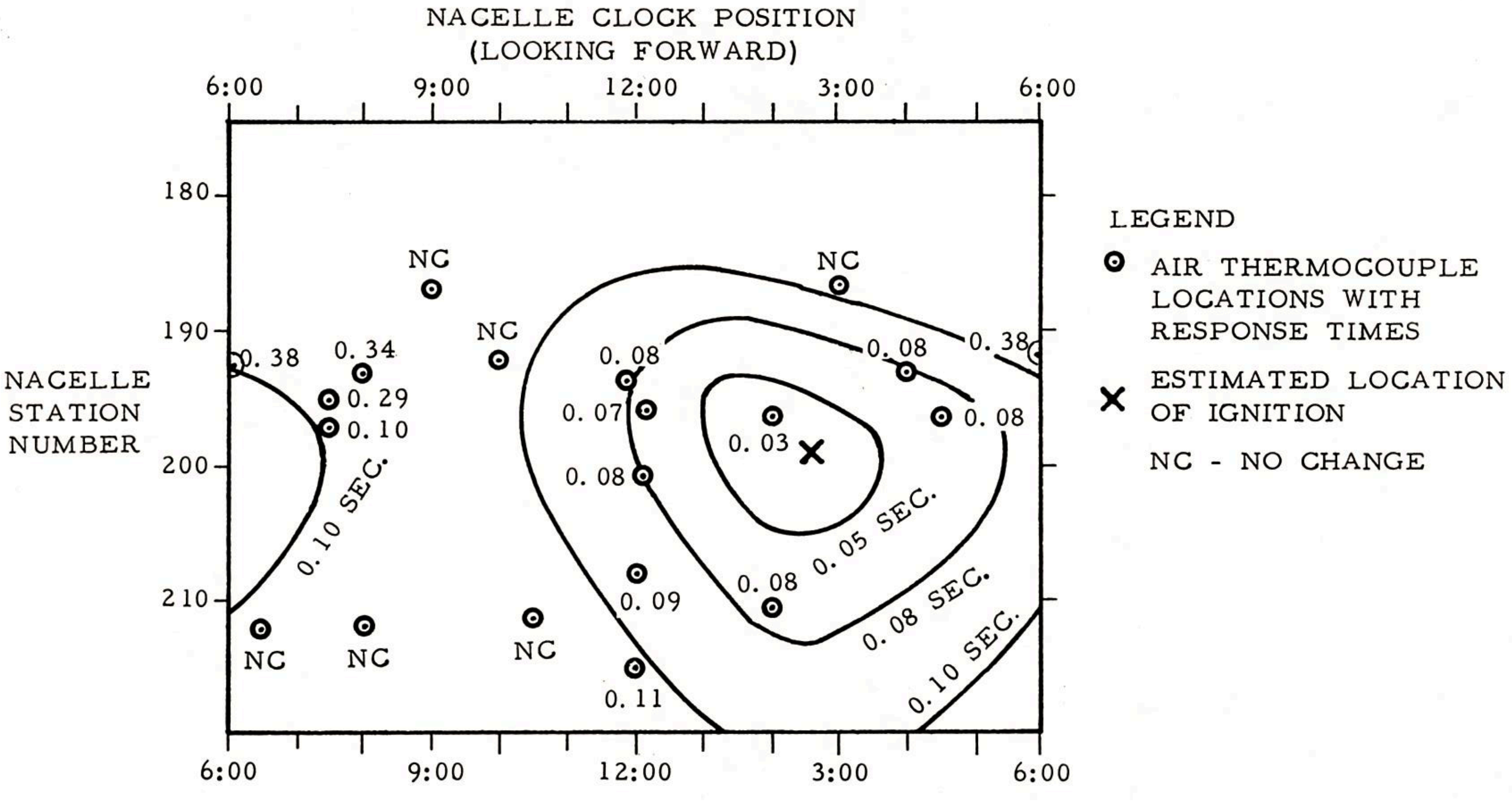


FIG. 4.4 - VARIATION OF EXTERNAL ENGINE CASE TEMPERATURE WITH ENGINE OPERATING LEVEL



ZONE I, CATEGORY IV TEST CONDITIONS
0.4 FACILITY MACH NUMBER
950°F EXHAUST GAS TEMPERATURE
0.3 GPM MIL-H-5606 HYDRAULIC FLUID @ 216 °F
41 COMPARTMENTAL AIR CHANGES PER MINUTE

FIG. 4.5 - NACELLE COMPARTMENTAL ISOCHRONAL IGNITION PATTERN

The cooling air temperature at the location of ignition for Zone I, Categories IV, V, and VI test runs, is based on the stabilized thermocouple readings prior to releasing the flammable fluids. The thermocouple readings were used to determine the isothermal pattern in the nacelle compartment. The cooling air temperature in the area where ignition occurred was then estimated from the isothermal pattern. The stabilized air thermocouple readings and isothermal lines for a typical test run are presented in Figure 4.6.

The isothermal pattern for the engine case and the stabilized case temperature prior to releasing the flammable fluid at the location of ignition were also determined in a similar manner. The stabilized case thermocouple readings and isothermal lines for a typical test run are presented in Figure 4.7. The localized hot area on the turbine case discussed previously is shown in this figure.

Explosive Classification of Ignitions

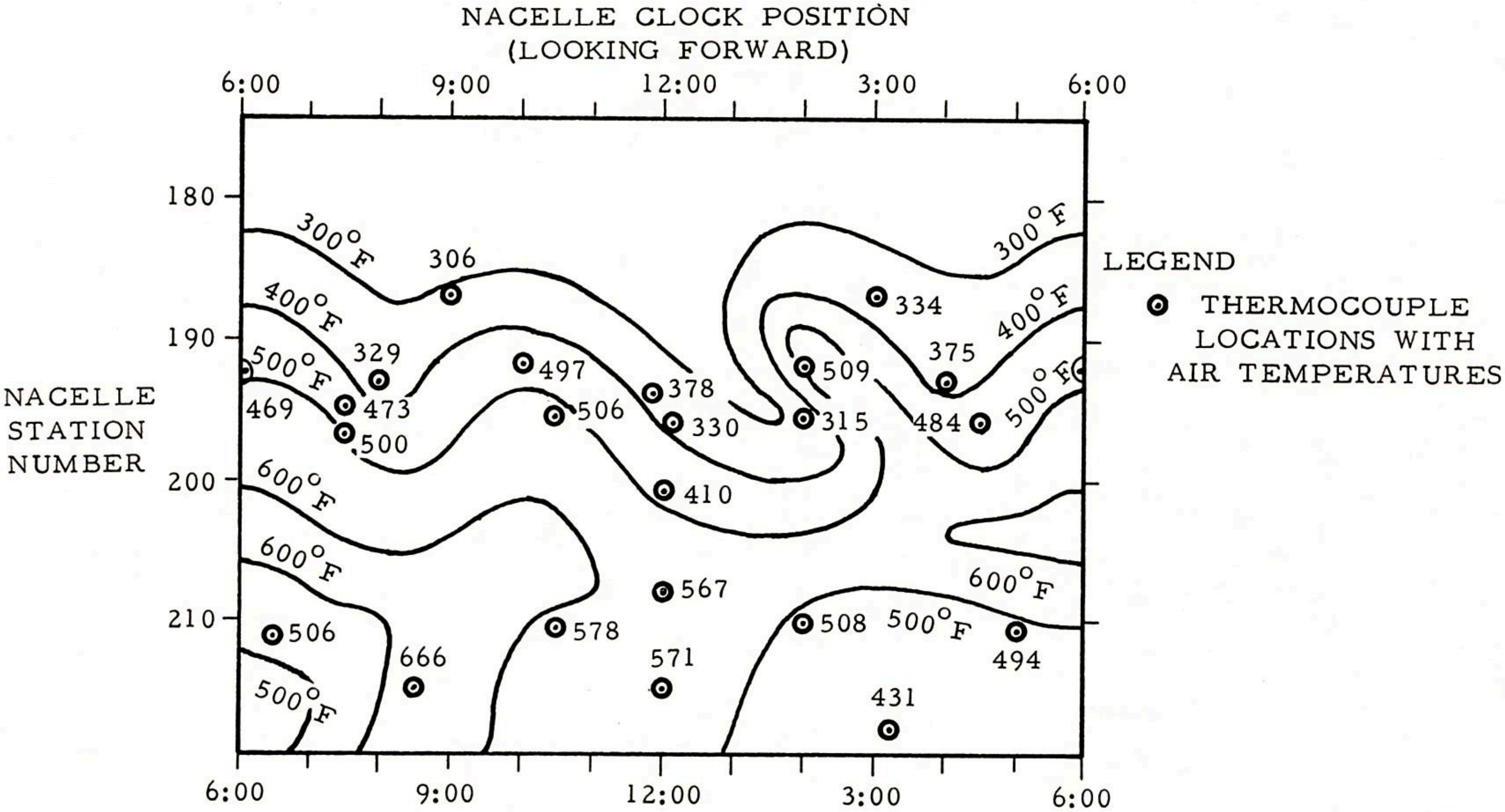
The scale used to classify the severity of the explosive ignitions during test runs in Zone I under Categories IV, V, and VI test conditions was developed on the basis of the time increment for the temperature wave to travel through an angle around the engine in both directions away from the location of ignition. The isochronal patterns were used to identify the location of ignition and to determine the increments of time required for the temperature wave to travel through a 50° angle around the engine starting at a position of 50° to either side of the location of ignition. The scale number represents the average of these two time increments in hundredths of a second. Therefore, the lower the scale number, the higher the flame propagation rate and the more severe the explosive ignition.

Ignition Hazard Test Data

The test conditions and results of the individual test runs in each of the four categories of tests in the nacelle compressor and accessory section are tabulated in Tables I to III.

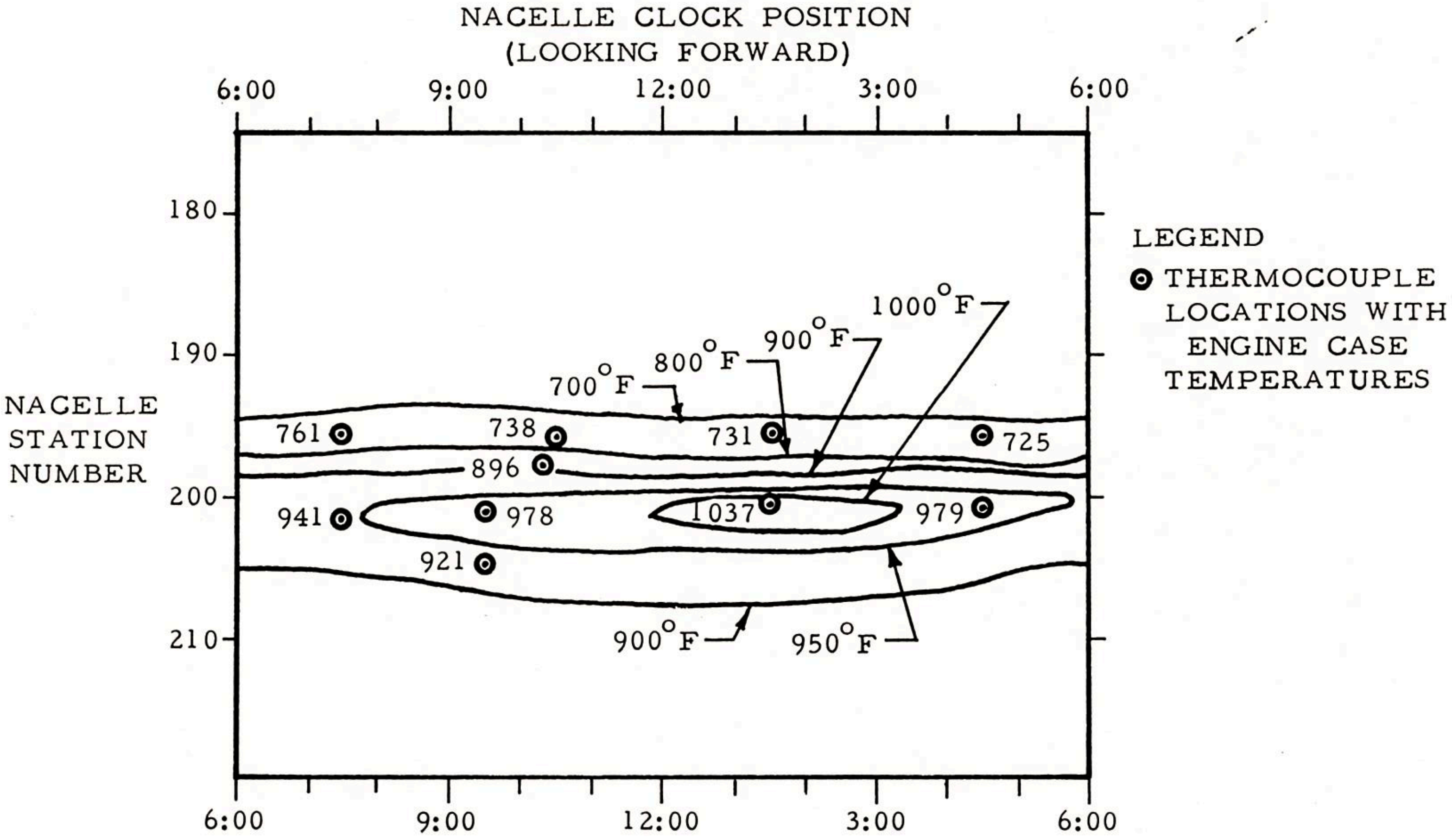
The test condition and results of the individual test runs in each of the six categories of tests in the nacelle combustor and turbine section are tabulated in Tables IV to XII.

Tables XIII and XIV identify the fluids release locations and the type of spray nozzles used throughout the ignition hazard investigation.



ZONE I, CATEGORY IV TEST CONDITIONS
0.4 FACILITY MACH NUMBER
950°F EXHAUST GAS TEMPERATURE
41 COMPARTMENTAL AIR CHANGES PER MINUTE

FIG. 4.6 - NACELLE COMPARTMENTAL ISOTHERMAL AIR PATTERN



ZONE I, CATEGORY IV TEST CONDITIONS
0.4 FACILITY MACH NUMBER
950 °F EXHAUST GAS TEMPERATURE
41 COMPARTMENTAL AIR CHANGES PER MINUTE

FIG. 4.7 - NACELLE COMPARTMENTAL ISOTHERMAL ENGINE CASE PATTERN

TABLE XIII

FLUID RELEASE LOCATIONS

Location	
A.	Nacelle Station 153, approximately 9:30 o'clock position spraying aft to diffuser case flange.
B.	Nacelle Station 164, approximately 2:30 o'clock position spraying from fuel and oil cooler to diffuser case flange.
C.	Nacelle Station 153, approximately 12:00 o'clock position spraying aft to diffuser case and fire seal.
D.	Nacelle Station 171, approximately 9:30 o'clock position aft of starter air duct pointing down, spraying parallel to diffuser case.
E.	Nacelle Station 173, approximately 12:00 o'clock position spraying aft toward and through holes in top of vertical fire seal.
F.	Nacelle Station 193, approximately 9:00 o'clock position aft of fire seal spraying toward turbine inlet case.
G.	Nacelle Station 196, approximately 8:00 o'clock position aft of fire seal spraying on turbine front flange area and the area diffusing to the flange.
H.	Nacelle Station 196, approximately 8:00 o'clock position aft of fire seal spraying toward turbine inlet case.

TABLE XIV

SPRAY NOZZLE DATA

Nozzle Type	Use	Fluid Spray Pattern	Fluid Atmoziation	Fluid Pressure Range (psig)	Fluid Flow Range (gpm)
A	Fuel	Full cone spray pattern projected at 30° angle spray	Relatively coarse	50 to 1050	0.3 to 2.2
B	Fuel	Full flat spray pattern	Fine	27 to 280	0.03 to 0.1
C	Lube Oils	Full solid stream	Coarse	3 to 43	0.01 to 1.0
D	Lube Oils	Full flat spray pattern	Coarse	1/2 to 36	0.5 to 1.0
E	Hydraulic Fluids	Hollow cone spray pattern	Extra Fine	220 to 1740	0.1 to 0.7

APPENDIX V

FIRE CHARACTERISTICS DATA SUPPLEMENT

The Fire Characteristics tests were conducted with a constant flow fuel release. The system recirculated the fuel so that the flow conditions could be established in the return line prior to releasing the fuel into the nacelle.

The nacelle temperature environment and flame patterns were determined from the temperature measurements at the following locations:

1. 34 unshielded number 30-gauge chromel-alumel air thermocouples installed at the locations used during the air temperature survey (Appendix III),

2. 10 unshielded number 30-gauge chromel-alumel air thermocouples below the horizontal strut firewall between Nacelle Station Numbers 127 and 222,

3. 32 number 20-gauge chromel-alumel engine case thermocouples installed at the locations used during the engine case temperature survey (Appendix III),

4. 20 number 24-gauge chromel-alumel skin thermocouples installed at the locations used during the nacelle skin survey (Appendix III).

The radiation environment in the nacelle compressor and accessory section was measured by flame sensors mounted at 1:00, 4:30, 7:00, and 10:30 o'clock and Nacelle Station Number 127 under the fan air duct. Each sensor was positioned viewing horizontally from fore to aft to provide 360° coverage of the annulus between the engine and the cowl doors. The sensors consisted of two-cell cadmium sulfide photo-resistive semiconductors. The red and blue cells were sensitive to light in the spectrum of 0.55 to 0.8 microns and 0.4 to 0.55 microns, respectively, and were connected in series as a voltage divider with the output taken from the center. Since a diffusion-type fire produces considerably more radiation in the 0.55 to 0.8 microns spectrum than in the 0.4 to 0.55 spectrum and since the cell resistance decreases with increasing radiation, a fire increased the voltage drop across the blue cell. The sensor output was therefore a measurement of the relative amount of radiation produced by a fire in the two spectrums and the intensity level of the radiation. Prior to installation on the test engine, each sensor was calibrated against the 5-inch-diameter pan fire used in the response time test of Reference 2.

The Fire Characteristics Phase was divided into the following four major series of tests:

1. The first series consisted of releasing and igniting fuel for a 10-second period at a rate of 0.3 gpm and at the locations and under the simulated flight conditions listed in Table I.

2. The second series of tests consisted of releasing and igniting fuel for a 10-second period at increasing rates until the fire of maximum intensity and size was reached. Test conditions for the second series of tests are tabulated in Table II.

3. The third series consisted of releasing and igniting fuel at several rates and allowing the fire to continue until either the air temperature above the engine reached a maximum of 1750°F for 5 seconds or burning occurred external to the nacelle. Table III lists the test conditions for the third test series.

4. The fourth series was conducted to compare the fire characteristics of jet fuels, Types A and B, and consisted of releasing and igniting the fuel under identical test conditions (See Table IV in body of report).

TABLE I

TEST CONDITIONS FOR FIRE CHARACTERISTICS STUDY - FIRST TEST SERIES

Jet Fuel Type B	Fuel Release Duration 10 second
Fuel Release Rate 0.3 gpm	Nozzle Type A (See Appendix IV, Table XIV)
Fuel Release Pressure 150 psig	

Test Condition	Facility Mach Number	Engine Power Setting (1)	Nozzle Location Number (2)
1	0.62	MC	1
2	0.5	MC	1
3	0.3	MC	1
4	0.62	MC	2
5	0.5	MC	2
6	0.3	MC	2
7	0.62	MC	3
8	0.5	MC	3
9	0.3	MC	3
10	0.62	MC	4
11	0.5	MC	4
12	0.3	MC	4
13	0.62	MC	5
14	0.5	MC	5
15	0.3	MC	5
16	0.5	CO	5
17	0.3	CO	5
18	0.1	CO	5
19	0.5	I	5
20	0.3	I	5
21	0.1	I	5
22	0.62	NRT	5
23	0.5	NRT	5
24	0.3	NRT	5
25	0.62	MC	6
26	0.5	MC	6
27	0.3	MC	6
28	0.62	MC	7
29	0.5	MC	7
30	0.3	MC	7

NOTES: (1) CO - Cut Off (Windmilling)
I - Idle
MC - Maximum Cruise Power
NRT - Normal Rated Thrust

(2) See Table III in body of report.

TABLE II

TEST CONDITIONS FOR FIRE CHARACTERISTICS STUDY - SECOND TEST SERIES

Jet Fuel Type B
Fuel Release Duration 10 seconds

Test Engine at
Maximum Cruise Power

Test Condition	Facility Mach Number	Fuel Release Rate (gpm)	Fuel Release Pressure (psig)	Nozzle Type (1)	Nozzle Location Number (2)
1	0.62	0.1	141	B	5
2	0.62	0.3	150	A	5
3	0.62	0.5	186	A	5
4	0.62	0.7	164	A	5
5	0.62	1.0	320	A	5
6	0.62	1.5	190	A	5
7	0.62	0.1	140	B	5
8	0.62	0.3	150	A	5
9	0.62	0.5	410	A	5
10	0.62	0.7	350	A	5
11	0.62	1.0	700	A	5
12	0.62	1.5	830	A	5
13	0.5	0.1	130	B	5
14	0.5	0.3	150	A	5
15	0.5	0.5	175	A	5
16	0.5	0.7	155	A	5
17	0.5	1.0	300	A	5
18	0.3	0.1	130	B	5
19	0.3	0.3	150	A	5
20	0.3	0.5	170	A	5
21	0.3	0.7	135	A	5
22	0.3	1.0	290	A	5
23	0.62	0.1	125	B	3
24	0.62	0.3	150	A	3
25	0.62	0.5	162	A	3
26	0.62	0.7	150	A	3
27	0.62	1.0	305	A	3
28	0.5	0.1	135	B	3
29	0.5	0.3	150	A	3
30	0.5	0.5	165	A	3
31	0.5	0.7	140	A	3
32	0.5	1.0	310	A	3
33	0.3	0.1	110	B	3
34	0.3	0.3	150	A	3
35	0.3	0.5	175	A	3
36	0.3	0.7	135	A	3
37	0.3	1.0	300	A	3

NOTES: (1) See Appendix IV, Table XIV.

(2) See Table III in body of report.

TABLE III

TEST CONDITIONS FOR FIRE CHARACTERISTICS STUDY - THIRD TEST SERIES

JET FUEL TYPE B

Test Condition	Facility Mach Number	Engine Power Setting (1)	Fuel Release Rate (gpm)	Fuel Release Pressure (psig)	Fuel Release Duration (sec)	Nozzle Type (2)	Nozzle Location Number (3)
1	0.3	MC	0.3	145	37	B	5
2	0.3	MC	0.3	143	89	B	5
3	0.5	MC	0.3	---	45	B	5
4	0.62	MC	0.1	145	76	A	5
5	0.62	MC	0.1	157	160	A	5
6	0.62	MC	0.5	178	78	B	5
7	0.62	MC	0.7	152	76	B	5
8	0.62	MC	0.3	150	86	B	5
9	0.62	MC	1.0	330	54	B	5
10	0.62	MC	1.5	190	36	B	3
11	0.5	MC	0.3	150	53	B	3
12	0.62	MC	1.0	350	77	B	7
13	0.62	MC	0.3	132	43	B	7
14	0.5	CO	0.3	140	77	B	7
15	0.5	MC	0.3	140	65	B	7
16	0.3	MC	0.3	138	56	B	7
17	0.62	MC	0.3	140	25	B	7
	0.5	I	0.3	140	75		7

NOTES: (1) CO - Cut Off (Windmilling)
I - Idle
MC - Maximum Cruise Power

(2) See Appendix IV, Table XIV.

(3) See Table III in body of report.

APPENDIX VI

FIRE AND OVERHEAT DETECTION DATA SUPPLEMENT

The installation and operating characteristics of the nine Fire and Overheat Detection Systems tested are described below:

1. Unit Fire Detector (UFD) System consisted of a thin wall 0.625-inch-diameter by 3.5-inch-long tube which expanded and contracted as the surrounding temperature increased or decreased. When the tube reached the preset alarm point, enclosed contacts were actuated. The UFD installation on the test engine is shown in Figure 6.1.

2. Continuous Fire Detector (CFD) System Number 1 consisted of 51 inches of 0.090-inch-diameter sensor element mounted in the center of a 1/2-inch-formed perforated protective tube. The sensor element consisted of an outer metal tube which enclosed a thermistor core and two conductors. As the element was heated, the thermistor resistance decreased proportionately to the square of the temperature increase. The monitoring control unit was activated when the sensing element resistance reached the alarm point. The CFD Number 1 installation on the test engine is shown in Figure 6.2.

3. CFD Numbers 2, 3, and 5 consisted of 51 inches of 0.040-inch-diameter sensor element mounted in the center of a 1/2-inch-formed perforated protective tube. The sensor element consisted of an outer metal tube which enclosed a solid core material, a filler material and an inert gas. The solid core material released a gas and produced a pressure rise in the tube when heated above the preset discrete alarm point. The inert gas in the tube expanded and also produced a pressure rise as the temperature increased. The sensor element was connected to a pressure-operated diaphragm switch. When the tube pressure increased to a preset point as a result of either the expanding inert gas or the released gas, the diaphragm closed electrical contacts and signalled an alarm. The alarm point was the only difference between CFD Numbers 2, 3, and 5. The installation of these detectors on the test engine was the same as CFD Number 1, Figure 6.2.

4. CFD Number 4 consisted of 51 inches of 0.090-inch-diameter sensor element mounted in the center of a 1/2-inch-formed perforated protective tube. The sensor element consisted of an outer metal tube which enclosed a material which had the characteristic of sharply decreasing in electrical resistance when heated to a preselected critical temperature. The control unit actuated an alarm when the sharp drop in resistance occurred. The CFD Number 4 installation on test engine was also the same as CFD Number 1, Figure 6.2.

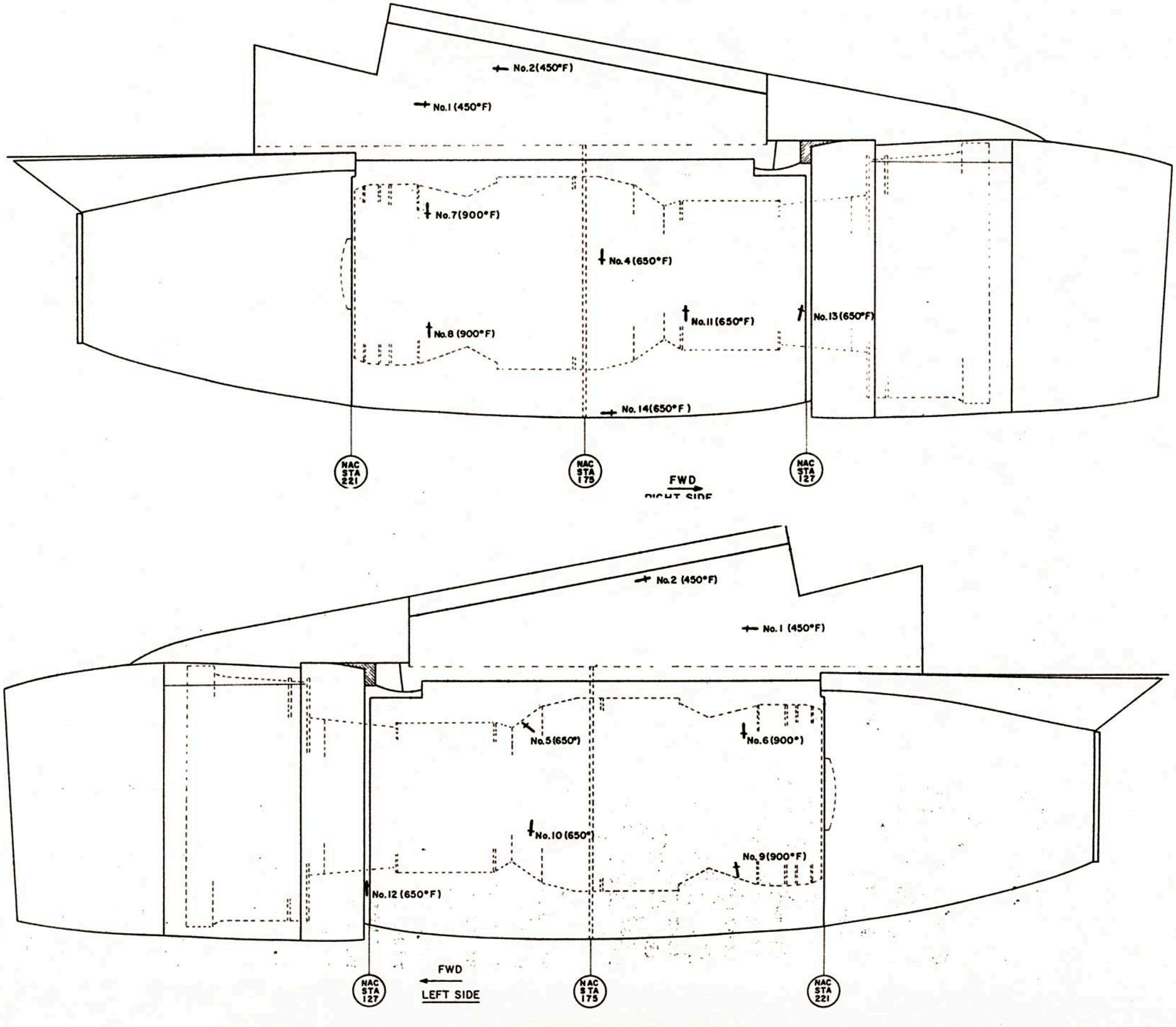


FIG. 6.1 - UNIT FIRE DETECTOR INSTALLATION

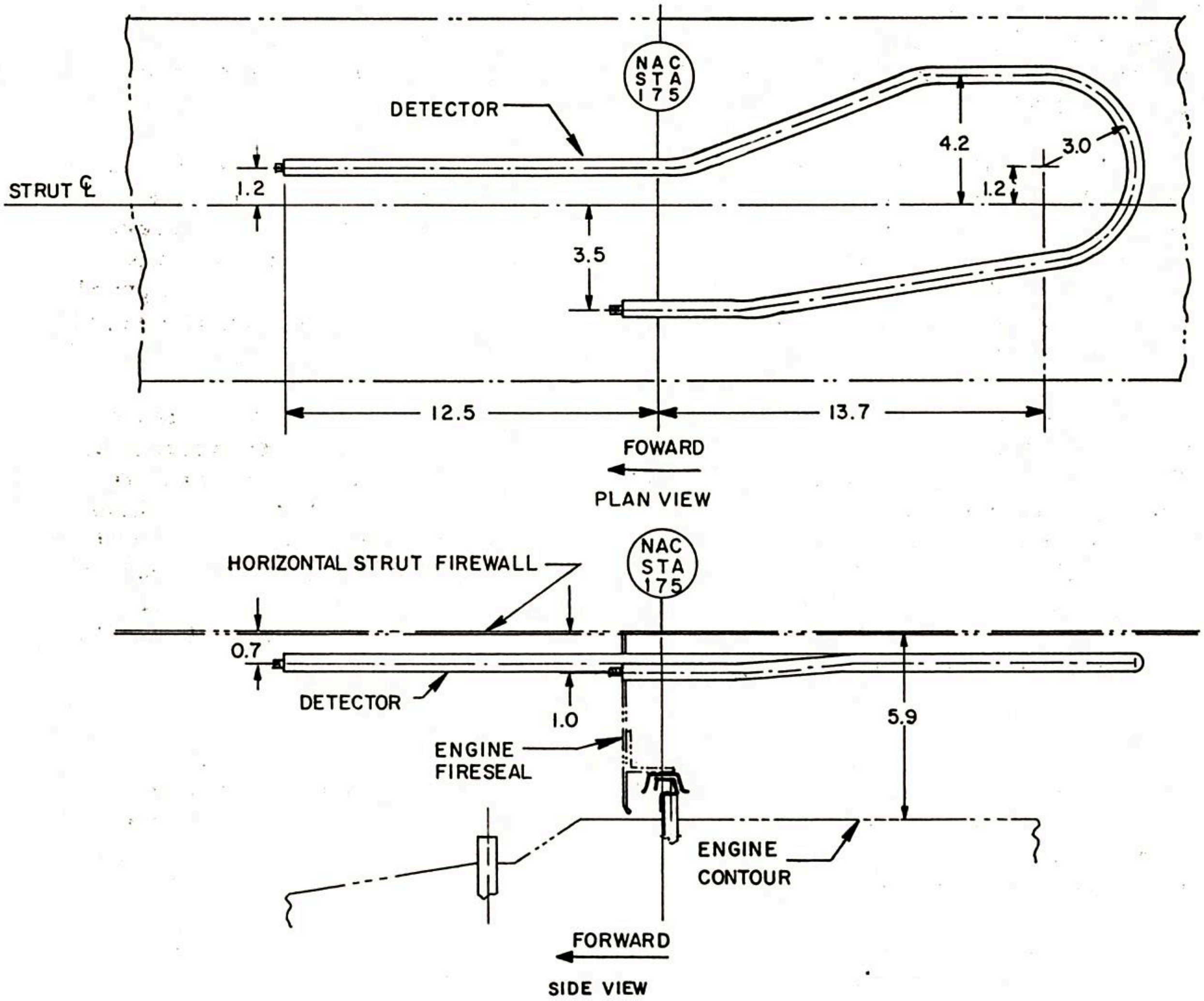


FIG. 6.2 - CONTINUOUS FIRE DETECTOR INSTALLATION (CFD 1, 2, 3, 4, AND 5)

5. CFD Number 6 had the same type sensor element and operating characteristics as CFD Number 2 except for the alarm point. However, CFD Number 6 had the sensor element spirally wound on a 1/4-inch support tube rather than running through the perforated tube. The installation of CFD Number 6 on the test engine is shown in Figure 6.3.

6. Surveillance Fire Detector (SFD) System Number 1 consisted of the four sensors used to measure the radiation environment (Appendix V). Each sensor was connected to a control unit which activated an alarm when the voltage output from the sensor reached a preset level.

7. SFD Number 2 consisted of four sensors (one at 1:00, 4:30, 10:30, and 7:00 o'clock positions) sensitive to near infrared radiation and insensitive to visible radiation. The sensor's photocell outputs were monitored through a control unit which amplified only flickering signals over a frequency range from 4 to 20 cycles per second. The control unit activated an alarm when the output from one or more sensors reached a preset level.

The major portion of the Fire and Overheat Detection Investigation was conducted concurrently with the Fire Characteristics Investigation. Therefore, the measurements, test procedures, and test conditions were the same as discussed in Appendix V. The remaining portion of the Fire and Overheat Detection Investigation consisted of a series of tests with the nacelle modified in an attempt to develop a simplified fire detector installation. The test procedures and conditions for this test series are presented in the body of this report, Table X. The modifications to the test installation are shown in Figure 31 and consisted of the following:

1. The installation of a 1 1/4-inch-diameter flush circular ram air inlet in the forward strut fairing to provide forced flow through the chimney into Zone II and to prevent fires from spreading into the forward strut fairing. It was estimated that this modification doubled the total airflow into the nacelle.

2. Sealing the vertical engine fireseal with a silicon rubber compound to prevent airflow into Zone I from Zone II.

3. Installing an enlarged drain vent with a flame arrester. The drain vent consisted of a 6 3/4- by 5 1/16-inch rectangular opening with fifty 0.0375-inch thickplates spaced 1/16-inch apart in the opening. This resulted in a free area between the plates (21-1/2 square inches) approximately twice the combined opened area through the engine fireseal and drain vent on the production installation.

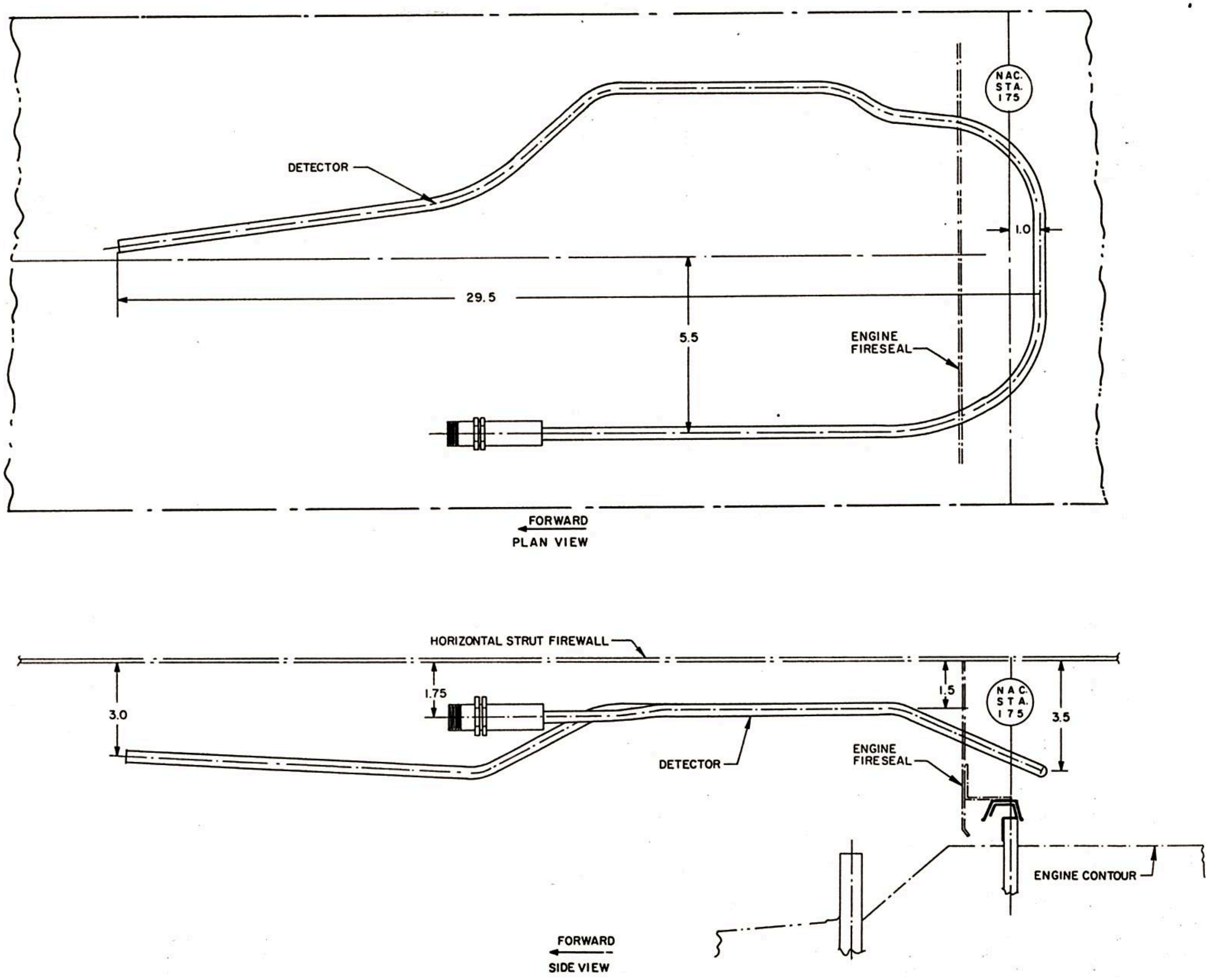


FIG. 6.3 - CONTINUOUS FIRE DETECTOR INSTALLATION (CFD 6)

The test engine operation was monitored with all the standard recommended instrumentation. This included the following:

1. Engine inlet air temperature (T_{t2}) was measured with the standard probe and read-out on a precision indicator.

2. Engine inlet air pressure and turbine discharge total pressure were measured with standard probes and read-out on an engine pressure ratio indicator.

3. Low (N_1) and high (N_2) compressor rotor speeds were measured with frequency generators and read-out on frequency counters.

4. Turbine discharge total temperatures were measured with the standard probes and read-out on a precision potentiometer-type indicator as individual and average temperatures.

5. Engine oil temperature was measured with the standard pickup and read-out on a precision indicator.

6. Engine oil pressure was measured with a differential pressure transmitter and read-out on a dial indicator and a light indication was provided in the control room for pressures below 28 psi.

7. The main oil strainer pressure drop was connected to a pressure differential switch and a light indication was provided in the control room.

8. Fuel flow was measured with a flowmeter and read-out on a digital counter.

9. Fuel pump inlet temperature was measured with an iron-constantan thermocouple installed in the inlet boss and read-out on a precision indicator.

10. Fuel pump inlet pressure was measured with a direct reading pressure gauge located in the supply line.

11. Fuel control signal pressure to the pressurization and dump valve was measured with a pressure transmitter and read-out on a dial indicator.

12. Engine vibrations were measured with standard pickups at standard manufacturer locations on the diffuser case, inlet case, and turbine exhaust case and read-out on a vibration meter.

13. Fuel filter pressure differential was connected to a standard pressure differential switch and a light indication provided in the control room.

14. Oil quantity was measured with a standard probe and read-out on a dial indicator.

Throughout the test program, all engine instrumentation was maintained in an operable condition except for vibration and N_1 pickups. All engine instrumentation, except for vibrations and temperatures recorded on an 18-point precision indicator, was immediately displayed to test personnel.

APPENDIX VII

FIRE CONTROL AND EXTINGUISHMENT DATA SUPPLEMENT

The Fire Control and Extinguishment Investigation was conducted with the test installation in either a production, modified production, or opened engine fireseal configuration. The production and opened engine fireseal configurations are described in Appendix III. The modified production configuration consisted of one or more of the following changes to the production configuration for the individual test series as indicated:

1. Fan discharge air entered Zone II through a 1/2-inch-diameter hole placed horizontally through both sides of the cooling air venturi duct to the CSD/generator.

2. The cowl door seams sealed with silicon rubber to minimize leakage.

3. The surge bleed valve blanked off and door closed and sealed.

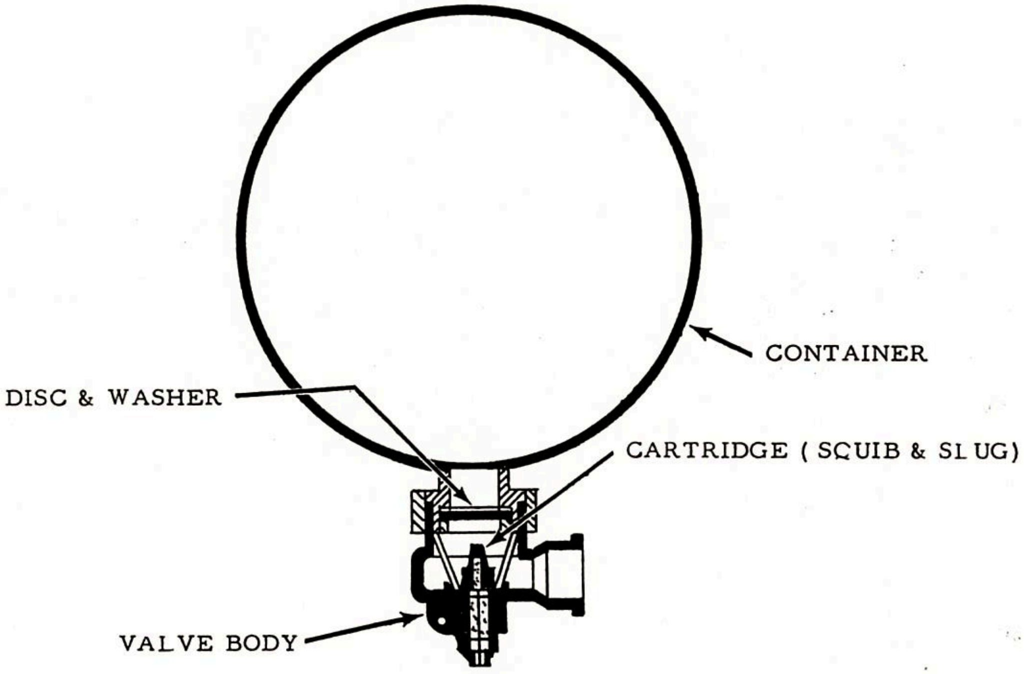
4. The cooling air blast tubes sealed with silicon rubber and a controlled auxiliary cooling air supply was either manifolded to each blast tube location or directed down both sides of the engine forward of the front mounts.

5. The cooling air venturi duct to the CSD/generator removed and openings blanked off.

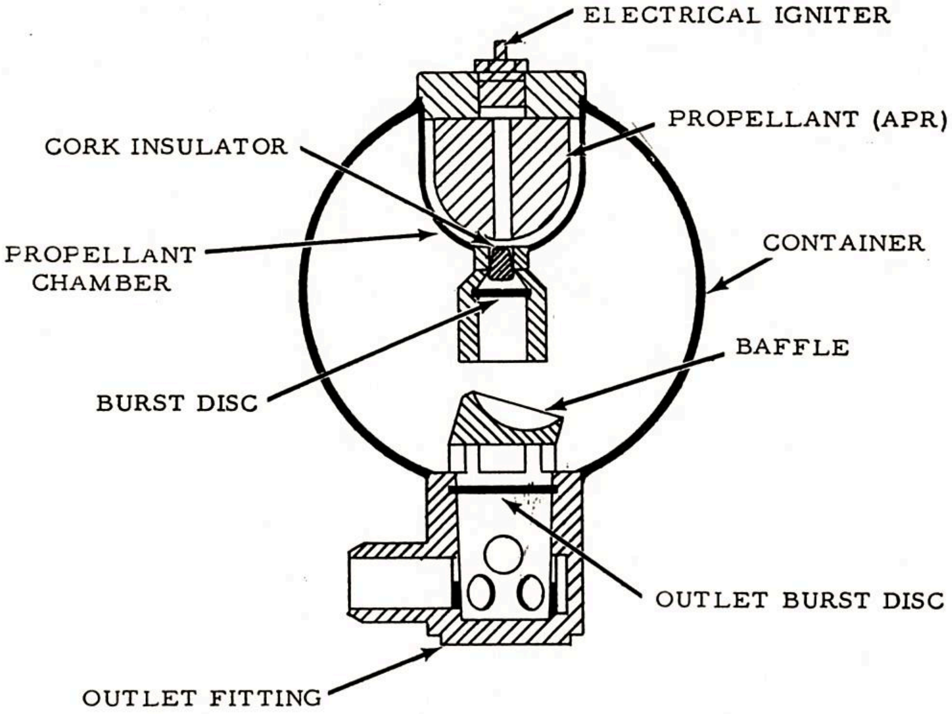
The nacelle air temperature environment and flame patterns were determined from temperature measurements with thermocouples installed at the locations used during the fire characteristics investigation (See Appendix V). When comparisons were made between two or more test runs, the thermocouple readings were used to determine the isothermal patterns in the nacelle compartment to assure near identical fire conditions.

The two types of fire extinguishing agent containers used are shown in Figure 7.1. The nitrogen container was equipped with a cartridge and disc-type valve in the outlet. The extinguishing agent was forced out of the container by nitrogen pressure when the electrically ignited squib fired a slug rupturing the frangible disc in the outlet.

The extinguishing agent was heated and forced out of the pyrotechnic container when a squib ignited the propellant, which burned and built up pressure sufficient to rupture the insulated burst disc at the propellant chamber outlet. The emerging propellant gases were deflected by a baffle and mixed with the agents increasing the pressure in the container and rupturing the main outlet burst disc.



NITROGEN CONTAINER
(224, 378, 536 OR 630 CU. IN.)



PYROTECHNIC CONTAINER
(70 CU. IN.)

FIG. 7.1 - CROSS-SECTION OF FIRE EXTINGUISHING AGENT CONTAINERS

The limits on the amount of agent in the pyrotechnic type container were established so that the volume occupied by the agent at 70°F was between approximately 50 and 90 percent of the total container volume.

The sequence of events for tests in which the fire extinguishing system was discharged normally followed one of the three schedules listed in Table I.

TABLE I

TEST SCHEDULES OF EVENTS

Event	Schedule A (sec)	Schedule B (sec)	Schedule C (sec)
Activate Ignitor	0	0	0
Initiate Fuel Release	5	5	5
Initiate Engine Shut Down	15	30	45
Deactivate Ignitor	18	33	48
Discharge Fire Extinguishant	20	35	50
Discontinue Fuel Release	45	60	75

If the fire was extinguished, the quantity of agent was decreased until either the fire was no longer extinguished by the test charge or the minimum allowable agent quantity for the container was reached. Likewise, if the fire was not extinguished, the quantity of agent was increased until either the test charge extinguished the fire or the maximum allowable agent quantity limit for the container was reached.

APPENDIX VIII

FIRE RESISTANCE AND DAMAGE DATA SUPPLEMENT

The test engine accumulated approximately 330 hours of operating time during the fire test program. In addition to the numerous compartment fires, the engine was subjected to the following abnormal type operation:

1. Repeated thermal shocks from application of fire extinguishing agents.

2. Frequent rapid reductions from high power to cutoff simulating emergency shutdowns.

3. Three known bird ingestions and one ingestion of small metal objects.

The fuel control was adjusted near the end of the program and the engine was operated for periods up to 5 minutes at power settings (to 985°F exhaust gas temperature and 10,030 rpm high compressor rotor speed) above the maximum allowable limits set by the manufacturer.

High engine oil consumption was encountered near the end of the test program during tests with the engine operating at high power settings. This was considered to be a result of deteriorated seals.

Engine vibration measurements taken at the close of the test program indicated that the engine was operating within acceptable vibration limits.

The engine installation was inspected by test personnel prior to removal from the test facility, and again, prior to and during reconditioning operations. The latter inspection is reported in Reference 3. The following is a summary of the major findings resulting from these inspections.

1. The skin aft of the forward strut fairing was patched on both sides of the strut. A 6-inch crack had developed in the strut skin on the right side downstream of the patched area. One of the aft strut attach shear bolts was partially yielded.

2. One right cowl door and two left cowl doors of the original four sets were completely destroyed. The remaining doors had internal stiffeners burned away and portions repaired, replaced, and reworked.

3. The fan thrust reverser actuators were severely corroded but considered operable. The primary thrust reverser actuators were burned and corroded and were not considered operable.

4. Reference 3 reports that the engine mount fittings were X-ray inspected and found to be structurally sound.

5. Structural bracing for the fan discharge duct was weakened and reinforced in the forward area of Zone II. Prior to reinforcing this area, the fan duct had distorted.

6. The throttle and fuel shutoff linkages were operable but badly deteriorated. Portions of the primary thrust reverser linkage was destroyed and the reverser was therefore inoperative.

7. The ignition system had one high tension cable open. The engine ignition boxes were not replaced and were operating satisfactorily at the completion of the program.

8. The engine wiring was generally in an extremely deteriorated condition. The insulation on the exhaust gas temperature thermocouple harness had deteriorated exposing the wire. Individual temperature pickup connector plugs were deteriorated and one total temperature probe was open.

9. The exterior surfaces of the engine case and engine components were coated with carbon and corroded. The lower portion of the low pressure compressor case was severely corroded and pitted.

10. The fuel and oil systems contained carbon and fragments of deteriorated seals. It is suspected that internal seals of the fuel control, fuel pump, thrust reverser actuators, fuel-oil cooler, etc. were damaged during the initial long duration fires. However, this was not verified by disassembly and inspection during the period of testing. The fuel nozzles were covered with carbon. The burner cans contained many cracks beyond allowable flight repair limits. One swirler was damaged beyond repair.

11. The first and second stages of the fan rotor blades had extensive foreign object damage.

12. The high pressure compressor and the turbine sections inspected from inlet and exhaust openings and the combustion section were reported to be in good condition.

Fluid Release Location (1)	Fluid Temperature (°F)	Nozzle Type (2)	Cooling Airflow (lb./sec.)	Ventila(6) Rate- (Changes/		Temperature at Ignition (7) Case (°F)	Temperature at Ignition (7) Cooling Air (°F)	Location of Ignition (8) Sta.	Location of Ignition (8) O/C	Ignition Type (9)
197	-	D	0.22	21	5	940	580	201	10:30	2
197	202	D	0.24	23	5	-	-	-	-	-
197	186	D	0.23	22	0	800	520	210	3:30	2
197	211	D	0.44	41	0	-	-	-	-	-
197	168	D	0.43	40	5	900	425	196	1:00	2
197	200	D	0.23	22	0	-	-	-	-	-
197	218	D	0.23	22	0		-	-	-	-

NOTES:
(1) Nacelle station number for a spray nozzle pos
(2) See Table XIV.
(3) x.xx indicates constant fluid flow; 0(x.xx) i
(4) Time at which constant fluid flow was obtaine
(5) Case temperature range between nacelle statio
(6) Estimated air temperature range at nacelle st
(7) Estimated temperatures at ignition location b
(8) Estimated location of ignition based on isoch
(9) Severity of ignition ranging from mild (7) to

Fluid Release Location (1)	Fluid Temperature (°F)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.)	Nacel Pressu (psia	Temperature at Ignition (6)		Location of Ignition (7)		Ignition Type (8)
					e F)	Cooling Air (°F)	Sta.	O/C	
195.6	180	0.03	3	13.1		-	-	-	-
195.6	182	0.03	3	-	0	510	200	11:00	1
195.6	-	0.03(9)	3(9)	-		-	-	-	-
201.6	102	0.03	3	13.0	5	600	200	10:30	6
201.6	120	0.25	24	-	5	600	201	10:00	7
201.6	122	0.85	77	-		-	-	-	-
201.6	191	0.63	58	13.4		-	-	-	-
201.6	166	0.60	55	-		-	-	-	-
201.6	180	0.24	23	-		-	-	-	-
201.6	154	0.24	23	-	5	500	201	11:00	6
201.6	176	0.39	37	-		-	-	-	-
201.6	173	0.38	35	-		-	-	-	-
201.6	220	0.38	35	-		-	-	-	-
201.6	196	0.39	37	-	0	500	203	3:30	5
201.6	216	0.45	41	-	0	425	199	2:30	2
201.6	224	0.59	54	-		-	-	-	-

NOTES:
(1) Nacelle station number for an open end 3/8 inch AN t
(2) x.xx indicates constant fluid flow; 0(x.xx) indicate
(3) Time at which constant fluid flow was obtained.
(4) Case temperature range between nacelle stations 200.
(5) Estimated air temperature range at nacelle station 2
(6) Estimated temperatures at ignition location based on
(7) Estimated location of ignition based on isochronal t
(8) Severity of ignition ranging from mild (7) to a viol
(9) Side cowl door seams leaking and nacelle ventilatio

Fluid Release Location (1)	Fluid Temperature (°F)	Cooling Airflow (lb./sec.)	Ventilation Rate (Changes/min.) 5)	Case (6) Temperature Max. (°F)	Case (6) Temperature Min. (°F)	Cooling Air Temperature(7) Max. (°F)	Cooling Air Temperature(7) Min. (°F)	Temperature at Ignition(8) Case (°F)	Temperature at Ignition(8) Cooling Air (°F)	Location Of Ignition (9) Sta.	Location Of Ignition (9) O/C	Ignition Type (10)
201.6	115	0.04	4	1037	976	610	290	-	-	-	-	-
201.6	145	0.06	6	1039	976	615	295	-	-	-	-	-
201.6	165	0.04	4	1033	937	605	200	-	-	-	-	-
201.6	178	0.06	6	1029	971	625	275	910	520	196	4:15	2
201.6	197	0.65	59	1000	917	540	345	-	-	-	-	-
201.6	195	0.49	45	1036	950	540	420	-	-	-	-	-
201.6	190	0.34	32	1036	917	535	350	-	-	-	-	-
201.6	167	0.23	22	1030	926	535	345	900	600	210	11:00	3
197	222	0.22	21	922 (954)	851	570	355	-	-	-	-	-
197	224	0.22	21	969 (994)	900	600	375	-	-	-	-	-
195.6	200	Min.	Min.	1072	1000	650	495	1060	510	201	1:00	6
195.6	200	Min.	Min.	1030	950	700	350	1015	390	202	2:00	5
195.6	200	Min.	Min.	965	895	620	280	895	600	204	10:00	1
195.6	173	Min.	Min.	1017	845	620	395	800	600	195	10:00	1
195.6	220	0.48	44	1003	889	510	390	-	-	-	-	-
195.6	210	0.49	45	1044	905	510	380	-	-	-	-	-
195.6	215	0.48	44	1062	951	590	375	-	-	-	-	-
195.6	217	0.29	28	1033	924	580	380	-	-	-	-	-
195.6	224	0.29	28	1083	971	600	440	-	-	-	-	-
195.6	226	0.08	8	1025	929	630	400	-	-	-	-	-
195.6	226	0.08	8	1076	985	650	380	-	-	-	-	-
195.6	226	Min.	Min.	991	886	660	410	-	-	-	-	-
195.6	178	Min.	Min.	1014	921	675	425	940	475	201	12:15	4
195.6	224	0.00 (11)	0 (11)	1046	977	680	350	-	-	-	-	-
195.6	220	0.06	6	1042	985	625	350	-	-	-	-	-
195.6	221	0.07	7	1031	985	640	350	-	-	-	-	-
195.6	223	0.03	3	1060	981	630	390	-	-	-	-	-
195.6	-	0.04	4	1053	944	625	390	-	-	-	-	-
195.6	145	0.04	4	1025	907	660	325	-	-	-	-	-
195.6	134	0.04	4	-	-	-	-	-	-	-	-	-
195.6	134	0.07	7	1029	979	640	350	-	-	-	-	-
195.6	160	0.04	4	1031	974	670	355	-	-	-	-	-
195.6	183	0.04	4	1000	907	675	290	-	-	-	-	-
195.6	203	0.04	4	1037	979	685	395	-	-	-	-	-
195.6	246	0.04	4	1029	956	645	300	-	-	-	-	-
201.6	190	0.44	41	1013	936	540	400	-	-	-	-	-
201.6	210	0.44	41	1017	932	535	410	-	-	-	-	-
201.6	186	0.23	22	1007	929	540	350	-	-	-	-	-
201.6	202	0.23	22	1013	925	570	350	-	-	-	-	-
201.6	-	0.23	22	1047	958	590	400	-	-	-	-	-
201.6	186	0.22	21	1031	987	626	350	995	550	201	4:30	2

NOTES:
(1) Nacelle station number for an open end 3/8
(2) x.xx indicates constant fluid flow; 0(x.xx)
(3) Time at which constant fluid flow was obtai
(4) Test engine power setting reduced to Idle.
(5) Referenced to zero time at start of Categor
(6) Case temperature range between nacelle stat
(7) Estimated temperature range at nacelle stat
(8) Estimated temperatures at ignition location
(9) Estimated location of ignition based on iso
(10) Severity of ignition ranging from a mild ex
(11) Zero controlled cooling airflow with exit v