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DESIGN STUDY OF RL10 DERIVATIVES

FINAL REPORT

VOLUME III, PART 1

PRELIMINARY INTERFACE CONTROL DOCUMENT

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Prepared for
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ABSTRACT

The Interface Control Document contains engine information necessary for installation of the baseline RL10 Derivative engines in the Space Tug vehicle. The ICD presents a description of the baseline engines and their operating characteristics, mass and load characteristics, and environmental criteria. The document defines the engine/vehicle mechanical, electrical, fluid and pneumatic interface requirements.

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FOREWORD

This technical report presents the results of the Design Study of RL10 Derivatives for Space Tug propulsion. The study was conducted by the Pratt & Whitney Aircraft Division of United Aircraft Corporation for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center under Contract NAS8-28989.

The results of this study are contained in the following four volumes, which are submitted in accordance with the data requirements of Contract NAS8-28989.

Volume I	Program Summary
Volume II	Engine Design Characteristics
Volume III, Part 1	Preliminary Interface Control Document
Volume III, Part 2	Operational and Flight Support Plan
Volume IV	Development Plans and Program Costs

This program was initiated in the middle of February 1973, with the technical effort being completed in seven months and the delivery of the final report on 15 December 1973. The study effort was conducted under the direction of the George C. Marshall Space Flight Center Science and Engineering organization with Mr. Frederick W. Braam as Contracting Officer's Representative. This effort was carried out by Pratt & Whitney Aircraft at their Florida Research and Development Center under the direction of Mr. J. P. B. Cuffe, Study Manager.

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SECTION A
INTRODUCTION

1. SCOPE

The purpose of this preliminary Interface Control Document (ICD) is to define the preliminary engine/tug interface requirements for the Category I engine and three baseline engines selected for study during this program. The group of three baseline engines selected for conceptual design definition, and the Category I engine are defined in the following subsections.

1.1 Engine No. 1 (Derivative IIA)

Engine No. 1 (Derivative IIA) is the baseline RL10A-3-3 engine modified to give desired Space Tug operating characteristics, including operation with two-phase propellants, and a two-position nozzle. The engine has the following modifications and operating modes:

a. Two-position nozzle, with recontoured primary section

b. Reoptimized injector

c. Tank head idle mode

d. Low thrust capability (defined as the lowest powered stable operating level achievable without significant design impacts)

e. Operation with two-phase propellants at both full and reduced thrust, with saturated propellants in the vehicle tanks and with no tank pressurization system

f. Capability for autogenous pressurization, that may be required on very long burn planetary missions.

The Derivative IIA engine will produce a nominal vacuum thrust of 15,000 lb at a specific impulse of 459.2 sec when operating at the design mixture ratio of 6.0 and the nominal chamber pressure of 400 psia. Engine operation at low (maneuver) thrust will be at 25% of full thrust. The engine has an installed length of 70 in. With the retractable nozzle in the extended position, the overall expansion ratio is 262:1.

1.2 Engine No. 2 (Derivative IIB)

Engine No. 2 (Derivative IIB) is the baseline RL10A-3-3 engine modified to give desired Space Tug operating characteristics, including operation in the pumped idle mode, with a two-position nozzle. The engine has the following modifications and operating modes:

a. Two-position nozzle, with recontoured primary section
b. Reoptimized injector
c. Tank head idle mode
d. Pumped idle mode with saturated propellants in vehicle tanks
e. Bootstrap autogenous pressurization.

The Derivative IIB engine will produce a nominal vacuum thrust of 15,000 lb at a specific impulse of 459.2 sec when operating at the design mixture ratio of 6.0 and the nominal chamber pressure of 400 psia. Engine operation at low thrust, in pumped idle mode, will be at 25% of full thrust. The engine has an installed length of 70 in. With the retractable nozzle in the extended position, the overall expansion ratio is 262:1.

1.3 Engine No. 3 (Category IV)

Engine No. 3 (Category IV), the RL10 Extension, uses the expander cycle and much of the RL10 technology, but it is a "clean sheet" design for maximum performance in the full capability Space Tug. The engine has a two-position nozzle, and is interchangeable with the RL10 Derivative IIA engine, having the same operating modes and propellant inlet interfaces.

The Category IV engine produces a nominal vacuum thrust of 15,000 lb at a specific impulse of 470.0 sec when operating at the design mixture ratio of 6.0 with a nominal chamber pressure of 915 psia. Maneuver thrust is 25% of full thrust. The installed engine length is 57 in. The overall nozzle expansion ratio (two-position nozzle extended) is 401:1.

1.4 Category I Engine

The Category I engine is the existing RL10A-3-3 engine with minimum modifications to requalify for operation under Space Tug conditions. The engine differs from the RL10A-3-3 as follows:

a. Nominal mixture ratio increased to 6.0 from 5.0

b. Reduced pump thermal conditioning losses by incorporation of trickle cooldown

c. Reduced NPSH requirements

d. Autogenous hydrogen tank pressurization

e. Increased life

The Category I engine will produce a nominal vacuum thrust of 15,000 lb and a specific impulse of 438 sec at the nominal operating conditions for mixture ratio and chamber pressure of 6.0 and 400 psia, respectively. The engine has a fixed position nozzle with an expansion ratio of 57:1 and an installed length of 70.1 in.

1.5 Test Capabilities

All the engines will be tested at the Pratt & Whitney Aircraft Florida Research and Development Center (FRDC) with a truncated two-position nozzle installed, where applicable, including nozzle actuation system, coolant supply and primary/secondary nozzle seal.

1.6 Terminology

Terminology used in this document is presented below:

a. Autogenous Pressurization - Any mode of operation in which the engine provides all of the vehicle tank pressurization gas required to sustain engine operation.

b. Bootstrap Autogenous Pressurization - Mode of operation in which the engine starts with saturated propellants in the vehicle tanks and provides the prepressurization required to be able to operate at full thrust.

c. Cooldown - Thermal conditioning of the engine cryogenic components, particularly the pumps.

d. Deceleration - Decreasing thrust from one power level to a lower level.

e. Full Thrust - Normal maximum thrust level for which the engine is designed and rated.

f. Maneuvering Thrust - Intermediate thrust level for medium ΔV requirements.

g. Normal Shutdown - Cessation of engine operation upon command.

h. Pumped Idle - Intermediate thrust level operation with turbopump rotating and saturated propellants in vehicle tanks for medium ΔV requirements. Provides hydrogen and oxygen bleed gases for bootstrap autogenous pressurization.

i. Steady-State Thrust - Operation at any of the three modes (tank head idle, maneuvering thrust, full thrust) in which engine thrust is essentially constant except for minor variations produced by changes in engine inlet conditions, tank pressurizing flowrates, etc.

j. Tank Head Idle - Pressure fed mode of operation (nonrotating turbopump) used for thermal conditioning of cryogenic components, and for producing low ΔV's for propellant settling and low thrust maneuvering.

1.7 Abbreviations and Symbols

Abbreviations and symbols used are presented below:

Item	Definition
amp	Amperes
CCW	Counterclockwise

Item	Definition
cm	Centimeter
db	Decibel
dia	Diameter
ϵ	Nozzle expansion ratio
ERP	Engine Reference Plane
EXT	Extended
F	Fahrenheit
ft	Feet
g	Gravitational constant
GH_2	Gaseous hydrogen
GMRV	Ground Mixture Ratio Valve
GN_2	Gaseous nitrogen
GO_2	Gaseous oxygen
GOX	Gaseous oxygen
He	Helium
hr	Hour
Hz	Hertz
I	Moment of Inertia
ID	Inside Diameter
in.	Inch(es)
JSC	Johnson Space Center
L	Length
lb	Pound(s)
LH_2	Liquid hydrogen
LO_2	Liquid oxygen
LSI	Low speed inducer

Item	Definition
max	Maximum
MFSOV	Main fuel shutoff valve
min	Minimum, minutes
MR	Mixture ratio
MSFC	Marshall Space Flight Center
mv dc	Millivolts, direct current
N/A	Not applicable
No.	Number
NPSH	Net positive suction head
NPSP	Net positive suction pressure
P	Pressure
PI	Pumped idle
psia	Pounds per square in., absolute
psig	Pounds per square in., gauge
PU	Propellant Utilization
R	Rankine, radius
rad	Radians
ref	Reference
rpm	Revolutions per minute
RTC	Retracted
sec	Second(s)
SOV	Shutoff Valve
T	Temperature
TBD	To be determined
THD	Thread
THI	Tank head idle

Item	Definition
V	Velocity
vac	Vacuum
vdc	Volts, direct current

SECTION B
MECHANICAL INTERFACE CONNECTIONS

1. GENERAL

1.1 Mechanical Connections

The Category I, Derivative IIA and IIB, and Category IV engines are designed for maximum interchangeability for ease of vehicle system integration. The mechanical connections between the engine and vehicle consist of the gimbal thrust mount and actuator attachment points, propellant inlets, pneumatic and electrical supply connections, and tank pressurization flow supply points. Mechanical interfaces for the four engines are shown in the installation drawings, figures B-1 through B-4. A dimensional comparison of the four engines is shown in table B-1. Figure B-5 provides dimensional references.

1.1.1 Gimbal Thrust Mount and Actuator Attachment

The gimbal thrust mount is a mechanical connection at the forward end of the engine gimbal. Thrust axis alignment provisions are included with each engine. Two attachment points for the gimbal actuators are also provided. The attachment points and the engine gimbal are designed for the degrees gimbaling and accelerations as shown in Section G.

1.1.2 Propellant Inlets

1.1.2.1 Inlet Diameters

The propellant inlet connections are made at the fuel and oxidizer inlet shutoff valves, with these interfaces located slightly below the gimbal interface. The inlet diameters of the Category I and Derivative IIB engines are the same as those of the RL10A-3-3 engine. The Derivative IIA and Category IV engines have increased pump inlet diameters for two-phase pumping capability. The estimated inlet diameters for the fuel and oxidizer inlet valves are shown in table B-2. Inlet line installation information and engine inlet dimensions are shown in figures B-6 through B-9.

1.1.2.2 Inlet Duct Straight Section

The inlet duct sections to the four engines should be configured to provide velocity and pressure profiles that do not exceed flat profiles by ±5%.

1.1.3 Pneumatic Connections

A single helium supply connection is provided on the electrical/pneumatic interface panel shown in figure B-10 and is located as previously shown in figures B-1 through B-4.

1.1.4 Tank Pressurization Connections

The hydrogen and oxygen tank pressurant supply connections are located at the forward end of the engine as previously shown in figures B-1 through B-4.

Table B-1. Dimensional Comparisons of Baseline Engines

Dimension	Description	Category I	Derivative IIA	Derivative IIB	Category IV
A	Y Axis to Fuel Inlet	11.750	11.750	11.750	11.750
A1	Z Axis to Fuel Inlet	0.0	0.0	0.0	0.0
B	Radius to Actuator Attach	10.172	10.172	10.172	10.172
C	Z Axis to Oxidizer Inlet	8.128	8.128	8.128	8.128
D	Y Axis to Oxidizer Inlet	9.419	9.419	9.419	9.419
E	ERP to Oxidizer Inlet	9.603	6.343	9.603	6.343
F	ERP to Fuel Inlet	8.738	7.058	8.738	7.058
G	Interface Diameter	2.876	2.876	2.876	2.876
H	Interface Height	0.240	0.240	0.240	0.240
J	ERP to Gimbal Plane	1.500	1.500	1.500	1.500
K	ERP to Actuator Attachment Point	32.874	32.874	32.874	32.874
L	Engine Length (EXT)	70.1	127.0	127.0	114
	(RTC)	N/A	70.1	70.1	57
M	Exit Diameter	39.54	79.6	79.6	66.2

All Dimensions in inches.

Table B-2. Engine Inlet Diameters

Engine	Oxidizer, in.	Fuel, in.
Category I	1.920	2.156
Derivative IIA	4.60	3.20
Derivative IIB	1.920	2.156
Category IV	4.60	3.20

1.1.5 Electrical Connections

Electrical connections to the engine will be provided by the use of connectors shown in figure B-10 at locations defined earlier in figures B-1 through B-4.

2. ACCESSORIES CHARACTERISTICS

2.1 Accessory Drive

The Category I and Derivative IIB engine accessory drive pads are located on the aft ends of their oxidizer pumps, and are identical to that of the RL10A-3-3 engine. The Derivative IIA and Category IV engines are not equipped with accessory drives.

2.1.1 Drive Pad Data

Table B-3 presents estimated drive pad data for the Category I and Derivative IIB engines.

Table B-3. Drive Pad Data

	Category I	Derivative IIB
Drive Pad Type	AND 20,000 Type X-A	AND 20,000 Type X-A
Speed Nominal, rpm	12,100	11,130
Acceleration Max, rpm/sec	38,000	9,900
Max Transient Speed, rpm	14,100	11,200
Max Continuous Torque, in.-lb	20	20
Max Static Torque, in.-lb	20	20
Direction of Rotation	CCW	CCW
Temperature at Pad Face, °R	Approx 80	80
Designed Accessory Load (1 g), lb	20	20
Designed Overhang Moment (1 g), in.-lb	90	90

2.1.2 Accessory Drive Leakage

The accessory drives of the Category I and Derivative IIB engines will not accept leakage of material from the vehicle-supplied accessory that will:

a. Be solid at or above 40°R

b. Enter the interface cavity at a flowrate sufficient to raise the interface cavity pressure to 18 psia (at vacuum ambient)

c. Otherwise introduce a hazardous condition.

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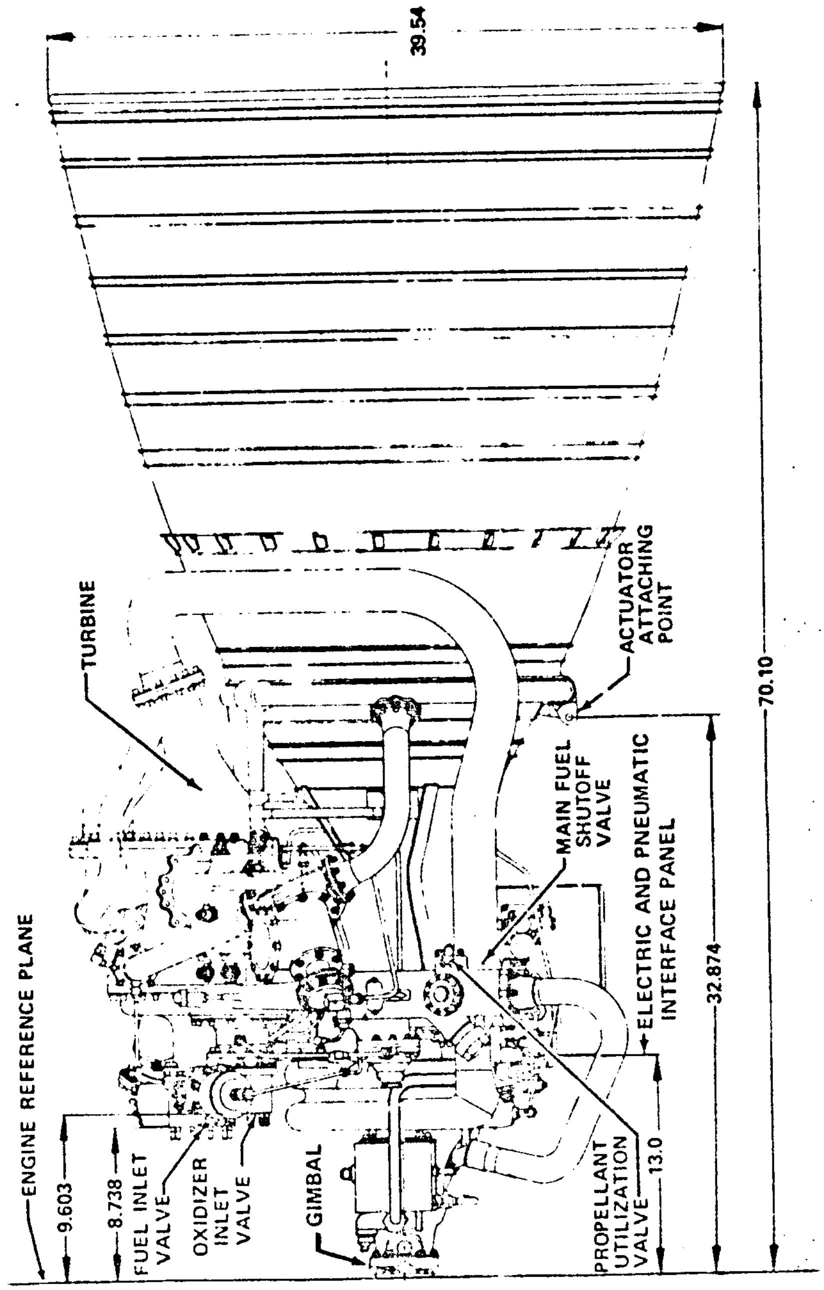

Figure B-1. RL10 Category I Installation Drawing (Sheet 1)

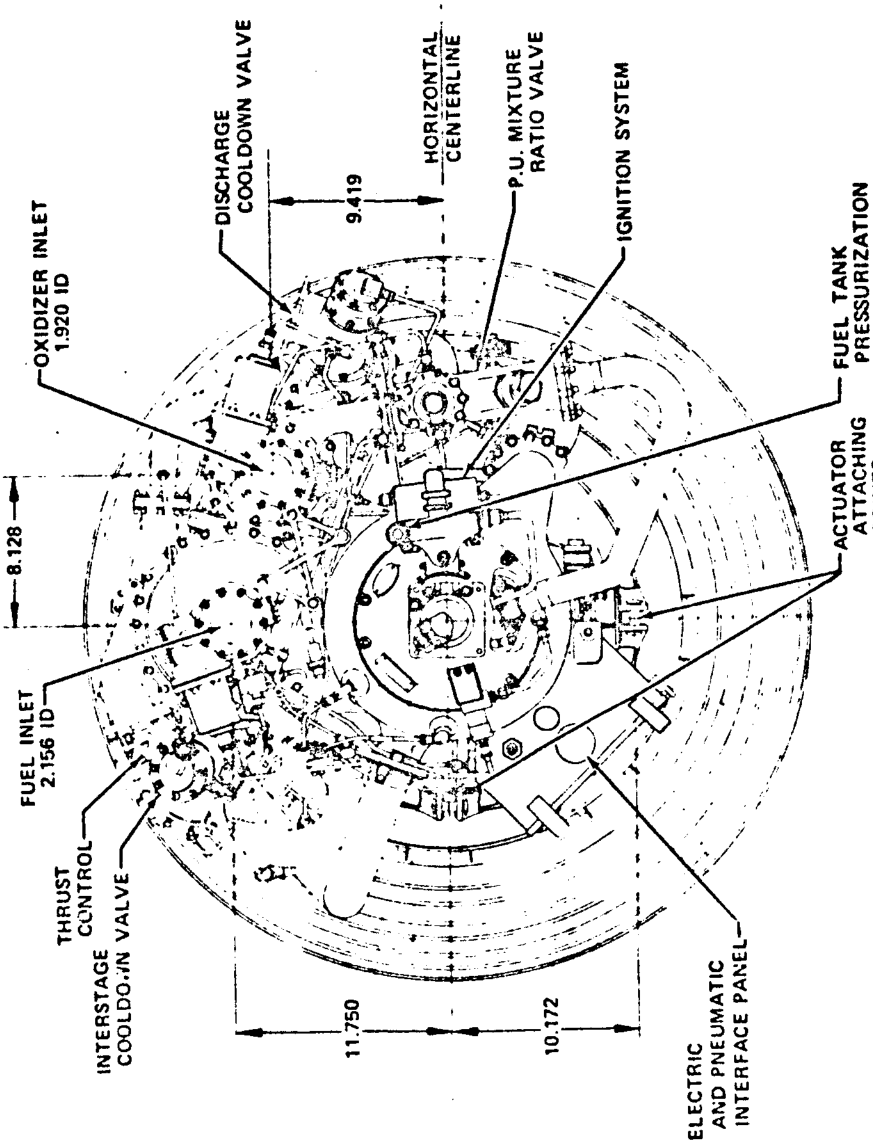

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Figure B-1. RL10 Category I Installation Drawing (Sheet 2)

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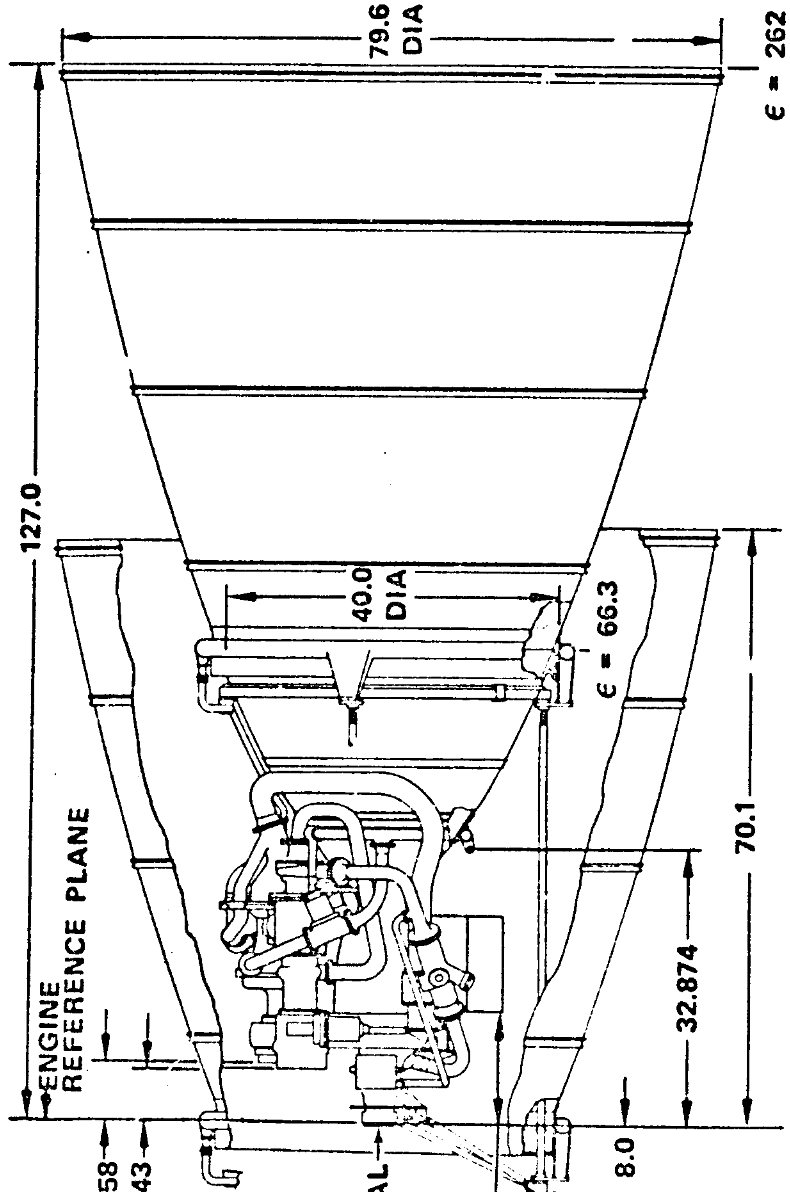

Figure B-2. Derivative IIA Engine Installation Drawing (Sheet 1)

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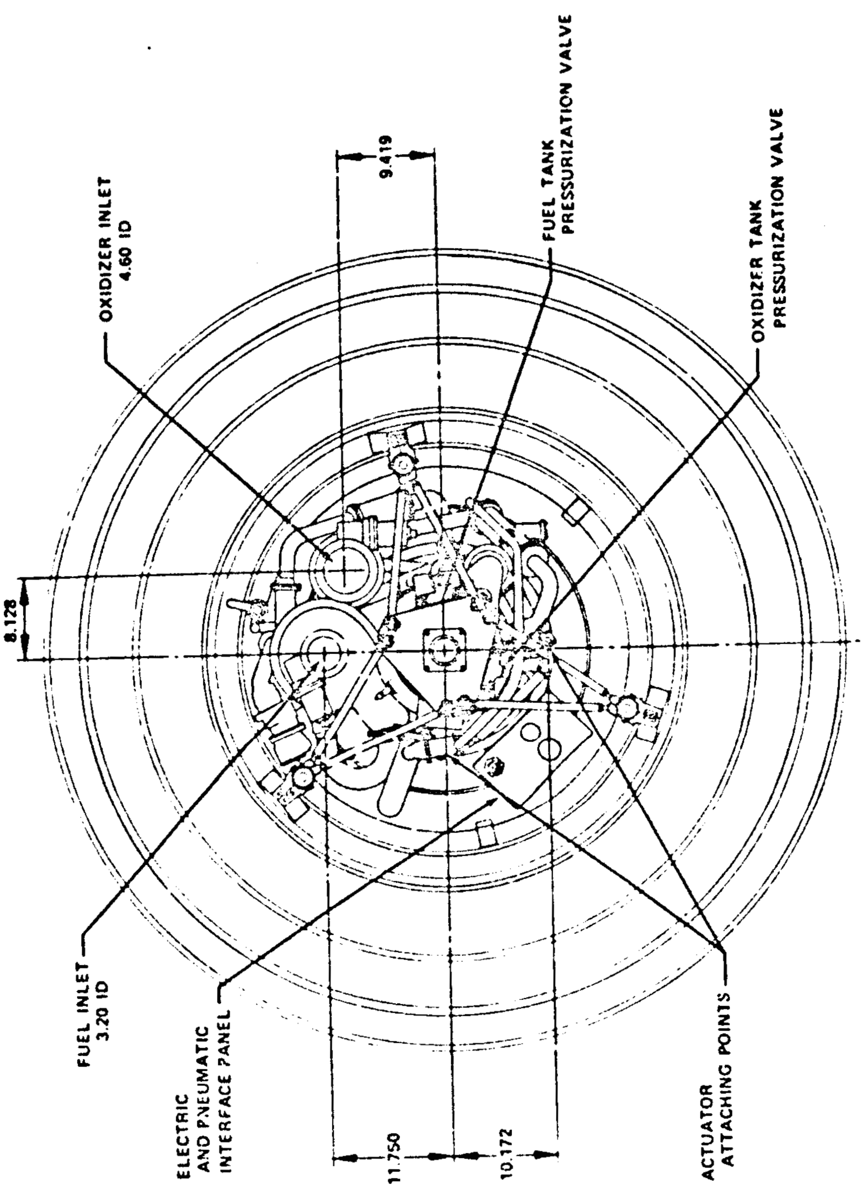

Figure B-2. Derivative IIA Engine Installation Drawing (Sheet 2)

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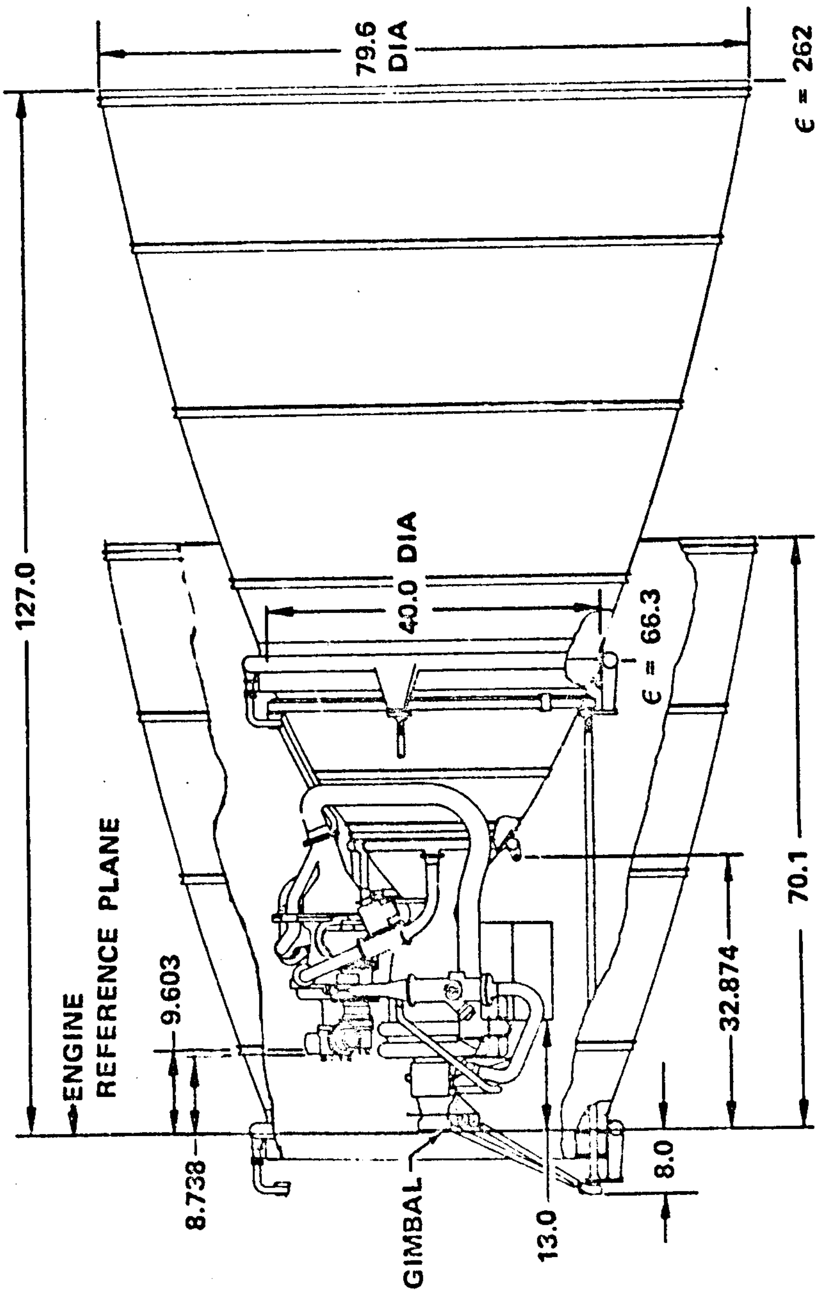

Figure B-3. Derivative IIB Engine Installation Drawing (Sheet 1)

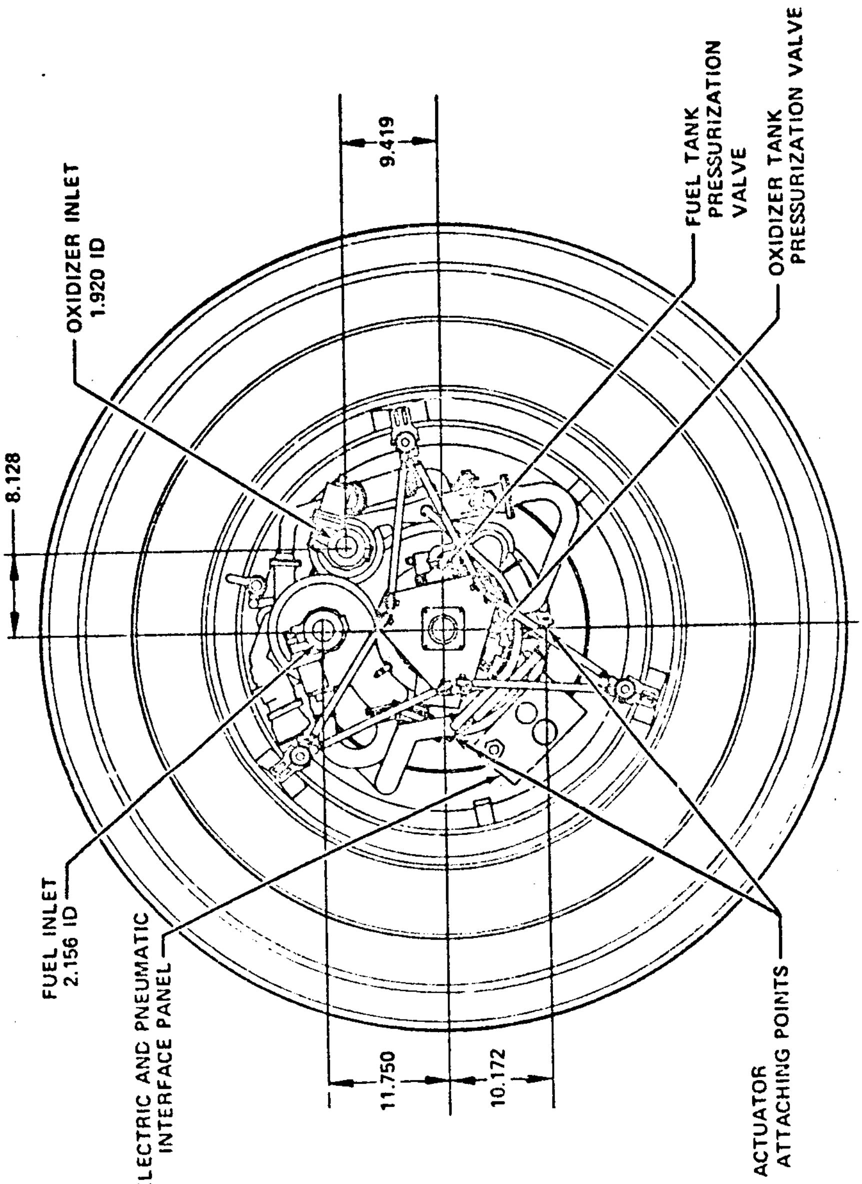

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Figure 5-3. Derivative IIB Engine Installation Drawing (Sheet 2)

FD 72042A

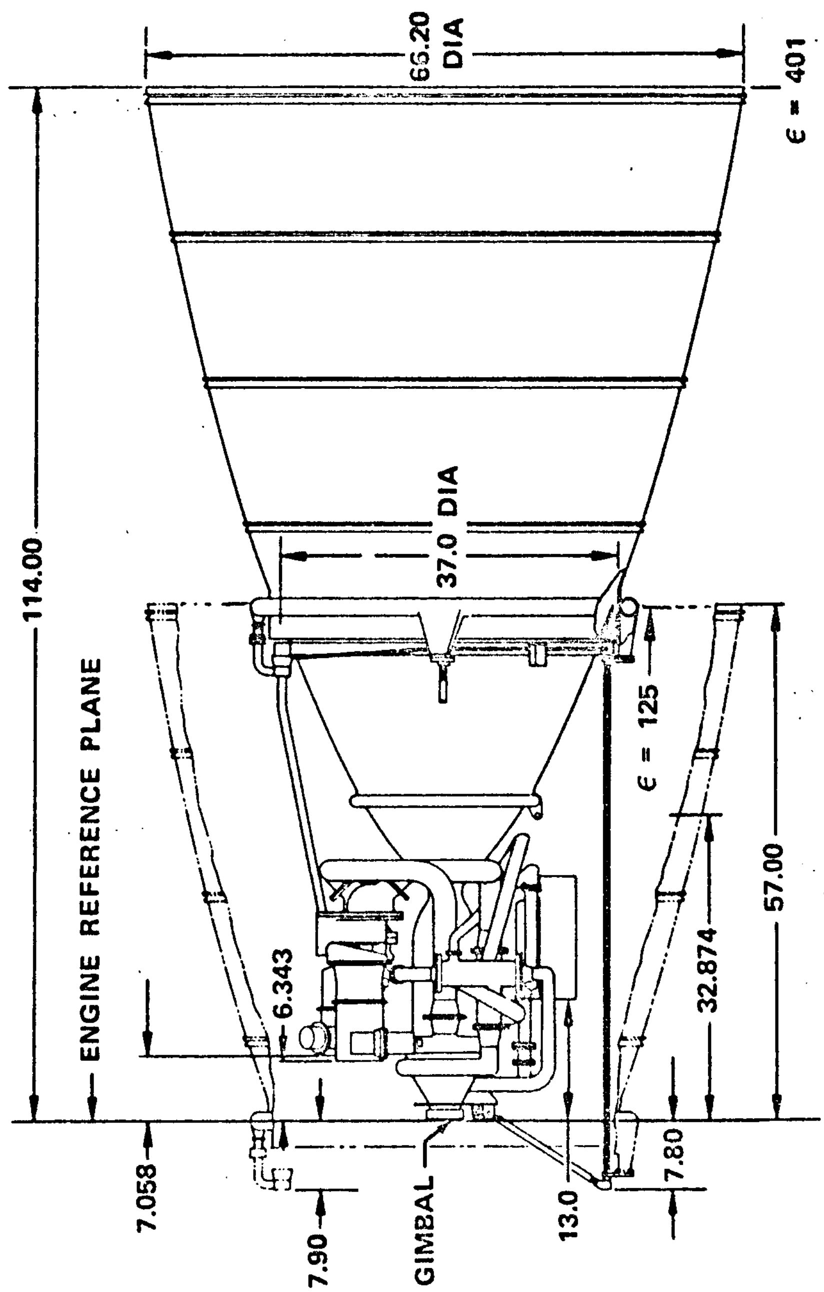

Figure B-4. Category IV Engine Installation Drawing (Sheet 1)

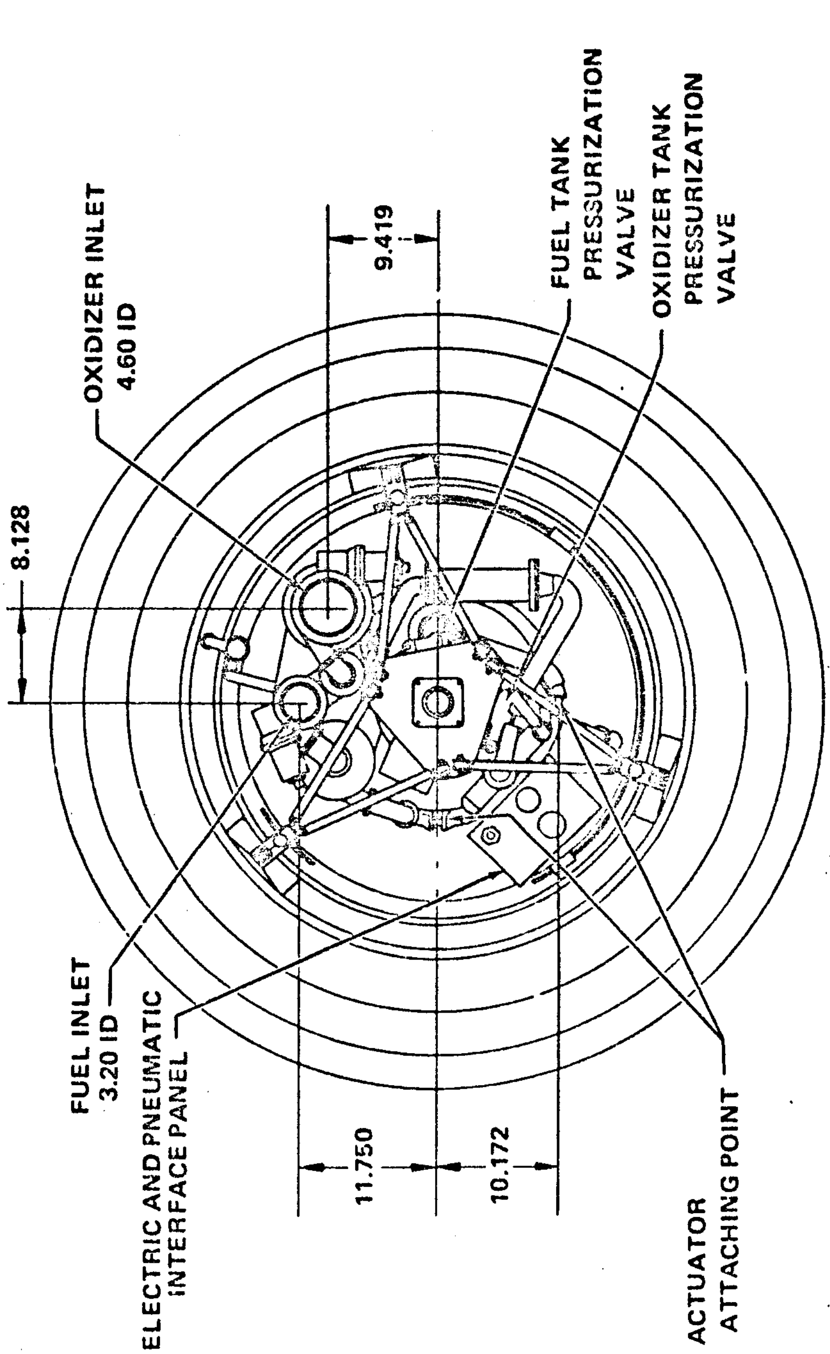

Figure B-4. Category IV Engine Installation Drawing (Sheet 2)

FD 68853

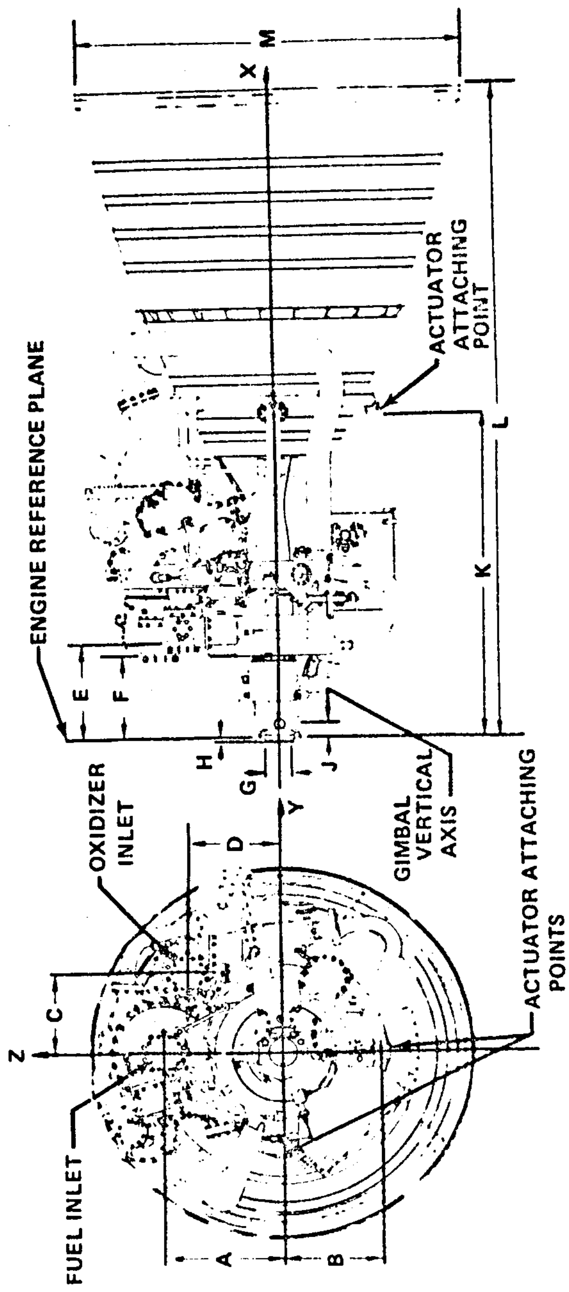

Figure B-5. RL10 Outline Installation Drawing

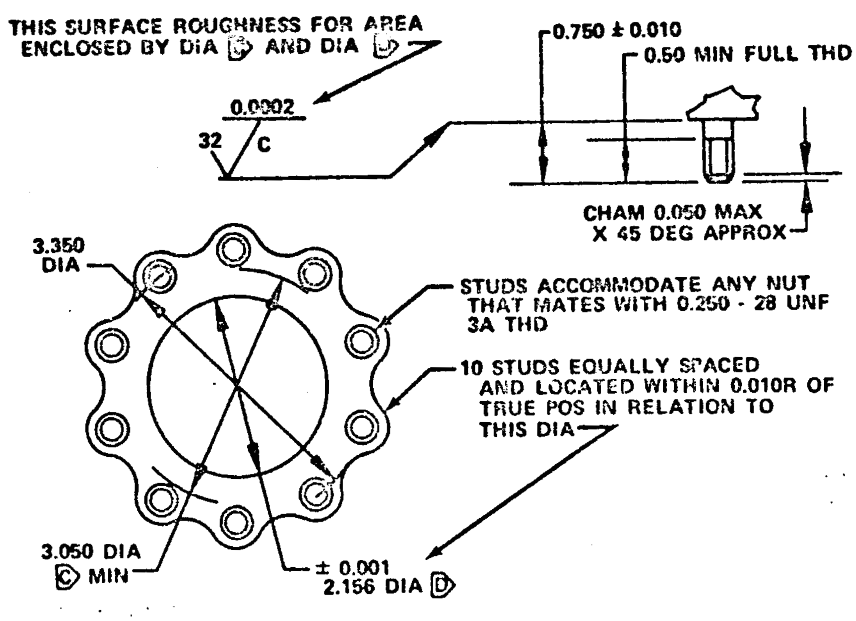

Figure B-6. Engine Fuel Inlet, Category I and Derivative IIB Engines FD 66800

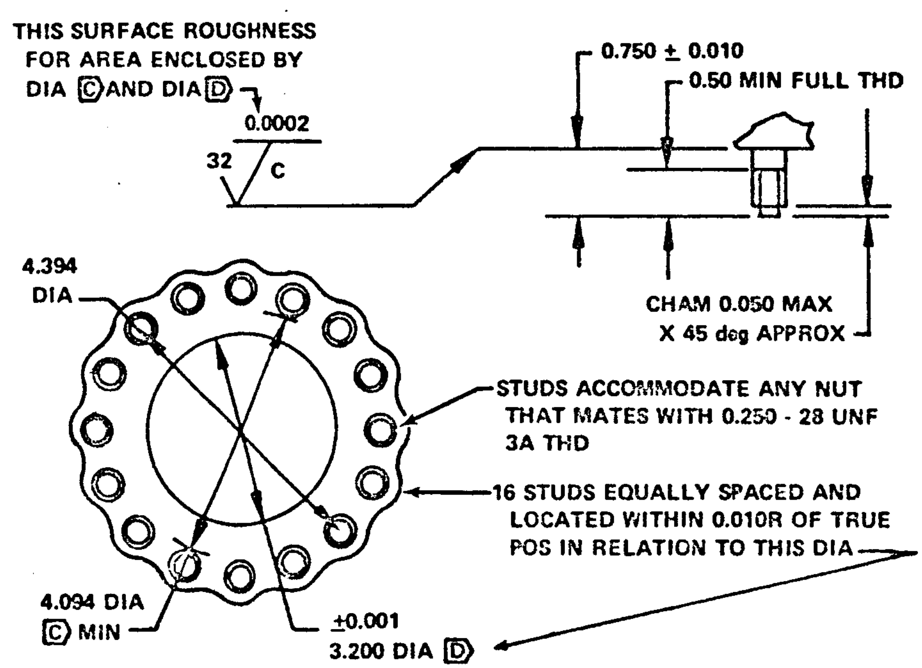

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Figure B-7. Engine Fuel Inlet, Derivative IIA and Category IV Engines

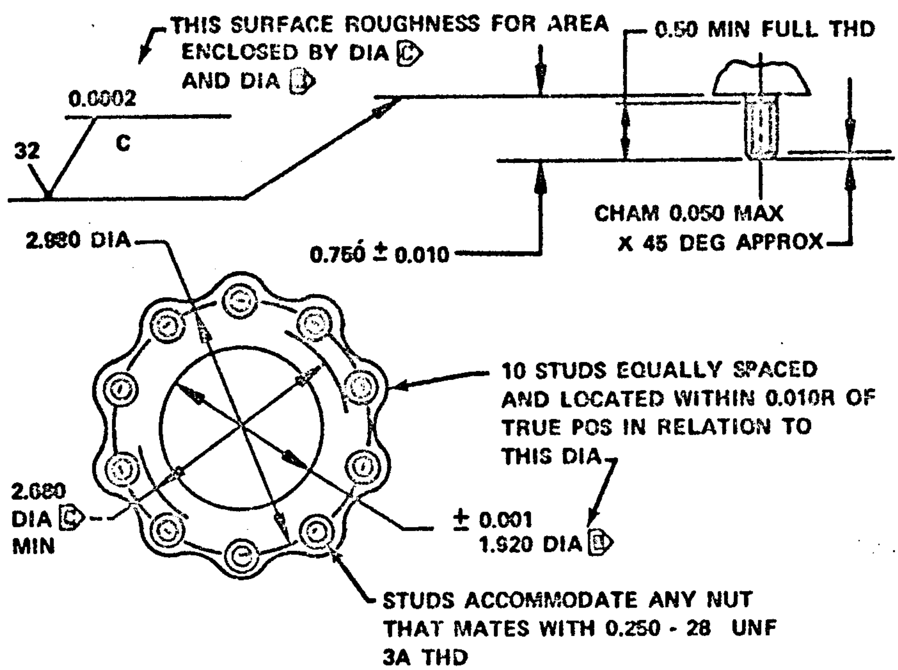

Figure B-8. Engine Oxidizer Inlet, Category I and Derivative IIB Engine FD 66801

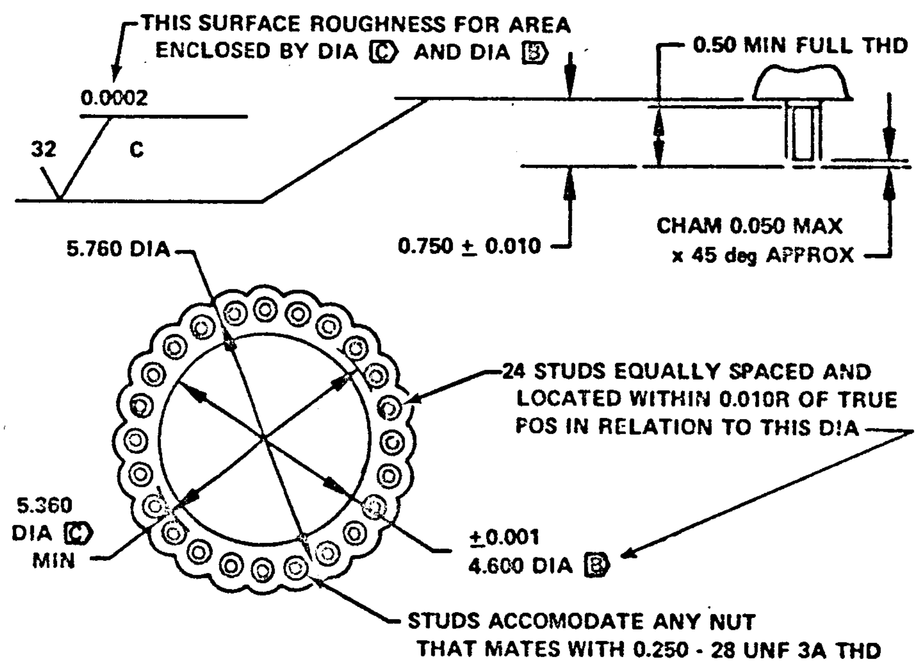

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Figure B-9. Engine Oxidizer Inlet, Derivative IIA and Category IV Engines

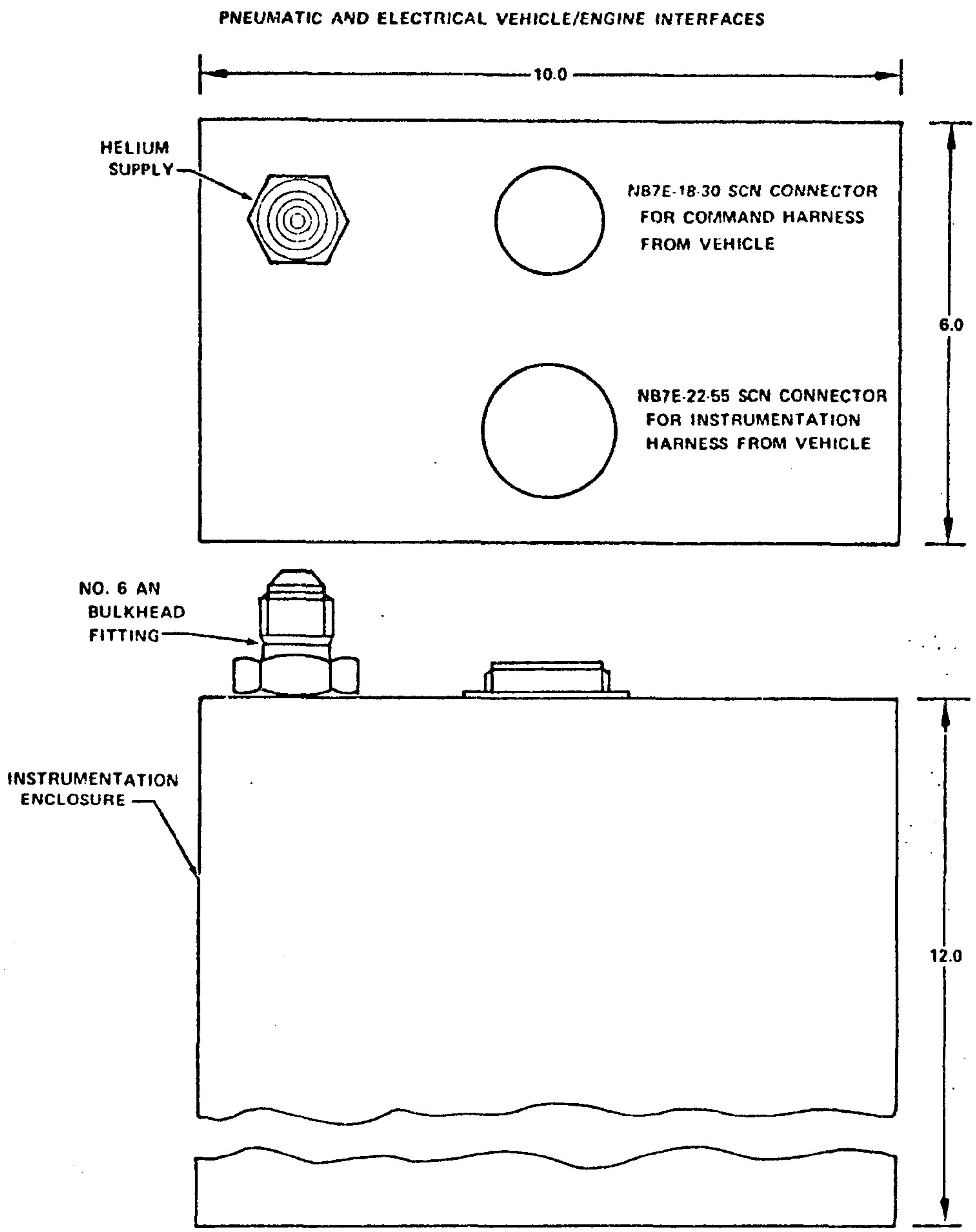

Figure B-10. Pneumatic and Electrical Vehicle/ Engine Interfaces FD 76011

SECTION C
ENGINE OPERATING CHARACTERISTICS

1. GENERAL

The Category I, Derivatives IIA and IIB, and Category IV engines will start, operate and shut down as indicated in the following subsections at altitudes (pressure levels) at or above 200,000 ft when the retractable nozzle (for applicable engines) is in the extended position and the proper interface operating conditions are supplied.

The RL10 derivative engines use the expander cycle to drive the fuel and oxidizer pumps. In this closed cycle, all propellants (except for normal ventage and vehicle tank pressurants) are combusted in the thrust chamber to provide useful thrust. Fuel is used to regeneratively cool the thrust chamber as well as provide turbopump power. High pressure hydrogen fuel supplied by the fuel pump enters the chamber cooling jacket as a liquid and it is discharged as a superheated vapor. This warm gaseous hydrogen is then expanded through the turbine(s) to drive the fuel and oxidizer pumps to produce the required system pressures. Hydrogen flow from the turbine(s) is injected into the thrust chamber combustor where it is combined and burned with high pressure oxidizer delivered directly from the oxidizer pump. The hot combustion products are then expanded in the thrust chamber nozzle to provide engine thrust.

Operation of the RL10 Derivative engines is dependent on vehicle-supplied electrical power and helium. A summary of engine electrical sequence requirements is provided in table C-1 for the Category I engine and for the Derivative IIA and IIB, and Category IV engines. Electrical power demand is presented in Section D.

Table C-1. Engine Electrical Sequence Requirements

Category I Engine				
	Prestart Solenoid Valve	Start Solenoid Valve	Oxidizer Bypass and Fuel Pump Interstage Bleed Solenoid Valve	Ignition System
Prestart (Trickle Cooldown)	X		X	
Start	X	X		X
Full Thrust	X	X		

Table C-1. Engine Electrical Sequence Requirements (Continued)

Derivative IIA and IIB and Category IV Engines

	Start Solenoid Valve	Bypass Solenoid Valve No. 1	Bypass Solenoid Valve No. 2	Fuel SOV Solenoid Valve	Ignition System	Extendible Nozzle Drive Motors
Prestart						X
Tank Head Idle	X	X			X	
Maneuver Thrust (pumped idle)	X		X	X	X	
Full Thrust	X			X		

X - Engine function requires vehicle-supplied power

1.1 Engine Operation

1.1.1 Category I Engine

Operation of the Category I engine is detailed in the propellant flow schematic shown in figure C-1 and in the sequence of operation chart presented in figure C-2.

Conditioning of the cryogenic engine components is initiated when vehicle-supplied electrical power energizes both the prestart and oxidizer bypass and fuel interstage bleed solenoid valves. Energizing the prestart solenoid valve allows high pressure vehicle-supplied helium to open the fuel and oxidizer inlet shutoff valves and to close down the port area in the fuel pump discharge cooldown and pressure relief valve to the area required for fuel pump cooldown. Energizing the oxidizer bypass and fuel interstage bleed solenoid valve permits vehicle supplied helium to close the oxidizer flow control bypass and the fuel pump interstage valve bleed area. Hydrogen cooldown flow passes through the fuel pump and out through the fuel pump discharge cooldown valve where it is dumped overboard through the fuel vent system. The hydrogen flowrate is set by the port area of the discharge cooldown valve. Oxygen cooldown flow passes through the oxidizer pump, through the oxidizer flow control valve and into the propellant injector where it is dumped overboard through the injector and thrust chamber. The oxygen flowrate is set by the oxidizer flow control valve area.

After engine thermal conditioning has been completed, electrical power is supplied by the vehicle to energize the ignition system and start solenoid. Electrical power is removed from the oxidizer bypass and fuel pump interstage bleed solenoid valve at this time thereby venting high pressure helium from the oxidizer flow control bypass and the fuel pump interstage bleed valve. With helium pressure removed, the oxidizer bypass opens to its maximum area to provide increased oxidizer flow and mixture ratio necessary for satisfactory ignition of the propellants in the igniter and engine combustion chamber. The fuel pump interstage bleed valve also opens to its maximum area to provide an overboard bleed that increases pump flow to assure stall-free pump operation during the engine acceleration. The fuel pump discharge cooldown and pressure relief valve fully closes and the main fuel shutoff valve fully opens upon application of helium pressure from the start solenoid valve. Opening the main fuel shutoff valve allows fuel to enter the chamber and ignition to take place upon achieving a combustible level of mixture ratio and unlit thrust chamber pressure.

As the turbopump accelerates, fuel pump discharge pressure closes the fuel pump interstage bleed valve. The oxidizer flow control valve main flow area opens during engine acceleration to provide increased oxygen to regulate chamber mixture ratio. Valve actuation is achieved by using oxidizer pump differential pressure. The thrust control, which is normally spring-loaded closed, opens near the end of the acceleration, when chamber pressure reaches a preset level, and bypasses fuel flow around the turbine to minimize thrust overshoot.

During full thrust operation the oxidizer flow control sets the engine mixture ratio. It incorporates provisions for ground adjustment of the main oxidizer flow area to set a desired nominal mixture ratio and for inflight adjustments to the area to vary the operating mixture ratio for vehicle propellant utilization purposes. The thrust control senses combustion chamber pressure and it positions a pneumatic servo which controls turbine bypass area to maintain a preset chamber pressure level as the engine inlet conditions and mixture ratio are varied. The thrust control incorporates a provision for ground adjustment of the nominal chamber pressure level. Gaseous hydrogen for fuel tank pressurization can be bled from the engine during full thrust operation. The fuel tank pressurization valve opens during the start transient as fuel injector pressure nears full thrust level and the valve remains open throughout steady-state engine operation.

Shutdown is initiated by the simultaneous removal of the vehicle-supplied electrical power to the start and prestart solenoid valves. When the solenoid valves are de-energized, helium is vented from the engine valves, permitting them to return to their normal nonoperating positions. The oxidizer pump inlet, oxidizer flow control bypass, fuel pump inlet, and the main fuel shutoff valves close stopping the flow of propellants to the engine and providing a rapid cessation of the combustion. The fuel pump interstage bleed and fuel pump discharge cooldown and pressure relief valves open, venting trapped fuel overboard. The fuel tank pressurization valve and oxidizer flow control main area close as fuel and oxidizer pressures in the engine decay during pump deceleration. Relative timing of the valves is controlled such that a rapid, repeatable shutdown of the engine is accomplished.

1.2 Derivative IIA and IIB Engines

The Derivative IIA and IIB engines are capable of operation at tank head idle, maneuvering thrust (pumped idle) or full thrust power levels. With minor exceptions, operation of the two engines is identical. Definition of Derivative IIA and IIB engine operation is detailed in the propellant flow schematics shown in figures C-3 and C-4 and in the sequence of operation chart, figure C-5.

Following deployment of the Space Tug from the Orbiter cargo bay, electrical power from the vehicle is supplied to the two electric motors causing the movable portion of the nozzle to translate to its fully extended position.

The engine is started in the tank head idle (THI) mode, to operate as a pressure-fed device without the turbopumps rotating to settle propellants and thermally condition the engine. Start is initiated when electrical power from the vehicle energizes the start solenoid valve, which allows vehicle-supplied, high pressure helium to open the propellant inlet valves and close the fuel vent valve while also feeding helium to two other solenoid valves. At start the turbine bypass solenoid valve No. 1 is also energized to open the turbine bypass valve to its maximum area. Simultaneously with the opening of the start solenoid and turbine bypass valves, the torch igniter system is energized by vehicle-supplied power. Hydrogen enters the engine through the fuel pump, flows through the thrust chamber cooling jacket and then bypasses the turbine via the turbine bypass valve and the GO_2 heat exchanger, to flow out through the fuel injector and the Because the oxidizer flow control is closed, oxidizer is routed through the GO_2 heat exchanger, the GO_2 control valve, and is finally injected into the thrust chamber combustor as a superheated vapor where it is mixed with the fuel flow. Thrust chamber ignition occurs as soon as a combustible level of mixture ratio and unlit thrust chamber pressure is achieved. As the engine is chilled down, propellant flowrates increase because valve flow areas are held constant. The GO_2 heat exchanger ensures that no dangerous increase in mixture ratio occurs when the oxidizer pump is conditioned by preventing any phase change in the oxidizer injector. No active control system is required.

The transition from THI to maneuvering thrust (pumped idle) is initiated when vehicle electrical power energizes the fuel solenoid valve to open the main fuel shutoff valve, de-energizes the bypass solenoid valve No. 1 to close the turbine bypass valve, and energizes the turbine bypass solenoid valve No. 2. Since all the hydrogen goes through the turbine, a high initial turbine torque is generated. As the engine accelerates, fuel turbine inlet pressure is routed through the turbine bypass solenoid valve No. 2 to reopen the turbine bypass valve to the position required for maneuvering thrust (pumped idle). The oxidizer control valve (spring-loaded closed) is simultaneously opened by oxidizer pump discharge pressure to the area required for maneuver thrust (pumped idle). This pressure also closes the spring-loaded GO_2 control valve. The fuel and oxidizer tank pressurization valves, also spring-loaded closed, are opened by the increasing engine system pressures. The spring-loaded nozzle coolant valve flow area is also increased as fuel pump pressure builds up.

Steady-state operation of the engines during maneuver thrust (pumped idle) does not require an active control system. Preset control areas assure safe operating conditions during this operational mode. The Derivative IIB engine provides gaseous fuel and oxidizer for bootstrap autogenous tank prepresssurization prior to acceleration to full thrust.

The acceleration from maneuvering thrust (pumped idle) to full thrust begins when electrical power from the vehicle to the turbine bypass solenoid valve No. 2 is removed. This vents hydrogen from the turbine bypass valve actuator, allowing the turbine bypass valve to close. The resultant additional fuel flow through the turbine causes the engine to accelerate to full thrust, the rate of acceleration being determined by the rate at which the turbine bypass valve is allowed to close. Increasing oxidizer pump differential pressure opens the oxidizer flow control to its full thrust flow area to regulate chamber mixture ratio. The thrust control valve is spring-loaded closed, but is opened when the thrust chamber pressure reaches approximately 360 psia permitting fuel flow to bypass the turbine to minimize thrust overshoot.

During full thrust operation, the oxidizer flow control sets the engine mixture ratio. It incorporates provisions for ground adjustment of the main oxidizer flow area to set a desired nominal mixture ratio (the GMRV) and for attaching an actuator for inflight adjustments to the area to vary the operating mixture ratio for vehicle propellant utilization. The thrust control senses combustion chamber pressure and positions a pneumatic servo, which controls turbine bypass area to maintain a preset chamber pressure level as the engine inlet conditions and mixture ratio are varied. The thrust control incorporates a provision for ground adjustment of the nominal chamber pressure level.

Deceleration of the Derivative IIA and IIB engines is initiated by the removal and application of electrical vehicle power from and to the appropriate engine solenoid valves. The engines can be decelerated from full thrust to maneuvering thrust (pumped idle) or to tank head idle. A deceleration from full thrust to tank head idle must pass through the maneuvering thrust (pumped idle) level. A minimum period of two seconds must elapse between descending power level commands.

Shutdown of the engines on vehicle command can be accomplished directly from full thrust, maneuvering thrust (pumped idle), or tank head idle. For the purpose of describing operation of the engines, the sequencing for a shutdown where the engine is decelerated from full thrust to maneuvering thrust (pumped idle) and is then shut down is presented below. The valve sequencing is as previously shown in figure C-5.

The deceleration from full thrust to maneuvering thrust (pumped idle) is initiated by supplying vehicle electrical power to the turbine bypass solenoid valve No. 2. This allows fuel turbine inlet pressure to open the turbine bypass valve to the required area for maneuvering thrust (pumped idle). The resultant decrease in turbine flow reduces turbine power, causing the engine to decelerate. As the oxidizer pump discharge pressure decays, the spring-loaded oxidizer flow control closes to its setting for maneuver thrust. The lower turbine inlet temperature at full thrust causes a slight thrust undershoot before conditions in maneuver thrust are stabilized. After the engine has decelerated to the maneuvering thrust (pumped idle) level, shutdown is initiated by removal of vehicle electrical power from the start solenoid, the fuel SOV solenoid and the turbine bypass solenoid No. 2 valves. Venting of helium from the start solenoid valve also vents the helium from the other two helium solenoid valves, the two inlet shutoff valves, and the fuel vent valve. As a result, the inlet shutoff valves close and the fuel vent valve opens to vent trapped fuel from the engine. The main fuel shutoff valve closes rapidly to cut off fuel flow to the injector. This abruptly terminates combustion in the thrust chamber, giving a smooth and repeatable cutoff. The spring-loaded oxidizer valves return to their normal positions as oxidizer pressure decreases. Oxygen downstream of the engine inlet shutoff valve vents out through the main chamber injector via the GO_2 control valve.

1.3 Category IV Engine

The operating mode capabilities as well as the operation of the Category IV engine are essentially identical to that described for the Derivative IIA and IIB engines in the prior subsection 1.2. In the Category IV engine, the functions of three of the valves of the Derivative IIA and IIB engines are incorporated within a single housing. The Category IV engine main fuel control replaces the fuel vent, thrust control and turbine bypass valves of the other engines. Definition of the Category IV engine operation is presented in the propellant flow schematic, figure C-6, and in the seqeuence of operation chart, figure C-7. For details of the operation of the Category IV engine, refer to the description provided in subsection 1.2 for the Derivative IIA and IIB engines.

2. STEADY-STATE OPERATING CHARACTERISTICS

Steady-state operating characteristics for the RL10 derivative engines are shown in table C-2 and in the cycle propellant flow schematics presented in figures C-8 through C-11. Off-design specific impulse and thrust characteristics for the engines at full thrust are presented in figures C-12 through C-14, and figures C-15 through C-17, respectively. The effects of changes in propellant inlet pressures and fuel tank pressurant flowrates on engine thrust, mixture ratio and vacuum specific impulse are shown in figures C-18 through C-32.

Table C-2. Engine Steady-State Design Point Operation

	Engine			
	Category I	Derivative IIA	Derivative IIB	Category IV
Full Thrust Operation				
Thrust (vac), lb	15,000+3%(1)	15,000+3%(1)	15,000+3%(1)	15,000+3%(1)
Mixture Ratio	6.0+3%(1)	6.0+3%(1)	6.0+3%(1)	6.0+3%(1)
Chamber Pressure, psia	400	400	400	915
Specific Impulse, sec	438+2.5(2)	459.2+2.8(2)	459.2+2.8(2)	470.0+2.8(2)
Required Inlet Condition				
Fuel	>14 ft NPSH	<40% vapor	>14 ft NPSH	<40% vapor
Oxidizer	>7.5 ft NPSH	<40% vapor	>7.5 ft NPSH	<40% vapor
Idle Mode Operation				
Maneuvering Thrust (Pumped Idle)				
Thrust (vac), lb	N/A	3,750	3,750	3,750
Mixture Ratio		6.0	6.0	6.0
Specific Impulse, sec		442.5	442.5	457.8
Tank Head Idle (With Liquid/Liquid Inlet Conditions)				
Thrust (vac), lb	N/A	157	157	73
Mixture Ratio		4.0	4.0	4.0
Specific Impulse, sec		387	387	385
Engine Life				
Firings/hr	≥190/5	≥190/5	≥190/5	300/10

(1) 3σ Variation. Includes effect of field replacement of components listed in Operations and Field Support Plan.
(2) Engine to Engine 3σ variations.

Warm hydrogen gas can be provided by the Category I engine and both warm hydrogen and oxygen gas can be provided by the Derivative IIA and IIB, and Category IV engines for use in vehicle tank pressurization . The estimated effects of varying pressurant flowrates on pressurant temperatures are shown in figures C-33 through C-41.

3. TRANSIENT OPERATING CHARACTERISTICS

3.1 Engine Start

3.1.1 Category I Engine

The Category I engine is designed to start and move to full thrust after engine thermal conditioning has been completed. The propellants in the vehicle tanks have to be settled and pressurized sufficiently to provide the engine with the NPSH levels required for full thrust operation.

Cooldown of the engine is initiated when vehicle-supplied electrical power energizes the engine solenoid valves. These solenoid valves permit vehicle-supplied high pressure helium to actuate the necessary valves to allow liquid hydrogen to pass through the fuel pump and then overboard through the fuel vent system. Similarly, liquid oxygen flows through the oxidizer pump and propellant injector and then overboard through the thrust chamber. Cooldown characteristics are provided in figures C-42 through C-47 for the oxidizer side, and in figures C-48 through C-52 for the fuel side. As an aid to the user, examples of the use of the cooldown curves are presented in table C-3.

After cooldown has been completed, vehicle-supplied electrical power to the engine solenoids causes the engine valves to be positioned for the acceleration and simultaneously energizes the ignition system. After ignition occurs in the thrust chamber combustor, the engine accelerates to full thrust with the engine valves being actuated as required during the acceleration by engine system pressures. The thrust and propellant flow characteristics for the start transient are shown in figures C-53 and C-54, respectively.

3.1.2 Derivative IIA, IIB and Category IV Engines

The Derivative IIA and IIB, and Category IV engines are designed for three-step start operation: start to tank head idle, acceleration from tank head idle to maneuvering thrust (pumped idle) and acceleration from maneuvering thrust (pumped idle) to full thrust. These engines must be started in this three-step sequence.

All three engines use the tank head idle (THI) mode of operation to settle propellants in the vehicle tanks and thermally condition the turbopumps prior to initiation of pumped operation. The engines can be started in THI with any combination of vapor, mixed phase or liquid propellants within the temperature-pressure limits shown in Section E, Engine Fluid Requirements. Thrust characteristics for the engines during tank head idle operation are presented in figures C-55 through C-57. After proper pump conditioning has been achieved, vehicle-supplied power to the engine solenoid valves initiates actuation of the engine control valves which permits the engine to accelerate to the maneuvering thrust (pumped idle) operating level (25% of full thrust). All three engines are capable of operating in the maneuvering thrust (pumped idle) mode with saturated propellants in the vehicle tanks. The Derivative IIB engine has a bootstrap autogenous pressurization capability by which the engine can prepressurize the vehicle tanks while at pumped idle prior to acceleration to full thrust. The Derivative IIA and Category IV engines are capable of acceleration to and operation at full thrust with saturated liquid propellants in the vehicle tanks. Acceleration characteristics from tank head idle to maneuvering thrust (pumped idle) and maneuvering thrust (pumped idle) to full thrust are shown in figures C-58 through C-65.

3.2 Engine Shutdown

3.2.1 Category I Engine

Shutdown is accomplished by removing the vehicle-supplied power from the engine solenoid valves. This causes the engine inlet shutoff valves and main fuel shutoff valve to close. At shutdown the fuel cooldown and bleed valves also open thereby permitting fuel trapped in the engine to be vented overboard. Relative valve timing is closely controlled to provide a rapid, repeatable shutdown. The Category I engine shutdown thrust characteristics are shown in figure C-66.

3.2.2 Derivative IIA, IIB and Category IV Engines

Deceleration and shutdown are initiated by vehicle-supplied power to the engine solenoid valves. The three engines may be shut down directly from full thrust or they can first be decelerated to maneuvering thrust (pumped idle) and then shut down. Shutdown from maneuvering thrust (pumped idle) can either be direct or the engine may be declerated to tank head idle before the shutdown is initiated. After a shutdown has been completed, all valves and control system components are in a position of readiness for the next engine firing. Estimated deceleration and shutdown characteristics for the Derivative IIA and IIB and Category IV engines are presented in figures C-67 and C-68.

Table C-3. Use of Cooldown Curves

Oxidizer pump housing temperature is expected to be 500°R; inlet conditions are 24 psia with NPSP of 8 psi; oxidizer flow control area is 0.05 $in.^2$

Case No. 1

Required oxidizer cooldown is 89 sec with 5.6 lb O_2 consumption (read from figure C-43).

Case No. 2

If oxidizer pump housing temperature was to be 350°R instead of the predicted 500°R, then:

a. Cooldown (350°R/.05 $in.^2$ valve area) requires 40 sec and 2.95 lb O_2 (read from figure C-43).

b. Flowrate at end of cooldown (+40 sec) = .97 lb/sec (read from figure C-47).

Therefore total O_2 used = 2.95 + .97 (89 -40) = 50.4 lb.

Case No. 3

If 5 sec overcooling of oxidizer pump is desired, then:

a. Flowrate at end of minimum cooldown of +89 sec (500°R/.05 $in.^2$ valve area) = .97 lb/sec (read from figure C-47).

b. Minimum consumption = 5.6 lb O_2 (read from figure C-43).

Therefore total O_2 used = 5.6 + (.97) (5) = 10.5 lb.

Fuel cooldown requirements are obtained in a manner similar to that shown for the oxidizer.

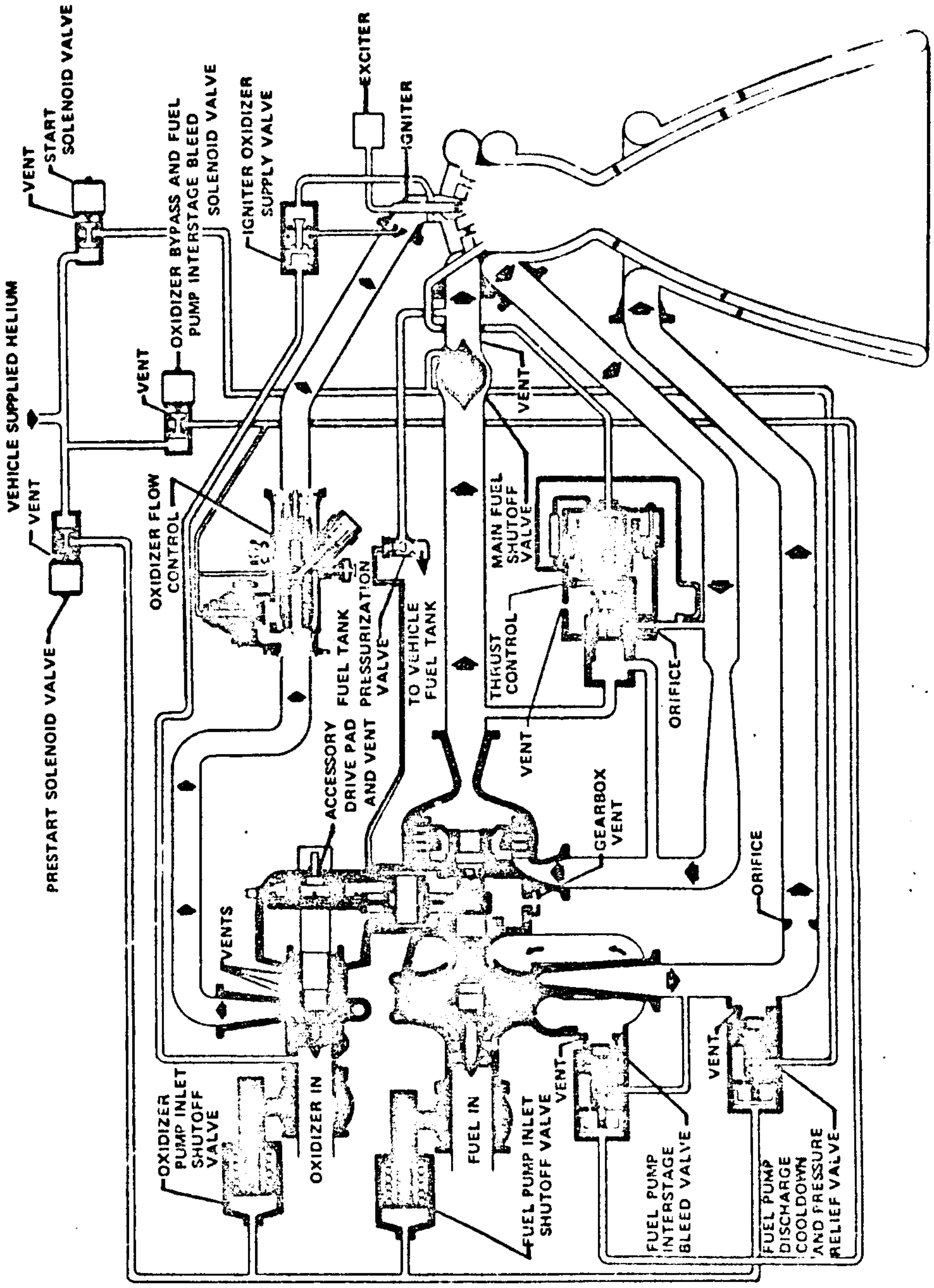

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Figure C-1. Propellant Flow Schematic for Category I Engine

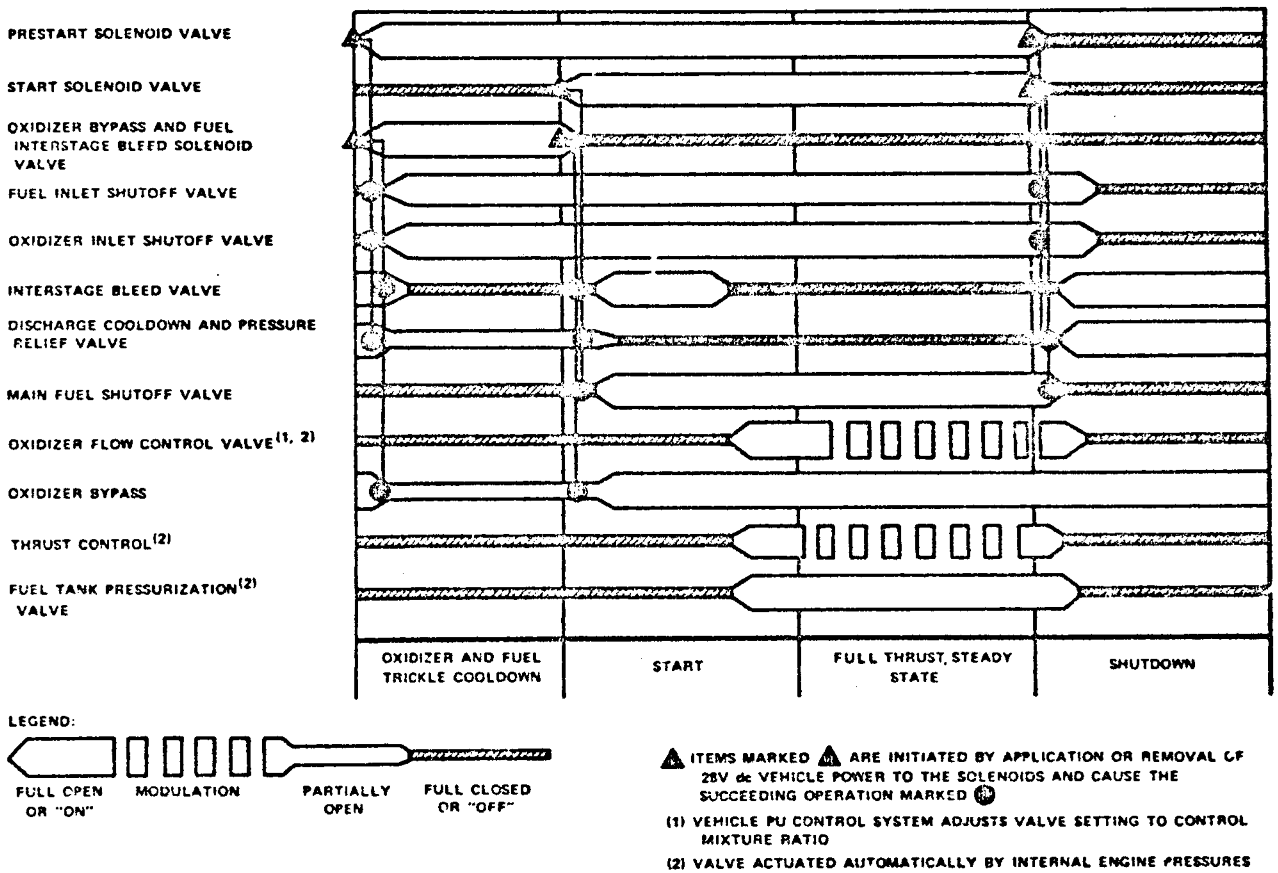

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Figure C-2. Engine Operation Valve Sequence Category I Engine

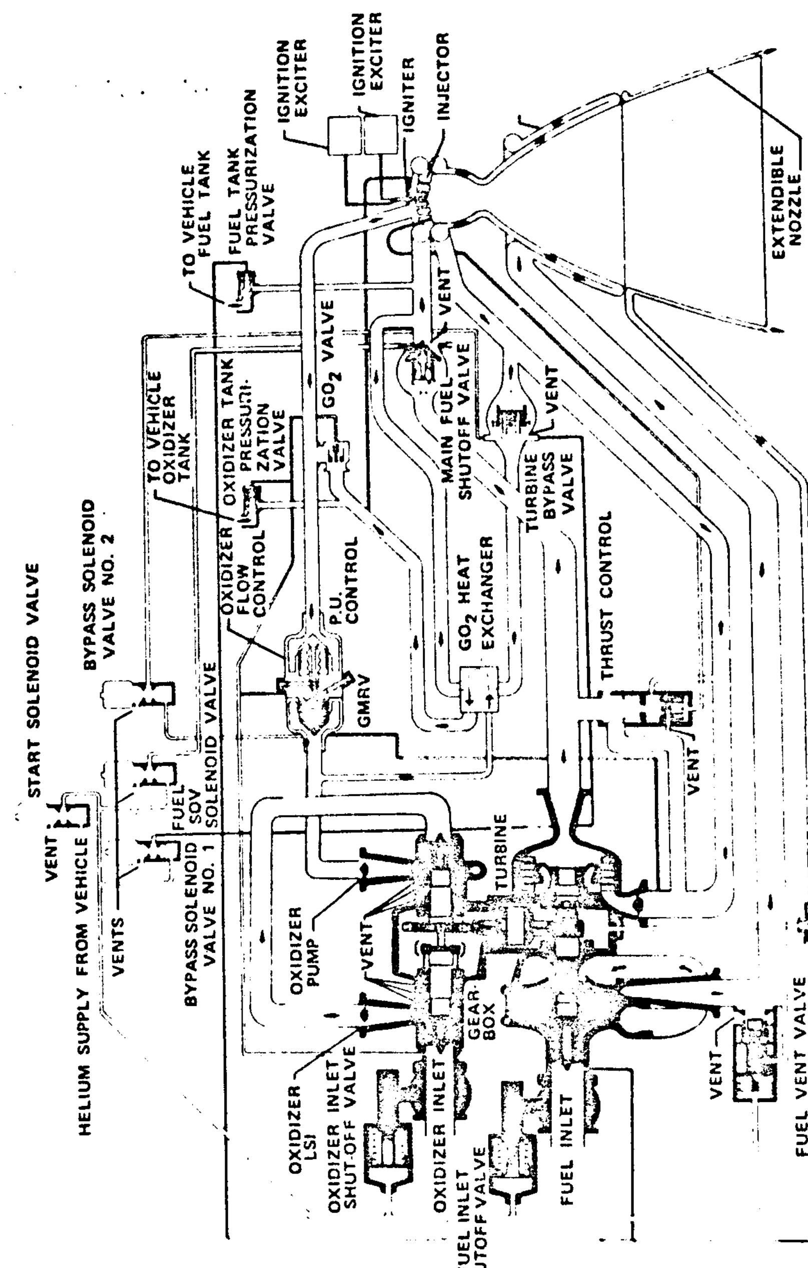

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Figure C-3. RL10 Derivative IIA Engine Propellant Flow Schematic

FD 74111A

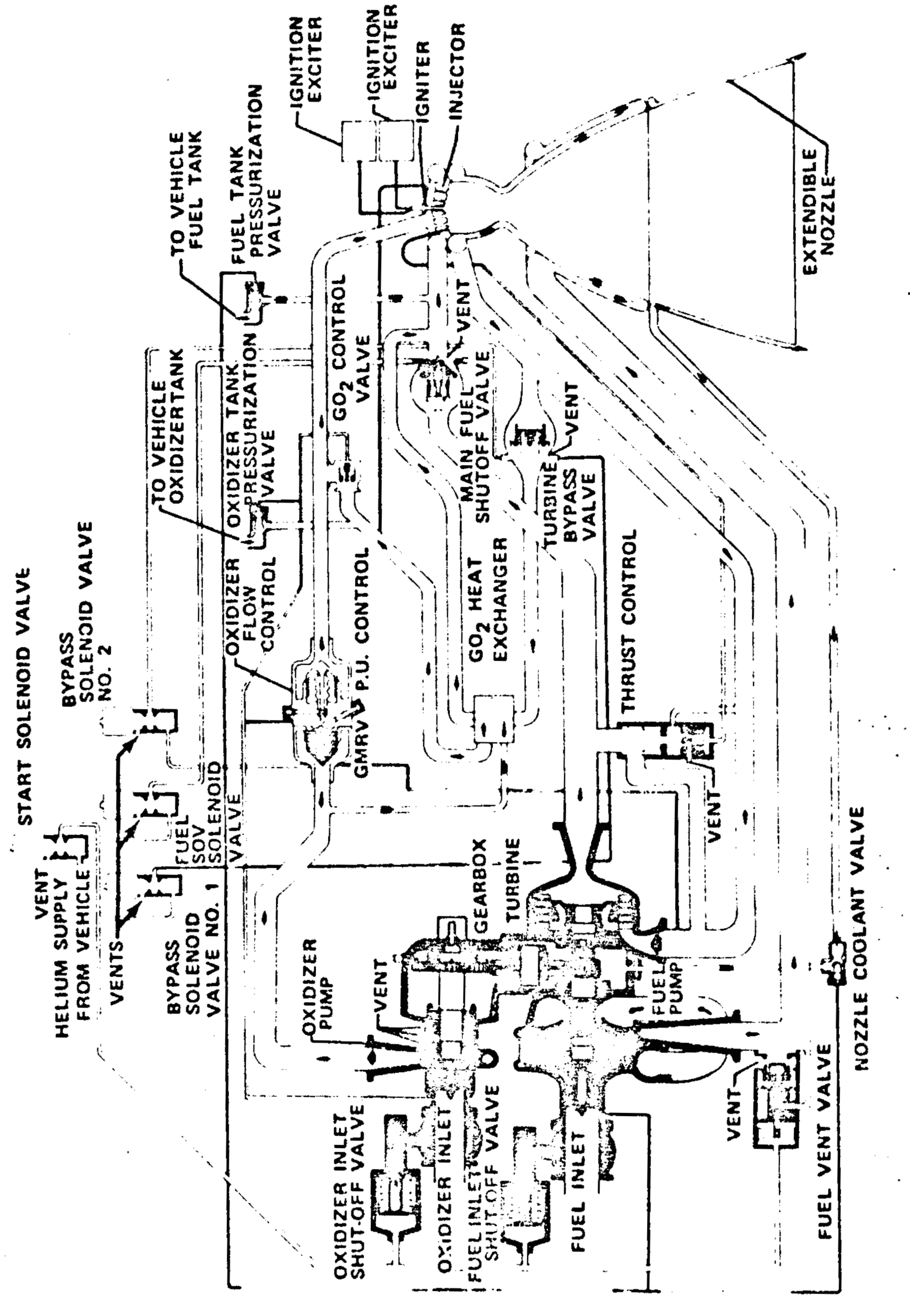


Figure C-4. RL10 Derivative IIB Engine Propellant Flow Schematic

FD 75262

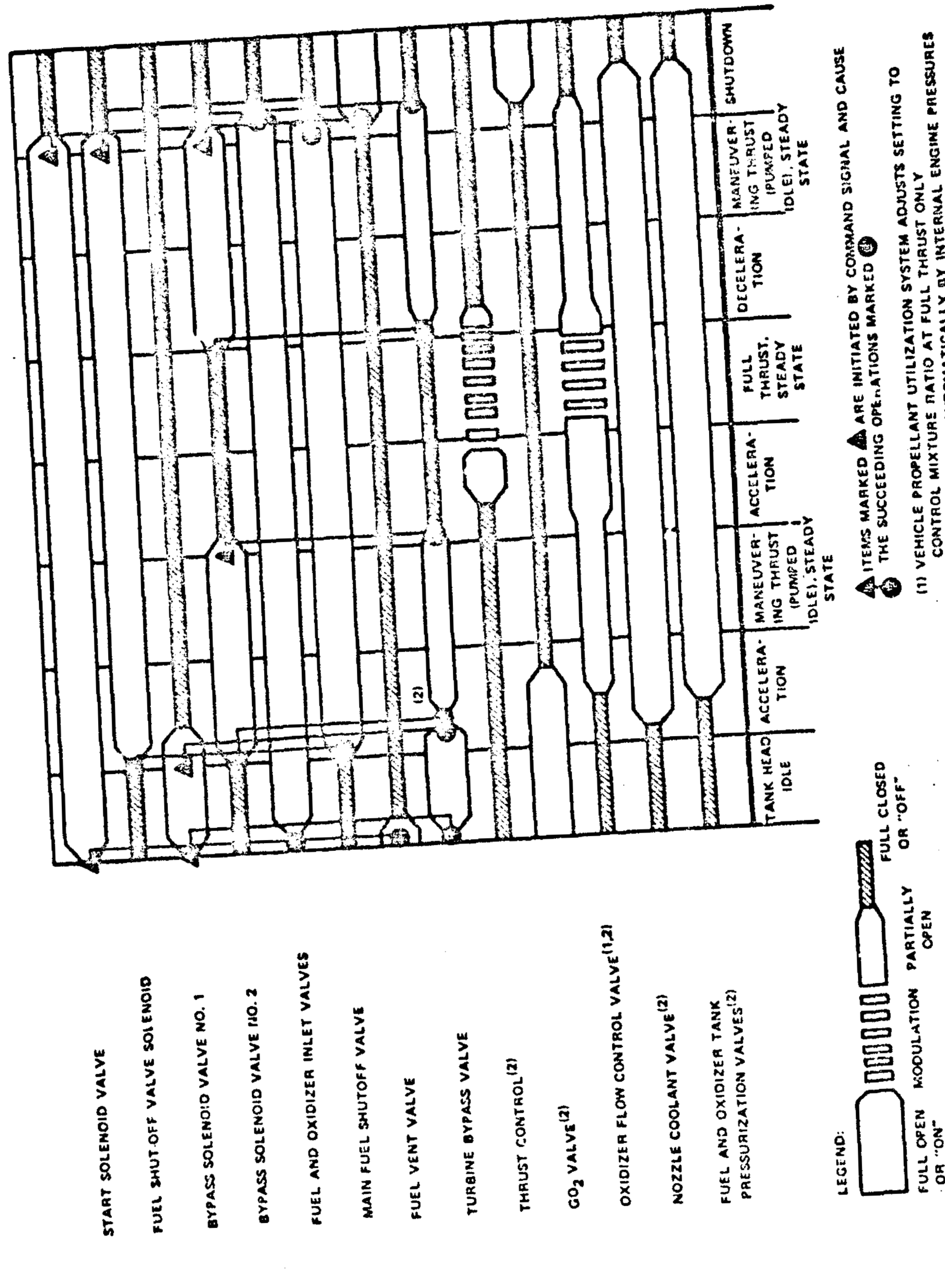


Figure C-5. Engine Operation Valve Sequence Derivative IIA and IIB Engines

FD 74113A

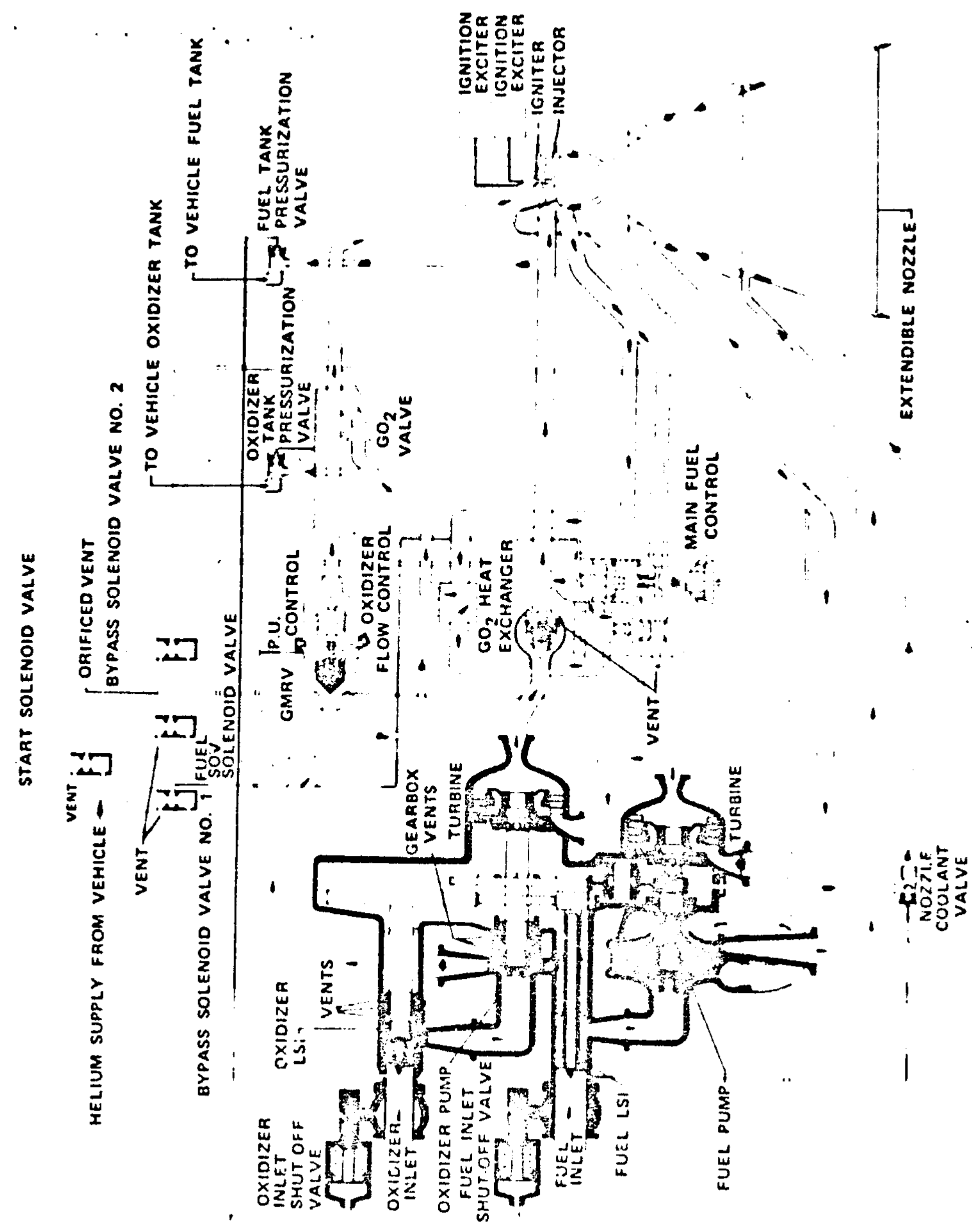
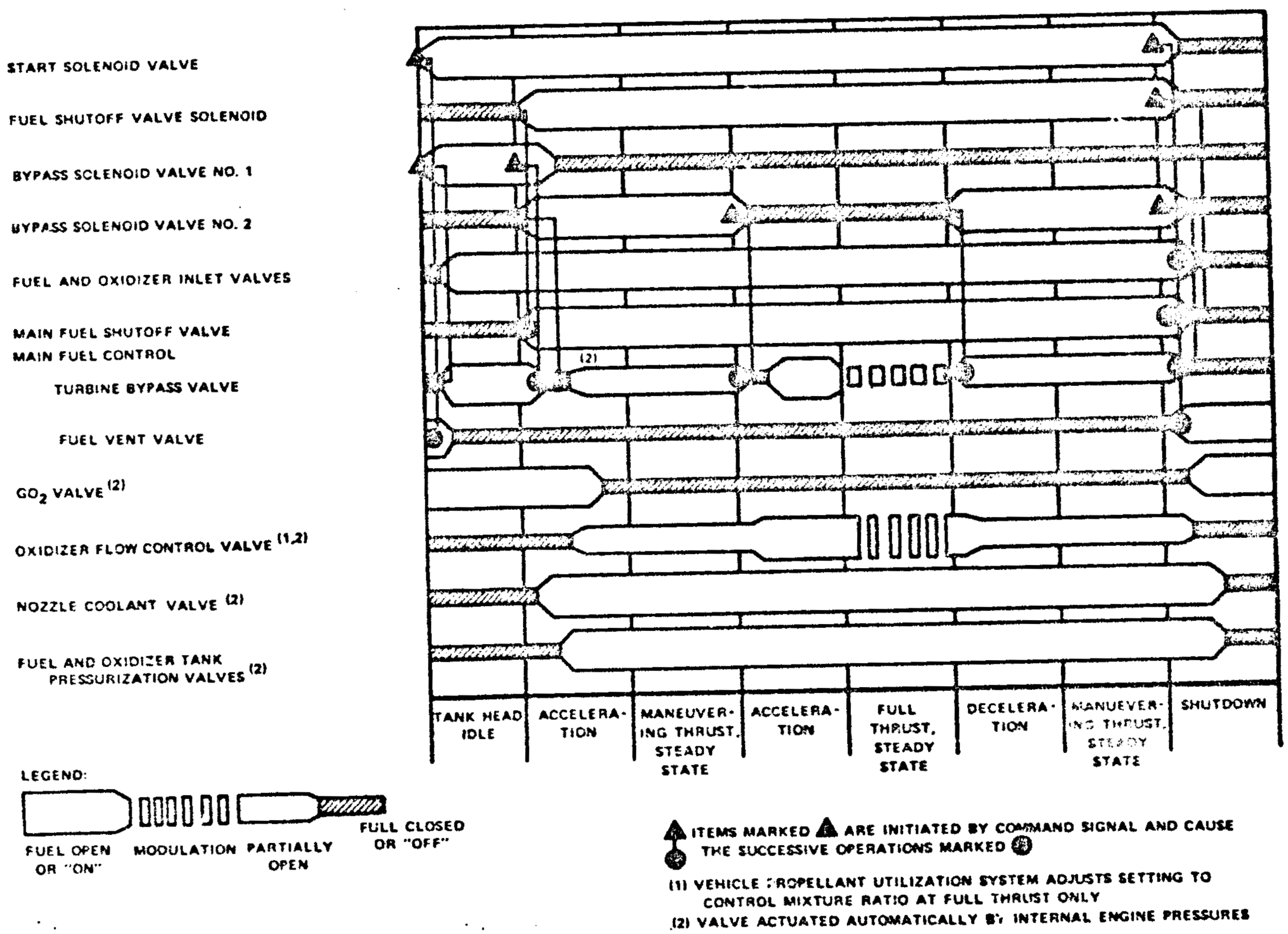


Figure C-6. RL10 Category IV Engine Propellant Flow Schematic



FD 75263

Figure C-7. Engine Operation Valve Sequence Category IV Engine

FD 66238B

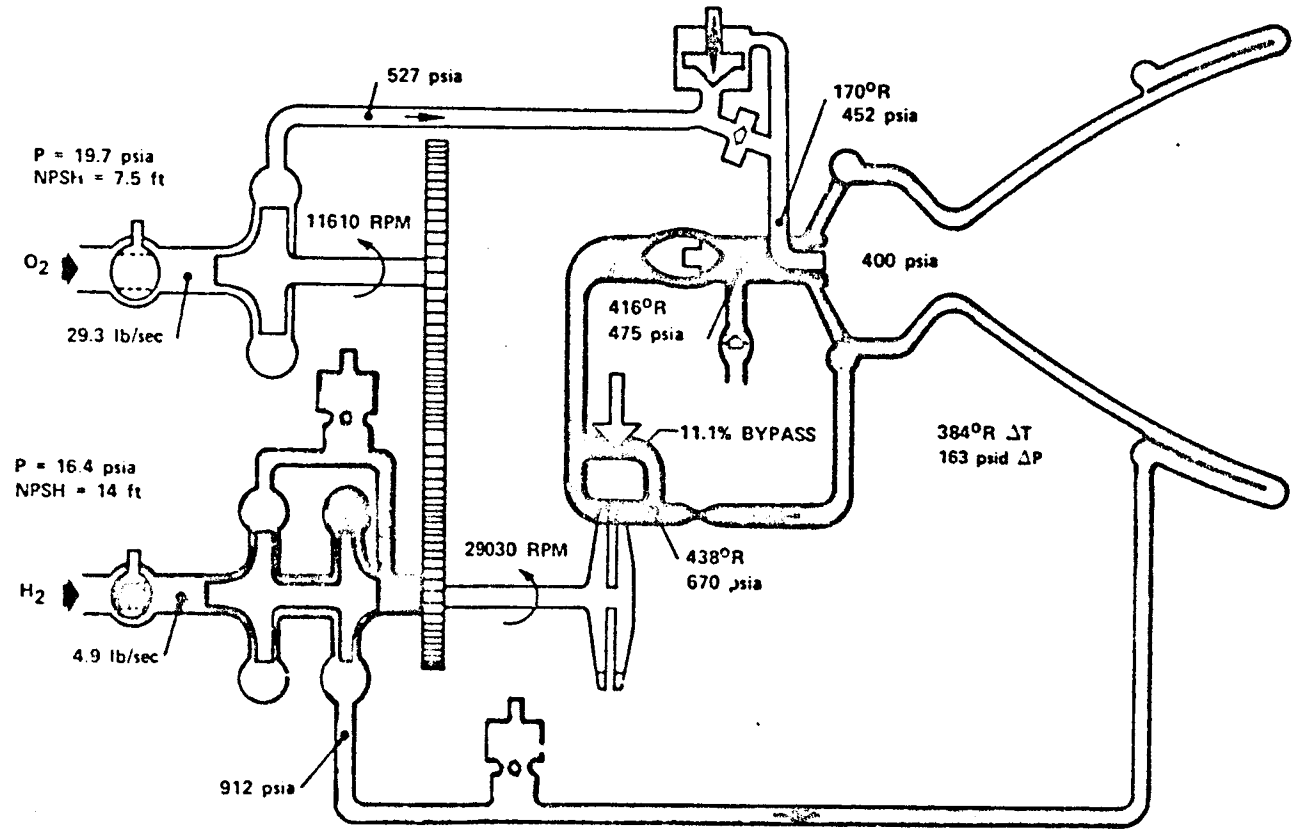


Figure C-8. Category I Propellant Flow Schematic Full Thrust (MR = 6.0)

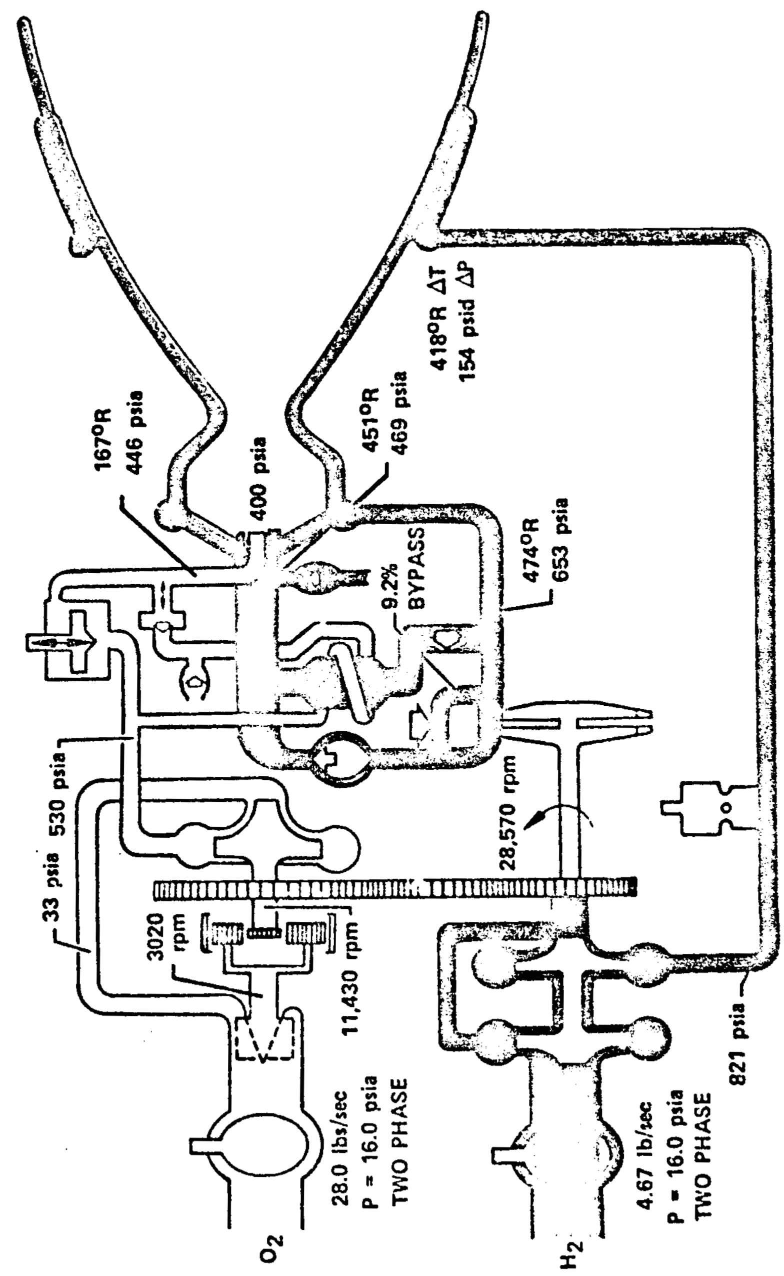


Figure C-9. Derivative IIA Propellant Flow Schematic at Full Thrust (MR = 6.0)

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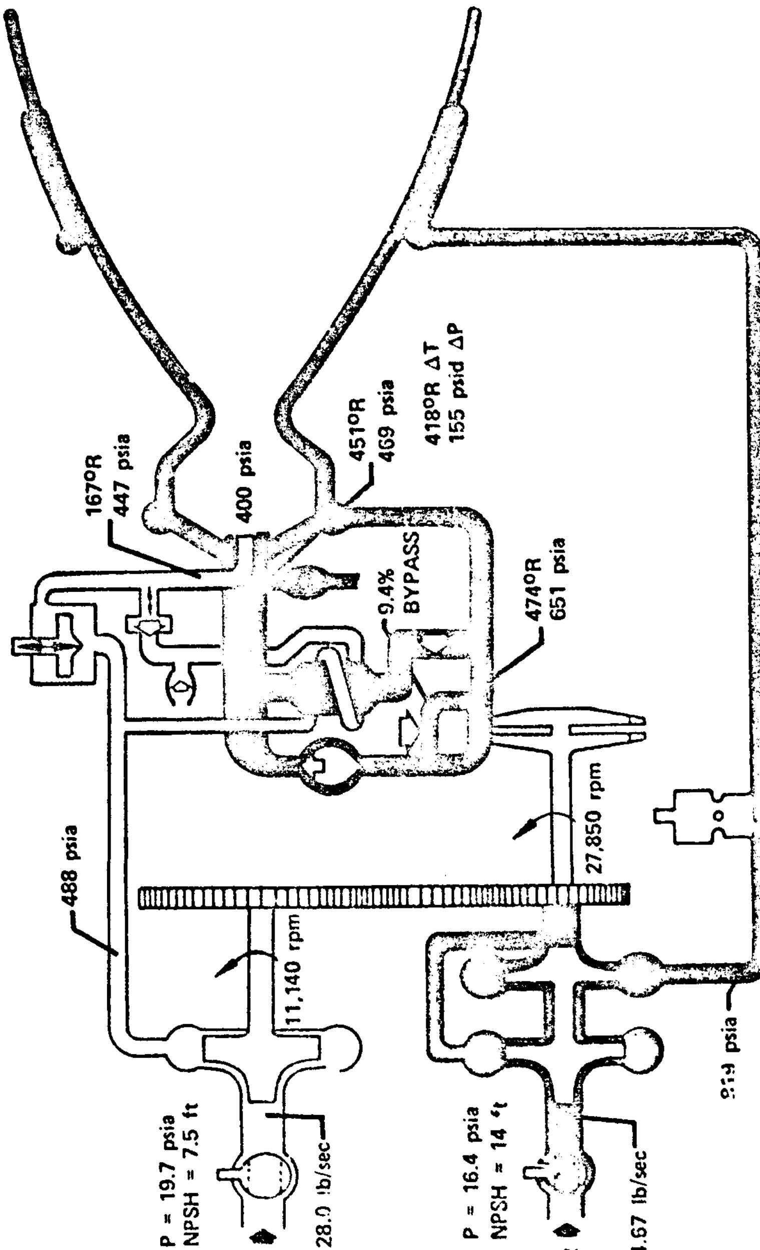

Figure C-10. Derivative IIB Propellant Flow Schematic at Full Thrust (MR = 6.0)

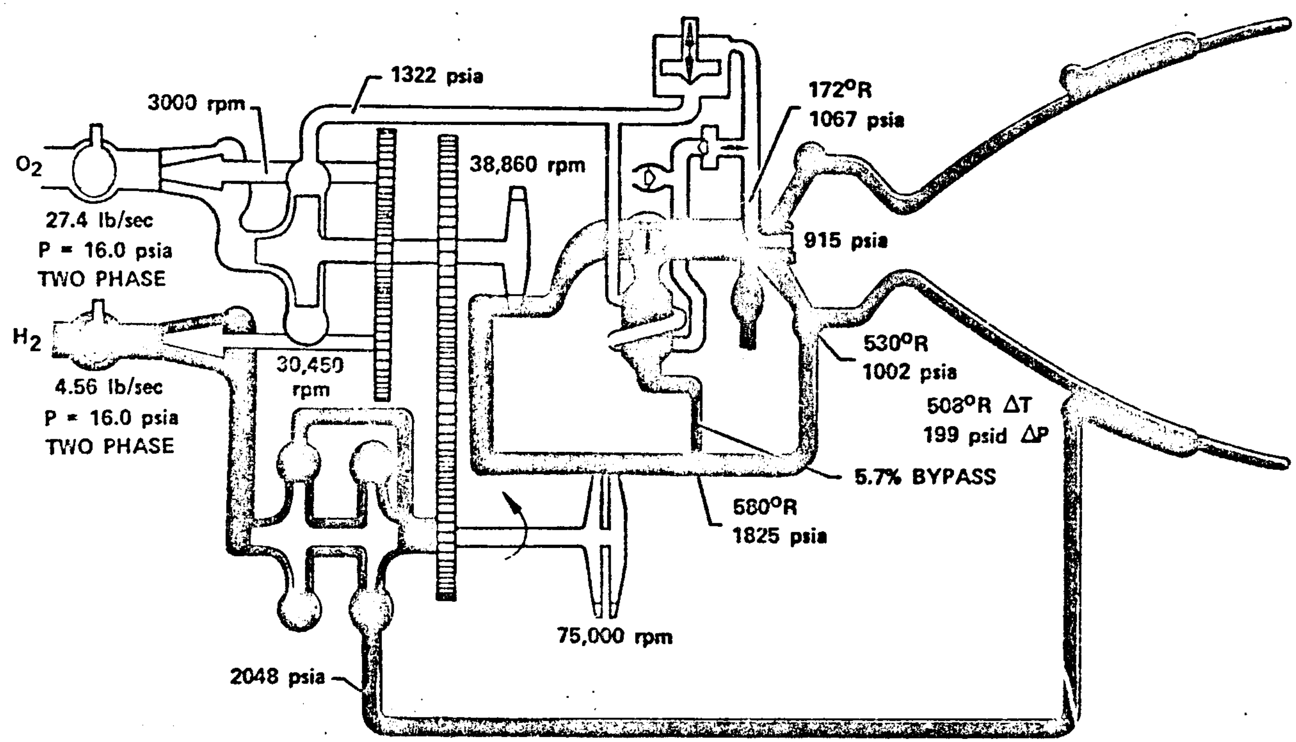

Figure C-11. Category IV Propellant Flow Schematic at Full Thrust (MR = 6.0)

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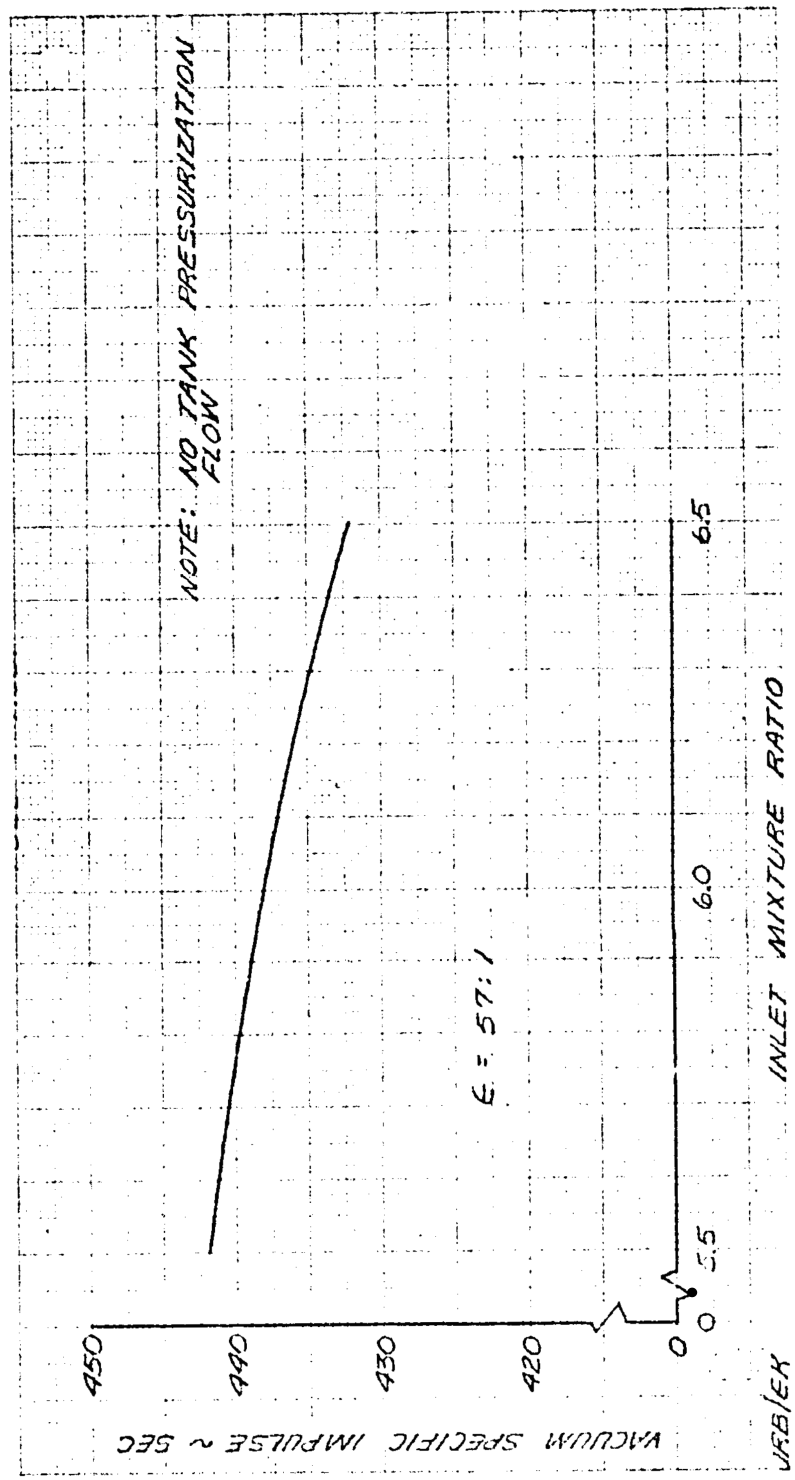

Figure C-12. Estimated Effect of Inlet Mixture Ratio on Vacuum Specific Impulse, Category I Engine, Full Thrust

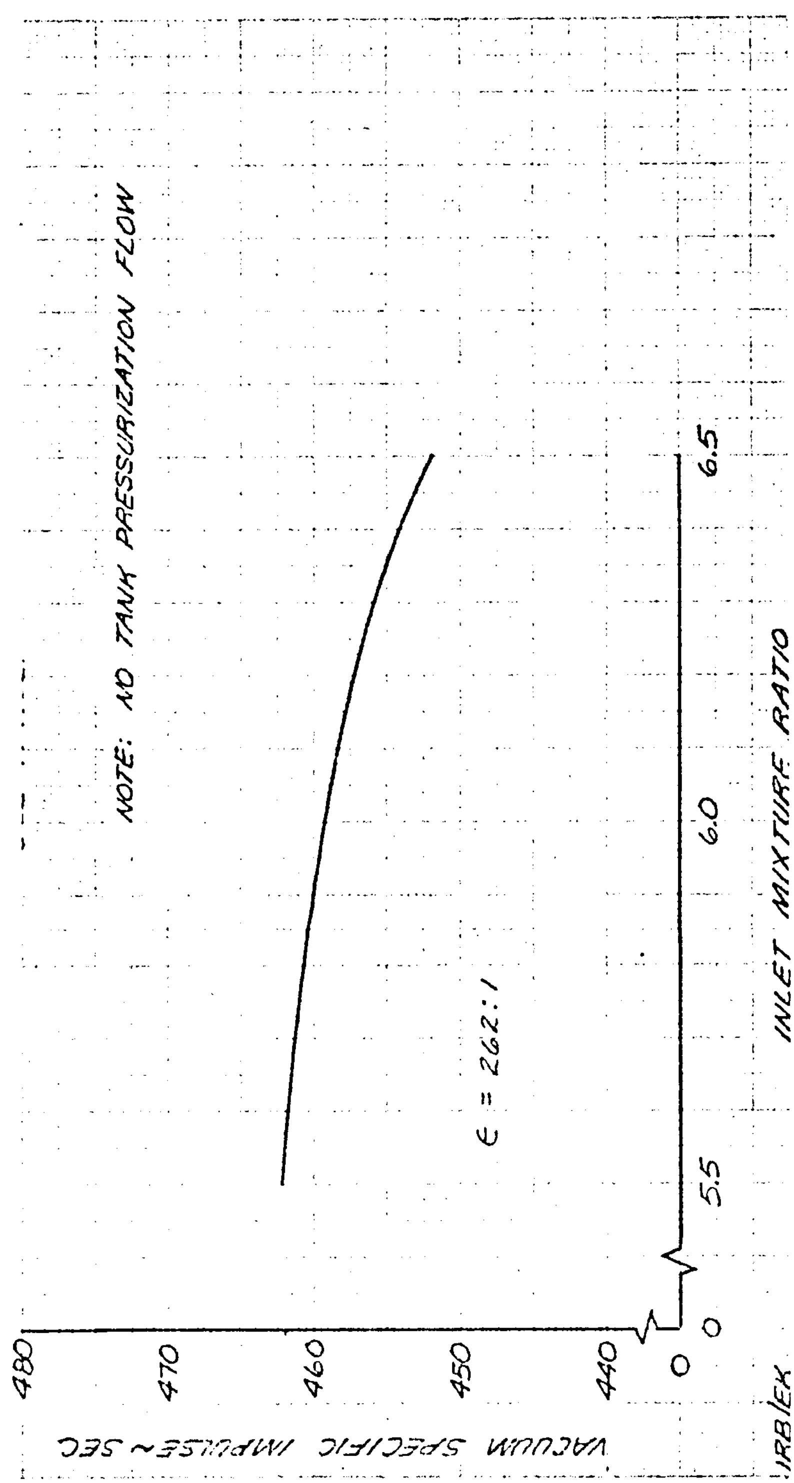

Figure C-13. Estimated Effect of Inlet Mixture Ratio on Vacuum Specific Impulse, Derivative IIA and IIB Engines, Full Thrust

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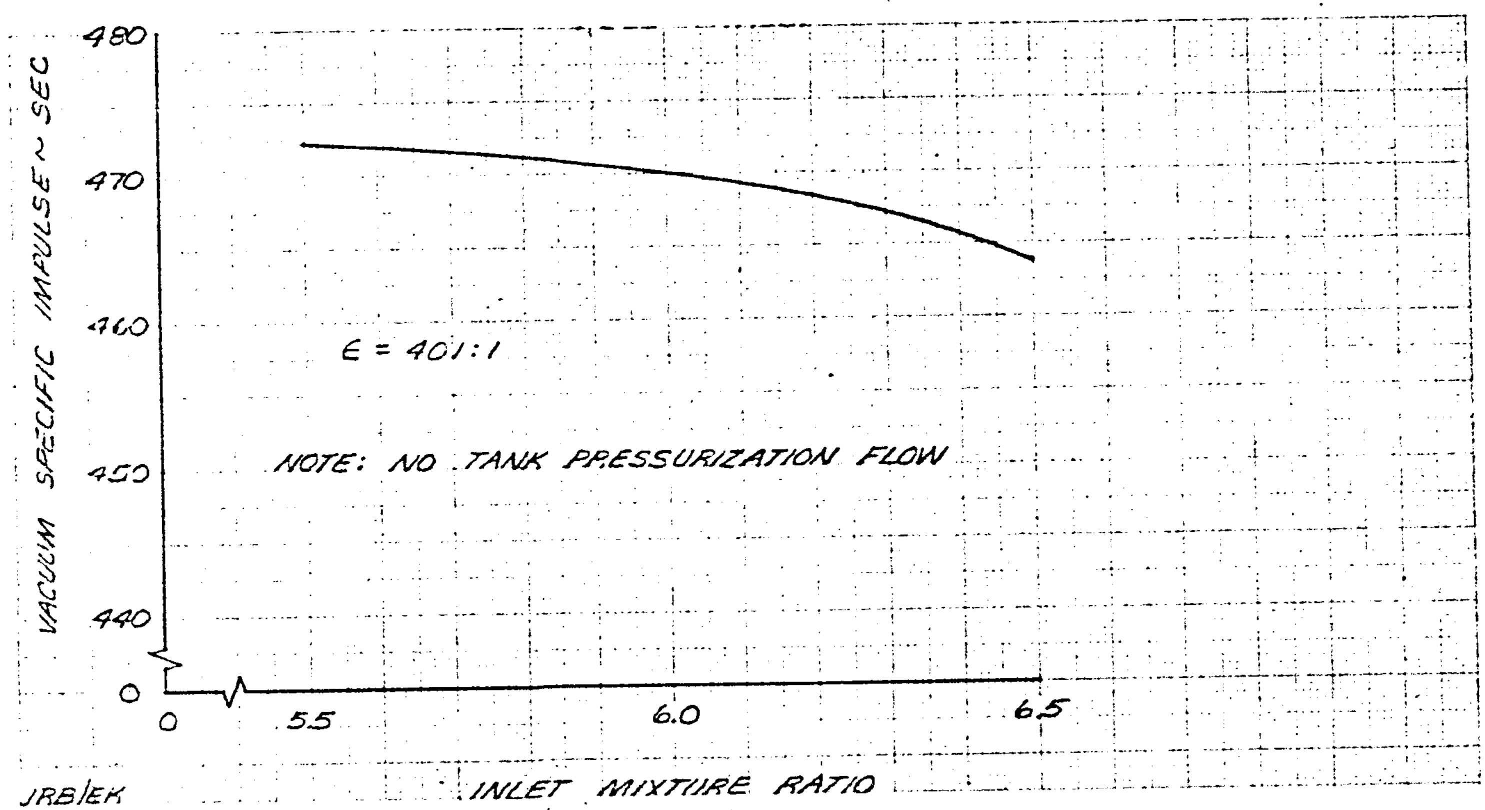

Figure C-14. Estimated Effect of Inlet Mixture Ratio on Vacuum Specific Impulse, Category IV Engine, Full Thrust

DF 96980

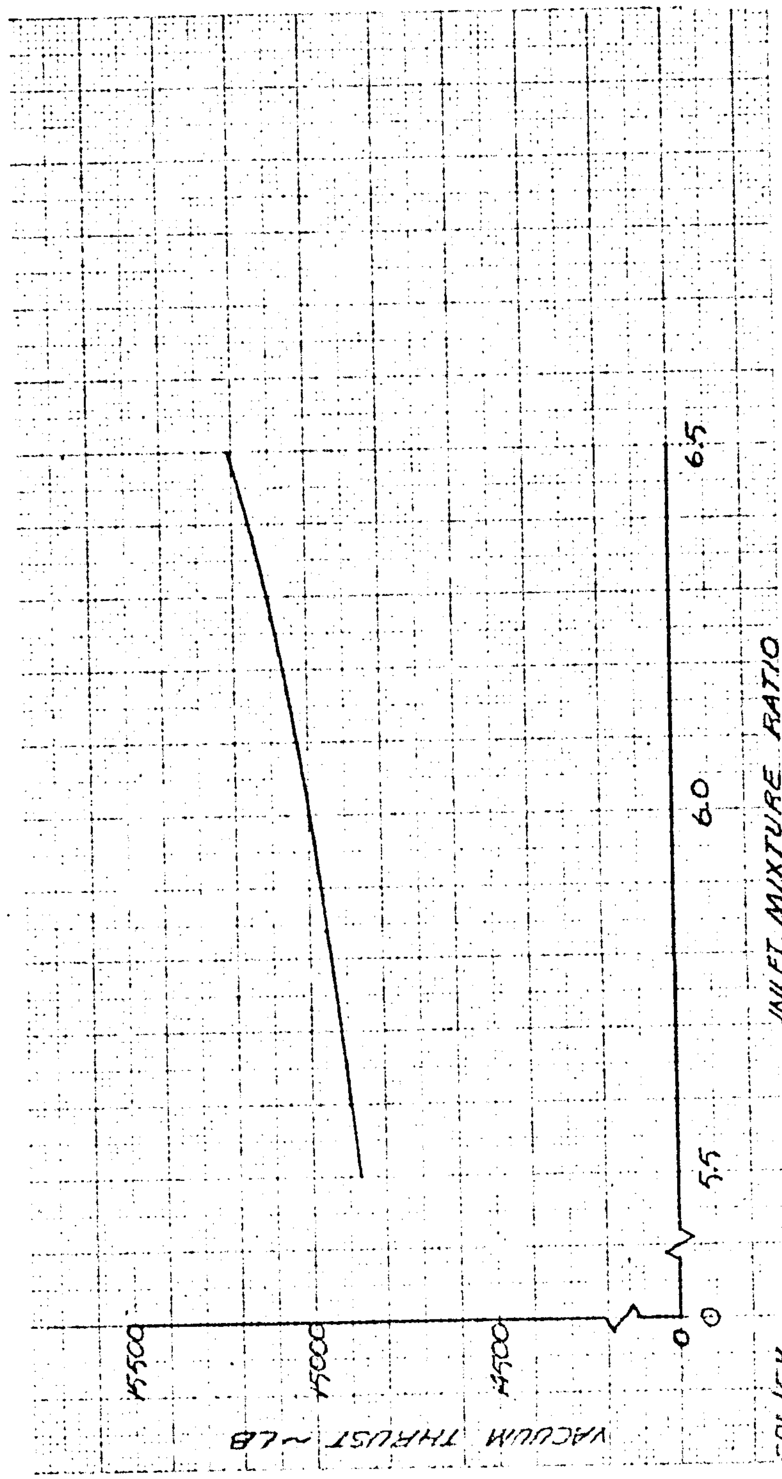

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Figure C-15. Estimated Effect of Inlet Mixture Ratio on Vacuum Thrust, Category I Engine, Full Thrust

DF 96979

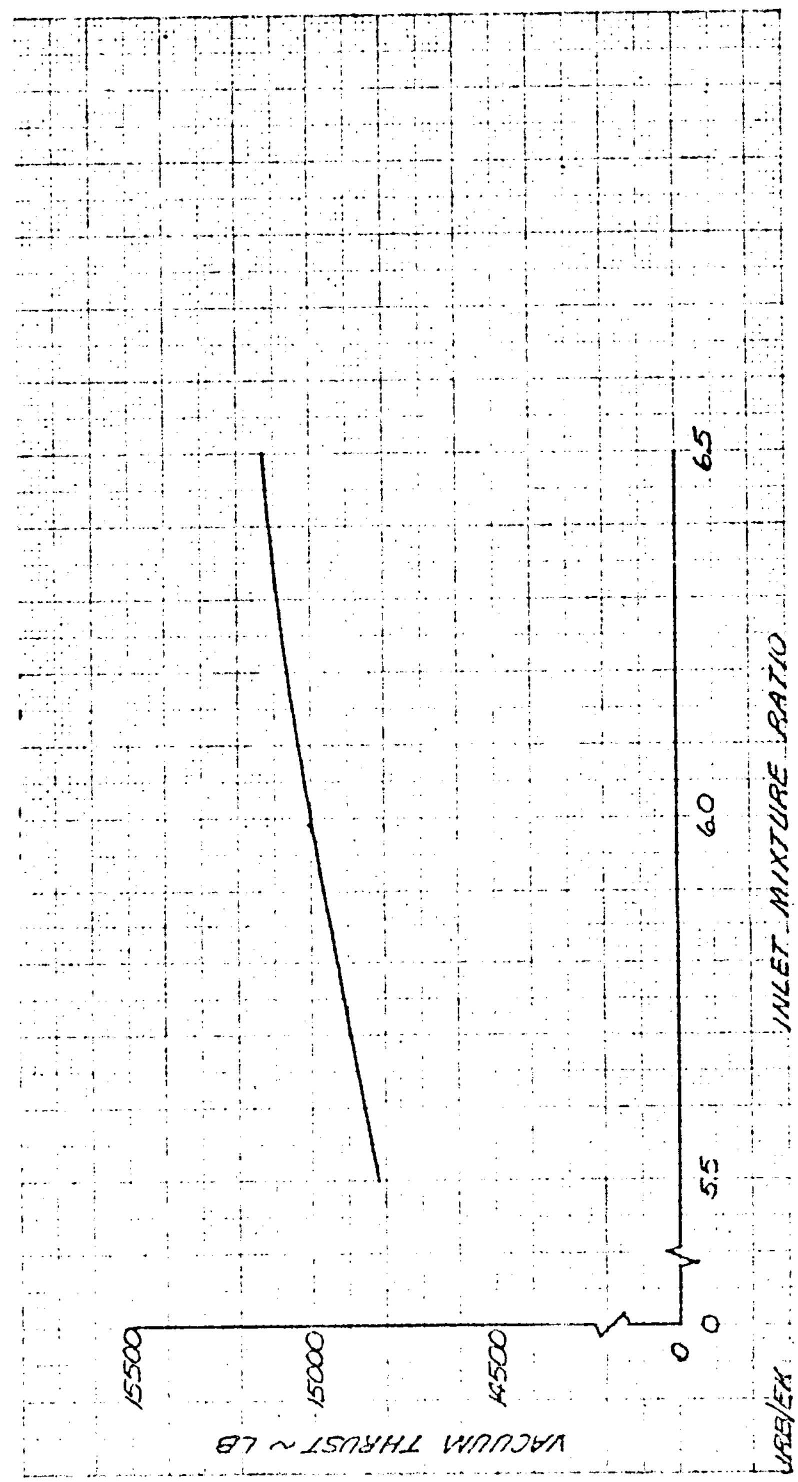

Figure C-16. Estimated Effect of Inlet Mixture Ratio on Vacuum Thrust, Derivative IIA and IIB Engines, Full Thrust

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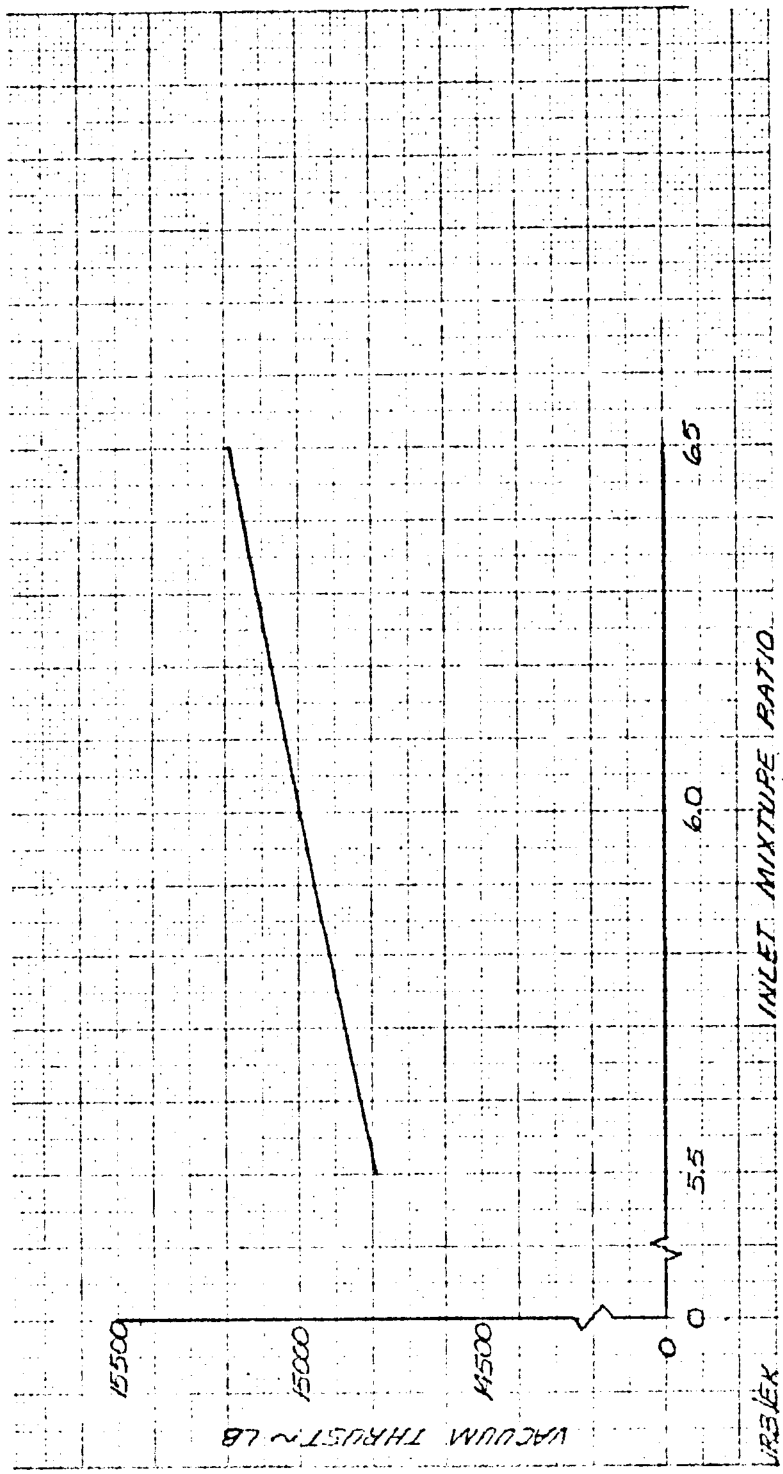

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Figure C-17. Estimated Effect of Inlet Mixture Ratio on Vacuum Thrust, Category IV Engine, Full Thrust

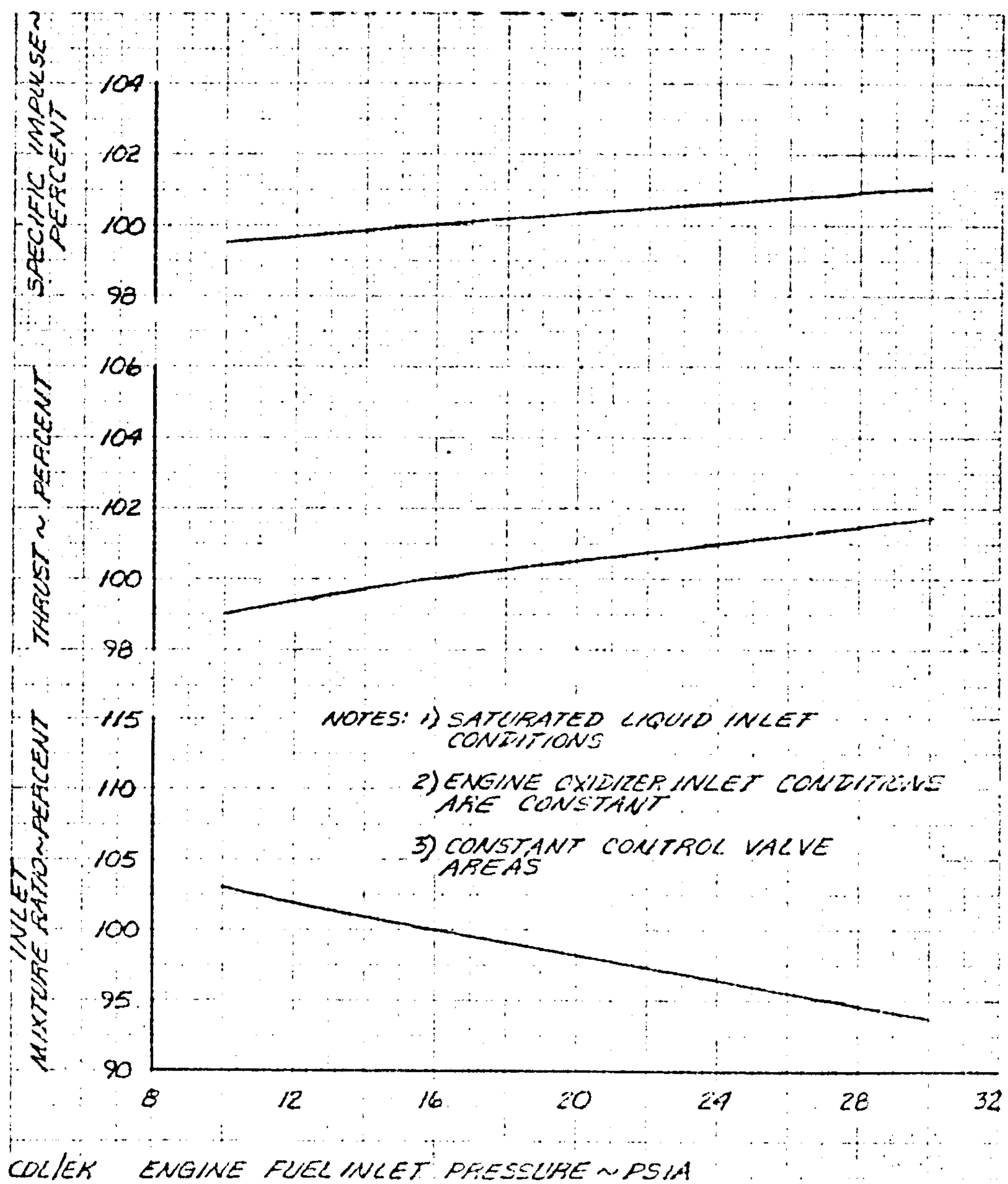

Figure C-18. Estimated Effect of Engine Fuel Inlet Pressure on Maneuver Thrust Operation, Derivative IIA Engine — DF 96516

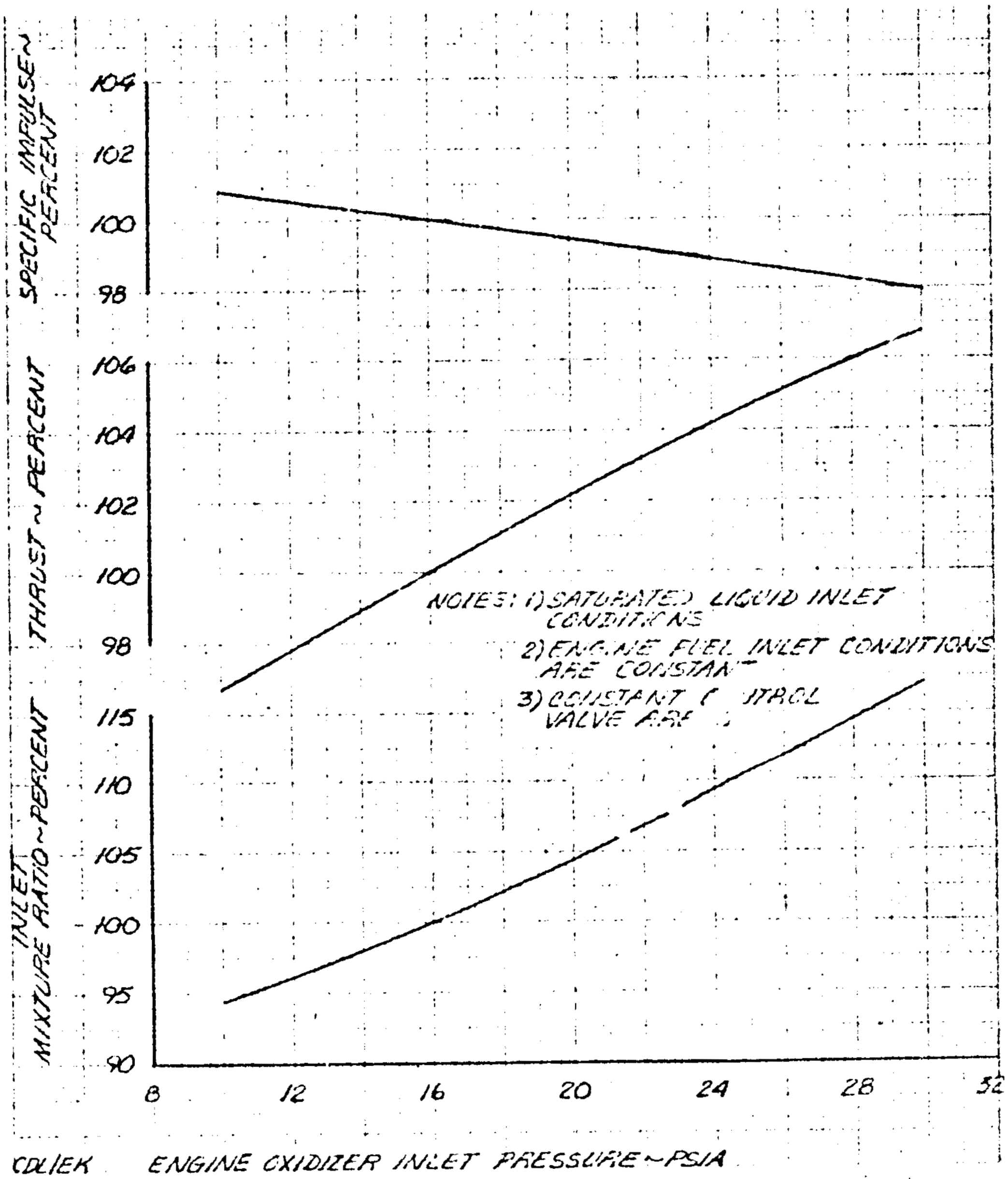

Figure C-19. Estimated Effect of Engine Oxidizer Inlet Pressure on Maneuver Thrust Operation, Derivative IIA Engine

DF 96517

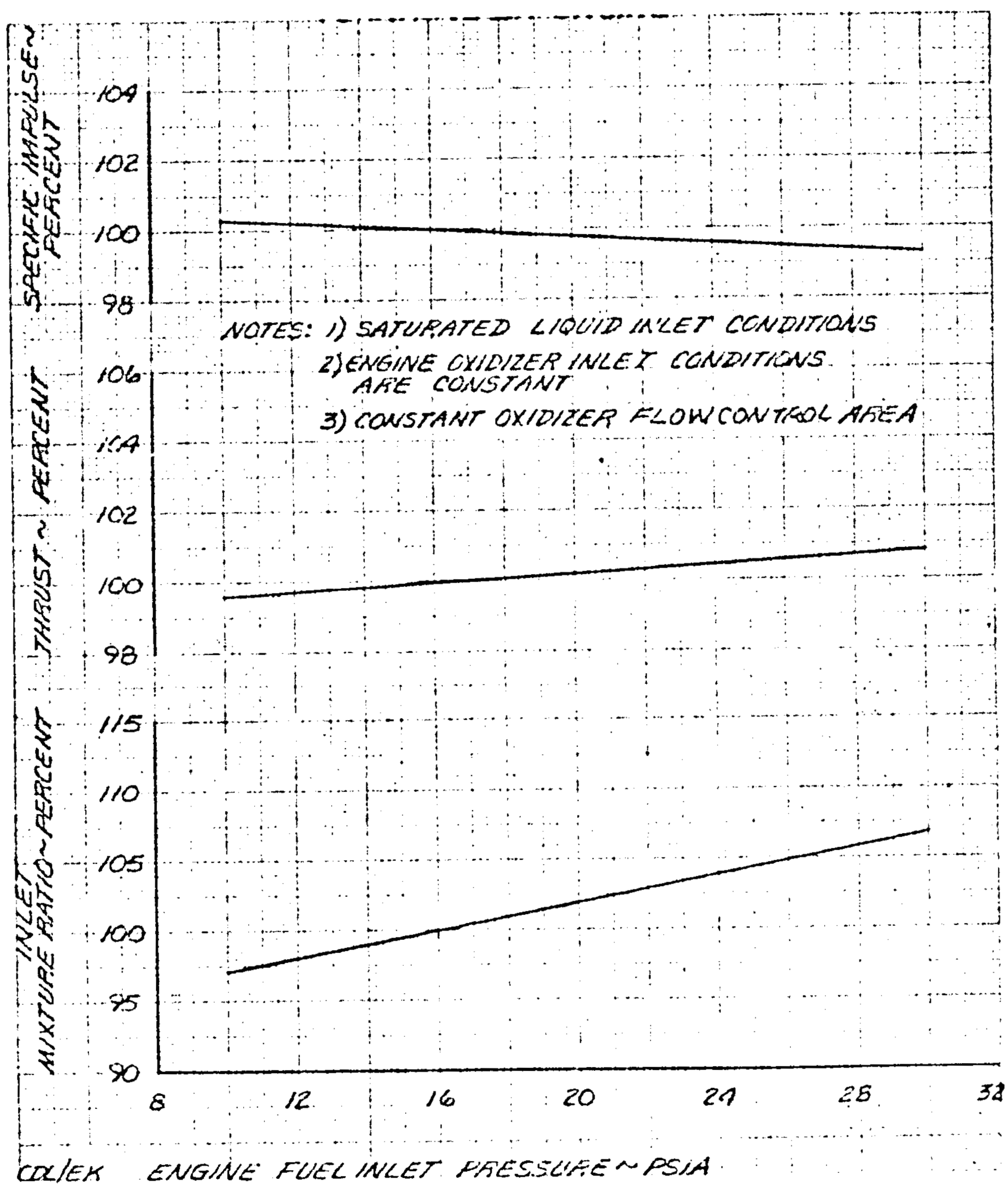

Figure C-20. Estimated Effect of Engine Fuel Inlet Pressure on Full Thrust Operation, Derivative IIA Engine

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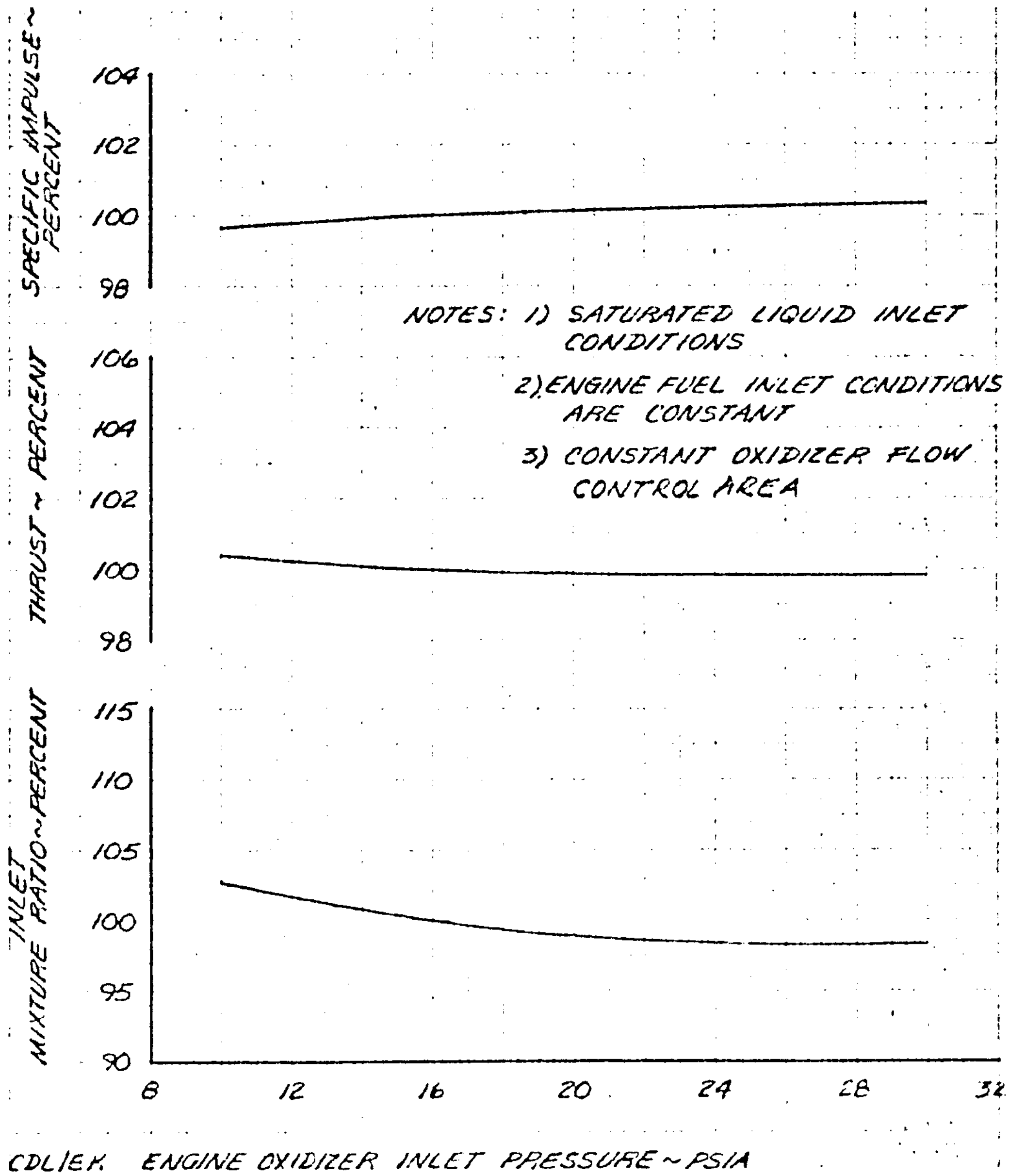

Figure C-21. Estimated Effect of Engine Oxidizer Inlet Pressure on Full Thrust Operation, Derivative IIA Engine

DF 96519

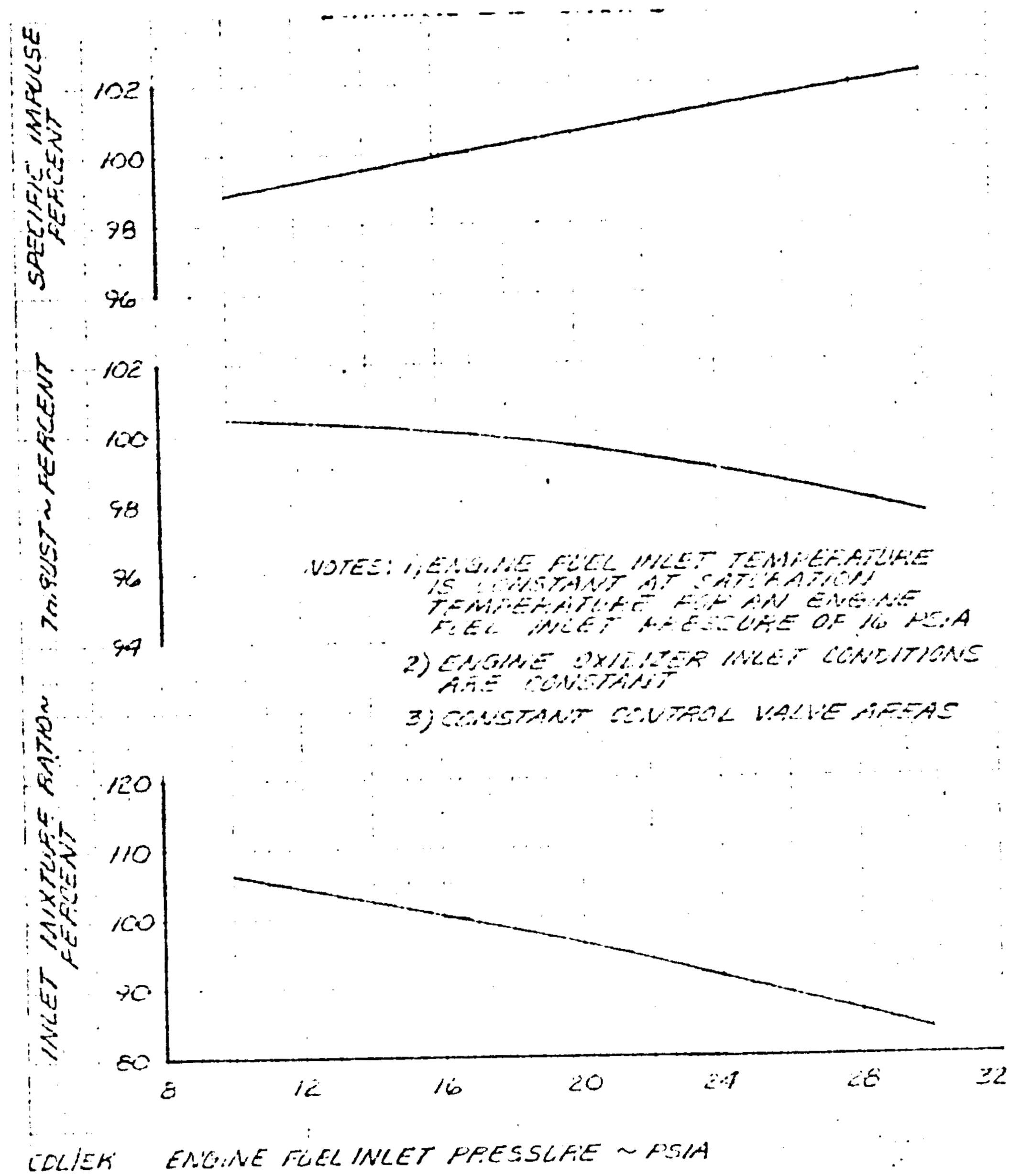

Figure C-22. Estimated Effect of Engine Fuel Inlet Pressure on Pumped Idle Operation, Derivative IIB Engine

DF 96520

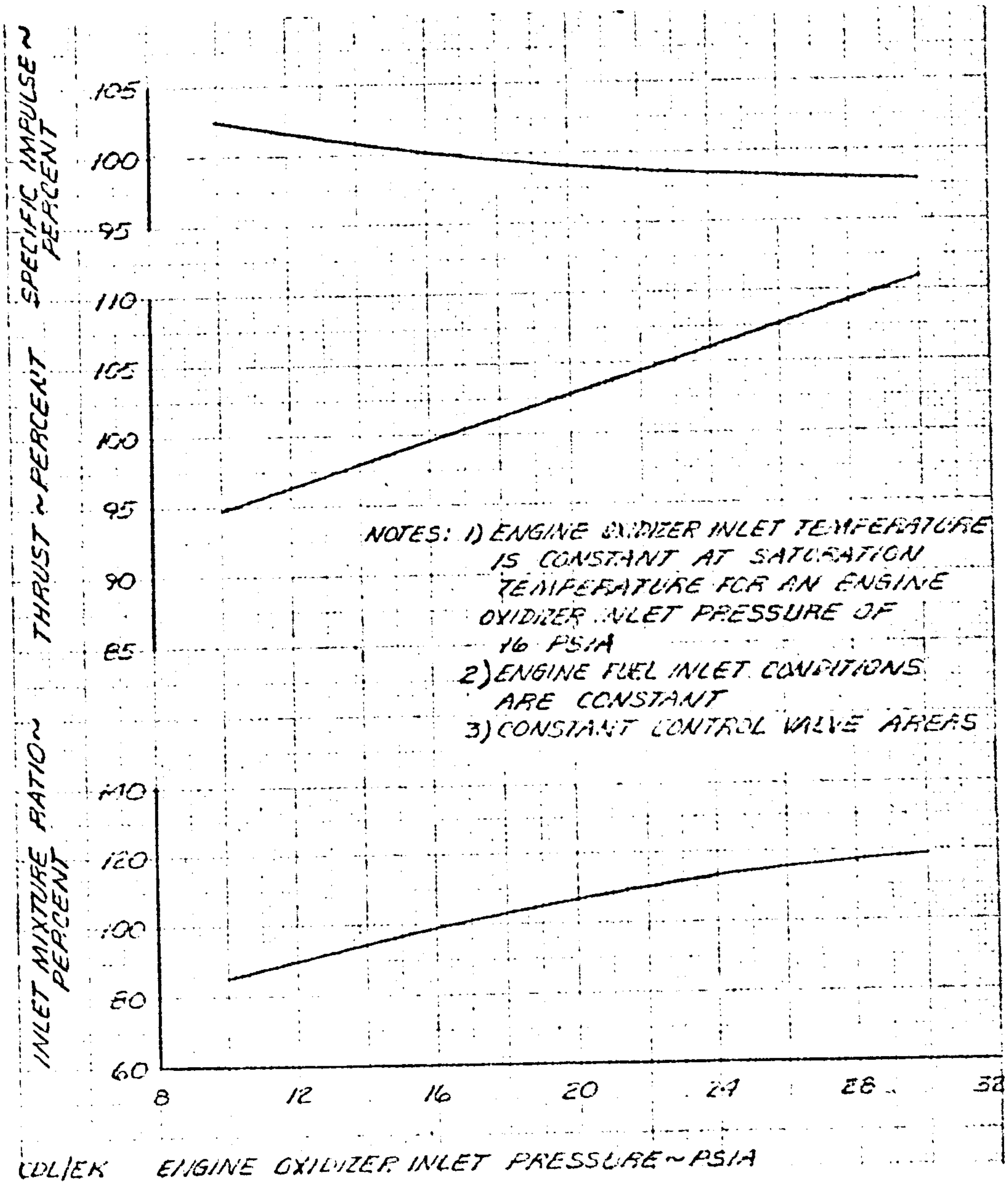

Figure C-23. Estimated Effect of Engine Oxidizer Inlet Pressure on Pumped Idle Operation, Derivative IIB Engine

DF 96521

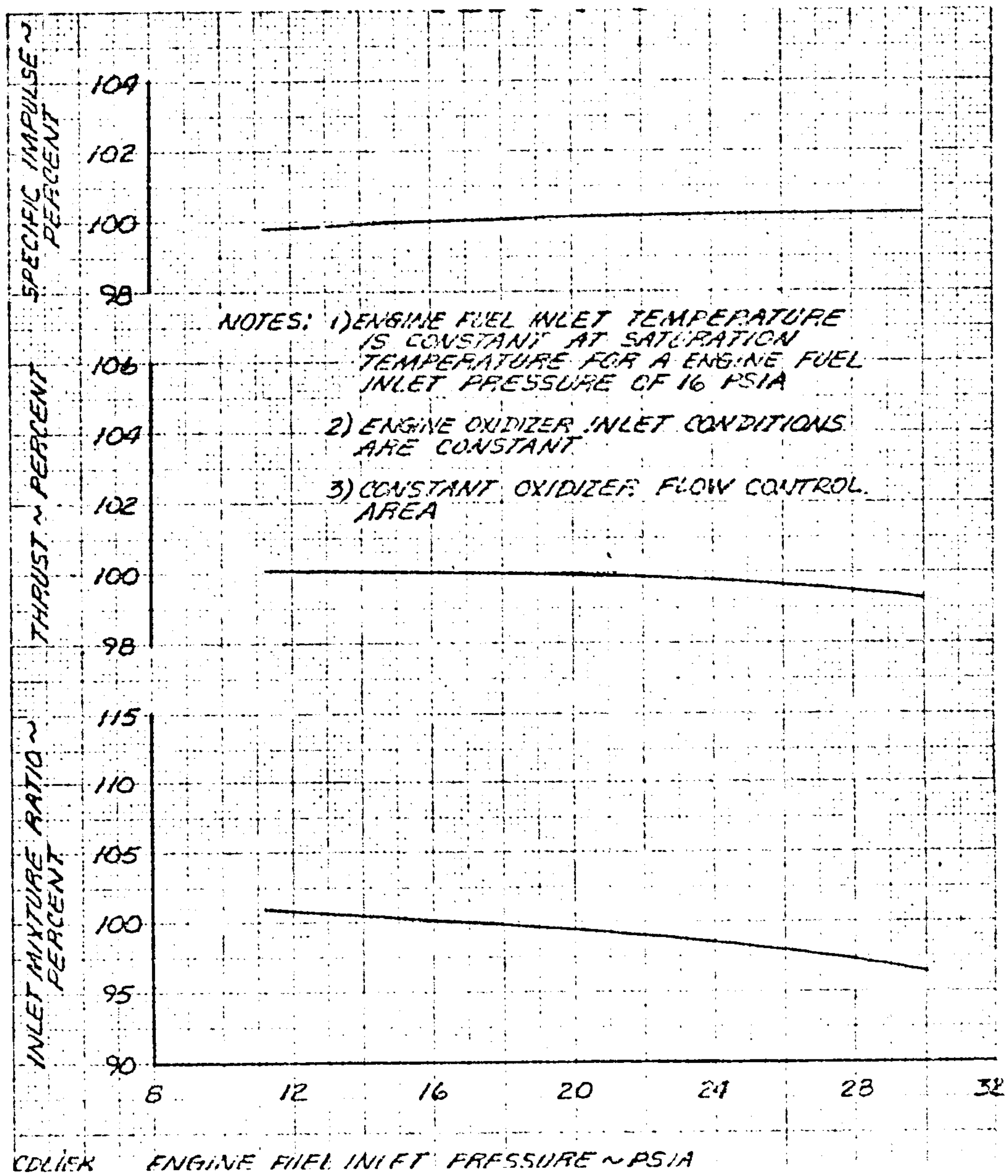

Figure C-24. Estimated Effect of Engine Fuel Inlet Pressure on Full Thrust Operation, Derivative IIB Engine

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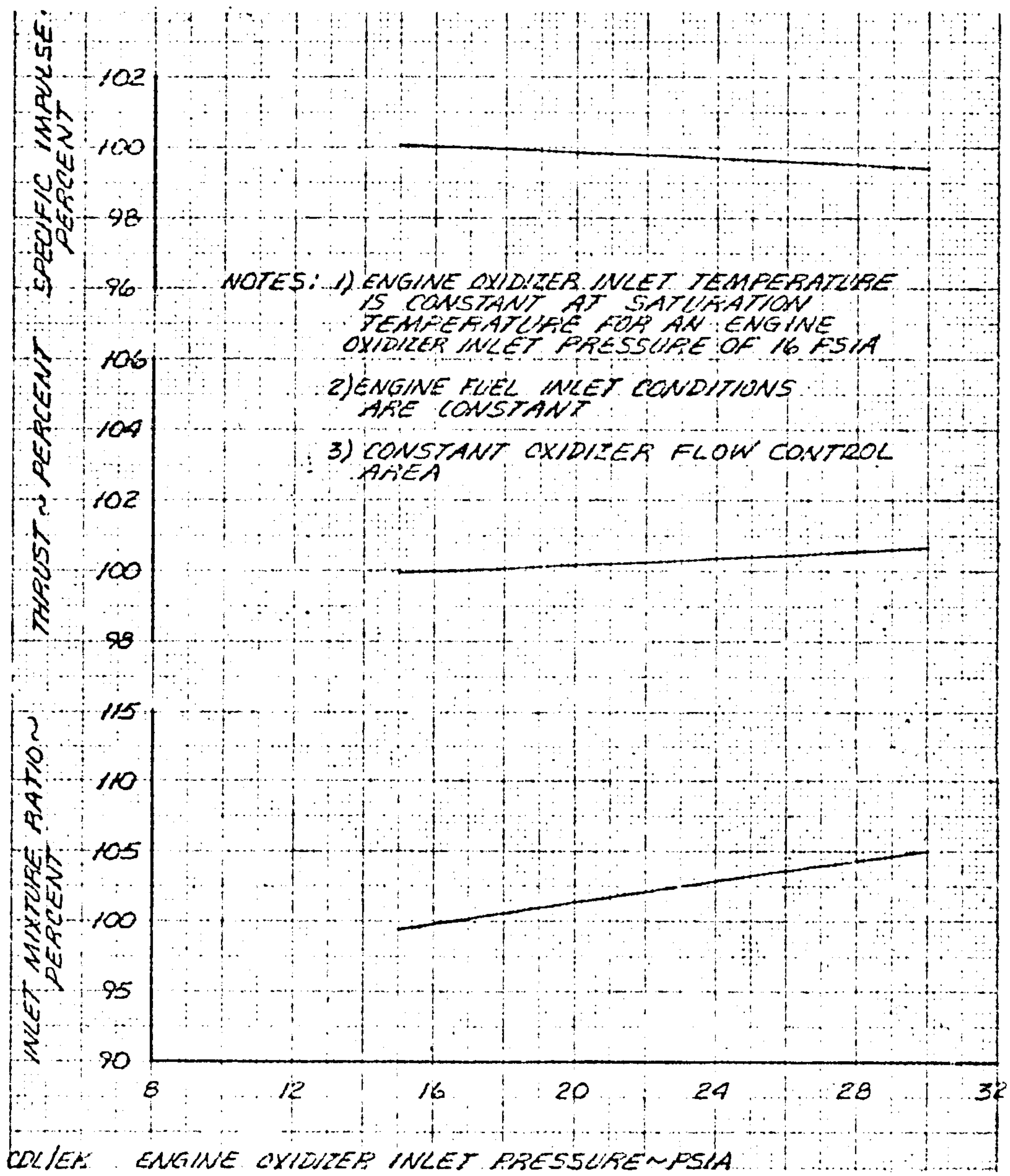


Figure C-25. Estimated Effect of Engine Oxidizer Inlet Pressure on Full Thrust Operation, Derivative IIB Engine

DF 96523

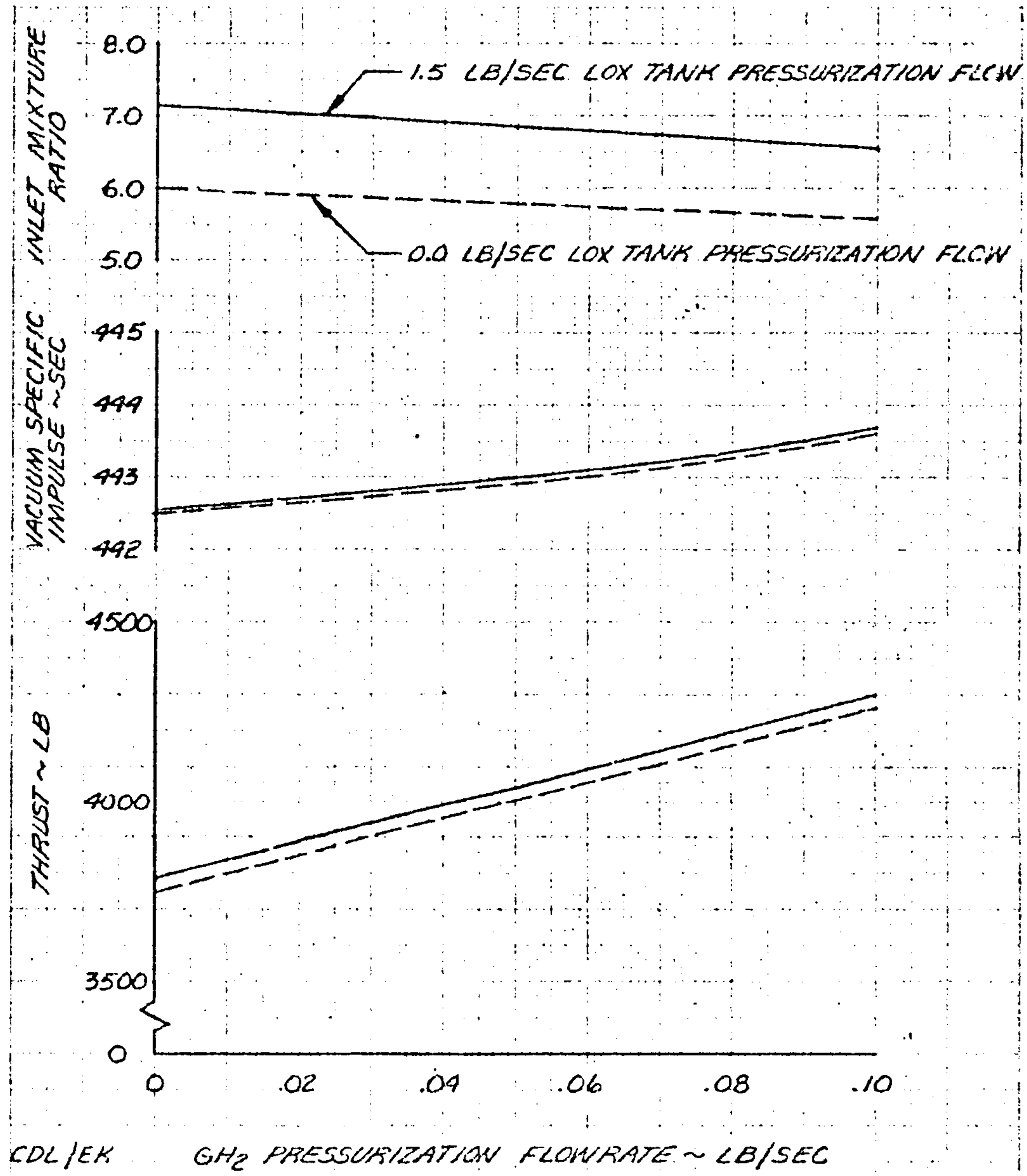


Figure C-26. Effect of Pressurization Flowrate on Pumped Idle Characteristics, Derivative IIB Engine DF 96426

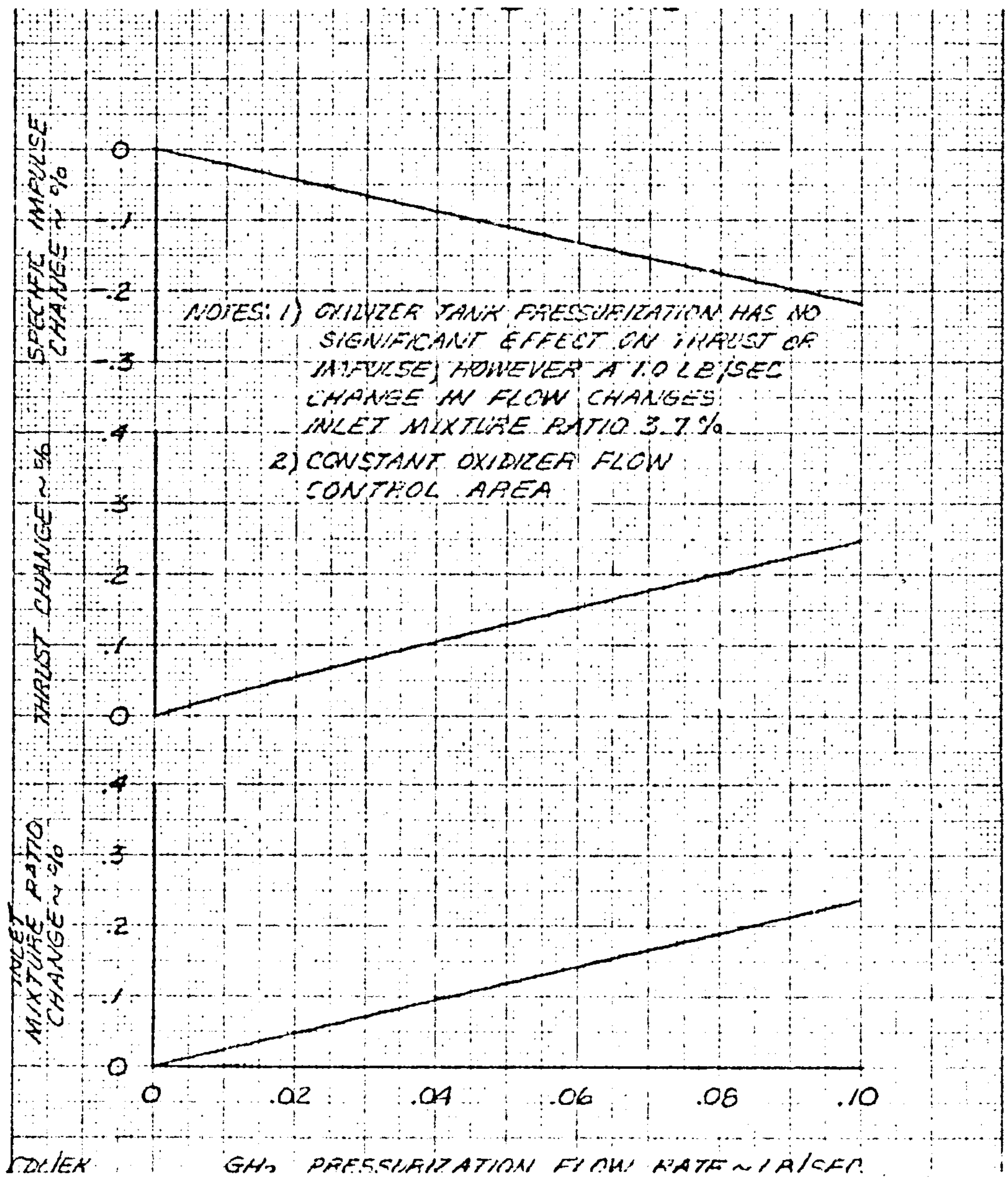


Figure C-27. Effect of Pressurization Flow on Engine Performance at Full Thrust, Derivative IIA Engine

DF 96608

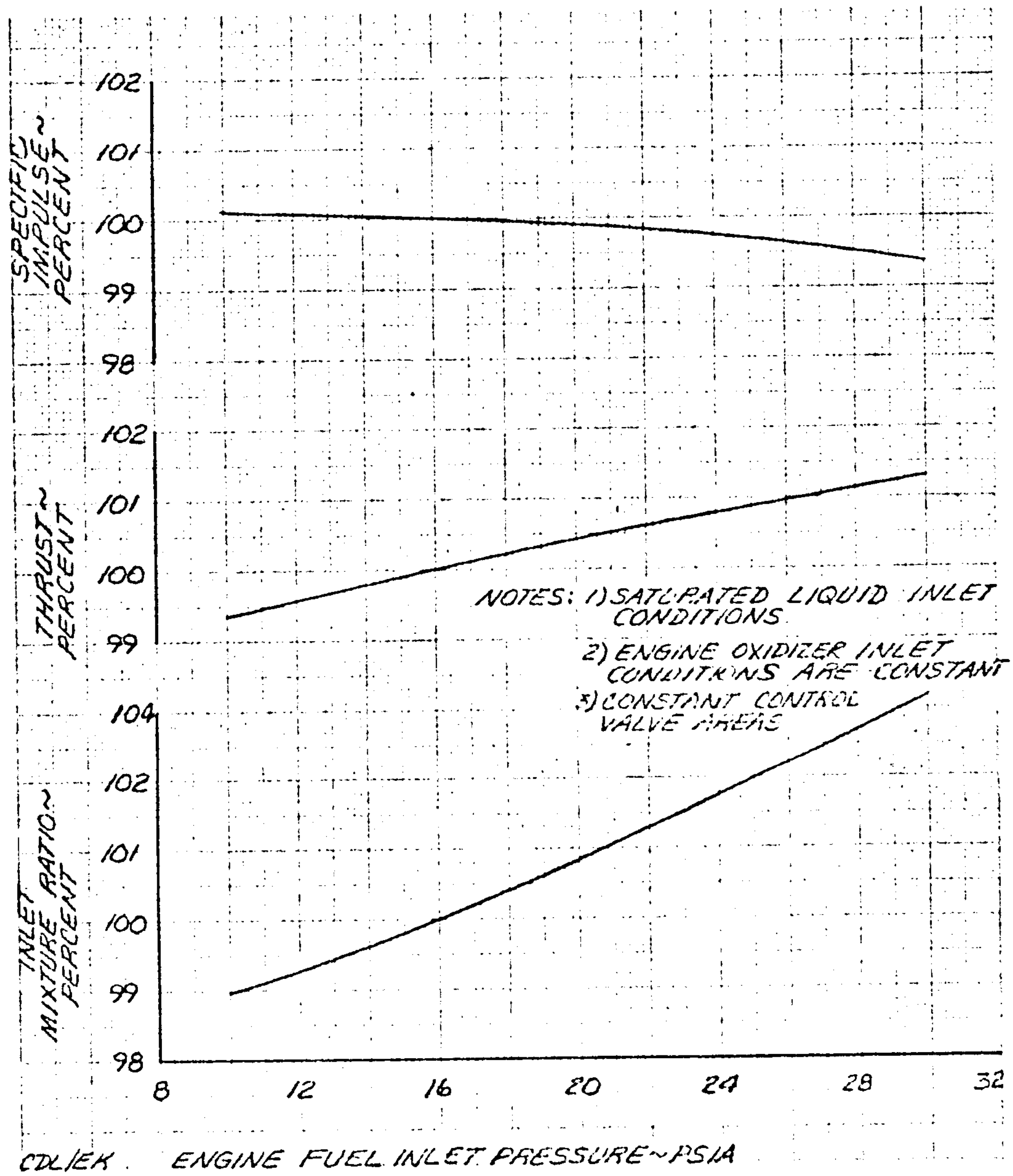


Figure C-28. Estimated Effect of Engine Fuel Inlet Pressure on Maneuver Thrust Operation, Category IV Engine

DF 96770

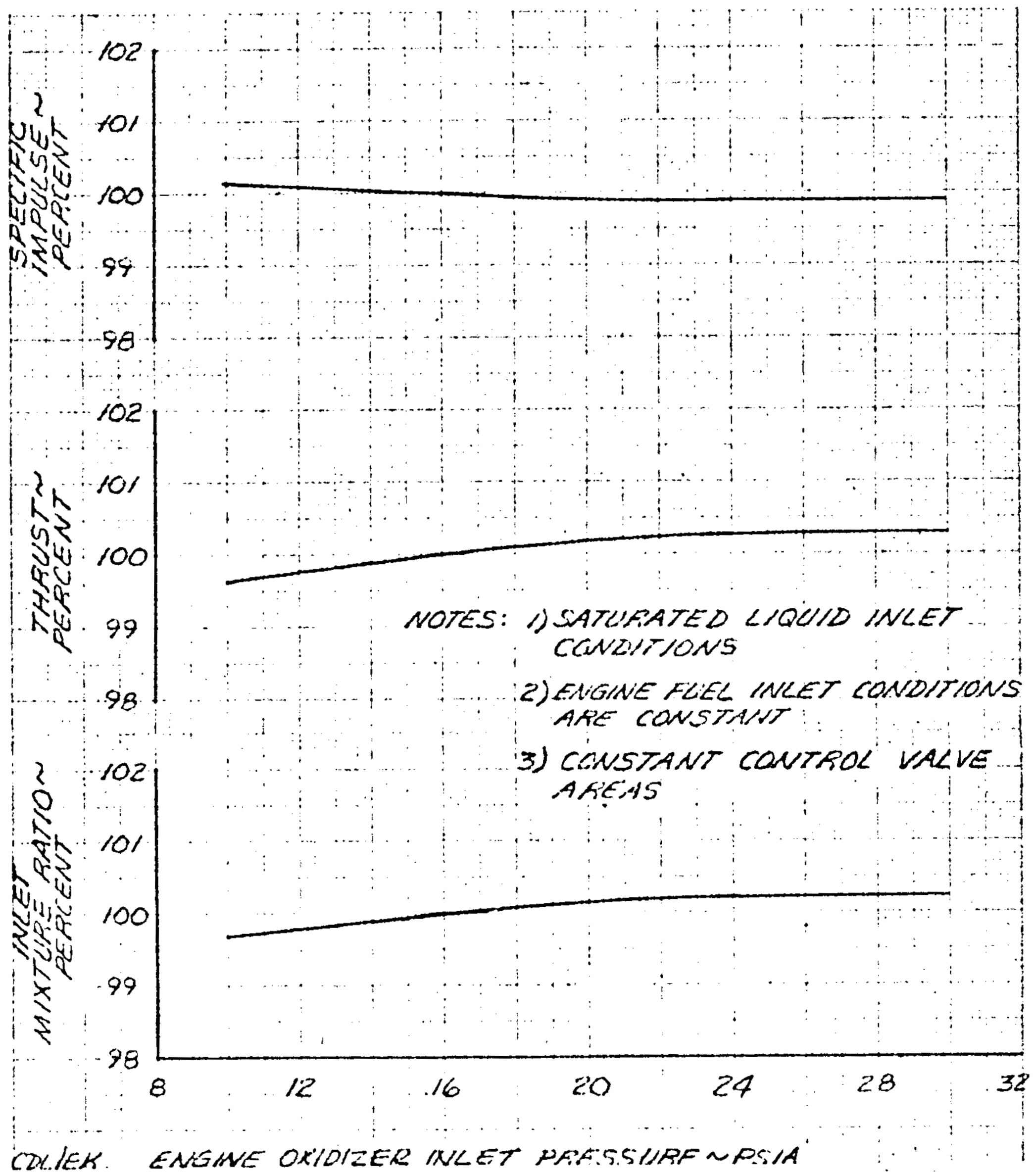


Figure C-29. Estimated Effect of Engine Oxidizer Inlet Pressure on Maneuver Thrust Operation, Category IV Engine

DF 96771

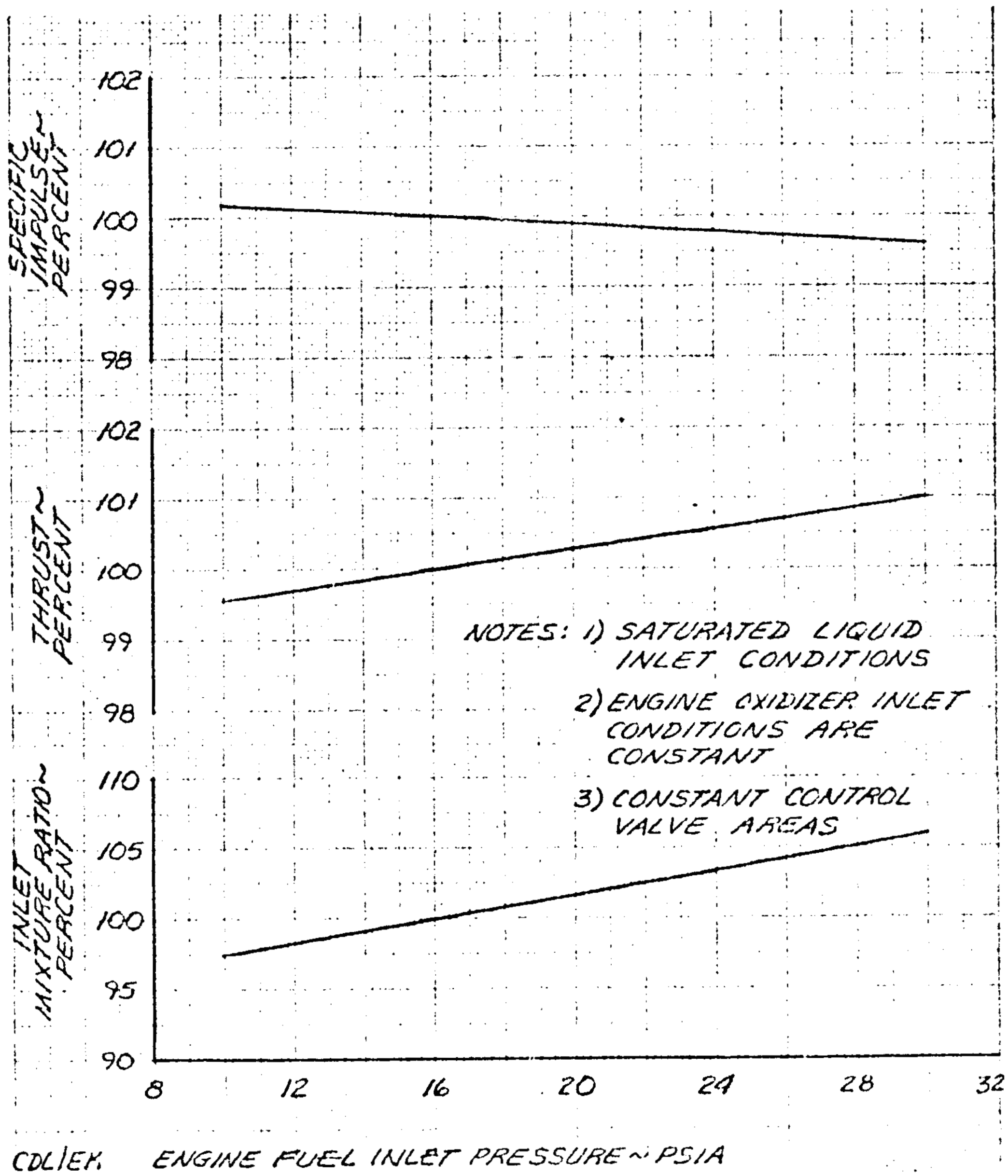


Figure C-30. Estimated Effect of Engine Fuel Inlet Pressure on Full Thrust Operation, Category IV Engine DF 96772

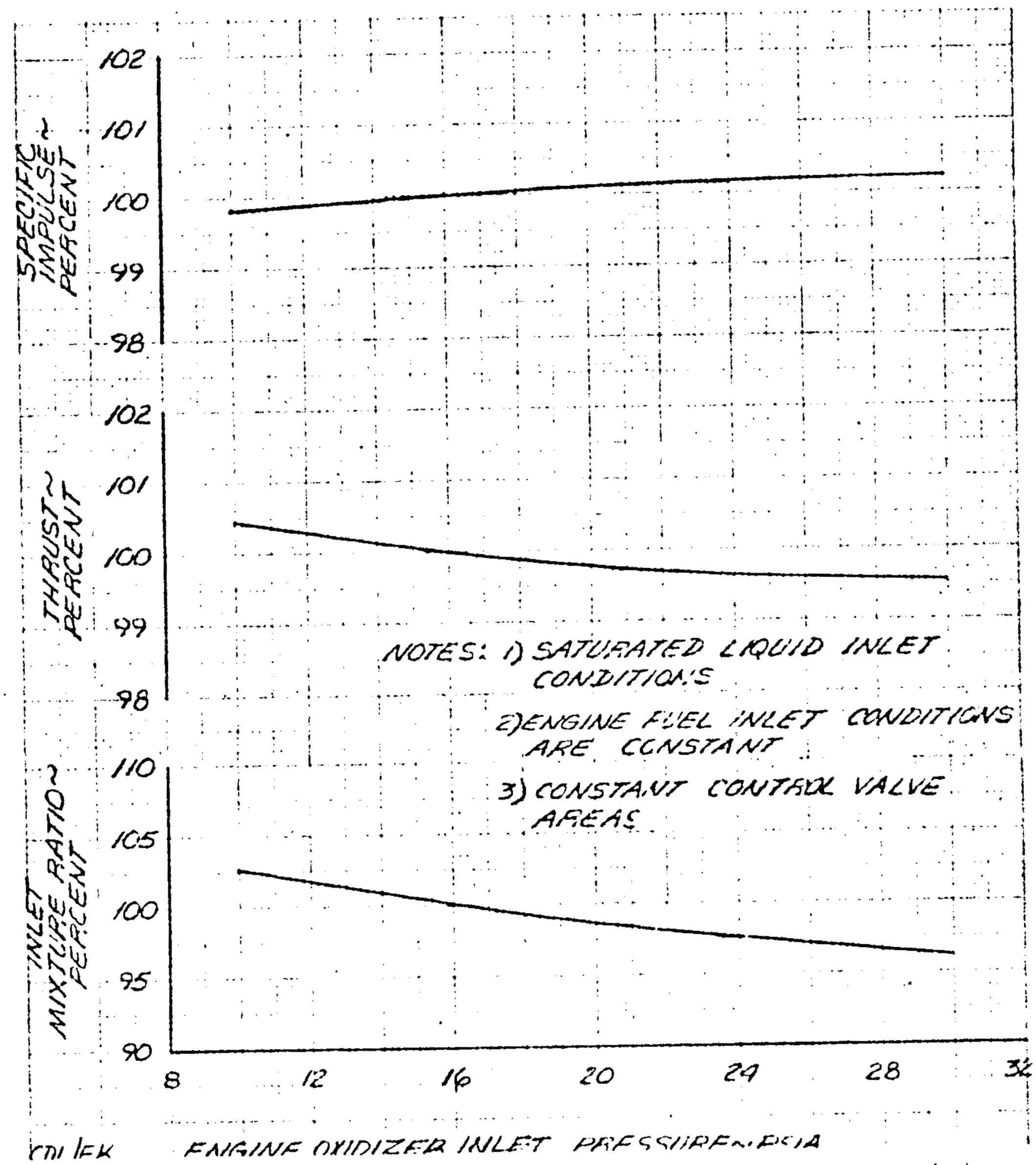


Figure C-31. Estimated Effect of Engine Oxidizer Inlet Pressure on Full Thrust Operation, Category IV Engine

DF 96773

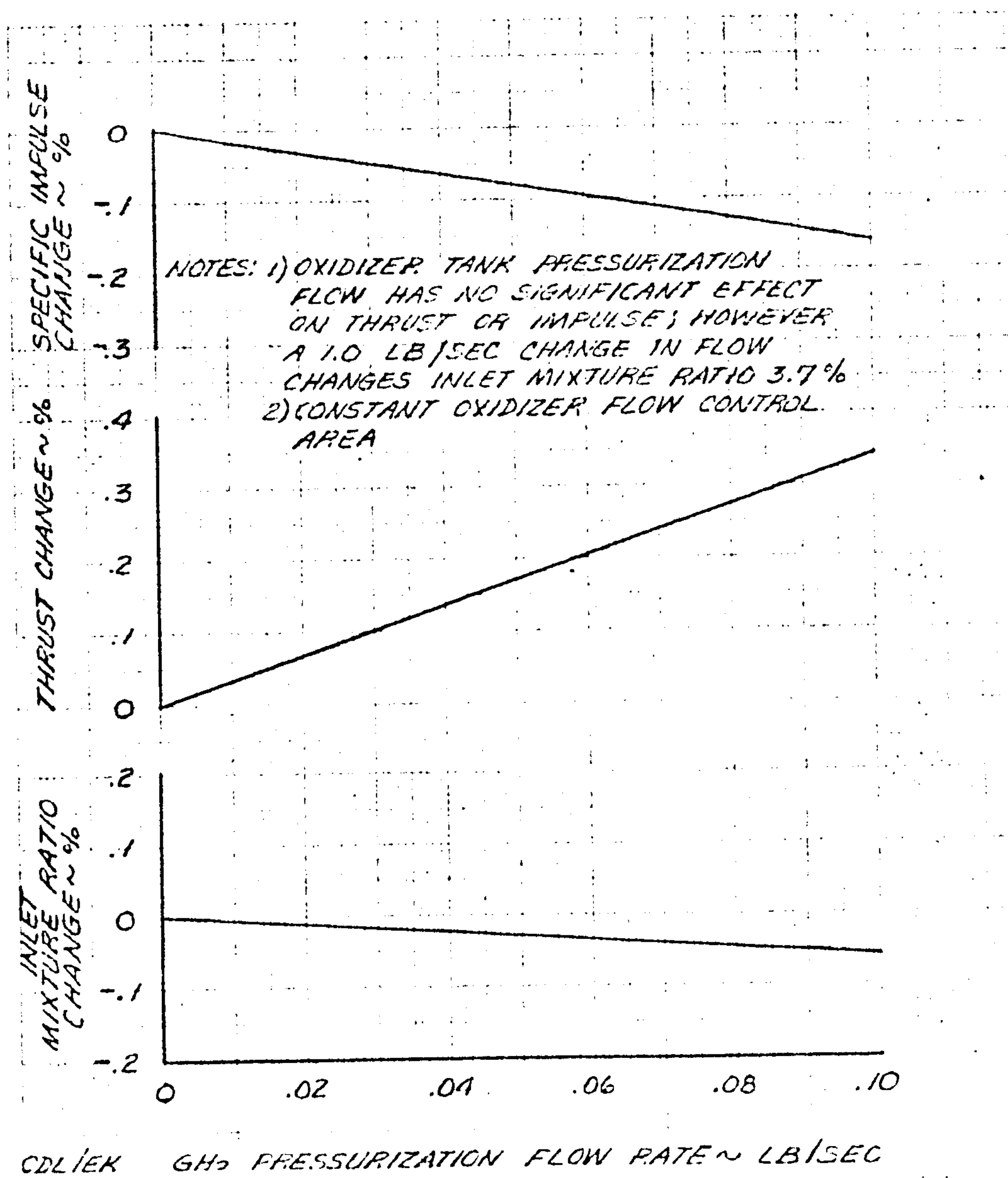


Figure C-32. Effect of Pressurization Flow on Engine Performance at Full Thrust, Category IV Engine

DF 96774

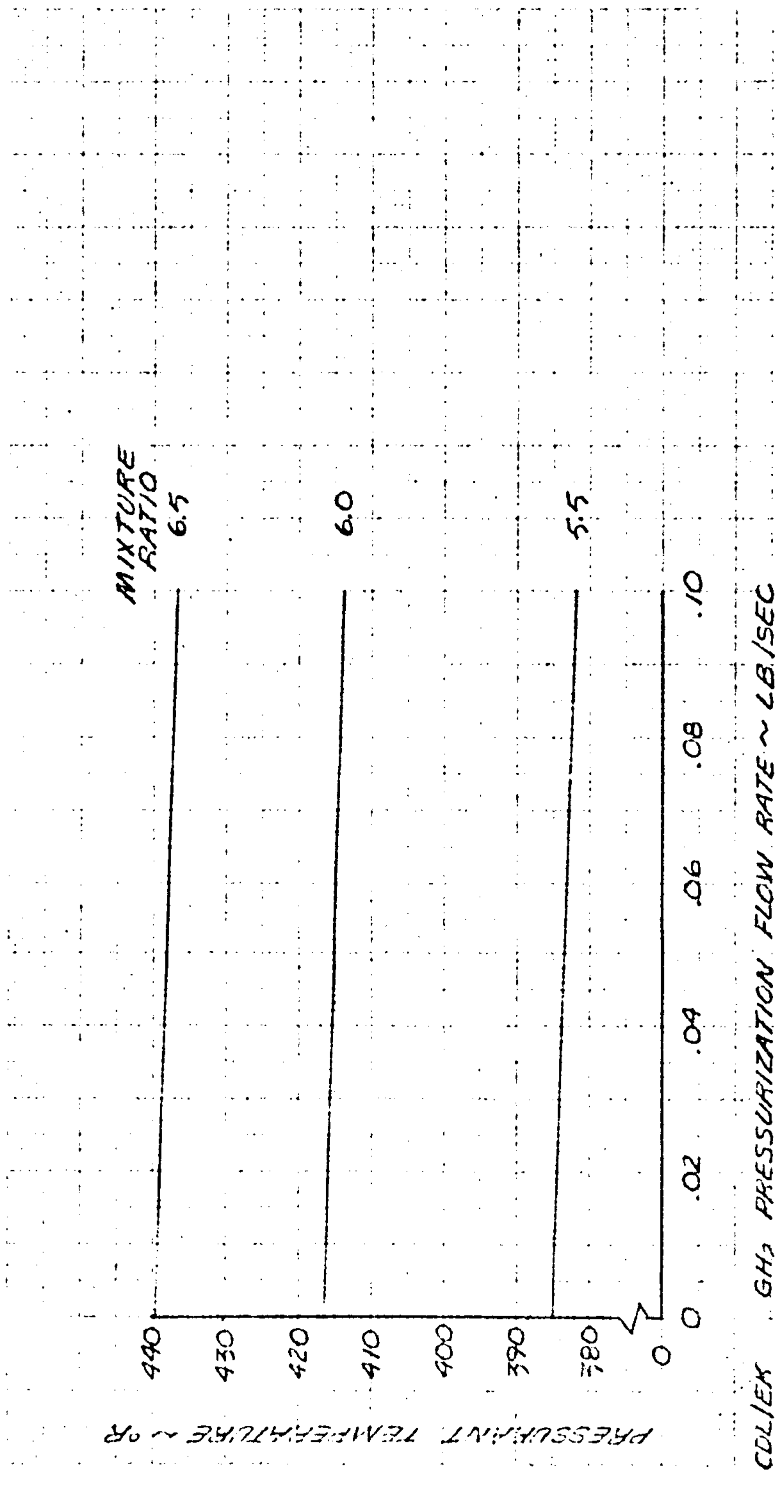


Figure C-33. Effect of Varying GH_2 Pressurization Flow on Pressurant Temperature, Category I Engine DF 94603

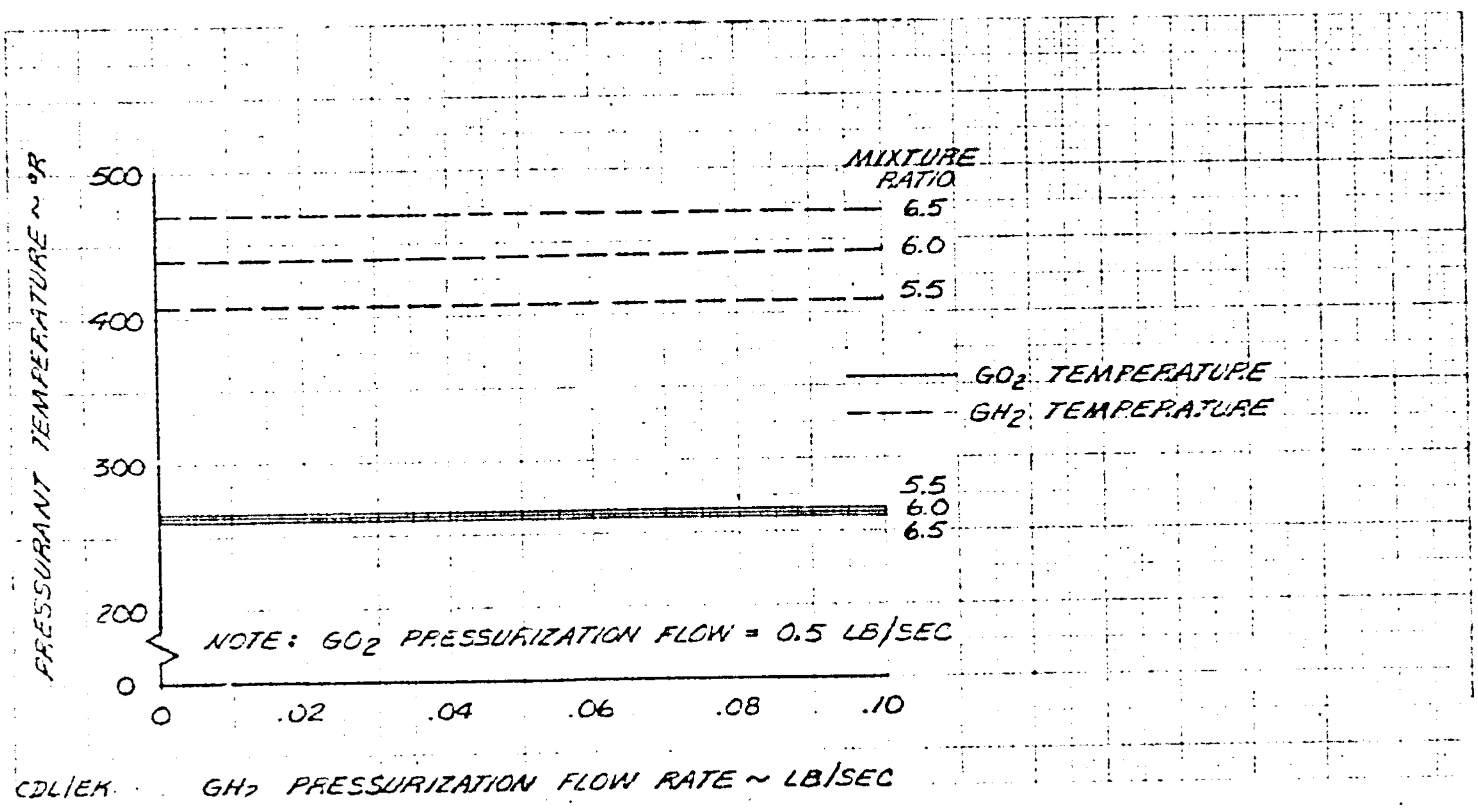


Figure C-34. Effect of Varying GH_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Derivative IIA Engine

DF 96509

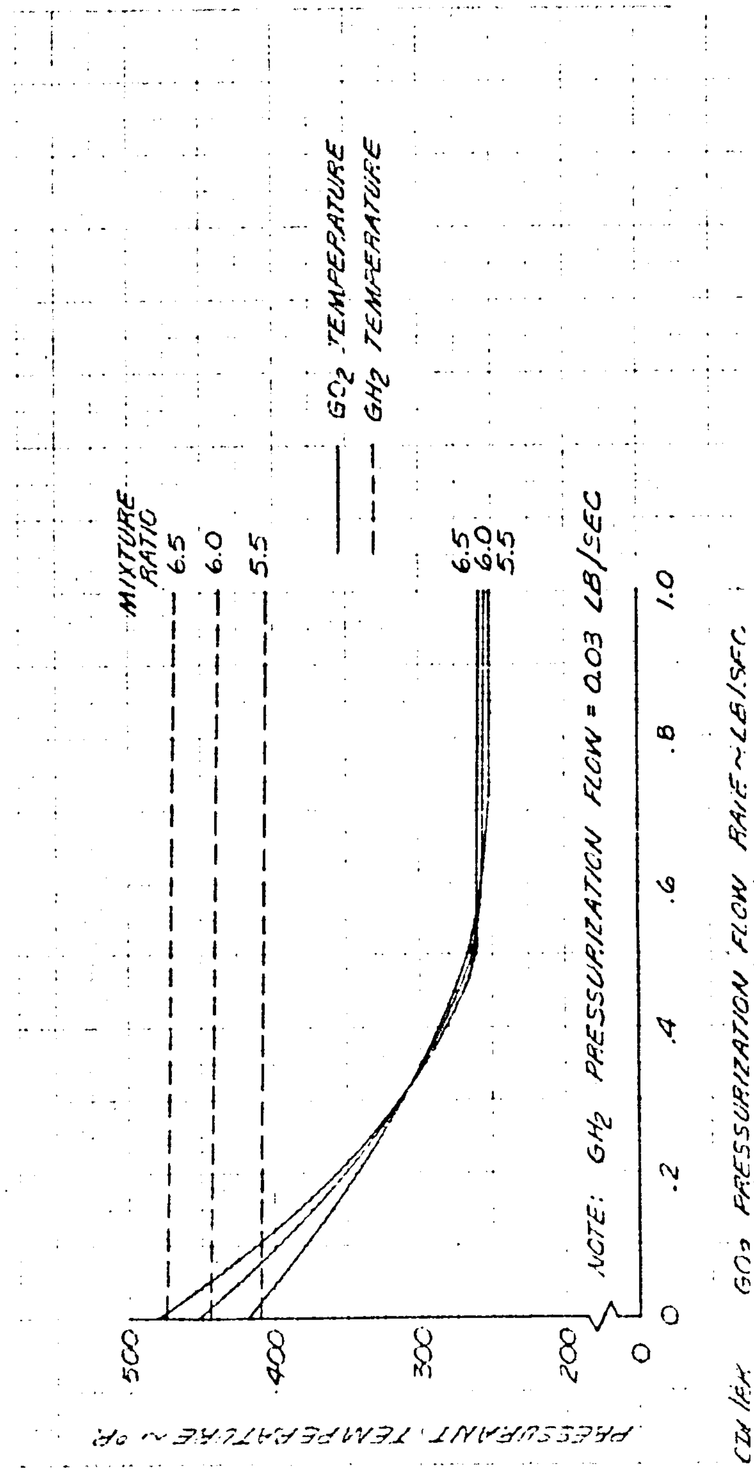
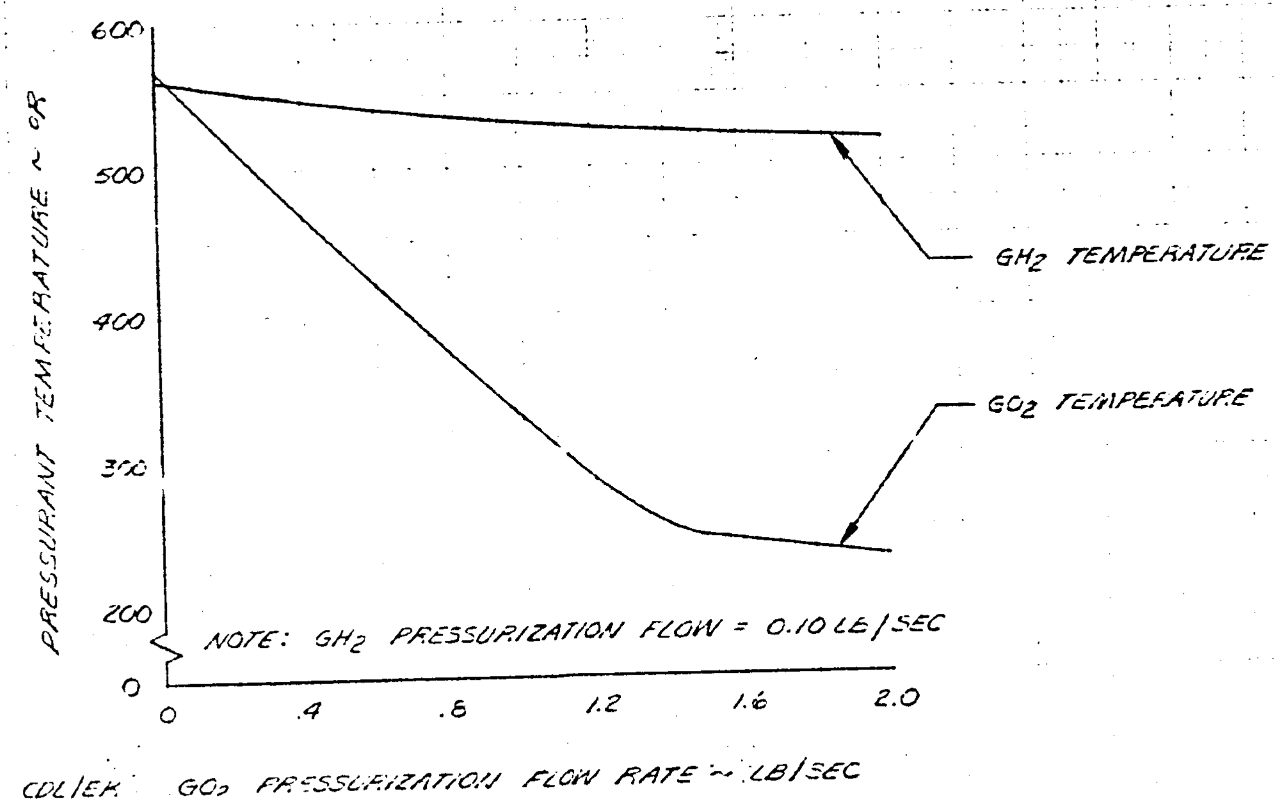


Figure C-35. Effect of Varying GO_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Derivative IIA Engine

DF 96510



DF 96424

Figure C-36. Effect of Varying GO_2 Pressurization Flow on Pressurant Temperature, Derivative IIB Engine, Pumped Idle Operation

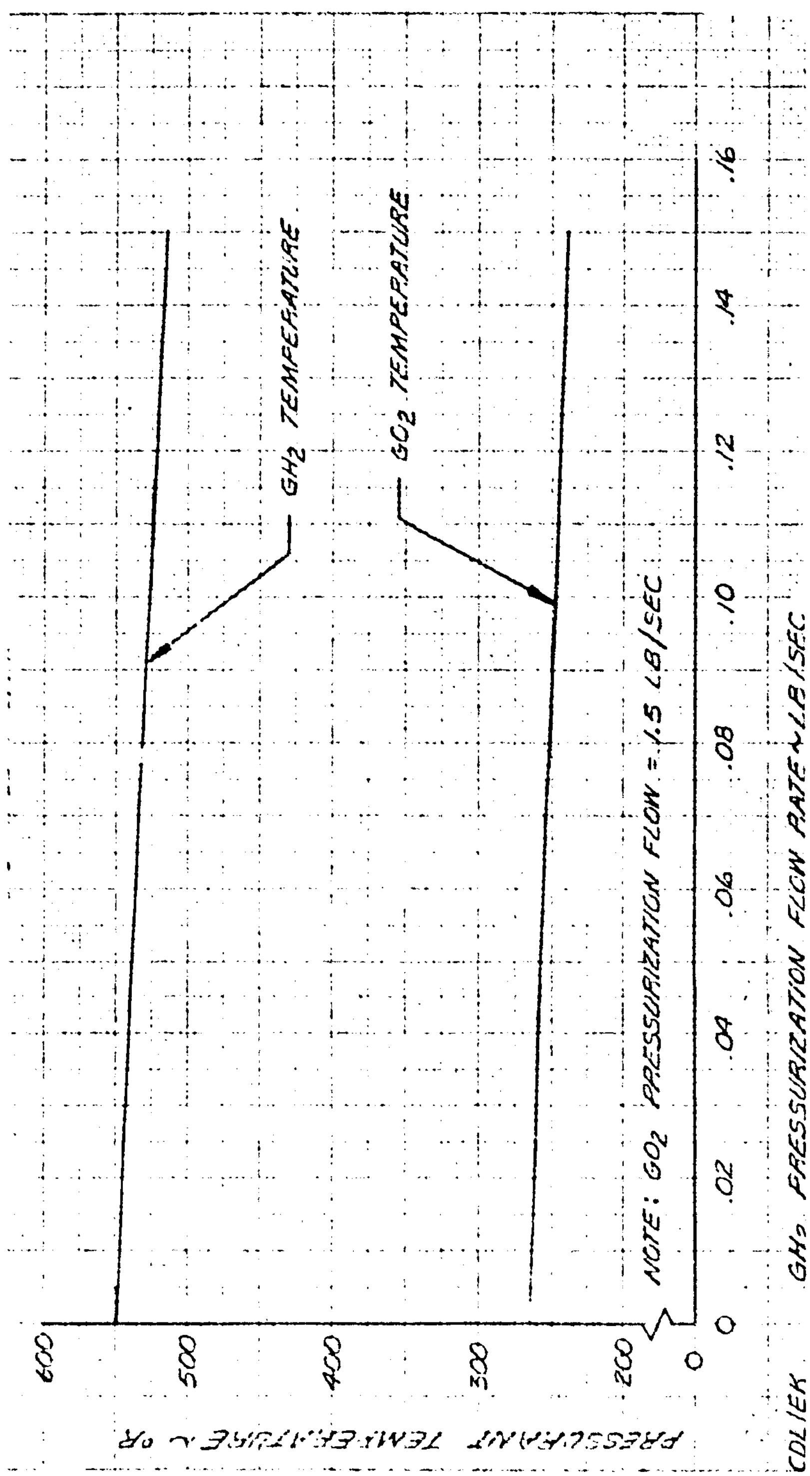


Figure C-37. Effect of Varying GH_2 Pressurization Flow on Pressurant Temperature, Derivative IIB Engine, Pumped Idle Operation

DF 96425

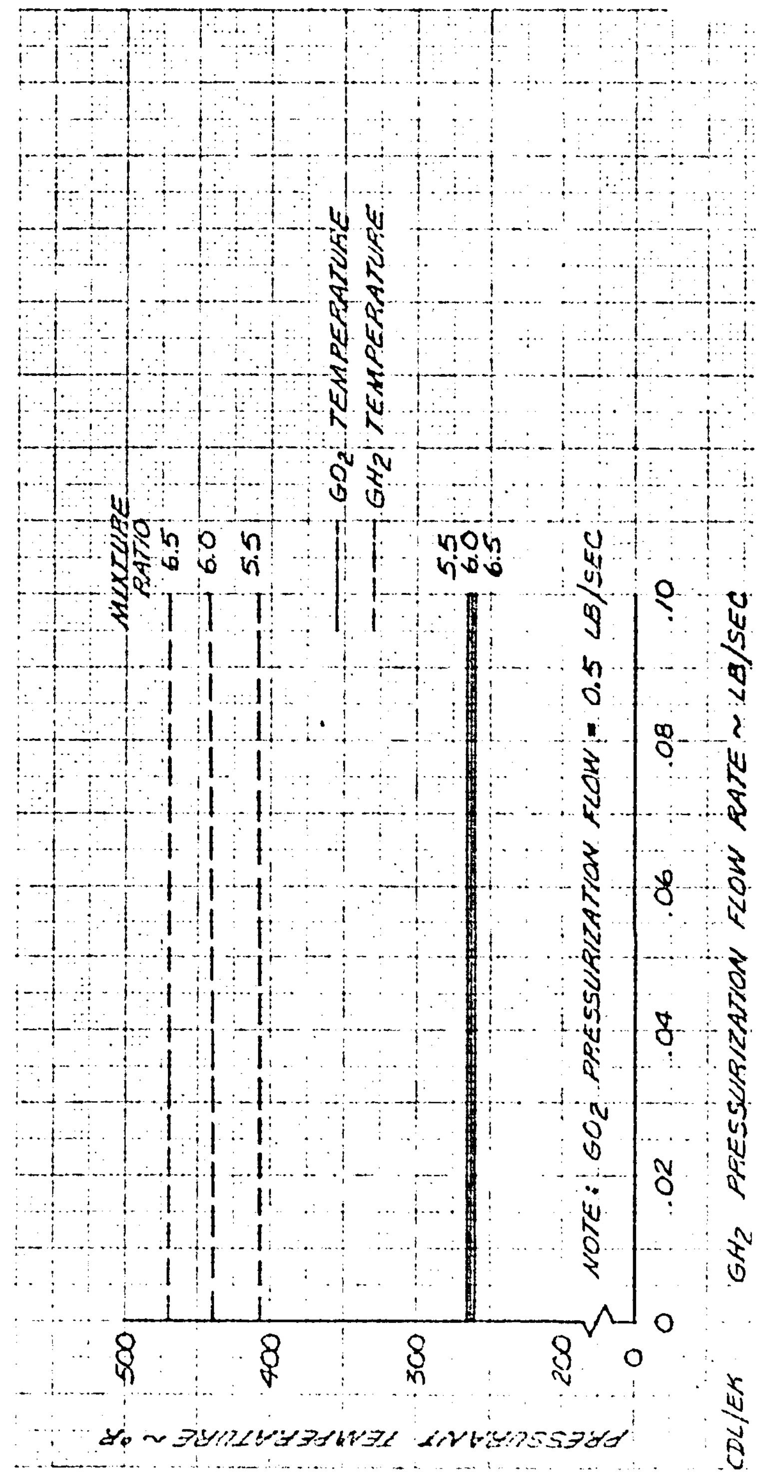


Figure C-38. Effect of Varying GH_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Derivative IIB Engine

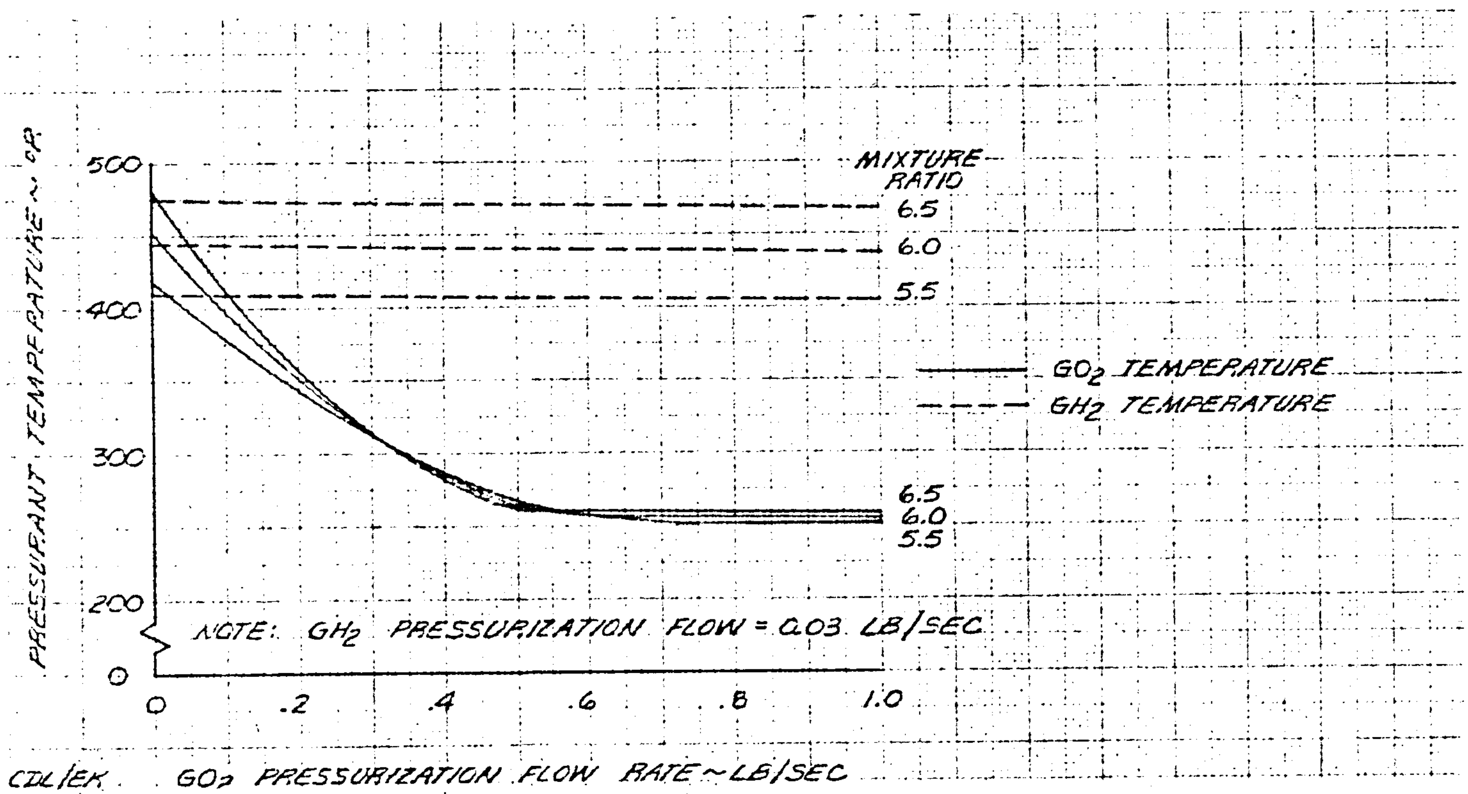


Figure C-39. Effect of Varying GO_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Derivative IIB Engine DF 96428

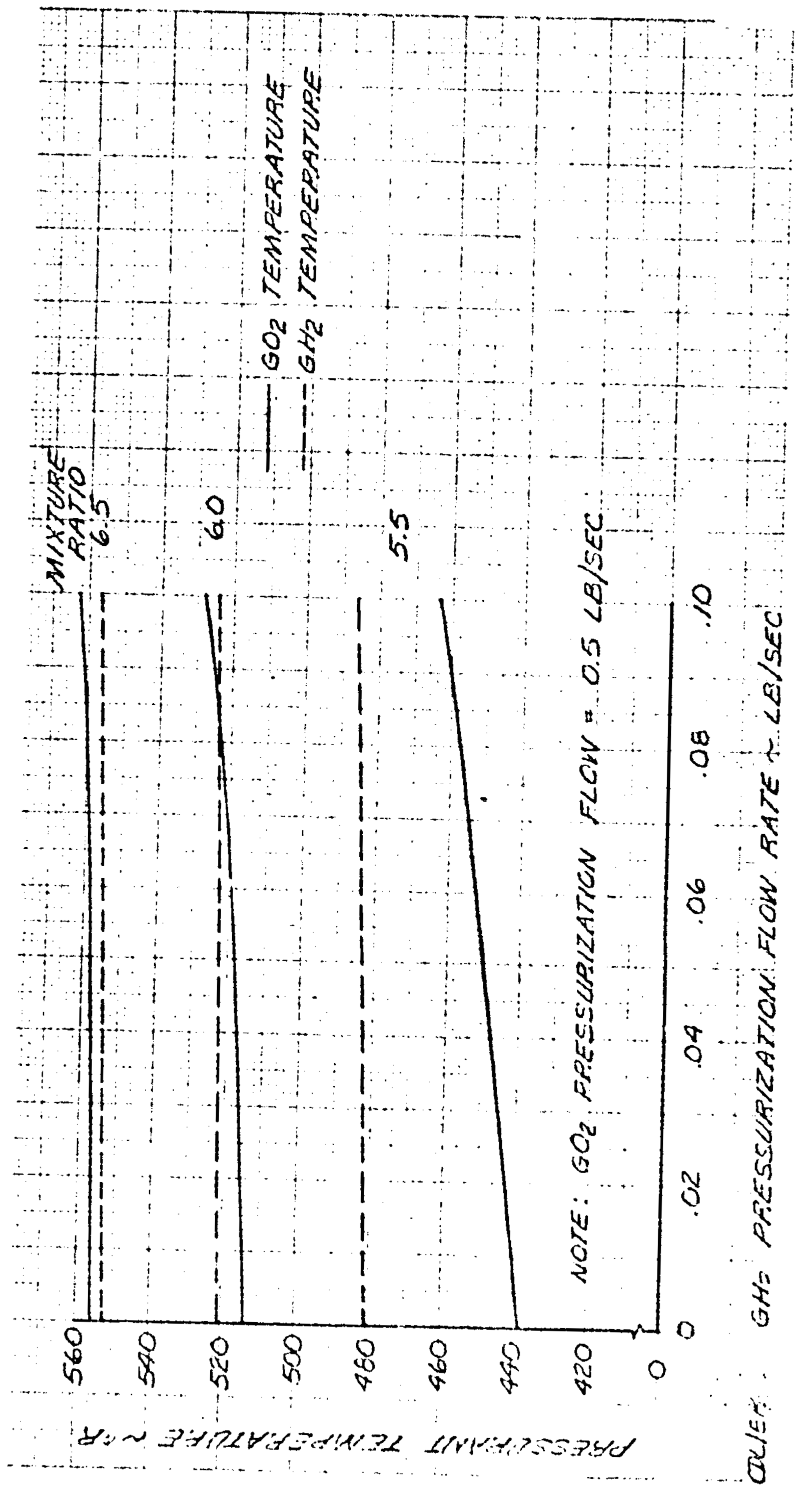


Figure C-40. Effect of Varying GH_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Category IV Engine

DF 96594

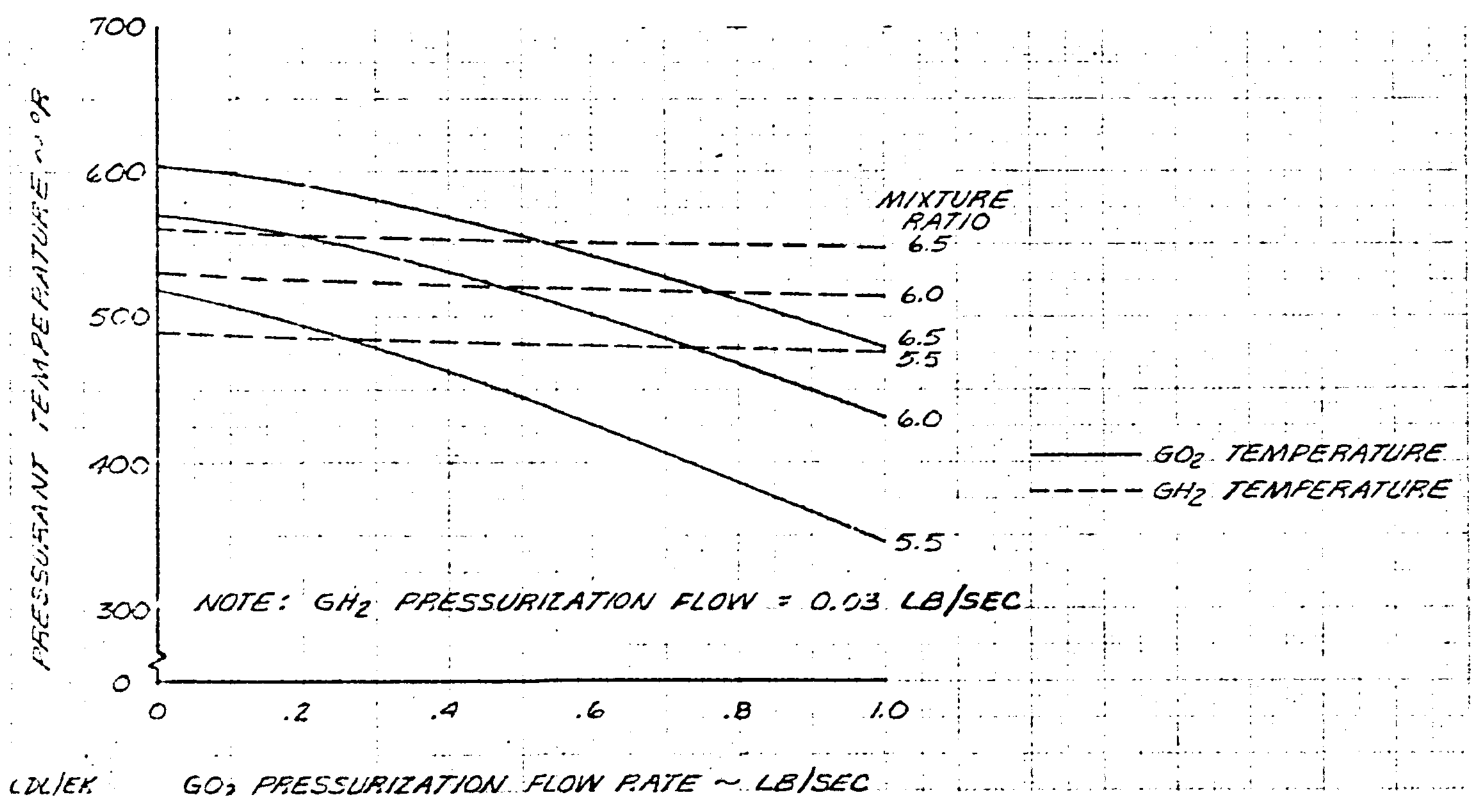
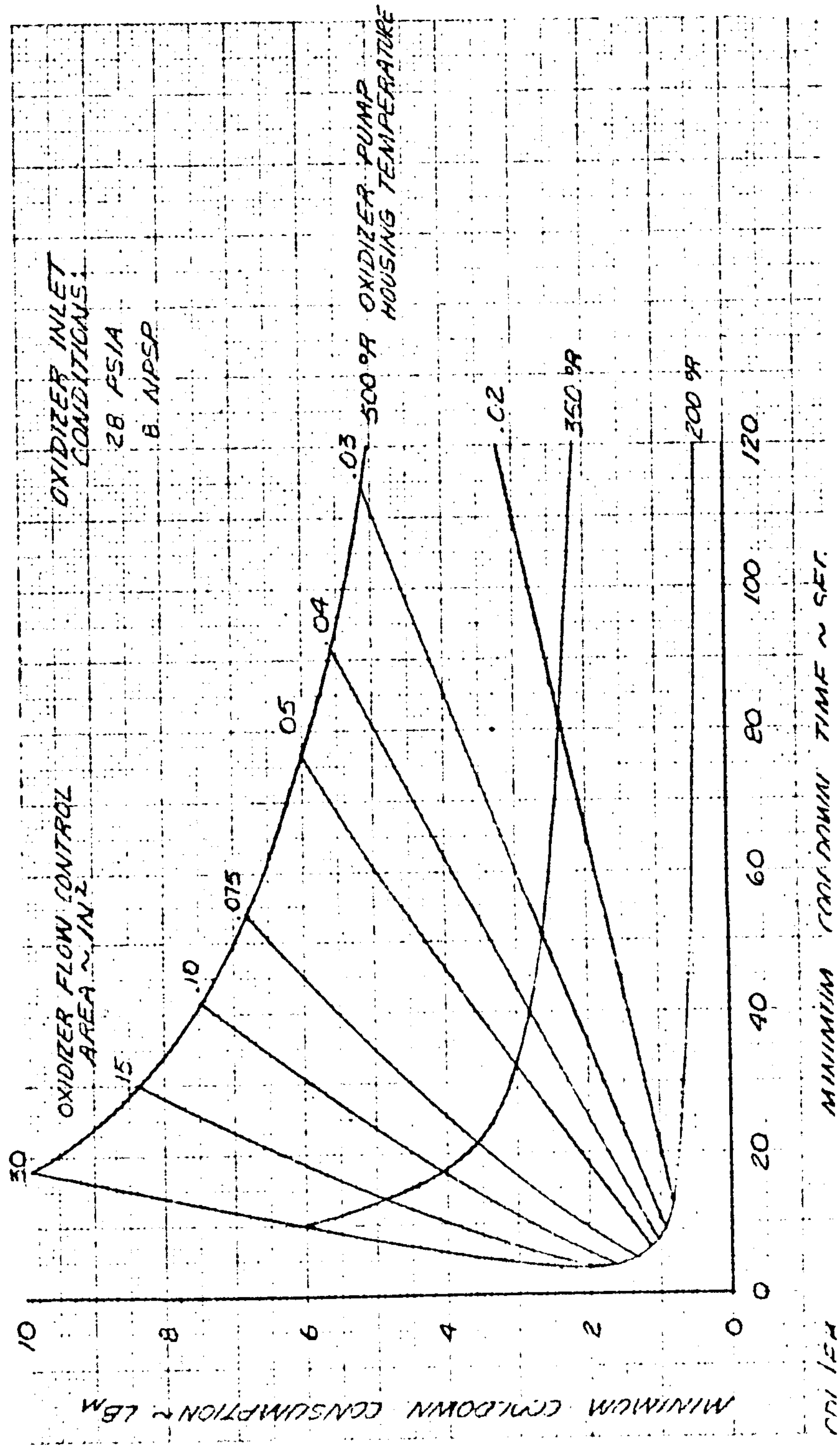


Figure C-41. Effect of Varying GO_2 Pressurization Flow on Pressurant Temperature at Full Thrust Operation, Category IV Engine DF 96604



DF 95443

Figure C-42. Oxidizer Cooldown Consumption Characteristics, Category I Engine, 28 psia, 8 NPSP

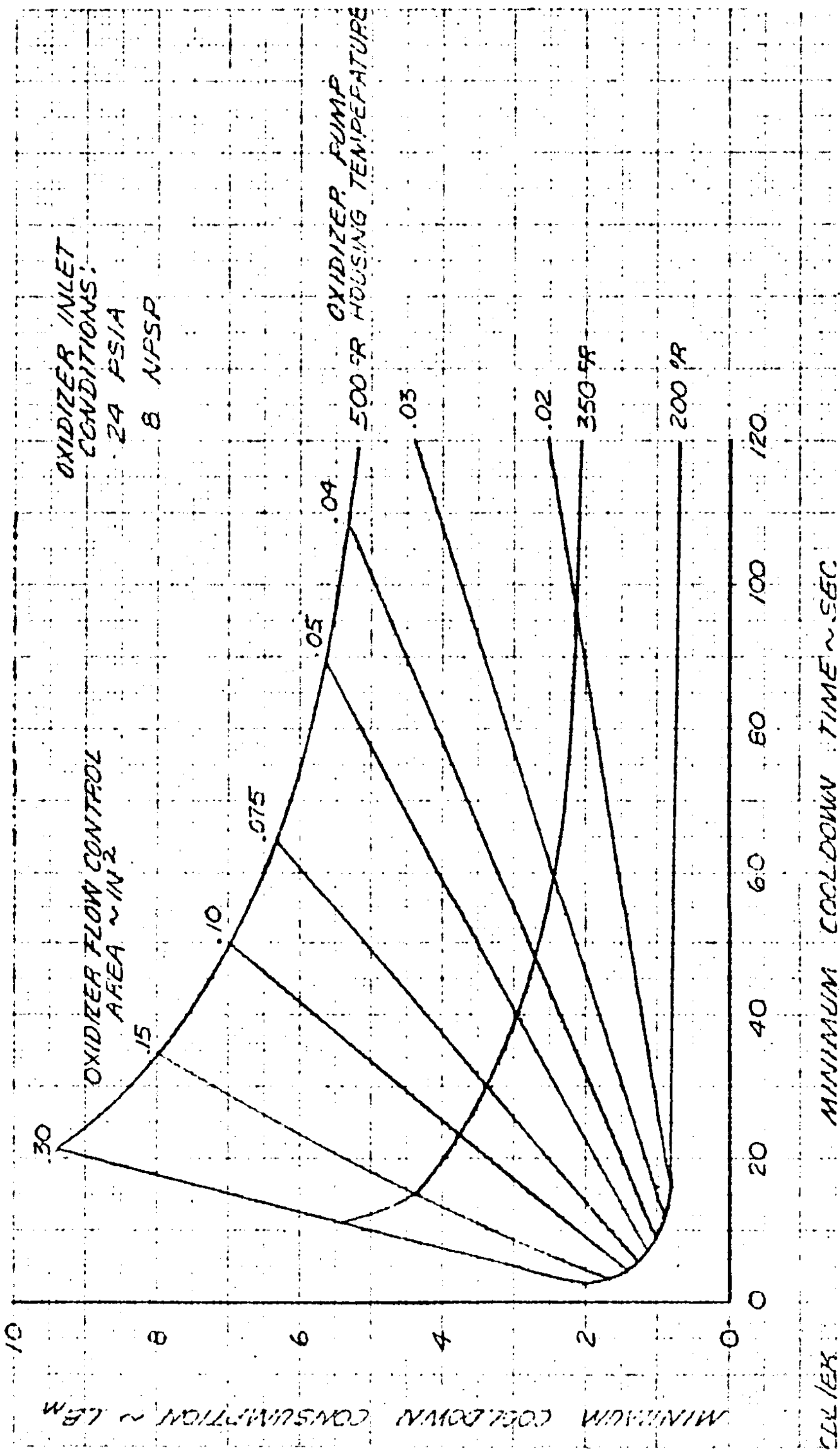


Figure C-43. Oxidizer Cooldown Consumption Characteristics, Category I Engine, 24 psia, 8 NPSP DF 95444

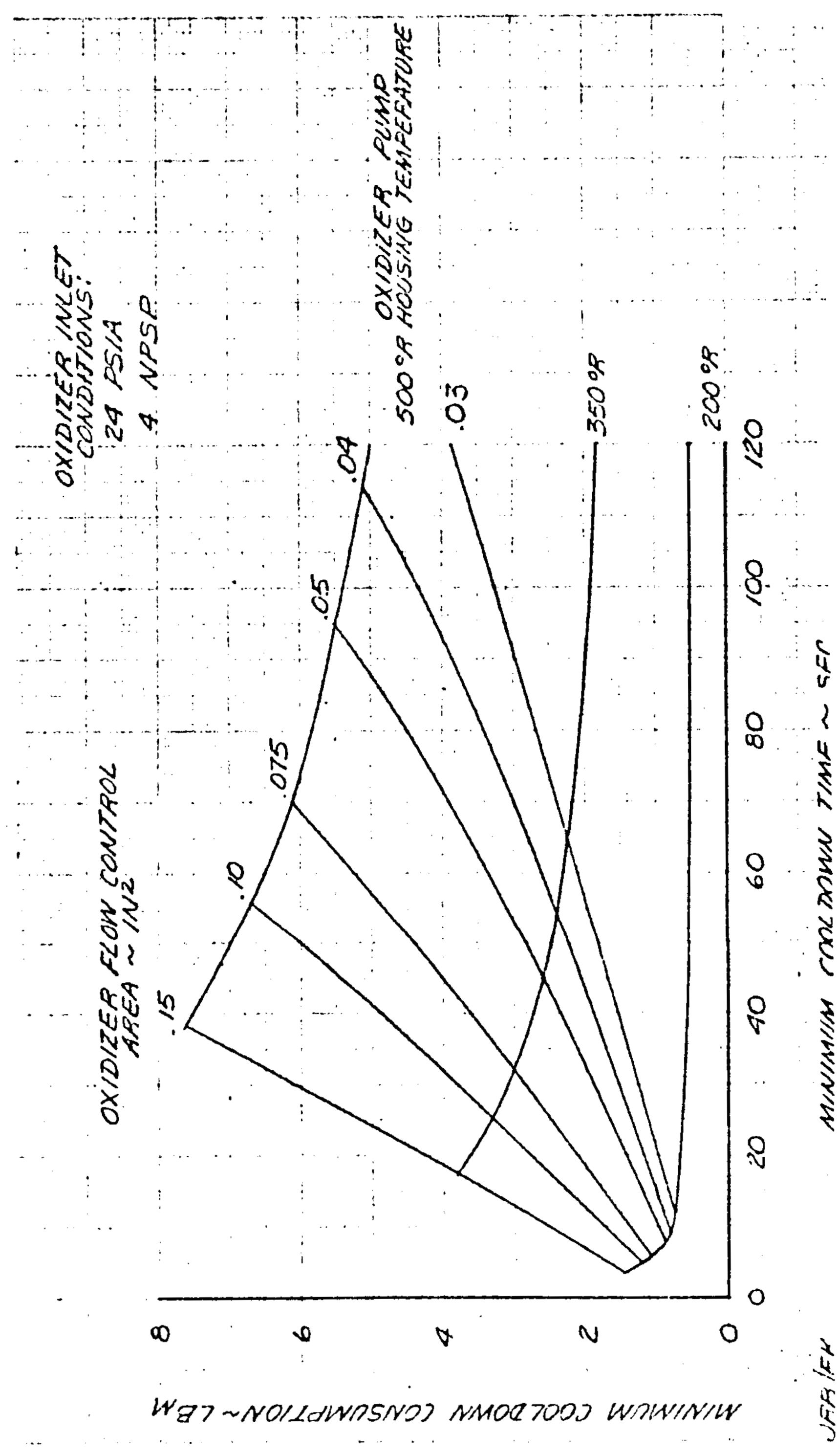


Figure C-44. Oxidizer Cooldown Consumption Characteristics, Category I Engine, 24 psia, 4 NPSP DF 96609

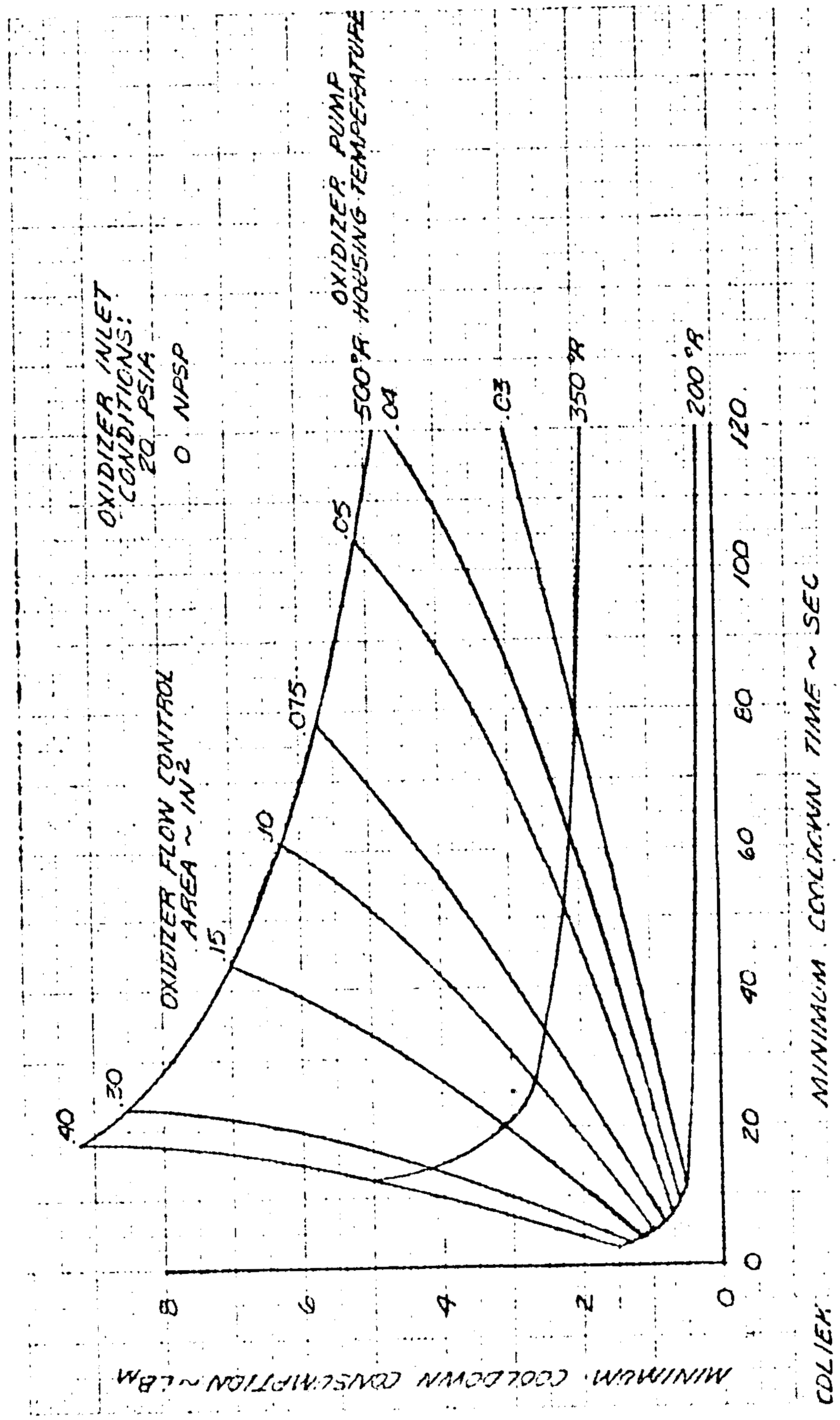


Figure C-45. Oxidizer Cooldown Consumption Characteristics, Category I Engine, 20 psia, 0 NPSP

DF 95445

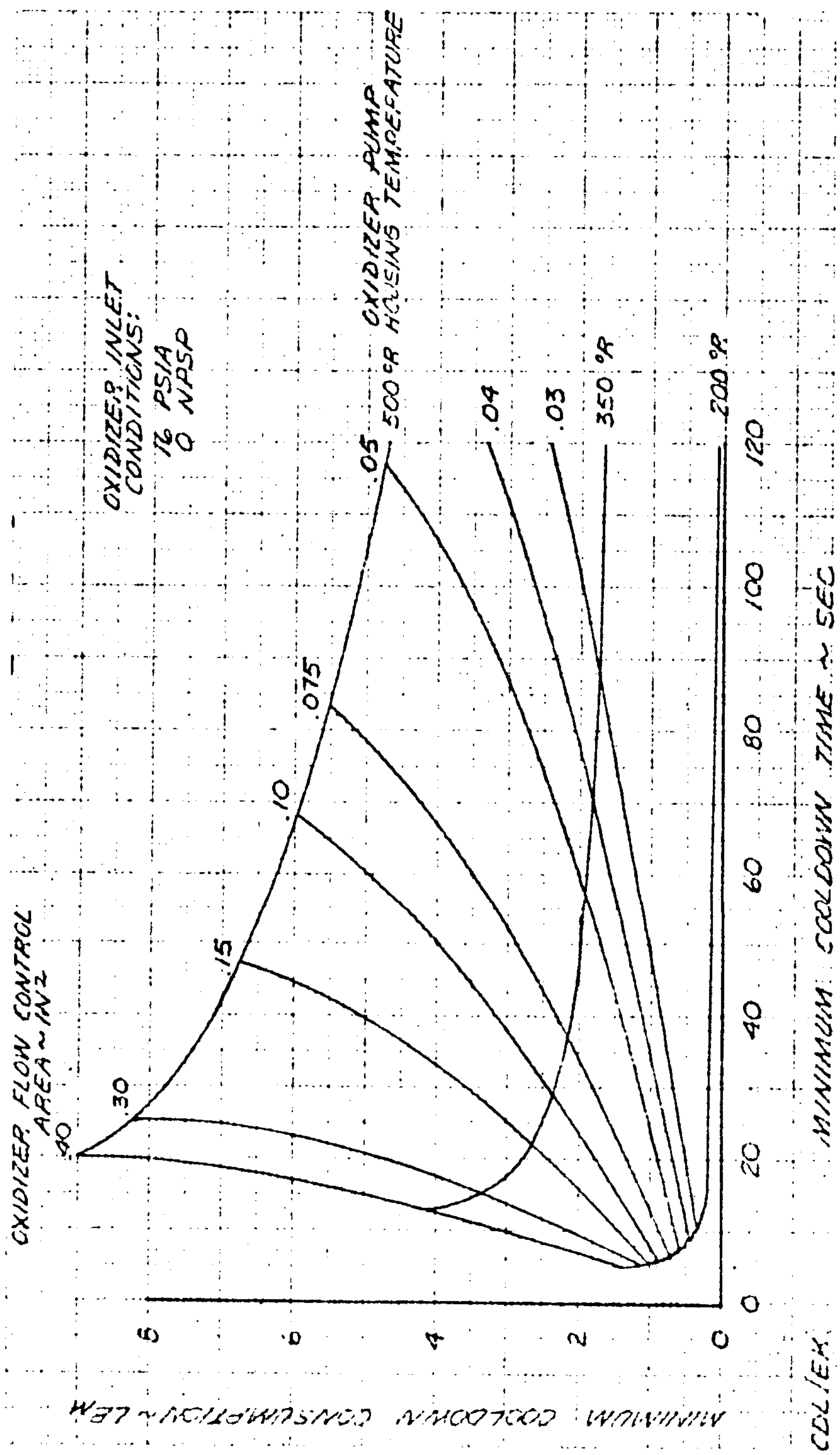


Figure C-46. Oxidizer Cooldown Consumption Characteristics, Category I Engine, 16 psia, 0-NPSP DF 95446

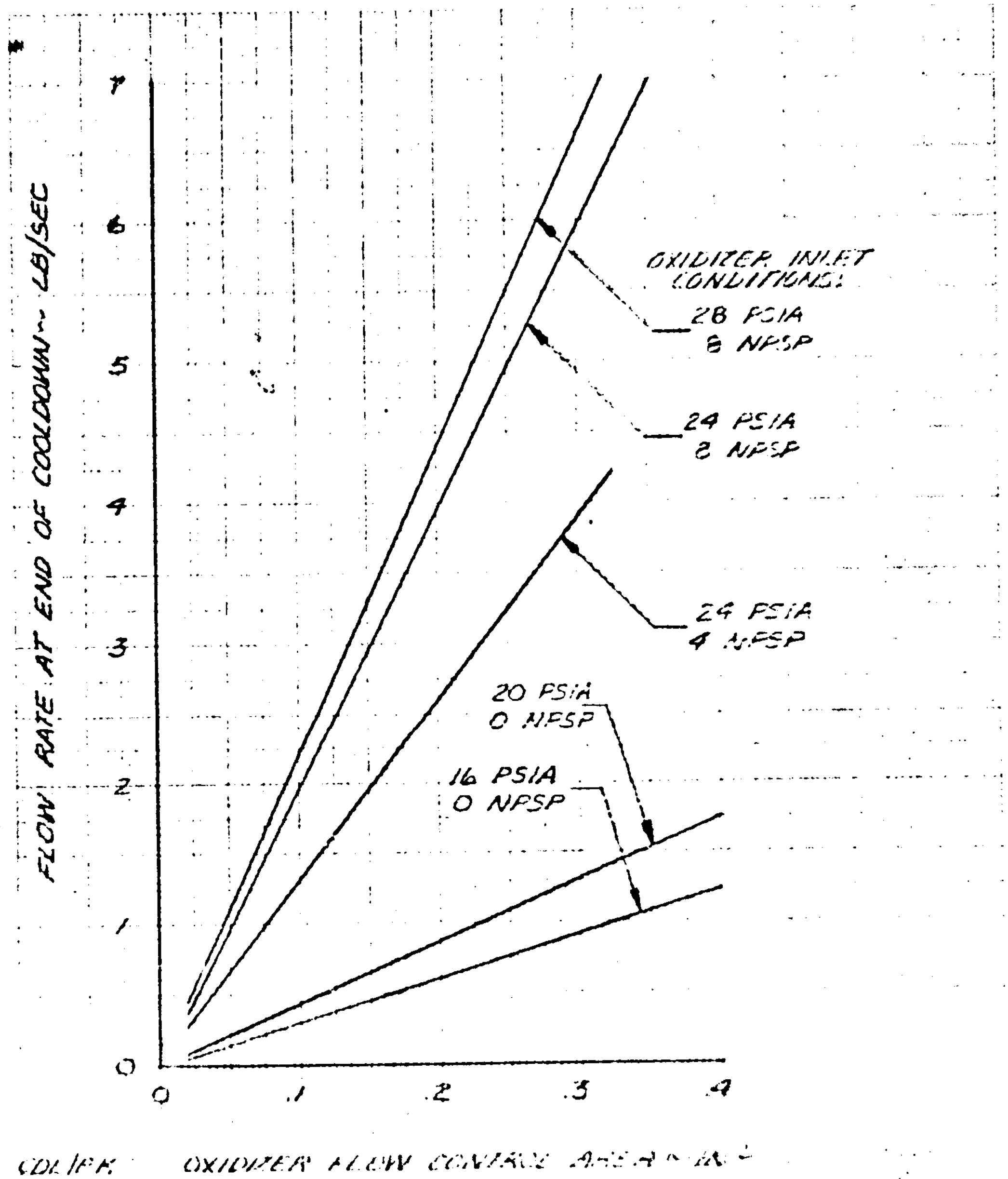


Figure C-47. Oxidizer Cooldown Final Flowrate Characteristics, Category I Engine

DF 95447

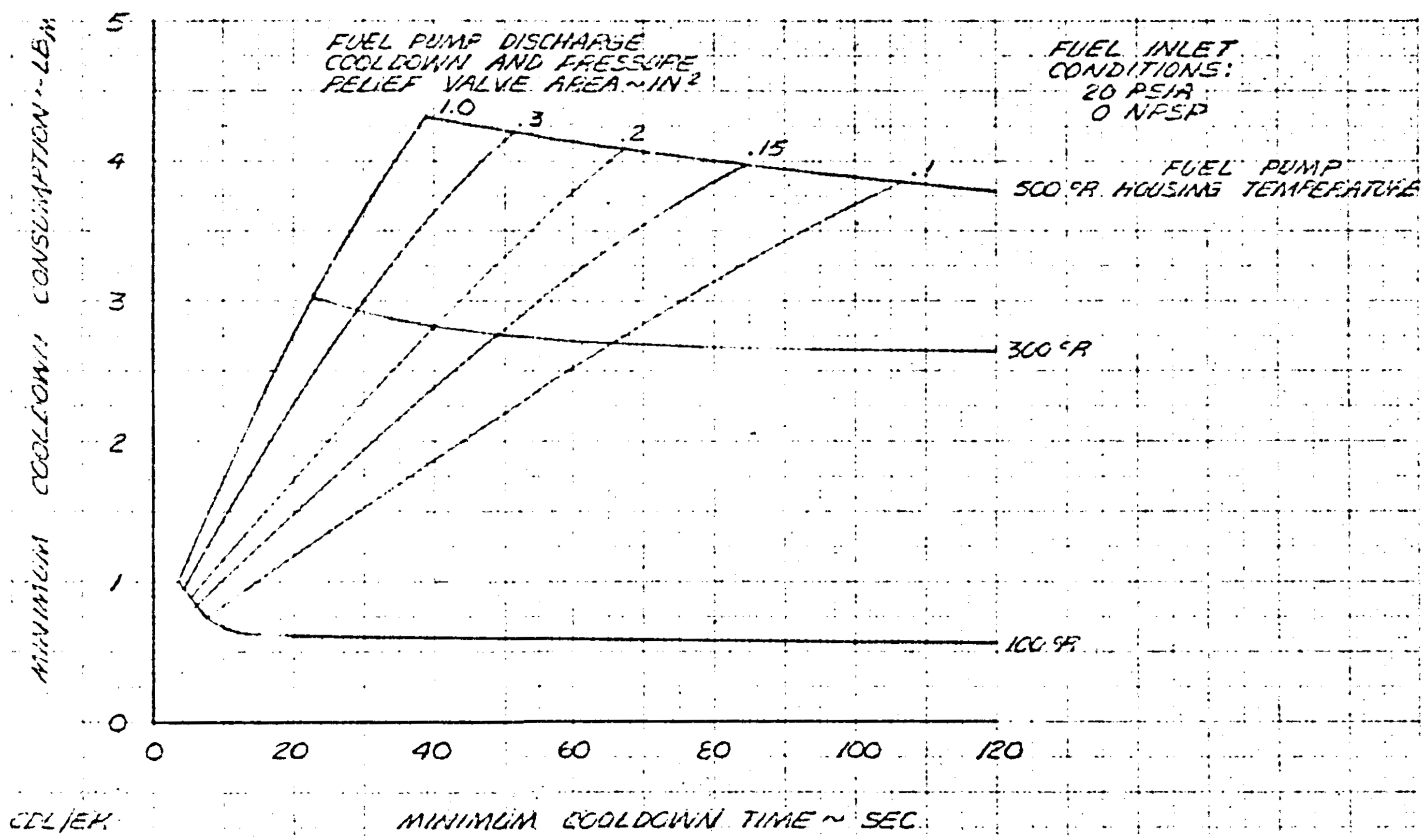


Figure C-48. Fuel Cooldown Consumption Characteristics, Category I Engine, 20 psia, 0 NPSP

DF 95633

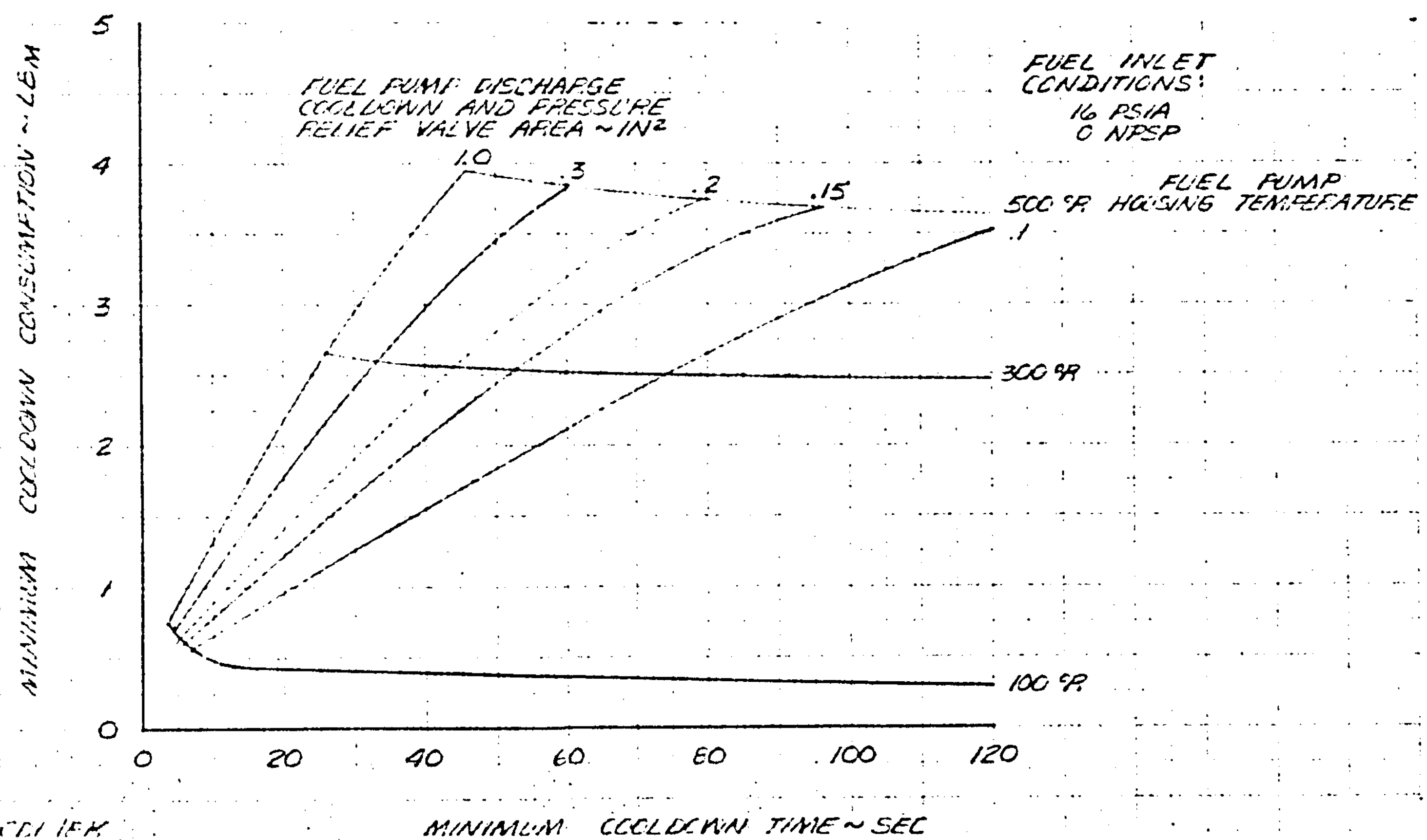


Figure C-49. Fuel Cooldown Consumption Characteristics, Category I Engine, 16 psia, 0 NPSP DF 95634

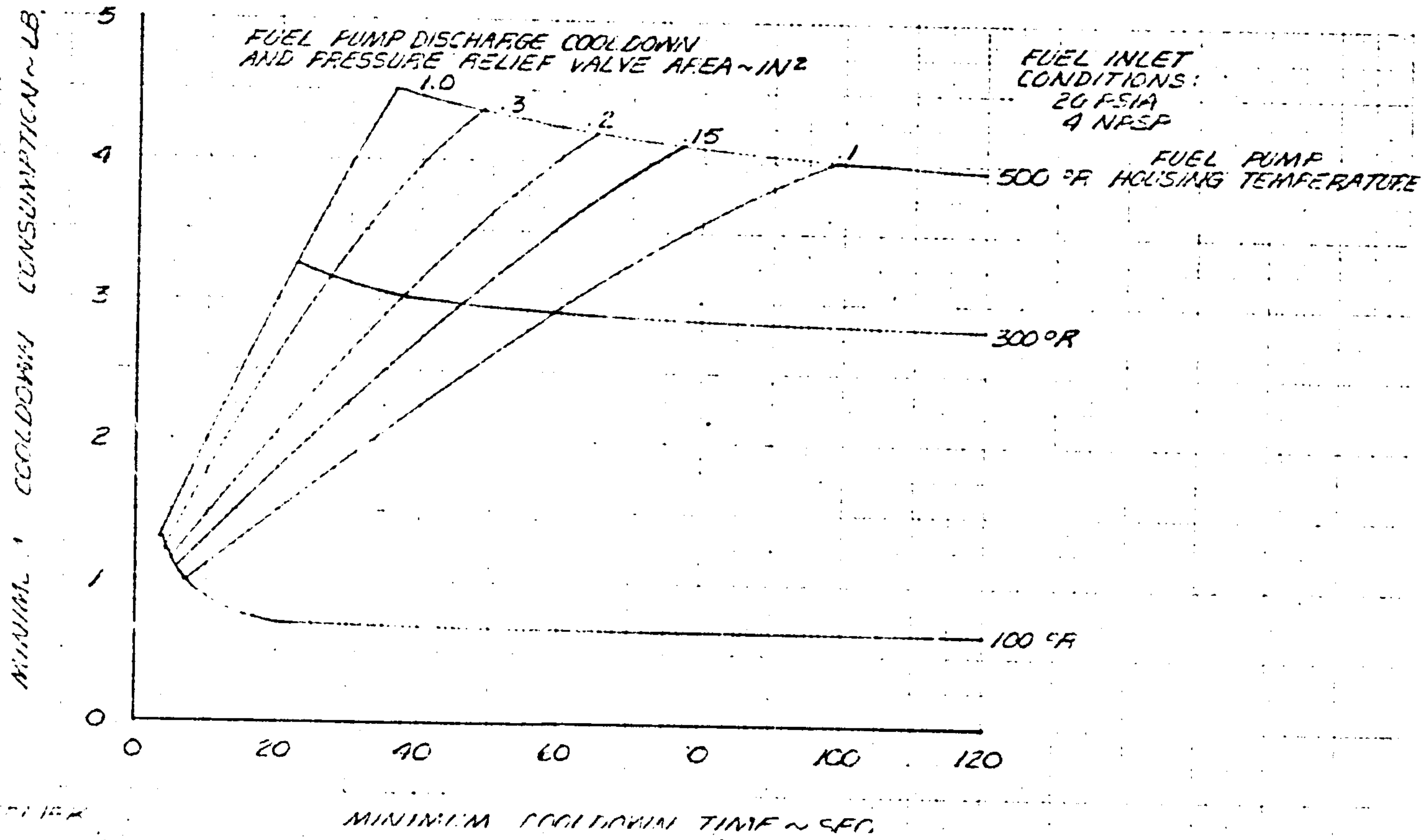


Figure C-50. Fuel Cooldown Consumption Characteristics, Category I Engine, 20 psia, 4 NPSP

DF 95635

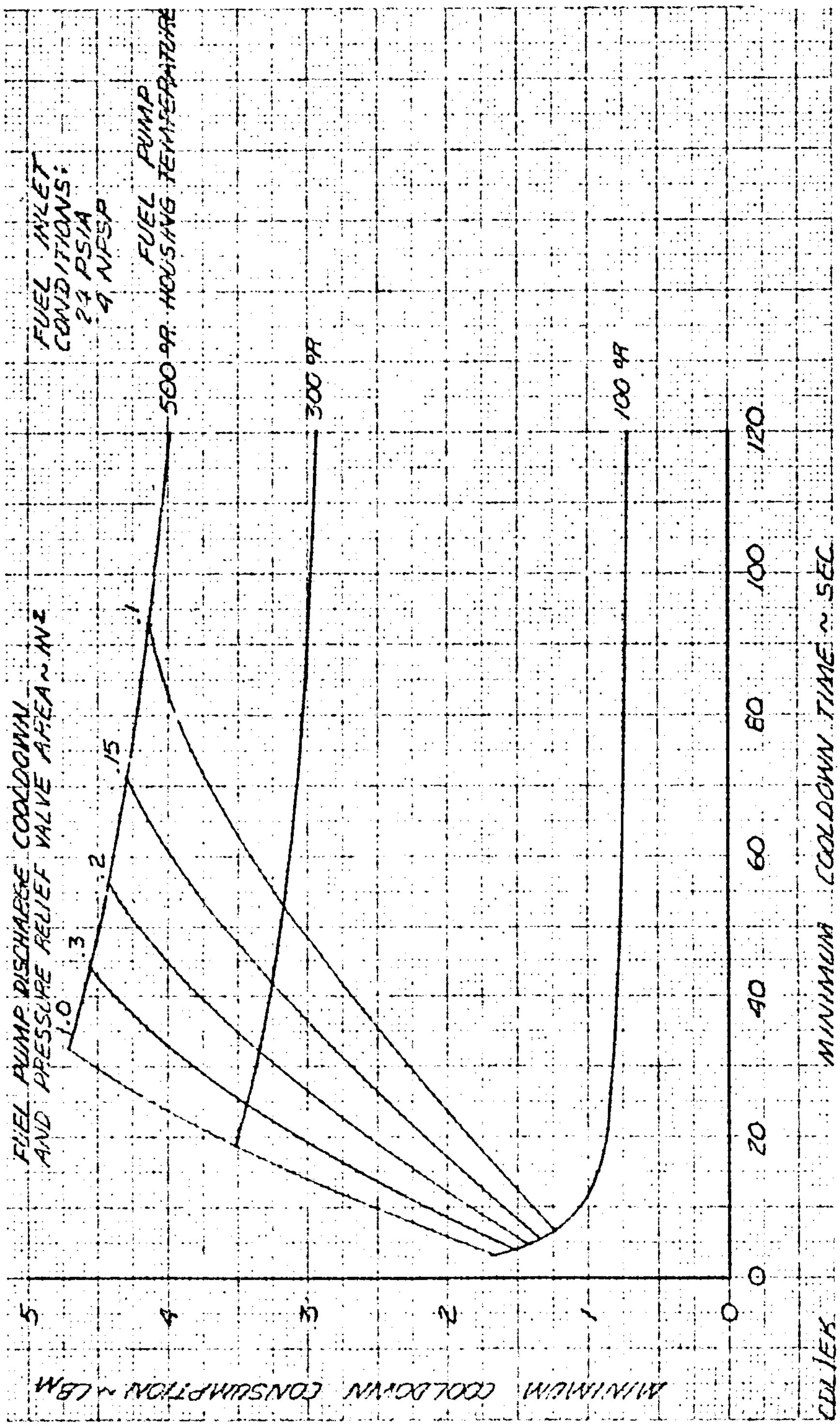


Figure C-51. Fuel Cooldown Consumption Characteristics, Category I Engine, 24 psia, 4 NPSP

DF 95636

C-2

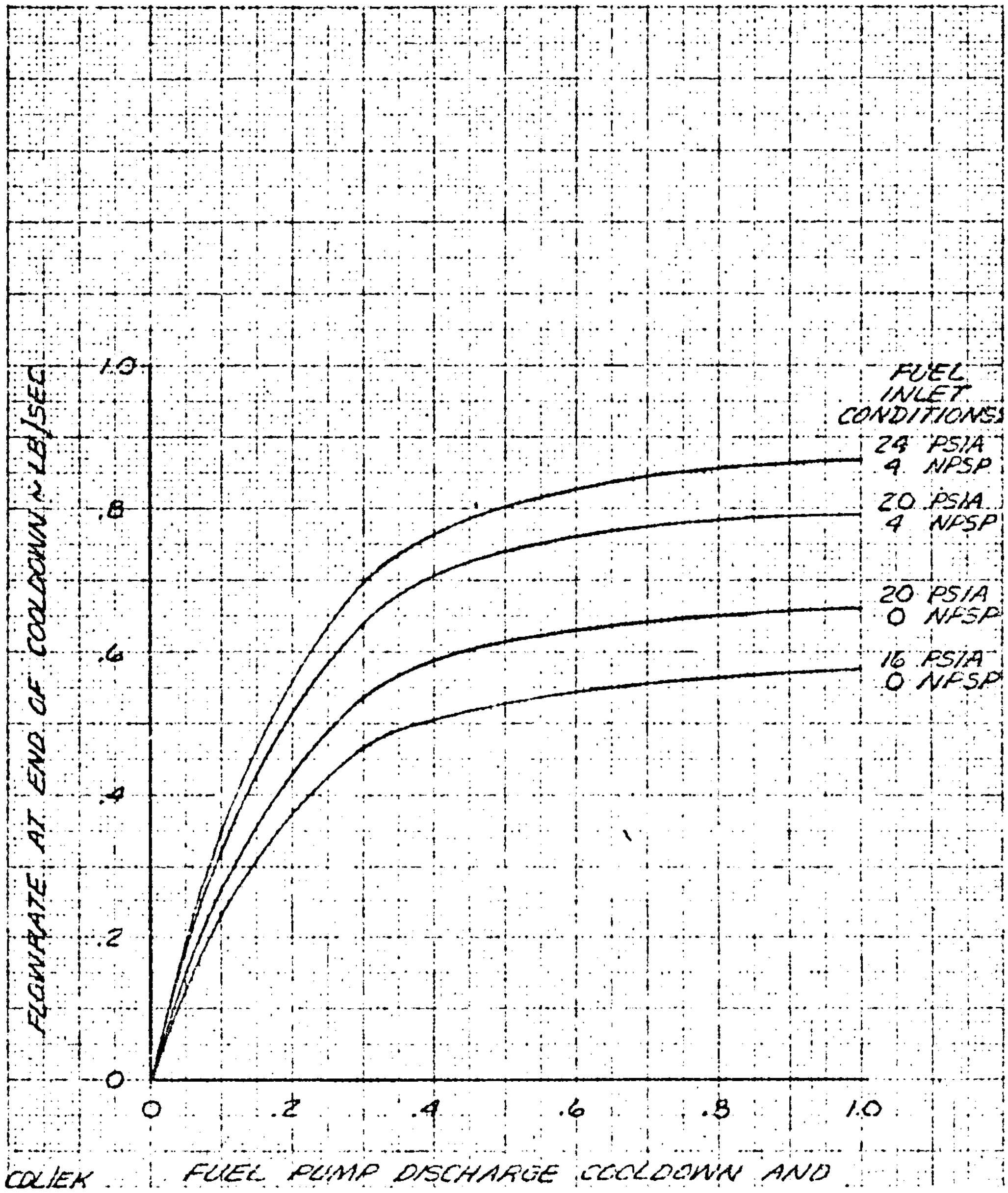
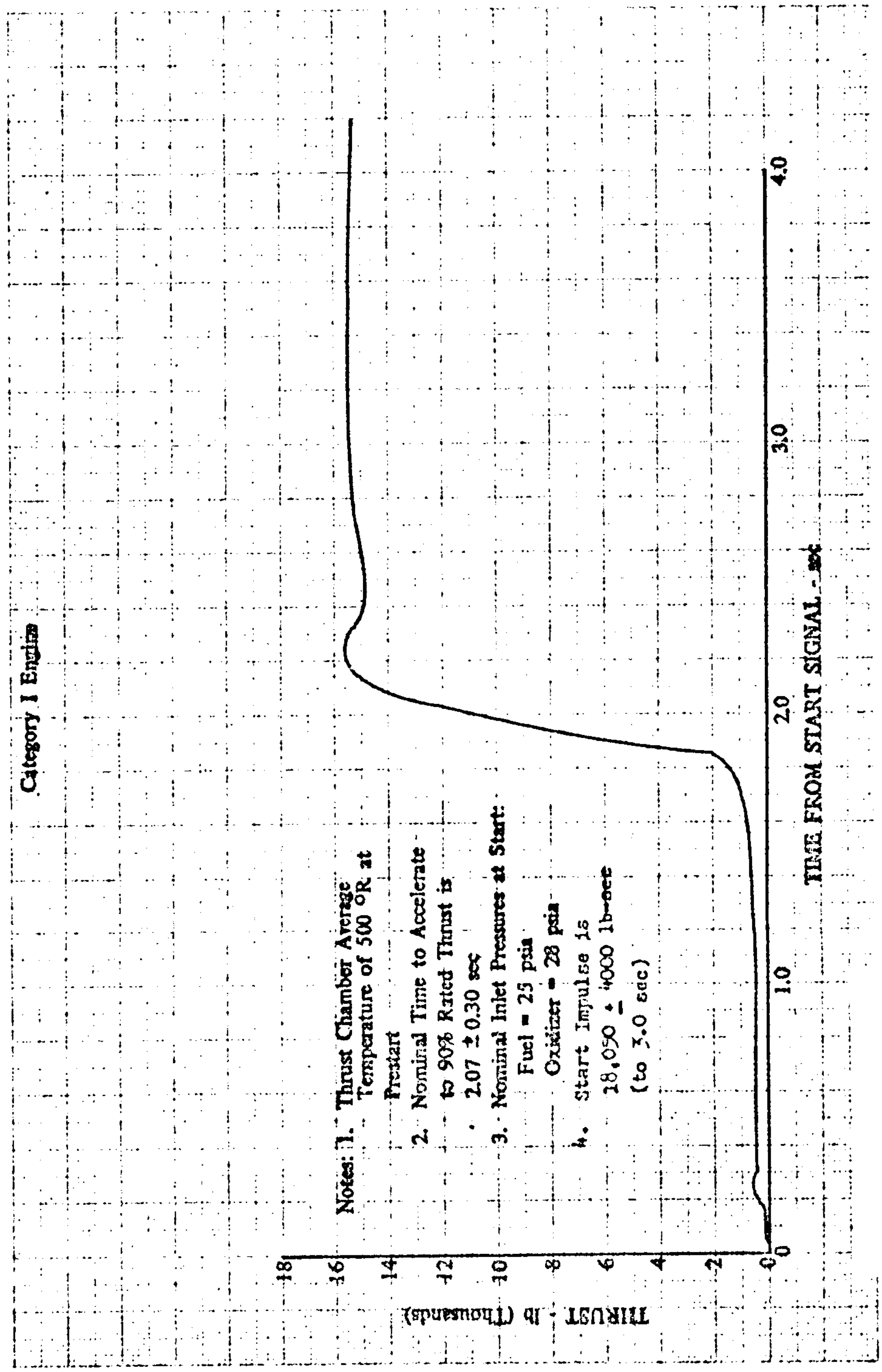


Figure C-52. Fuel Cooldown Final Flowrate Characteristics Category I Engine DF 95637



DF 94545

Figure C-53. Estimated Start Transient Thrust vs Time, Category I Engine

DF 97087

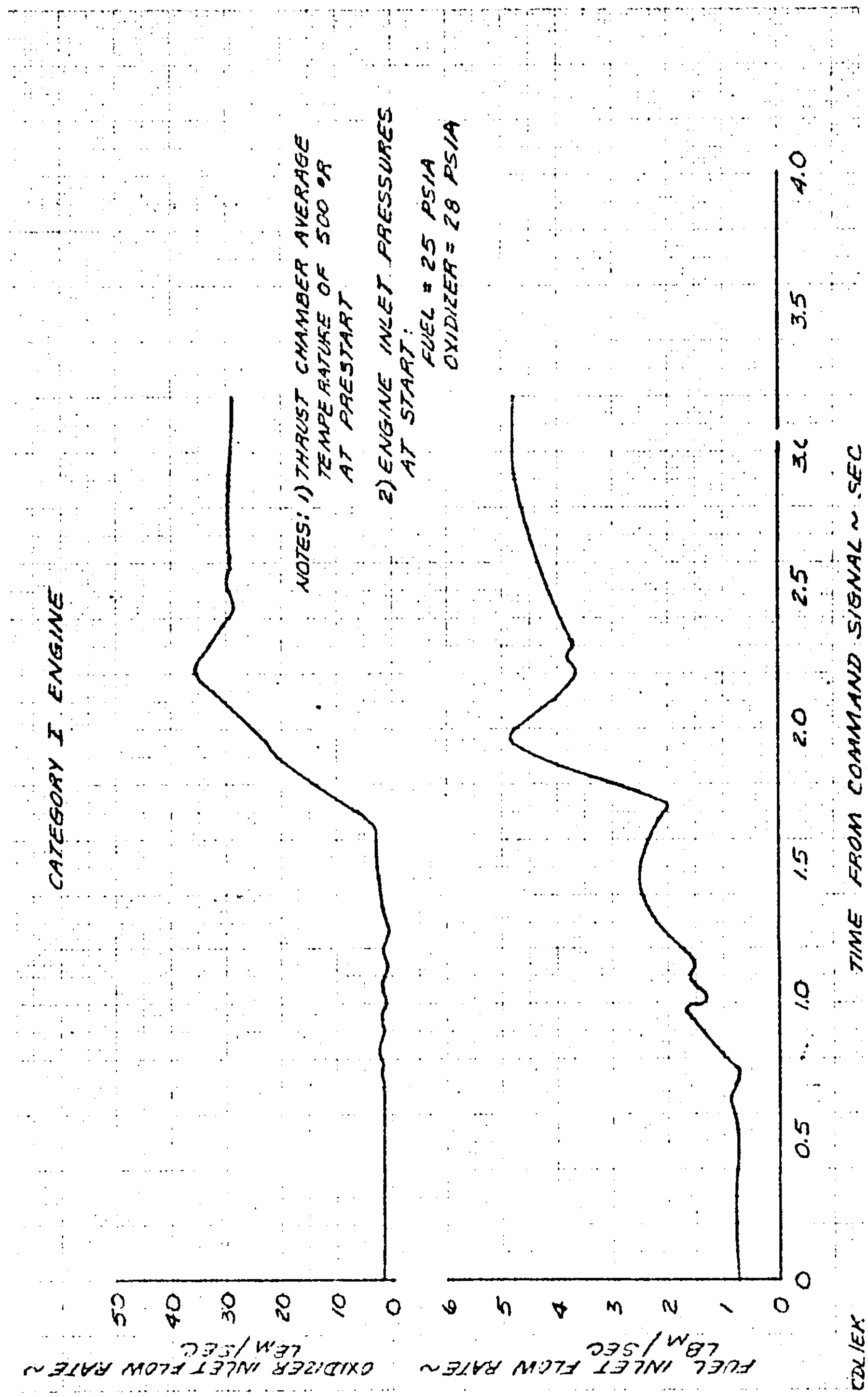


Figure C-54. Estimated Start Transient Flowrates, Category I Engine

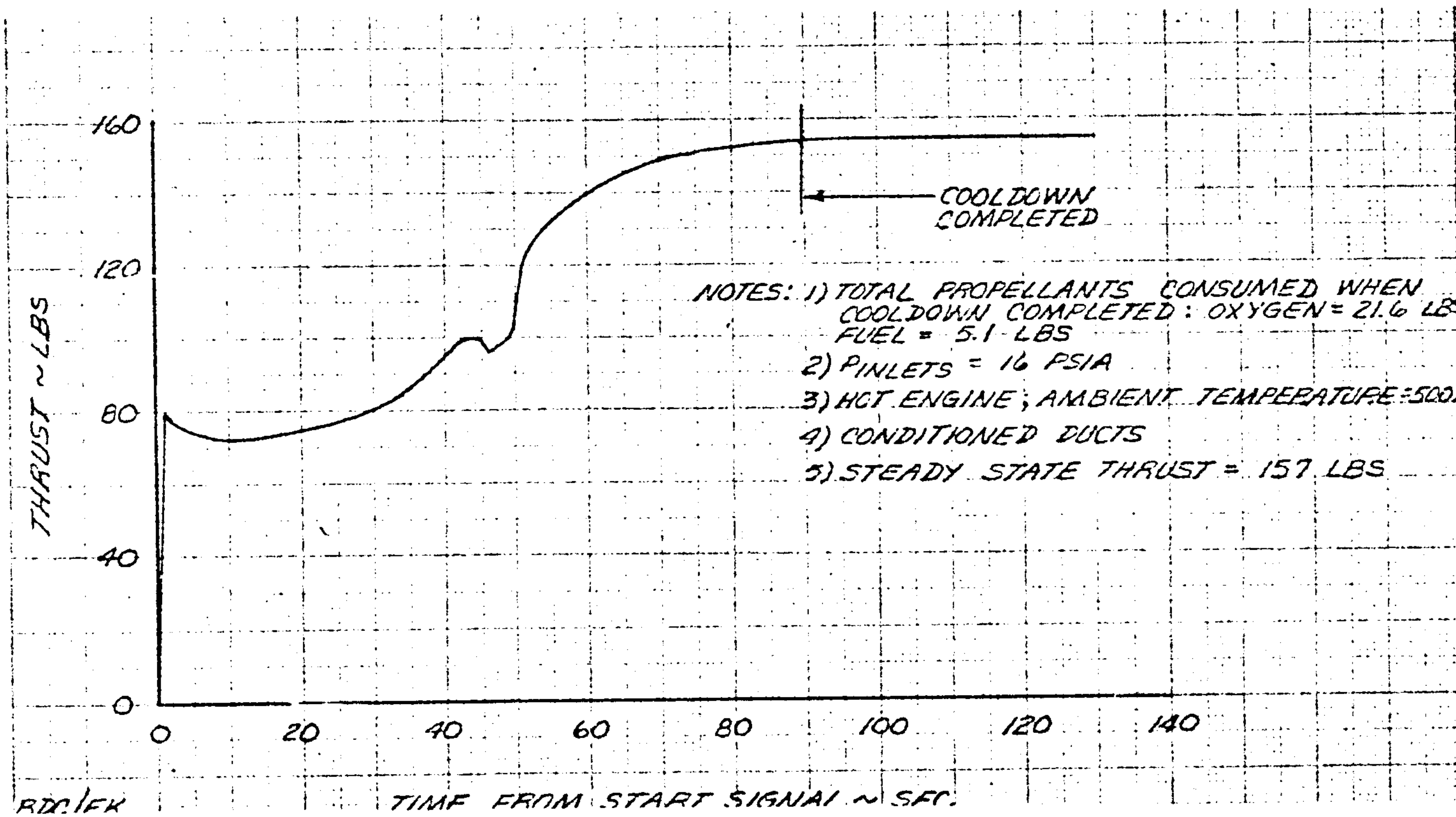


Figure C-55. Tank Head Idle Transient Thrust, Derivative IIA Engine

DF 96983

DF 96984

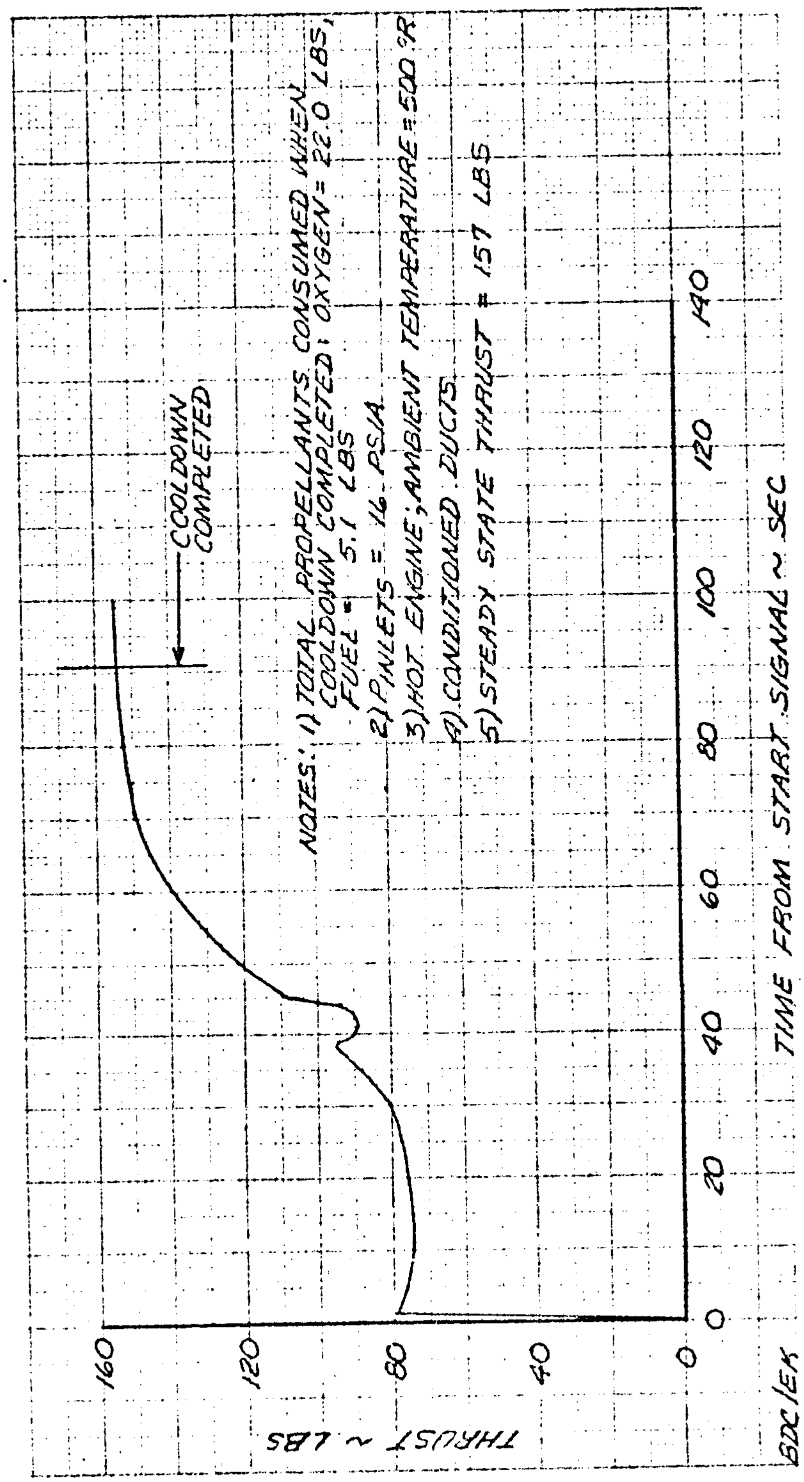
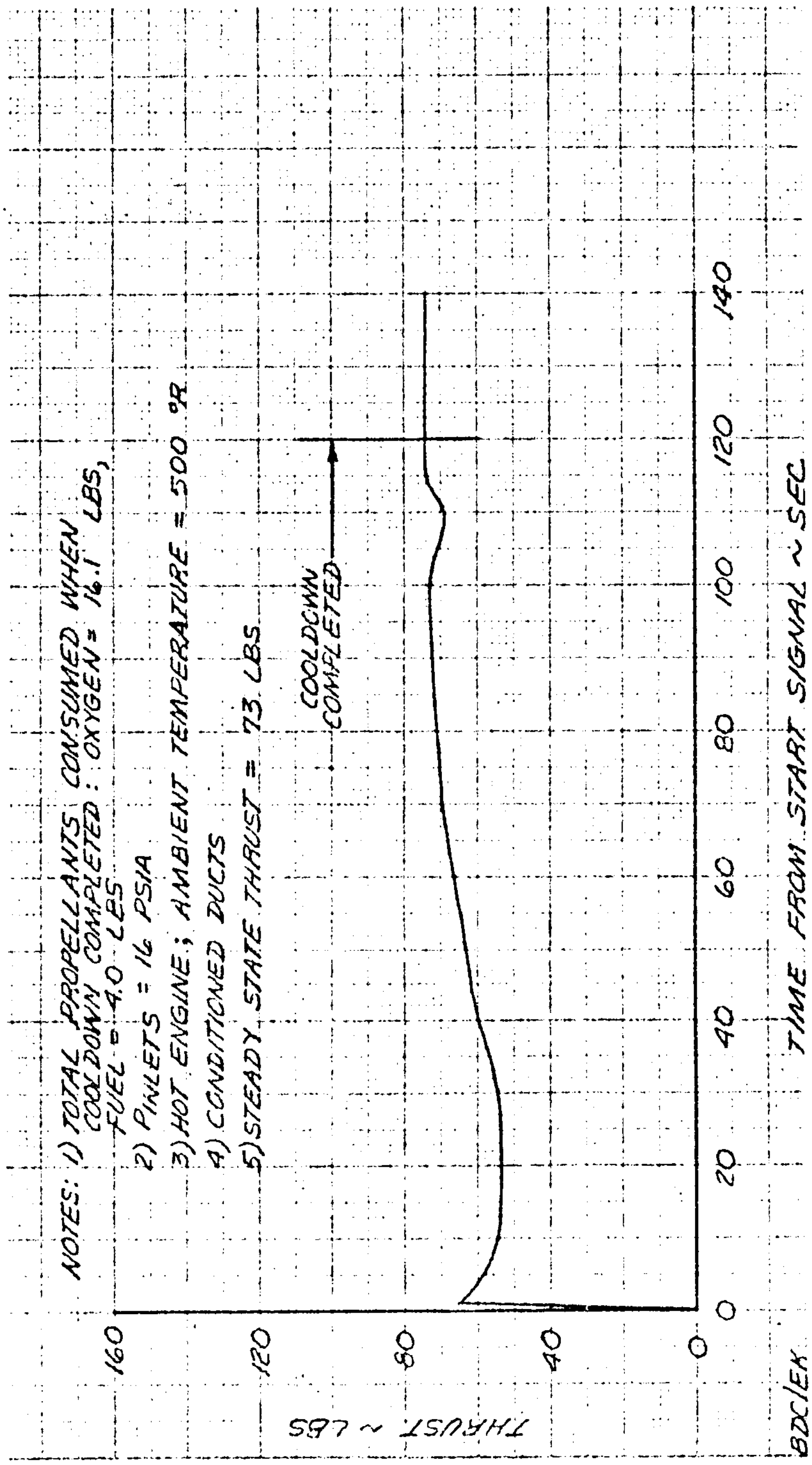
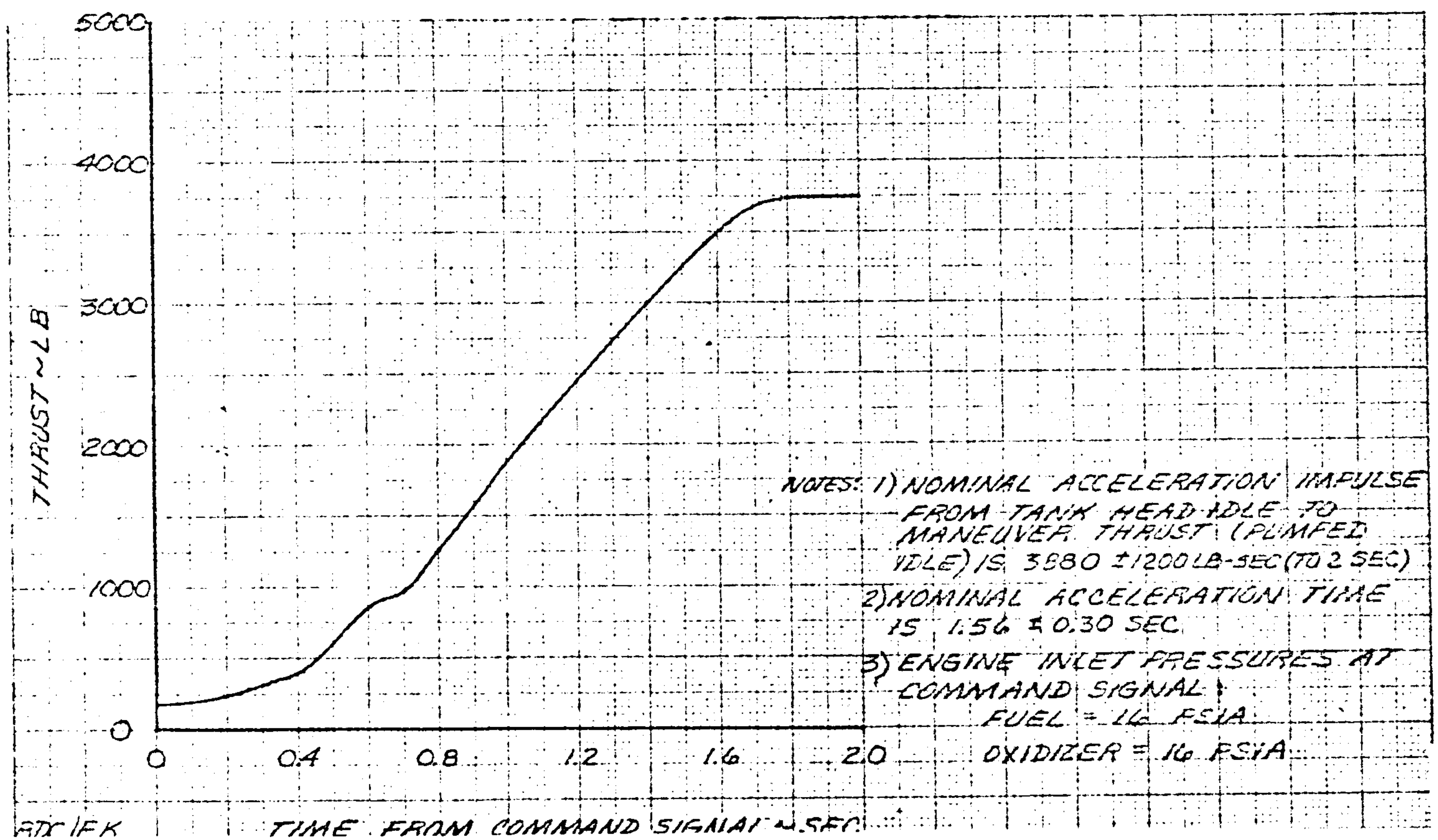


Figure C-56. Tank Head Idle Transient Thrust, Derivative IIB Engine



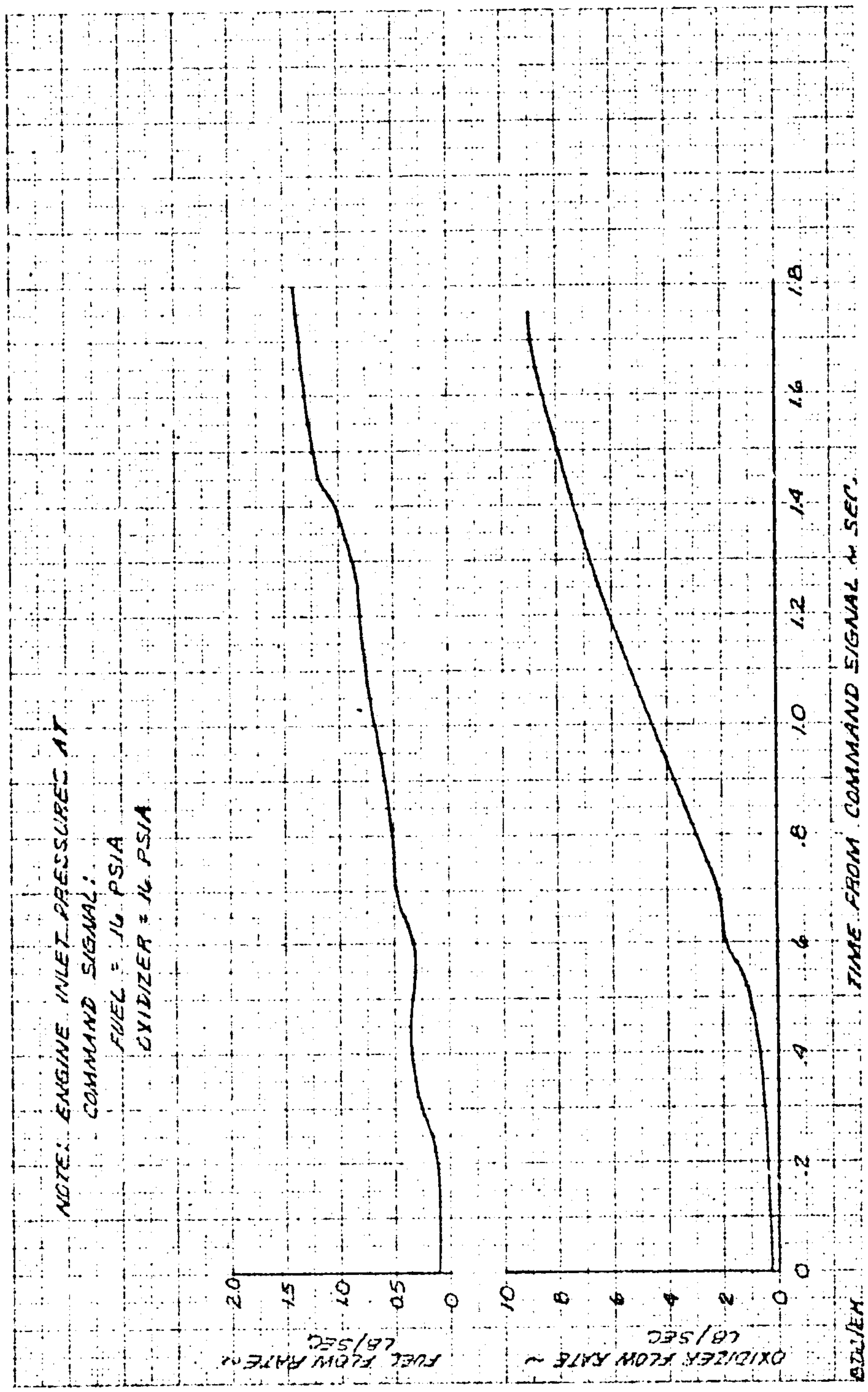
DF 96985

Figure C-57. Tank Head Idle Transient Thrust, Category IV Engine



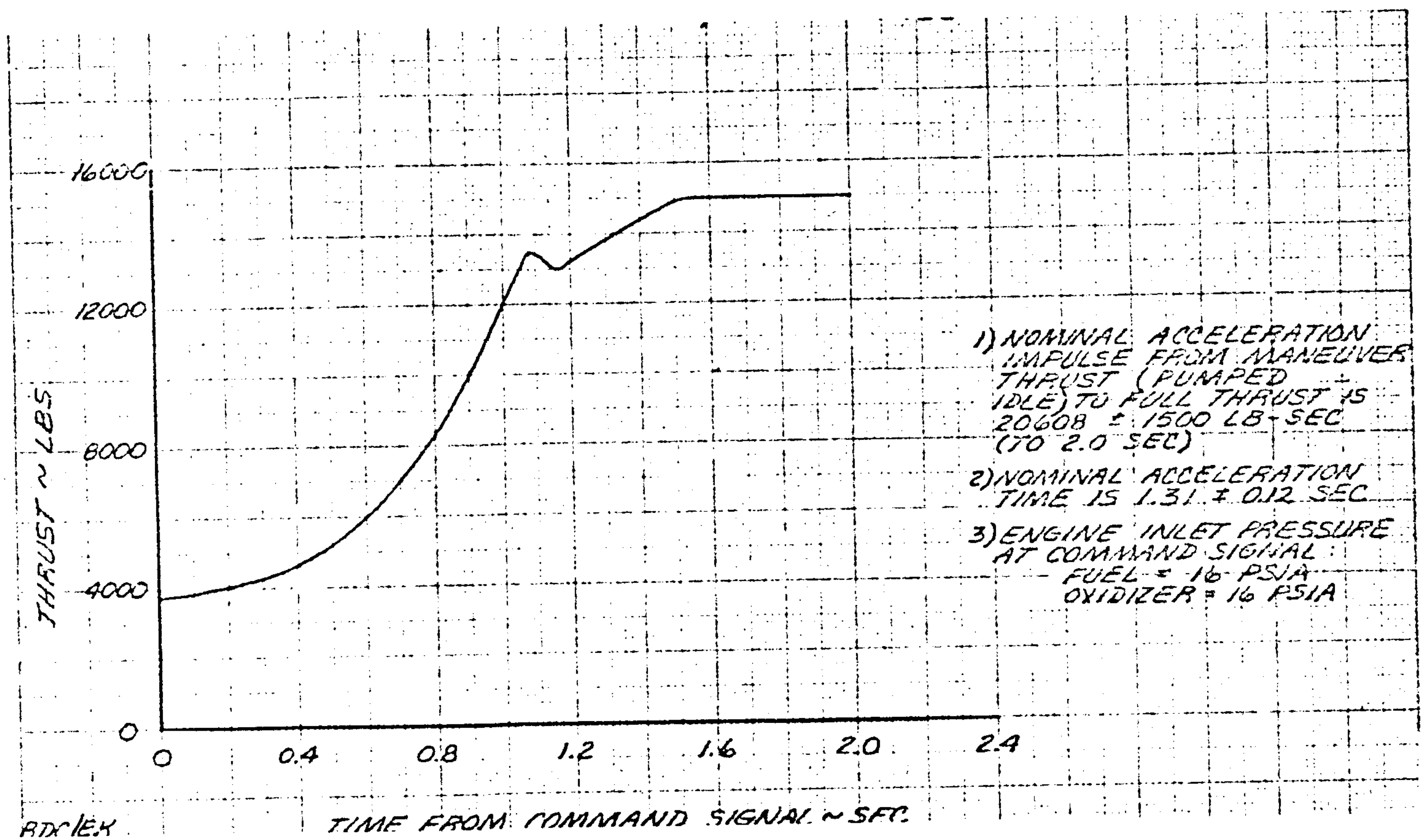
DF 96619

Figure C-58. Estimated Tank Head Idle to Maneuver Thrust (Pumped Idle) Transient Thrust, Derivative IIA and IIB Engines



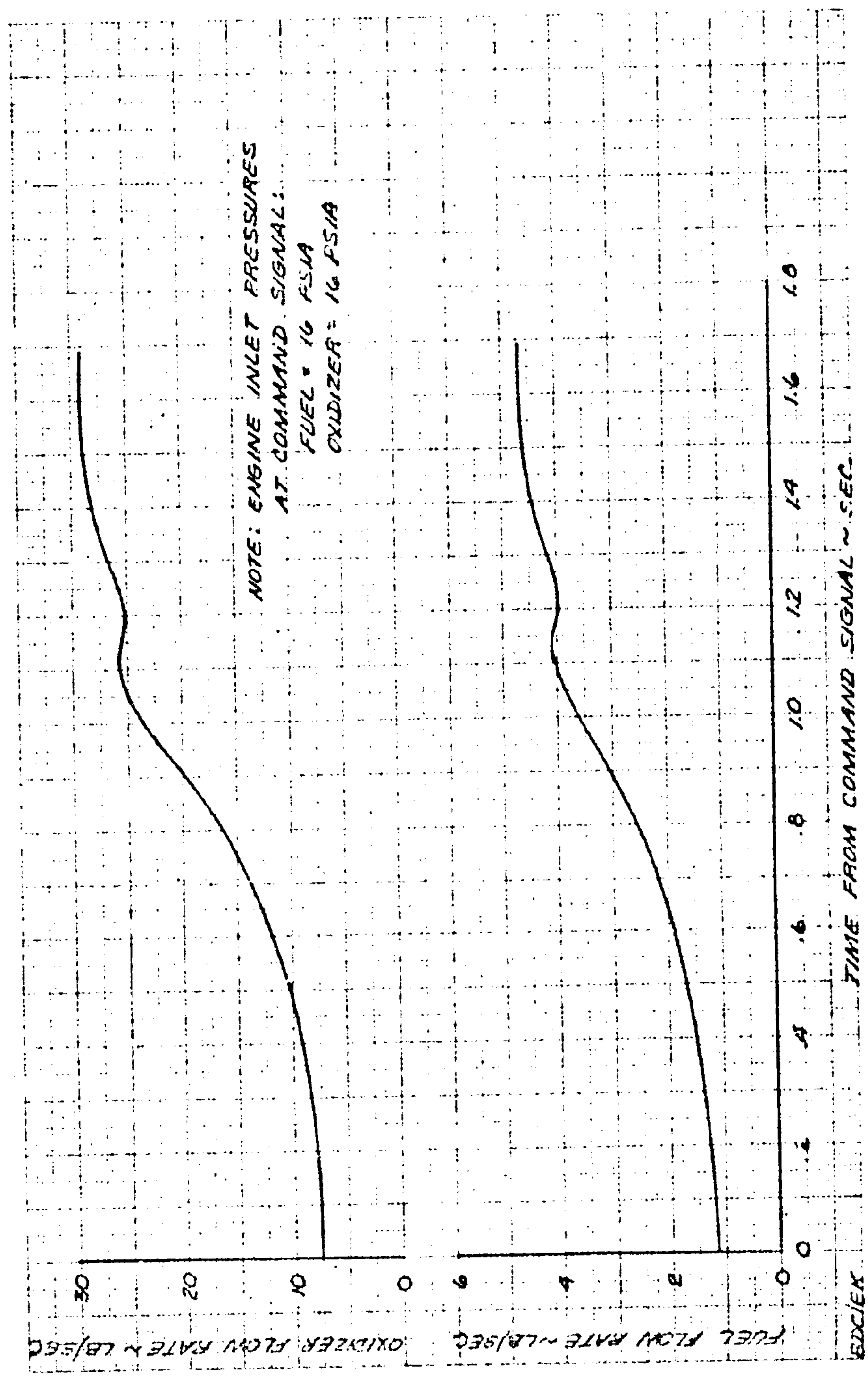
DF 96620

Figure C-59. Estimated Tank Head Idle to Maneuver Thrust (Pumped Idle) Transient Flowrates, Derivative IIA and IIB Engines



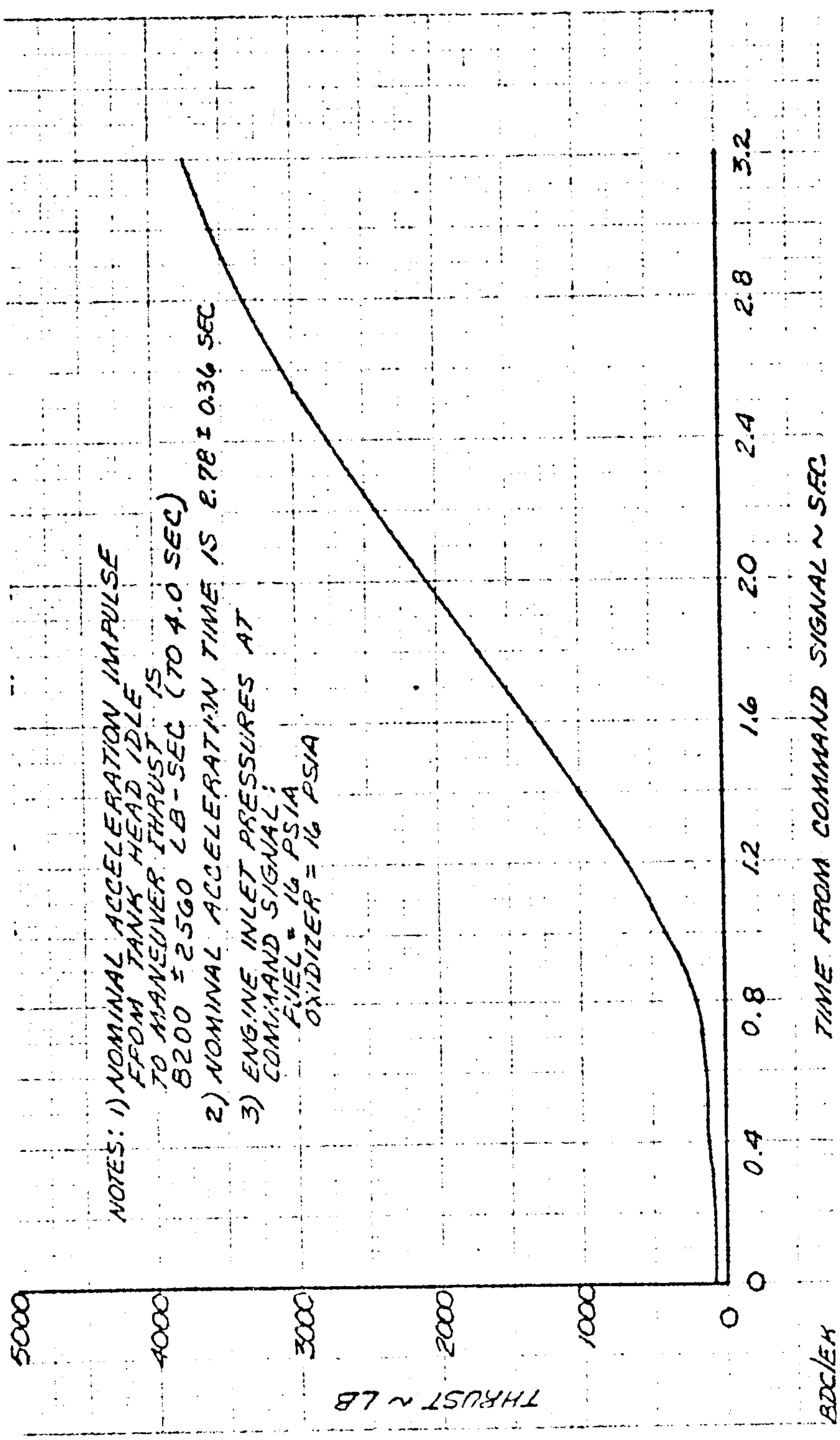
DF 96621

Figure C-60. Estimated Maneuver Thrust (Pumped Idle) to Full Thrust Transient Thrust, Derivative IIA and IIB Engines



DF 96622

Figure C-61. Estimated Maneuver Thrust (Pumped Idle) to Full Thrust Transient Flowrates, Derivative IIA and IIB Engines



DF 97085

Figure C-62. Estimated Tank Head Idle to Maneuver Thrust Transient Thrust, Category IV Engine

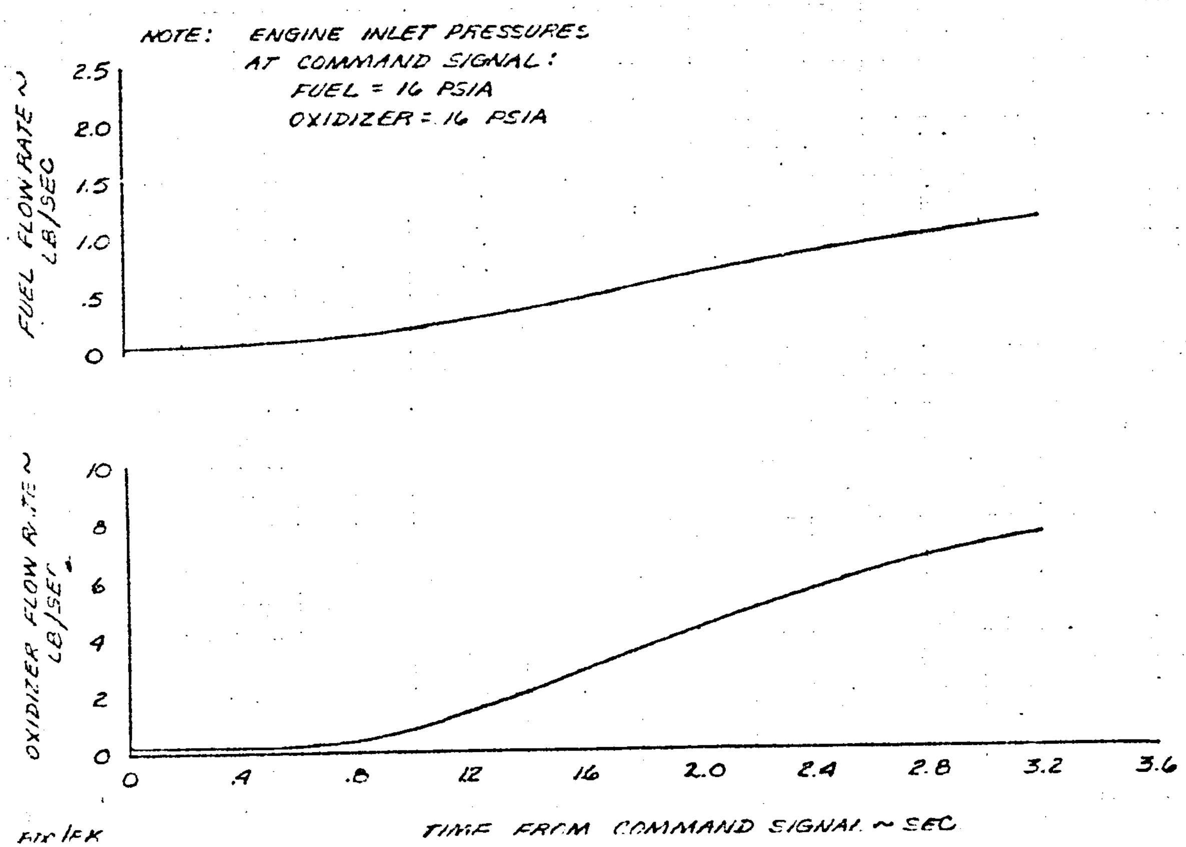


Figure C-63. Estimated Tank Head Idle to Maneuver Thrust Transient Flowrates, Category IV Engine

DF 97086

DF 97082

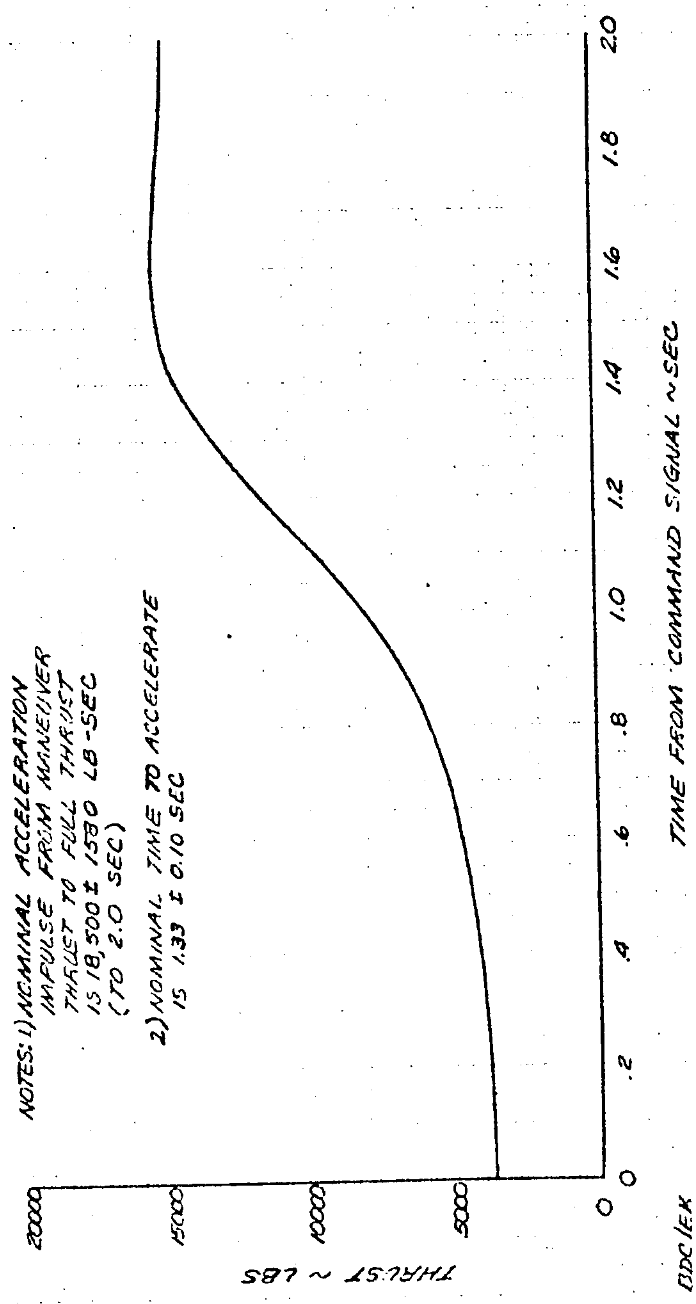


Figure C-64. Estimated Maneuver Thrust to Full Thrust Transient Thrust, Category IV Engine

DF 97083

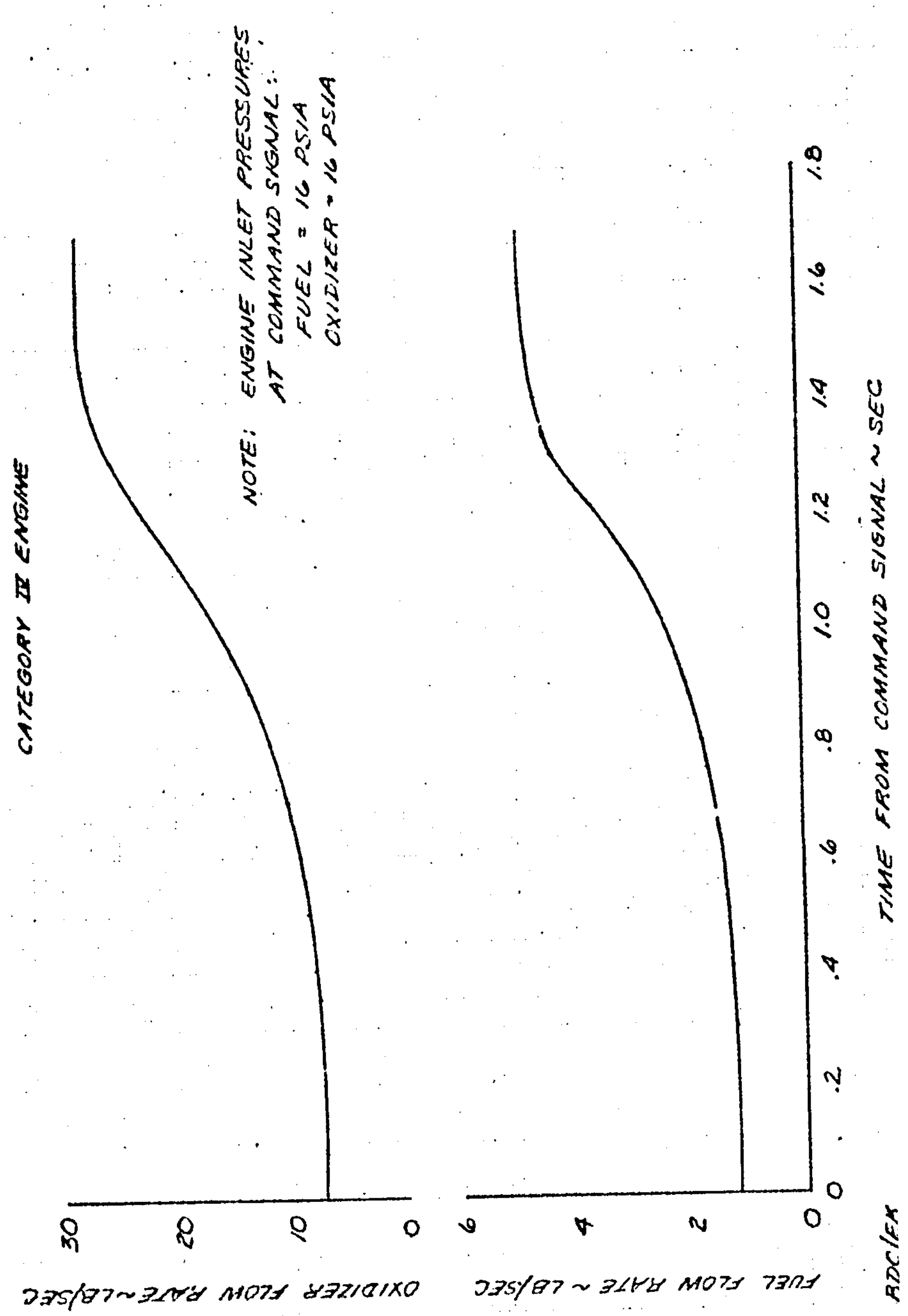


Figure C-65. Estimated Maneuver Thrust to Full Thrust Transient Flowrates, Category IV Engine

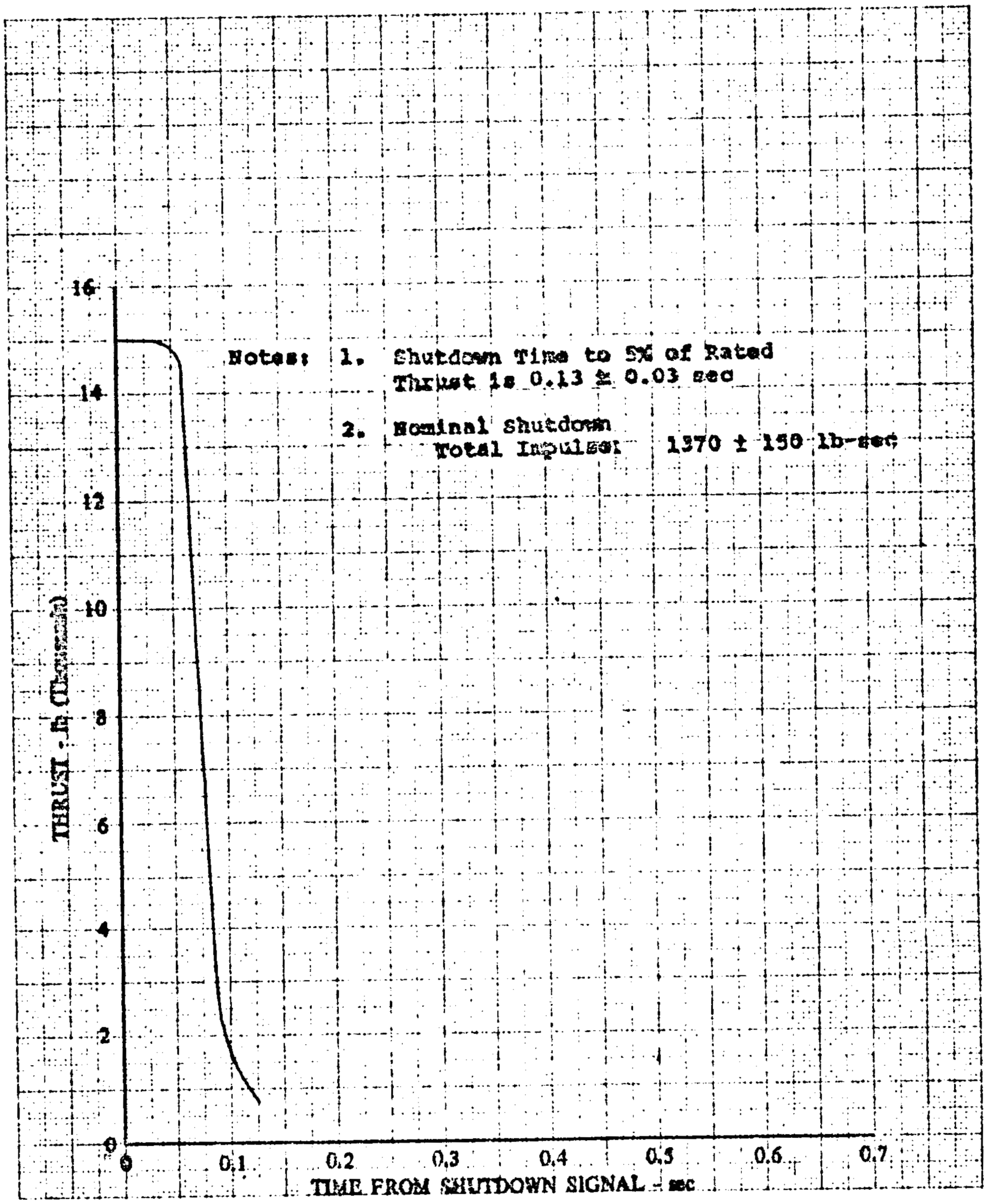


Figure C-66. Estimated Shutdown Transient Thrust vs Time, Category I Engine

DF 94558

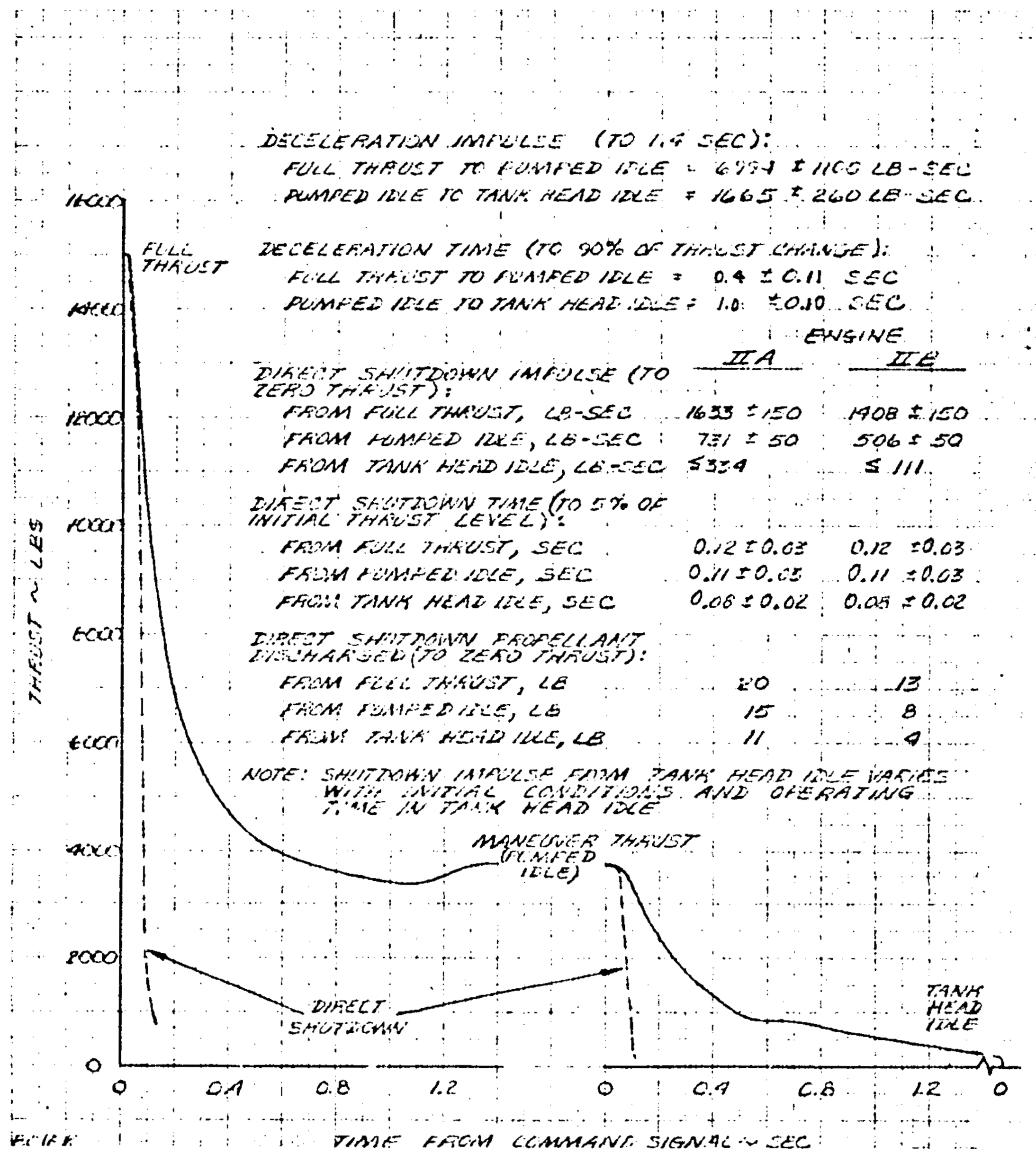


Figure C-67. Deceleration and Shutdown Transients, Derivative IIA and IIB Engines DF 96623

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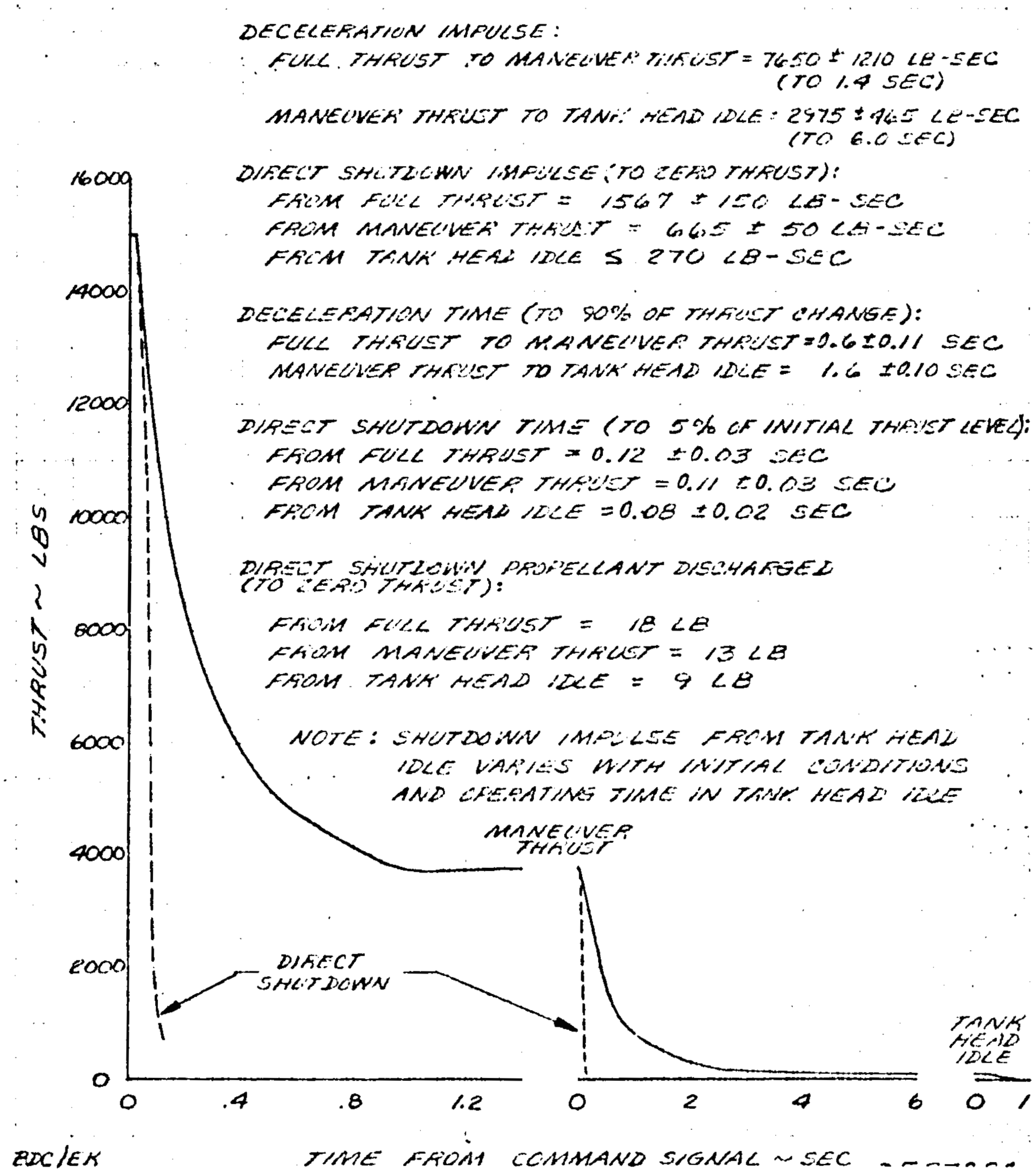


Figure C-68. Estimated Deceleration and Shutdown Transients, Category IV Engine DF 97084

SECTION D
ENGINE ELECTRICAL REQUIREMENTS

1. GENERAL

1.1 Engine Ignition and Controls Electrical Requirements

The engines require a 28 vdc electrical supply for propellant valve actuation, the engine ignition system, instrumentation power supply and the heater for environmental control of the instrumentation enclosure, and extendible nozzle translating mechanism drive motor (except for Category I engine). Steady-state 20-30 vdc is acceptable. The estimated current demand characteristics are shown in figures D-1 through D-3. Specific current requirements are given in table D-1.

Table D-1. Engine Current Requirements

	Category I	Engine Derivative IIA	Derivative IIB	Category IV
Ignition System (each exciter), amp	2.5	2.5	2.5	1.25
Solenoids (each), amp	2.0	2.0	2.0	1.0
Instrumentation, amp	0.3	0.3	0.3	0.3
Heater,* amp	2.0	2.0	2.0	2.0

*Thermostatically controlled heater operating intermittently to control the environment of the instrumentation enclosure.

The Category I engine ignition system requires 2.5 amp for a minimum of 1.5 sec during each starting cycle. The Derivative IIA and IIB, and Category IV engines require 5.0 amp and 2.5 amp for their respective ignition systems which can be deenergized 1.5 sec after initiation of the transition from tank head idle to maneuver thrust (pumped idle) operation.

The maximum current demand for the Category I occurs at the time of the start signal while for the Derivative IIA and IIB, and Category IV engines the peak demand occurs during pumped idle. In addition to the current demands previously shown in figures D-1 through D-3, an intermittent demand by the instrumentation box heater for 2 amp may occur during the engine operational period. The two nozzle translating mechanism electric drive motors require a total of 3.2 amp (at 28 vdc) for one minute when the extendible nozzle is deployed or retracted. Two motors are used for redundancy to increase the translating system reliability. The extendible nozzle is translated while the engine is in a nonfiring condition.

1.2 Engine Instrumentation Requirements

Engine instrumentation required to provide for engine readiness checks, system performance verification, engine control and malfunction detection is shown in table D-2. Figure D-4 shows a typical instrumentation schematic.

Table D-2. Engine Instrumentation Requirements

	Category I Engine Range & Units	Category I Engine Uncertainty (1)	Derivative IIA & B Engines Range & Units	Derivative IIA & B Engines Uncertainty (1)	Category IV Engine Range & Units	Category IV Engine Uncertainty (1)
Engine Supplied						
Fuel Pump						
Housing Temperature	35-660°R	±6°R	35-660°R	±6°R	35-660°R	±6°R
Discharge Pressure	0-1200 psia	±2%	0-1200 psia	±2%	0-2500 psia	±2%
Oxidizer Pump						
Housing Temperature	150-660°R	±6°R	150-660°R	±6°R	150-660°R	±6°R
Discharge Pressure	0-800 psia	±2%	0-800 psia	±2%	0-2000 psia	±2%
Rotational Speed	0-15,000 rpm	±4%	0-15,000 rpm	±4%	0-50,000 rpm	±4%
Thrust Chamber						
Chamber Pressure	0-500 psia	±2%	0-500 psia	±2%	0-1200 psia	±2%
Low Range Chamber Pressure	N/A	N/A	0-15 psia	±2%	0-25 psia	±2%
Chamber Coolant Discharge Temperature	200-1200°R	±15°R	200-1200°R	±15°R	200-1200°R	±15°R
Miscellaneous						
Nozzle Extension Contact Switches (2)	N/A	N/A	switch	-	switch	-
Igniter Exciter Monitor Voltage	0-10 vdc	±5%	0-10 vdc	±5%	0-10 vdc	±5%
Solenoid Current Monitor (3)	0-20 mv dc	±5%	0-20 mv dc	±5%	0-20 mv dc	±5%
Thrust Control Position Indicator	0-100%	±5%	0-100%	±5%	0-100%	±5%
Gearbox Vibration Accelerometer	5 g	±10%	5 g	±10%	5 g	±10%
Recommended Vehicle Supplied						
Engine Fuel Inlet Pressure	0-50 psia	±2%	0-50 psia	±2%	0-50 psia	±2%
Engine Fuel Inlet Temperature	34-46°R	±0.2°R	34-46°R	±0.2°R	34-46°R	±0.2°R
Engine Oxidizer Inlet Pressure	0-50 psia	±2%	0-50 psia	±2%	0-50 psia	±2%
Engine Oxidizer Inlet Temperature	155°-200°R	±0.2°R	155°-200°R	±0.2°R	155°R-200°R	±0.2°R
Propellant Utilization Valve Angle	±74 deg	±2%	±74 deg	±2%	±74 deg	±2%
Vehicle Supply Voltage	0-45 vdc	±2%	0-45 vdc	±2%	0-45 vdc	±2%
Helium Supply Pressure	0-600 psia	±5%	0-600 psia	±5%	0-600 psia	±5%

(1) $U = \pm(B + t_{0.95}S)$, percent of full scale unless indicated otherwise.
(2) Two switches required (nozzle retracted and nozzle extended positions).
(3) Three measurements for Category I, four required for all other engines.

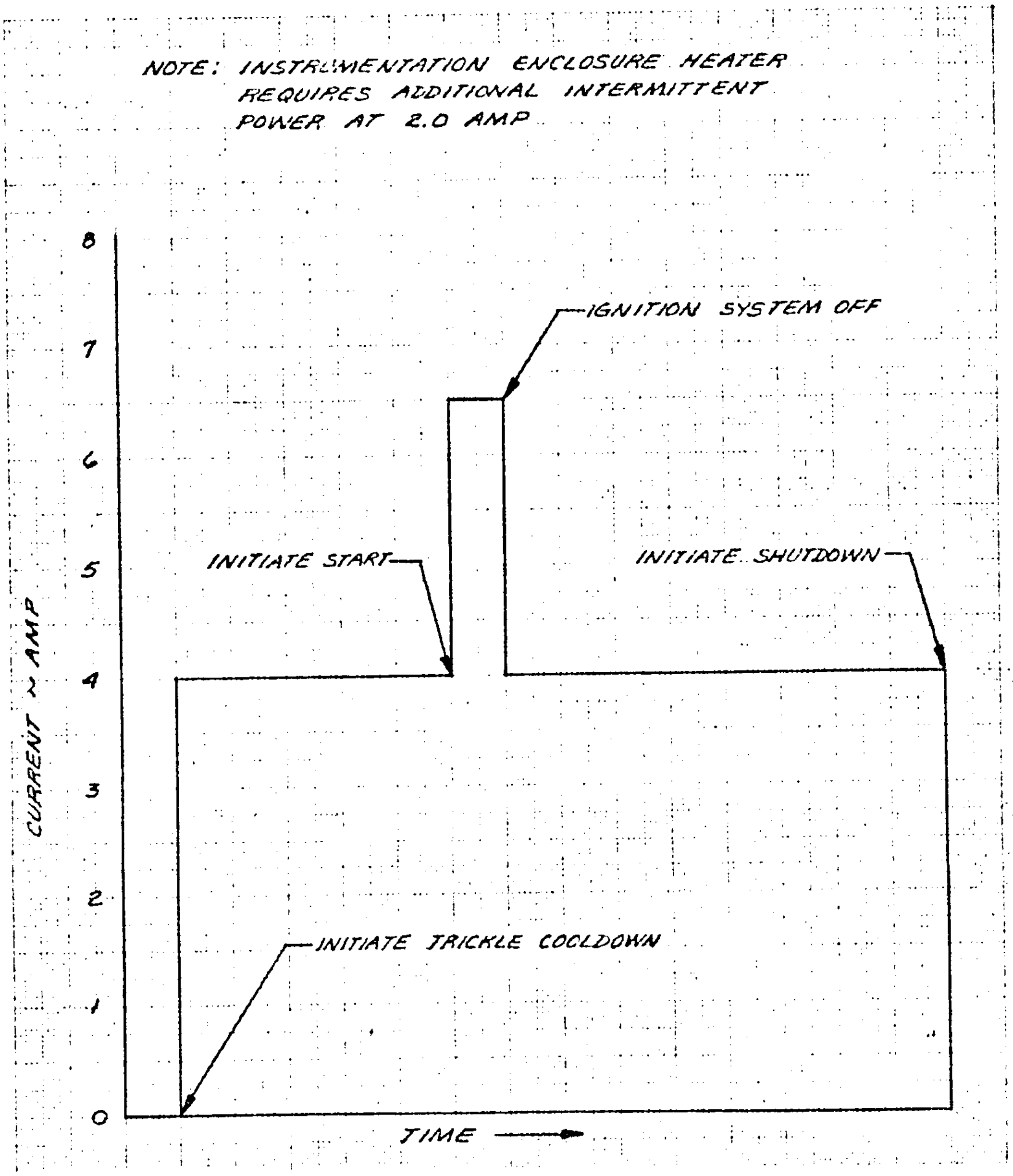


Figure D-1. Estimated Maximum Current Demand, Category I Engine

DF 94565

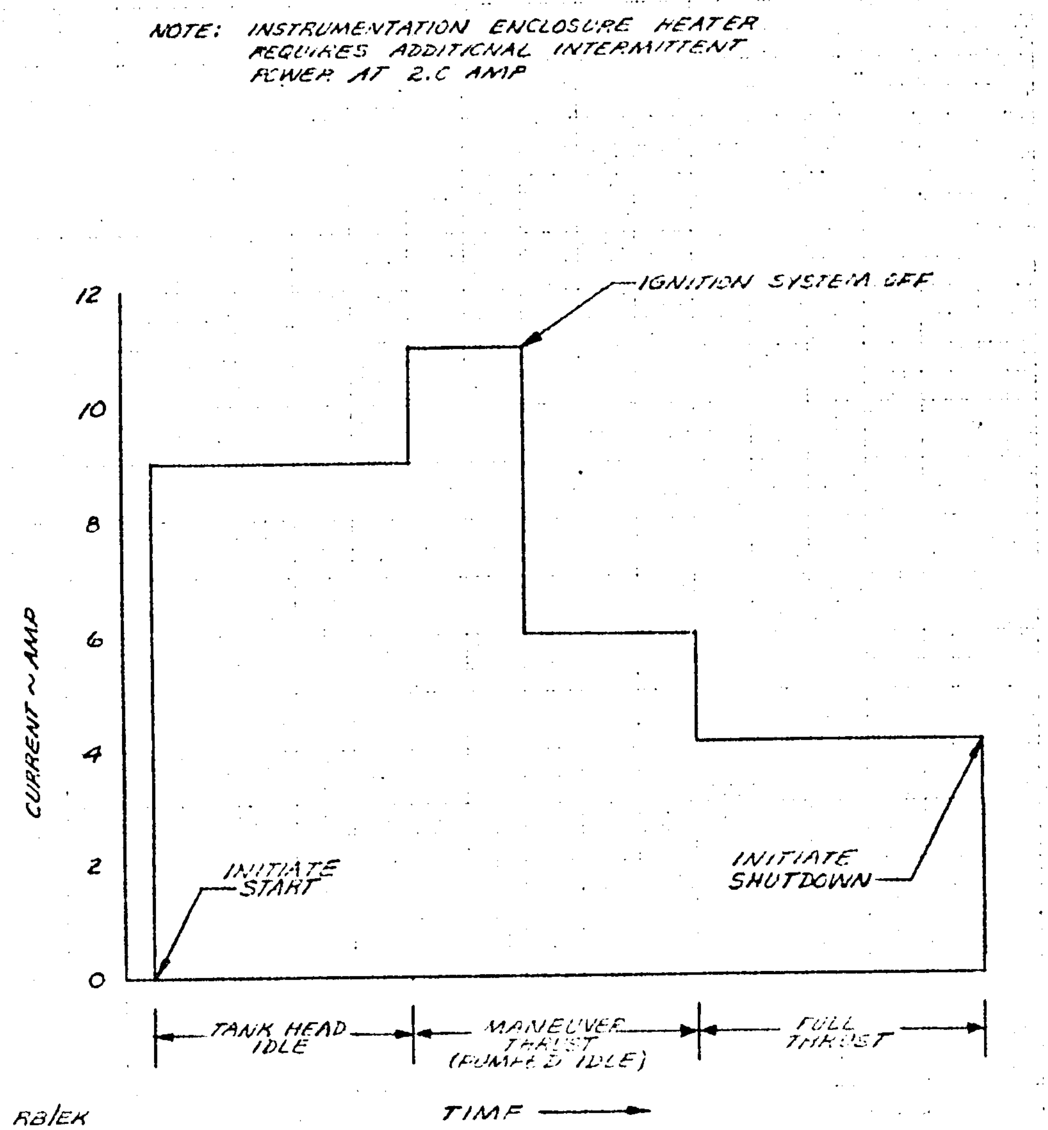


Figure D-2. Estimated Maximum Current Demand, Derivative IIA and IIB Engines

DF 97079

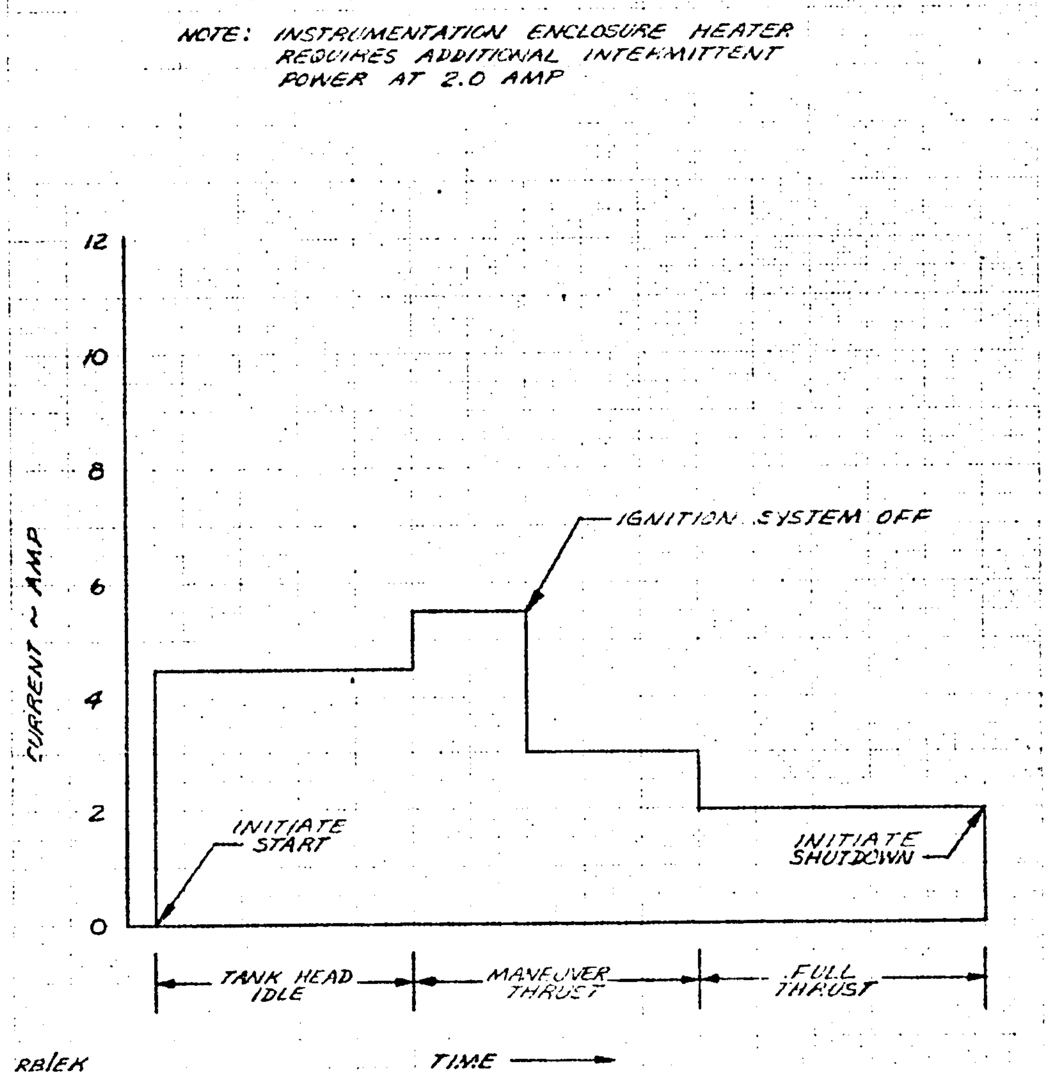
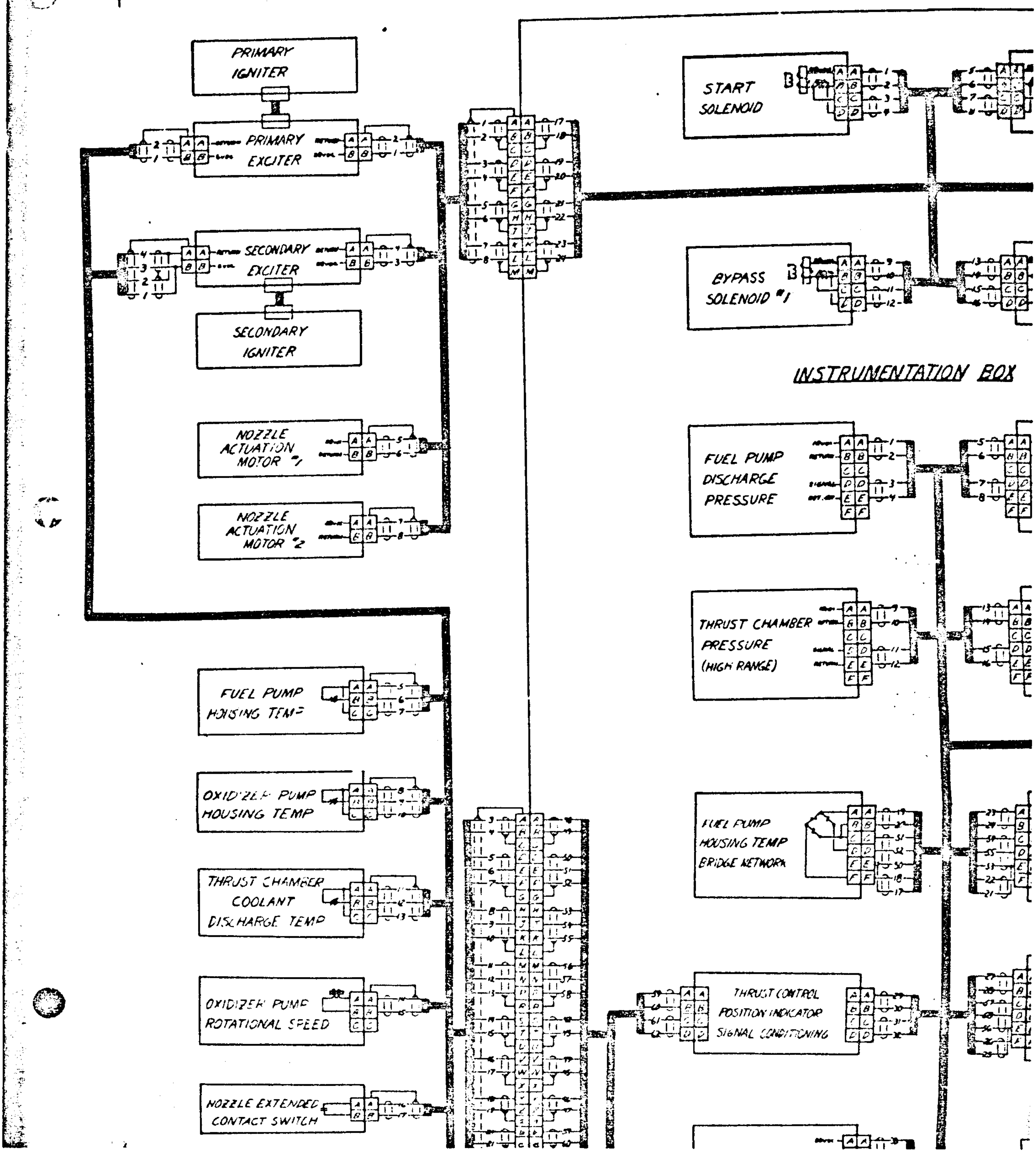


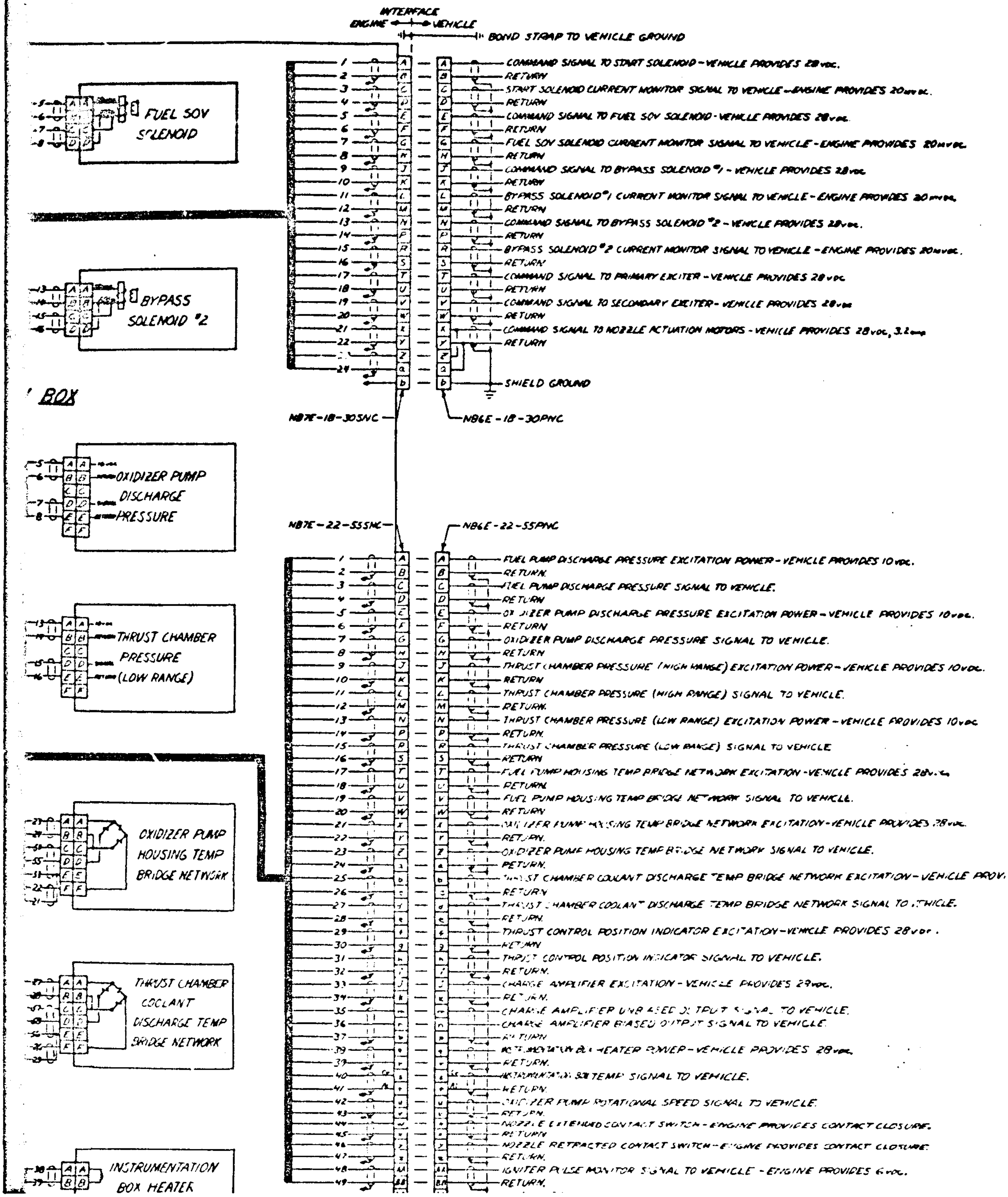
Figure D-3. Estimated Maximum Current Demand, Category IV Engine

DF 97078

FOLDOUT FRAME 1

FOLDOUT FRAME 2




INTERFACE
ENGINE VEHICLE
BOND STRAP TO VEHICLE GROUND
FUEL SOV SOLENOID
BYPASS SOLENOID *2
BOX
COMMAND SIGNAL TO START SOLENOID - VEHICLE PROVIDES 28vdc.
RETURN
START SOLENOID CURRENT MONITOR SIGNAL TO VEHICLE - ENGINE PROVIDES 20mvdc.
RETURN
COMMAND SIGNAL TO FUEL SOV SOLENOID - VEHICLE PROVIDES 28vdc.
RETURN
FUEL SOV SOLENOID CURRENT MONITOR SIGNAL TO VEHICLE - ENGINE PROVIDES 20mvdc.
RETURN
COMMAND SIGNAL TO BYPASS SOLENOID *1 - VEHICLE PROVIDES 28vdc.
RETURN
BYPASS SOLENOID *1 CURRENT MONITOR SIGNAL TO VEHICLE - ENGINE PROVIDES 20mvdc.
RETURN
COMMAND SIGNAL TO BYPASS SOLENOID *2 - VEHICLE PROVIDES 28vdc.
RETURN
BYPASS SOLENOID *2 CURRENT MONITOR SIGNAL TO VEHICLE - ENGINE PROVIDES 20mvdc.
RETURN
COMMAND SIGNAL TO PRIMARY EXCITER - VEHICLE PROVIDES 28vdc
RETURN
COMMAND SIGNAL TO SECONDARY EXCITER - VEHICLE PROVIDES 28vdc
RETURN
COMMAND SIGNAL TO NOZZLE ACTUATION MOTORS - VEHICLE PROVIDES 28vdc, 3.2amp
RETURN
SHIELD GROUND
NB7E-18-30SNC
NB6E-18-30PNC
OXIDIZER PUMP DISCHARGE PRESSURE
NB7E-22-55SNC
NB6E-22-55PNC
THRUST CHAMBER PRESSURE (LOW RANGE)
OXIDIZER PUMP HOUSING TEMP BRIDGE NETWORK
THRUST CHAMBER COOLANT DISCHARGE TEMP BRIDGE NETWORK
INSTRUMENTATION BOX HEATER
FUEL PUMP DISCHARGE PRESSURE EXCITATION POWER - VEHICLE PROVIDES 10vdc.
RETURN
FUEL PUMP DISCHARGE PRESSURE SIGNAL TO VEHICLE.
RETURN
OXIDIZER PUMP DISCHARGE PRESSURE EXCITATION POWER - VEHICLE PROVIDES 10vdc.
RETURN
OXIDIZER PUMP DISCHARGE PRESSURE SIGNAL TO VEHICLE.
RETURN
THRUST CHAMBER PRESSURE (HIGH RANGE) EXCITATION POWER - VEHICLE PROVIDES 10vdc.
RETURN
THRUST CHAMBER PRESSURE (HIGH RANGE) SIGNAL TO VEHICLE.
RETURN
THRUST CHAMBER PRESSURE (LOW RANGE) EXCITATION POWER - VEHICLE PROVIDES 10vdc
RETURN
THRUST CHAMBER PRESSURE (LOW RANGE) SIGNAL TO VEHICLE
RETURN
FUEL PUMP HOUSING TEMP BRIDGE NETWORK EXCITATION - VEHICLE PROVIDES 28vdc
RETURN
FUEL PUMP HOUSING TEMP BRIDGE NETWORK SIGNAL TO VEHICLE.
RETURN
OXIDIZER PUMP HOUSING TEMP BRIDGE NETWORK EXCITATION - VEHICLE PROVIDES 28vdc.
RETURN.
OXIDIZER PUMP HOUSING TEMP BRIDGE NETWORK SIGNAL TO VEHICLE.
RETURN.
THRUST CHAMBER COOLANT DISCHARGE TEMP BRIDGE NETWORK EXCITATION - VEHICLE PROV
RETURN
THRUST CHAMBER COOLANT DISCHARGE TEMP BRIDGE NETWORK SIGNAL TO VEHICLE.
RETURN.
THRUST CONTROL POSITION INDICATOR EXCITATION - VEHICLE PROVIDES 28vdc.
RETURN
THRUST CONTROL POSITION INDICATOR SIGNAL TO VEHICLE.
RETURN.
CHARGE AMPLIFIER EXCITATION - VEHICLE PROVIDES 29vdc.
RETURN.
CHARGE AMPLIFIER UNBIASED OUTPUT SIGNAL TO VEHICLE.
CHARGE AMPLIFIER BIASED OUTPUT SIGNAL TO VEHICLE.
RETURN
INSTRUMENTATION BOX HEATER POWER - VEHICLE PROVIDES 28vdc.
RETURN.
INSTRUMENTATION BOX TEMP SIGNAL TO VEHICLE.
RETURN.
OXIDIZER PUMP ROTATIONAL SPEED SIGNAL TO VEHICLE.
RETURN.
NOZZLE EXTENDED CONTACT SWITCH - ENGINE PROVIDES CONTACT CLOSURE.
RETURN
NOZZLE RETRACTED CONTACT SWITCH - ENGINE PROVIDES CONTACT CLOSURE.
RETURN.
IGNITER PULSE MONITOR SIGNAL TO VEHICLE - ENGINE PROVIDES 6vdc.
RETURN.

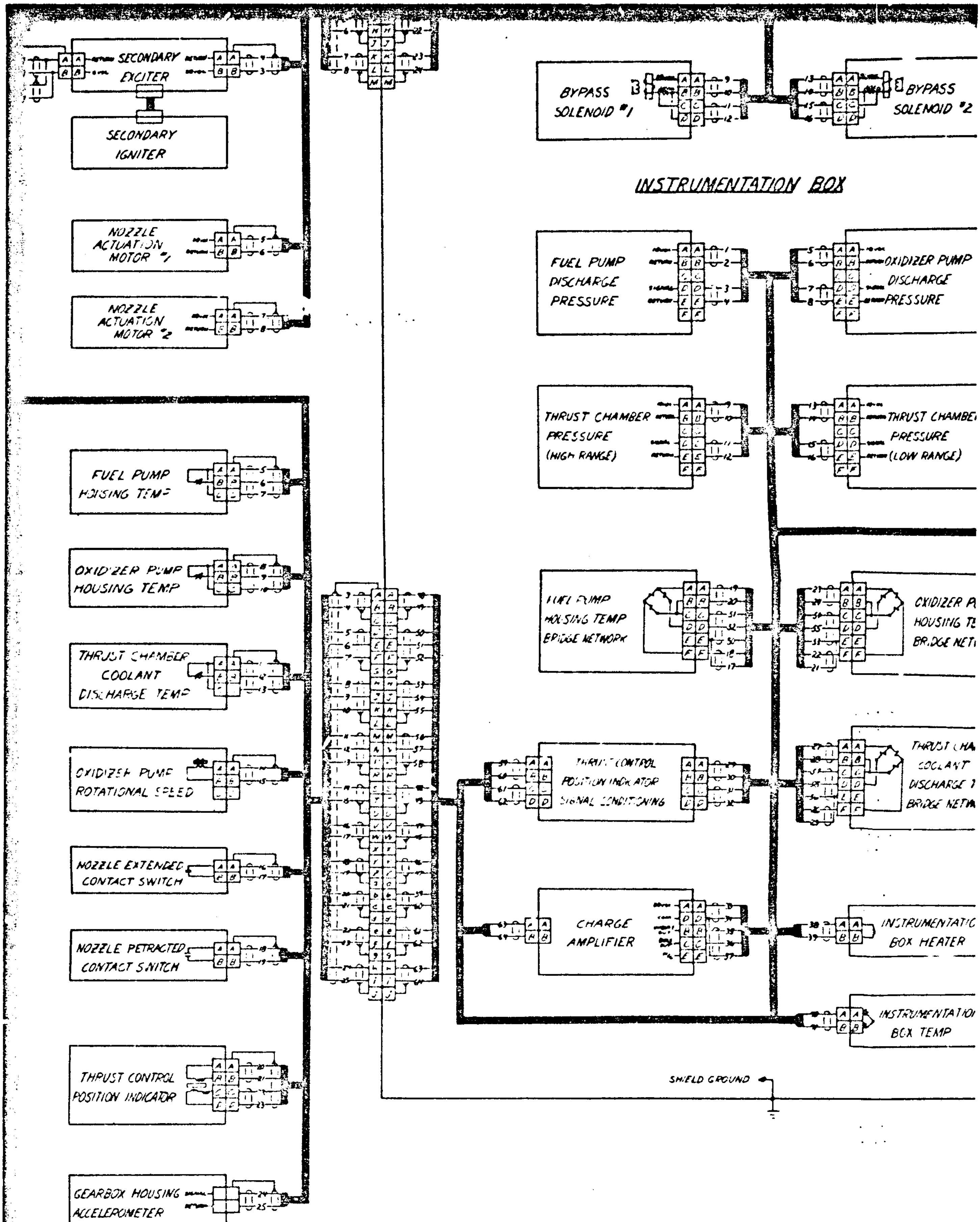
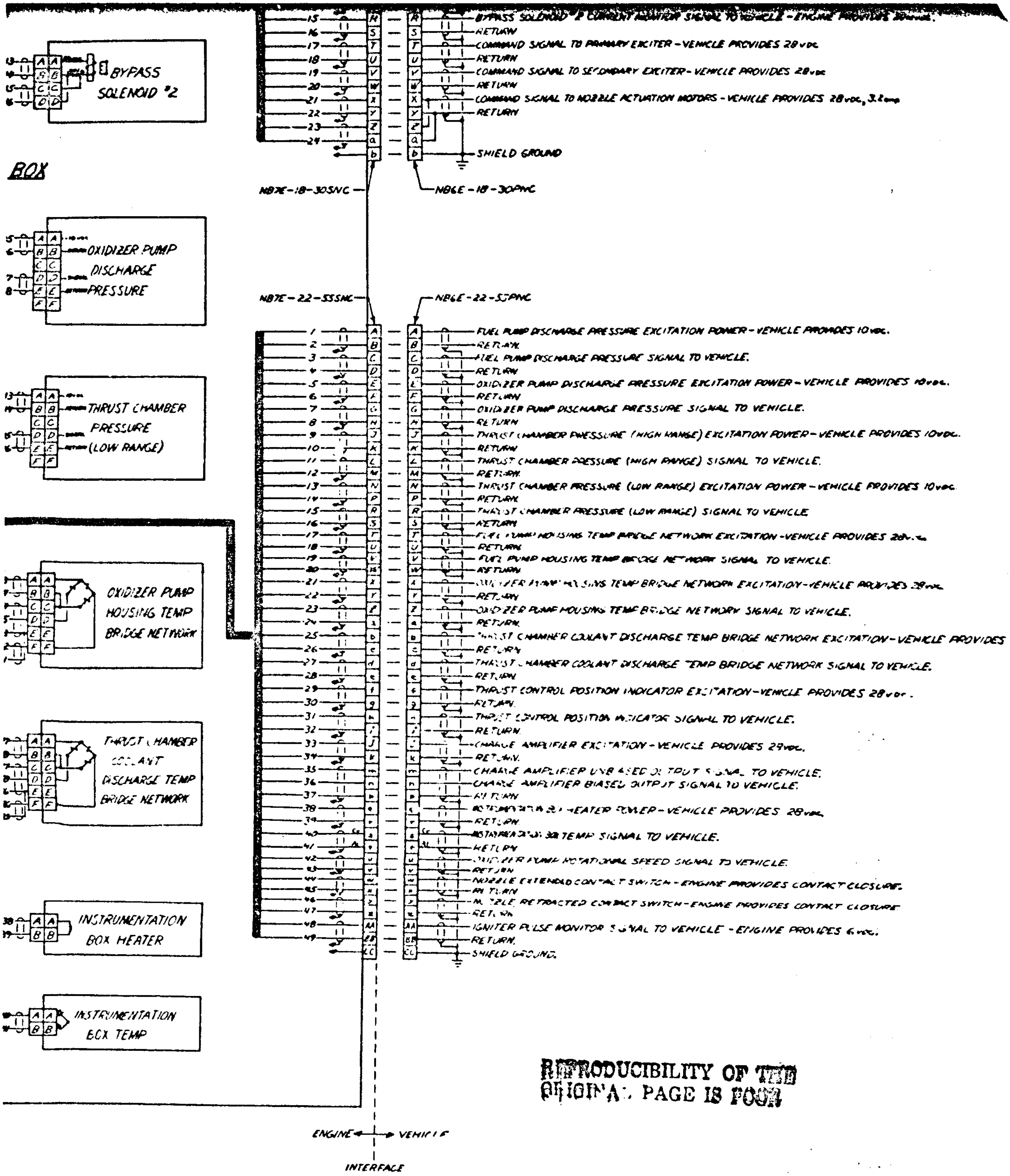


Figure D-4 Electrical Wiring Schematic



FOLDOUT

FD 76713

SECTION E
ENGINE FLUID REQUIREMENTS

1. GENERAL

1.1 Propellant Criteria

1.1.1 Fuel

Liquid hydrogen must be supplied in accordance with MSFC Specification No. 365A or MIL-P-27201 at the nominal weight flowrates shown in table E-1 (full thrust and a nominal mixture ratio of 6.0):

Table E-1. Nominal Fuel Flowrates

Engine	Weight Flow, lb/sec
Category I	4.89
Derivative IIA	4.69
Derivative IIB	4.69
Category IV	4.56

The hydrogen must be supplied within the limits specified on figures E-1 through E-3. The effects of mixture ratio on minimum fuel NPSP requirements are shown in figure E-4.

1.1.2 Oxidizer

Liquid oxygen must be supplied in accordance with Specification No. MIL-P-25508 or equivalent at the nominal weight flowrates shown in table E-2 (full thrust and a nominal mixture ratio of 6.0):

Table E-2. Nominal Oxidizer Flowrates

Engine	Weight Flow, lb/sec
Category I	29.3
Derivative IIA	28.14
Derivative IIB	28.14
Category IV	27.36

The oxygen must be supplied within the limits specified on figures E-5 through E-7. The effects of mixture ratio on minimum oxidizer NPSP requirements for the Category I and Derivative IIB engines are as previously shown in figure E-4.

1.1.3 Propellant Ventage

The ventage of propellant overboard is shown in table E-3.

Table E-3. Nominal Ventage of Fluid Overboard

Engine		Engine Not Operating, lb/min	Tank Head Idle, lb/min	Pumped Idle, lb/min	Full Thrust, lb/min
A.	Hydrogen				
	Category I	0.00023	N/A	N/A	4.8*
	Derivative IIA	0.00004	0.1	0.4*	1.1*
	Derivative IIB	0.00023	0.1	0.4*	1.0*
	Category IV	0.00004	0.1	0.4*	1.1*
B.	Oxygen				
	Category I	0.0047	N/A	N/A	1.5
	Derivative IIA	0.0009	0.1	1.2*	3.0*
	Derivative IIB	0.0047	0.1	0.6*	1.5*
	Category IV	0.0009	0.1	1.2*	3.0*

*Does not include tank pressurization flow

1.2 Pneumatic Requirements

The engine systems require a 470 ± 30 psia supply of gaseous helium to the engine helium supply connection. This pneumatic supply of regulated helium actuates various valves such as the fuel and oxidizer inlet valves, vent valve, main fuel shutoff valve, and turbine bypass valve. The estimated total helium usage is 0.044 lb for each firing. Leakage from the pneumatic system is summarized in table E-4.

Table E-4. Estimated Pneumatic Requirements

Engine	Nonoperating, lb/min	Tank Head Idle, lb/min	Maneuver Thrust (Pumped Idle), lb/min	Full Thrust, lb/min
Category I	0.0018	N/A	N/A	0.0018
Derivative IIA	0.0006	0.0018	0.0018	0.0018
Derivative IIB	0.0006	0.0018	0.0018	0.0018
Category IV	0.0001	0.0003	0.0003	0.0003

1.3 Engine Purge Requirements

In order to prevent moisture contamination of the RL10 derivative engines, a purge is required while on the ground and during the descent phase when the Tug is in the Orbiter. Dry, 500°R helium in accordance with MIL-P-27407 is to be supplied at a pressure of 6 psig. It is recommended that the helium be supplied to the engine combustion chamber through the nozzle, the exit of which must be sealed to prevent the purge gas from flowing out the nozzle. The purge gas will therefore enter the propellant injector and flow into both the fuel and oxidizer sides of the engine. The purge gas fills the oxidizer side, with a small portion of it flowing past the oxidizer shaft seals into the vent cavities, and then overboard. The purge flows back through the fuel side of the engine and overboard through the fuel vent or fuel pump interstage bleed and discharge cooldown valves which are open when the Category I and Derivatives IIA and IIB engines are in a nonoperating mode. In the Category IV engine, the fuel-side purge goes overboard through the main fuel control vent. The estimated helium purge flowrate is 7 lb/hr.

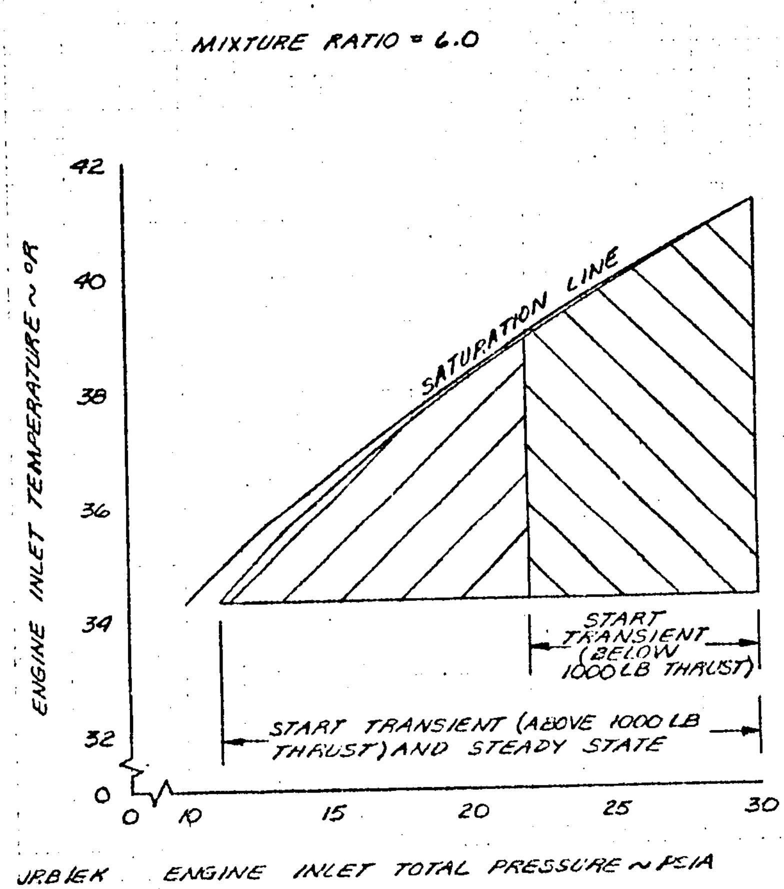


Figure E-1. Required Fuel Conditions at Engine Inlet, Category I Engine

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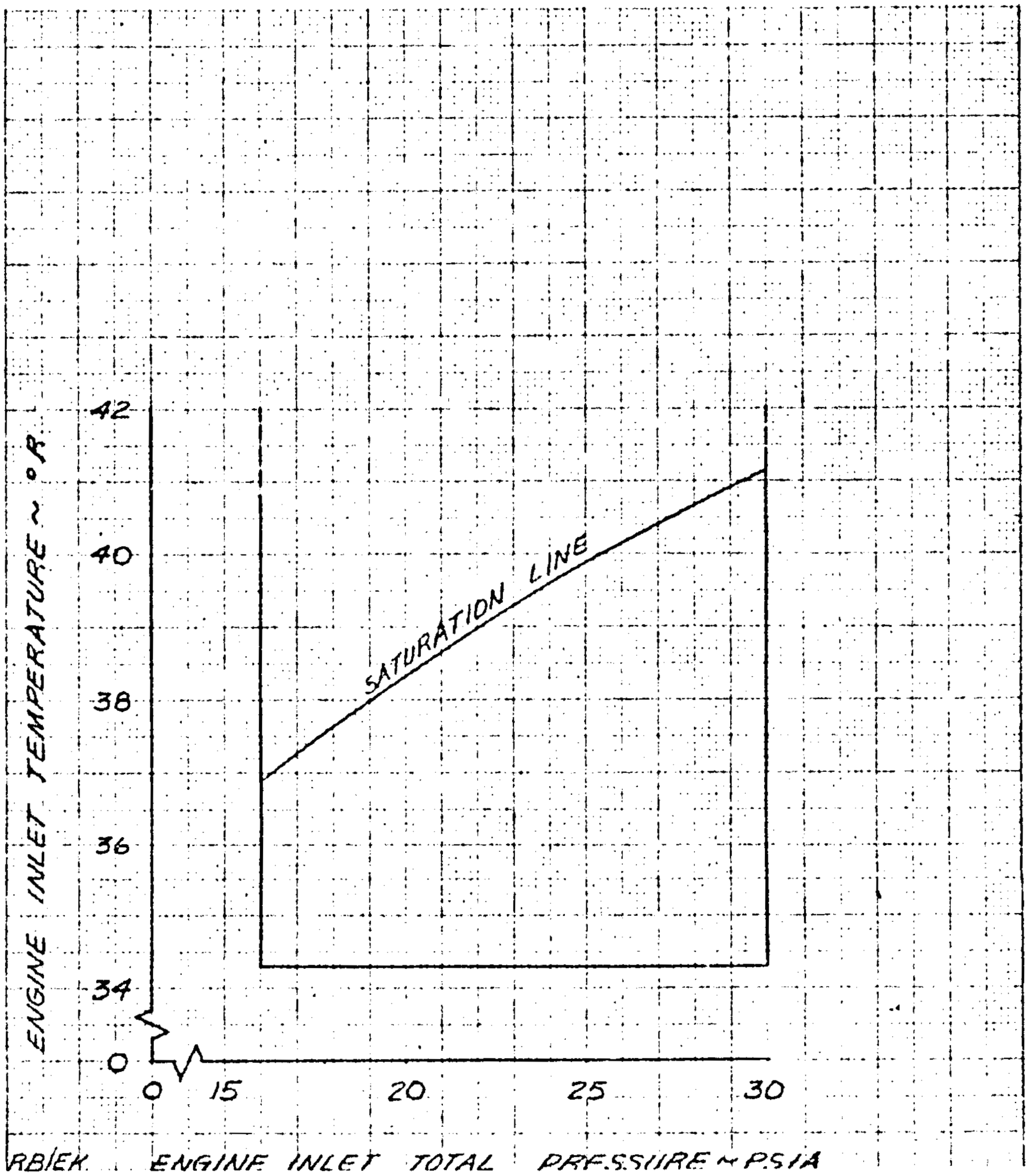

Figure E-2. Allowable Fuel Conditions for Tank Head Idle Start, Derivative IIA, IIB and Category IV Engines DF 96914

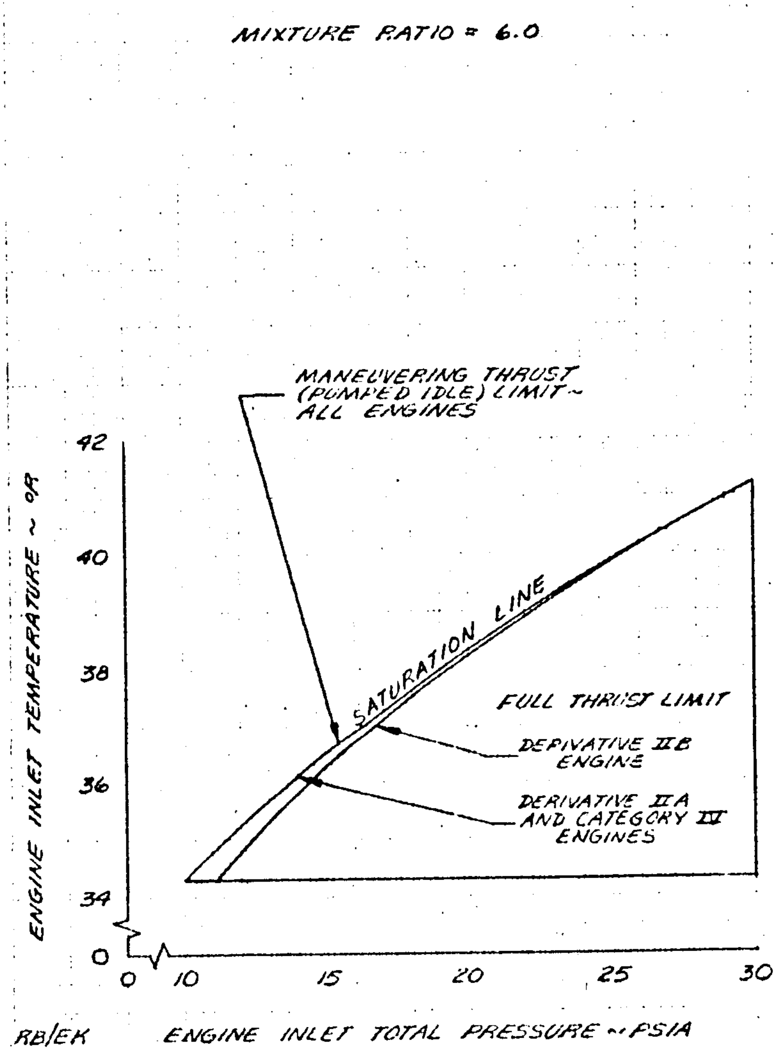

Figure E-3. Required Fuel Conditions at Engine Inlet, Derivatives IIA and IIB and Category IV Engines Maneuver and Full Thrust

DF 96907

DF 96972

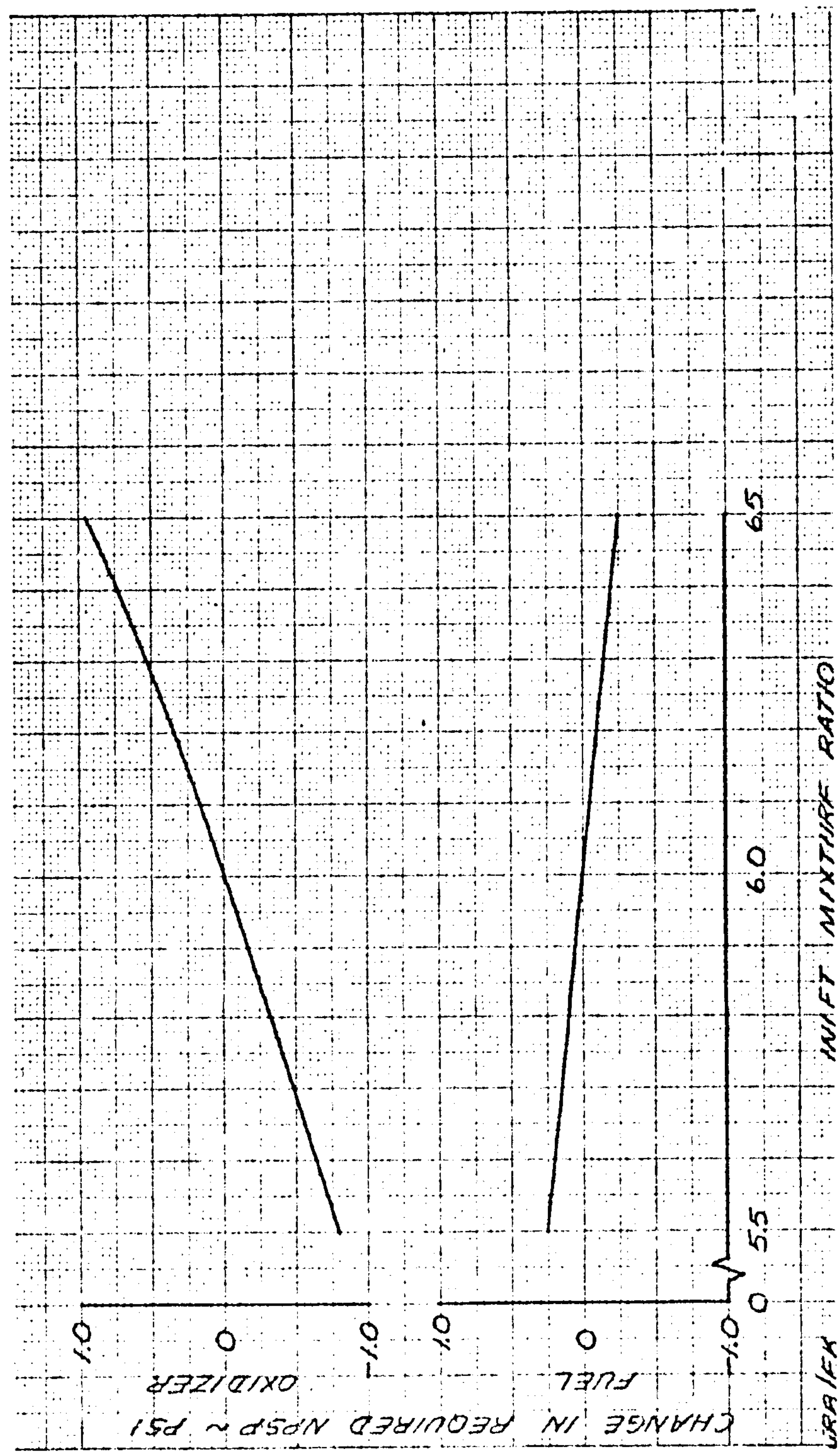

Figure E-4. Effect of Mixture Ratio on Required Engine Inlet NPSP, Category I and Derivative IIB Engines

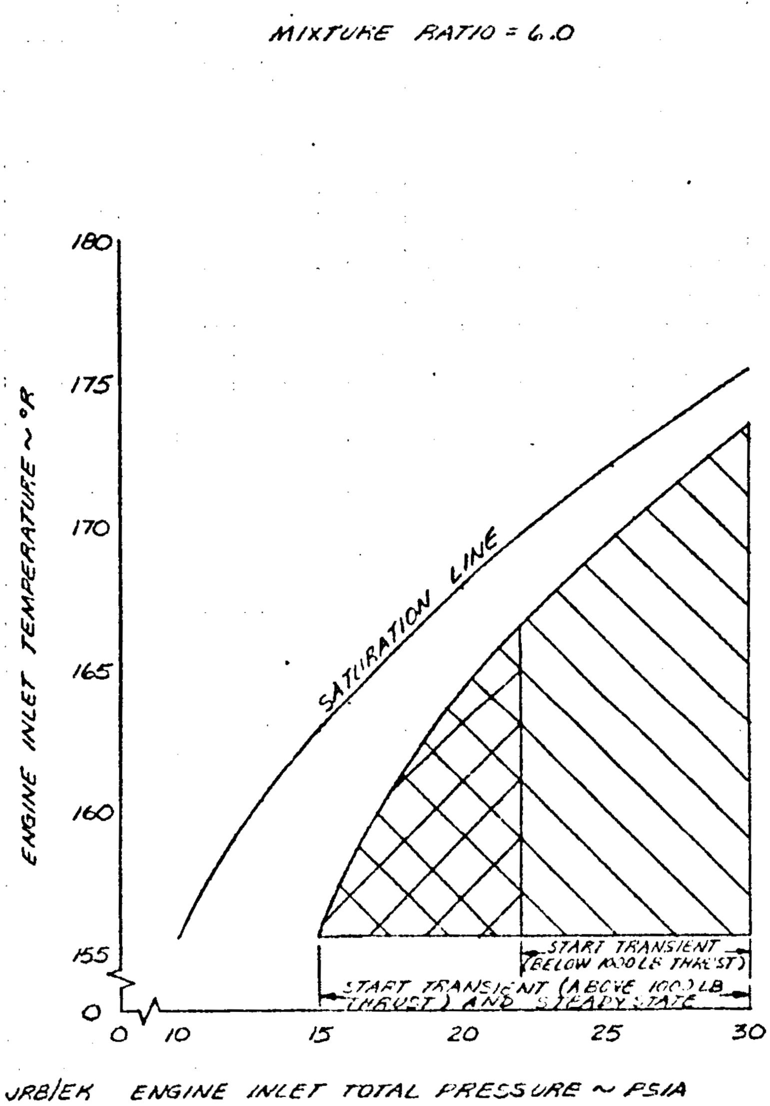

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Figure E-5. Required Oxidizer Conditions at Engine Inlet, Category I Engine

DF 96974

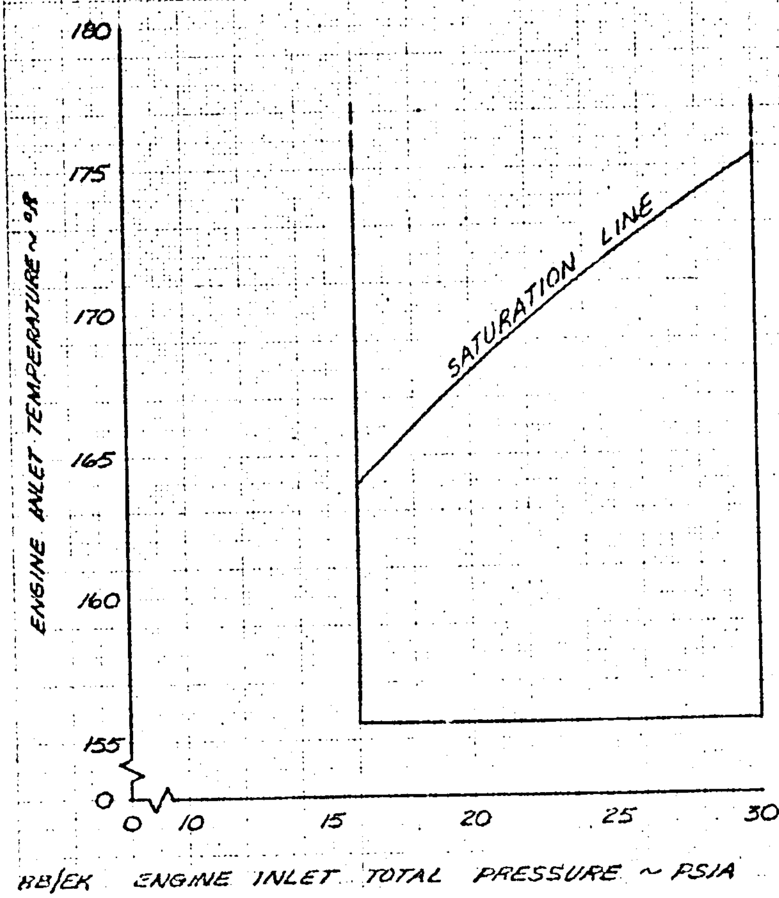

Figure E-6. Allowable Oxidizer Conditions for Tank Head Idle Start, Derivative IIA, IIB and Category IV Engines

DF 96913

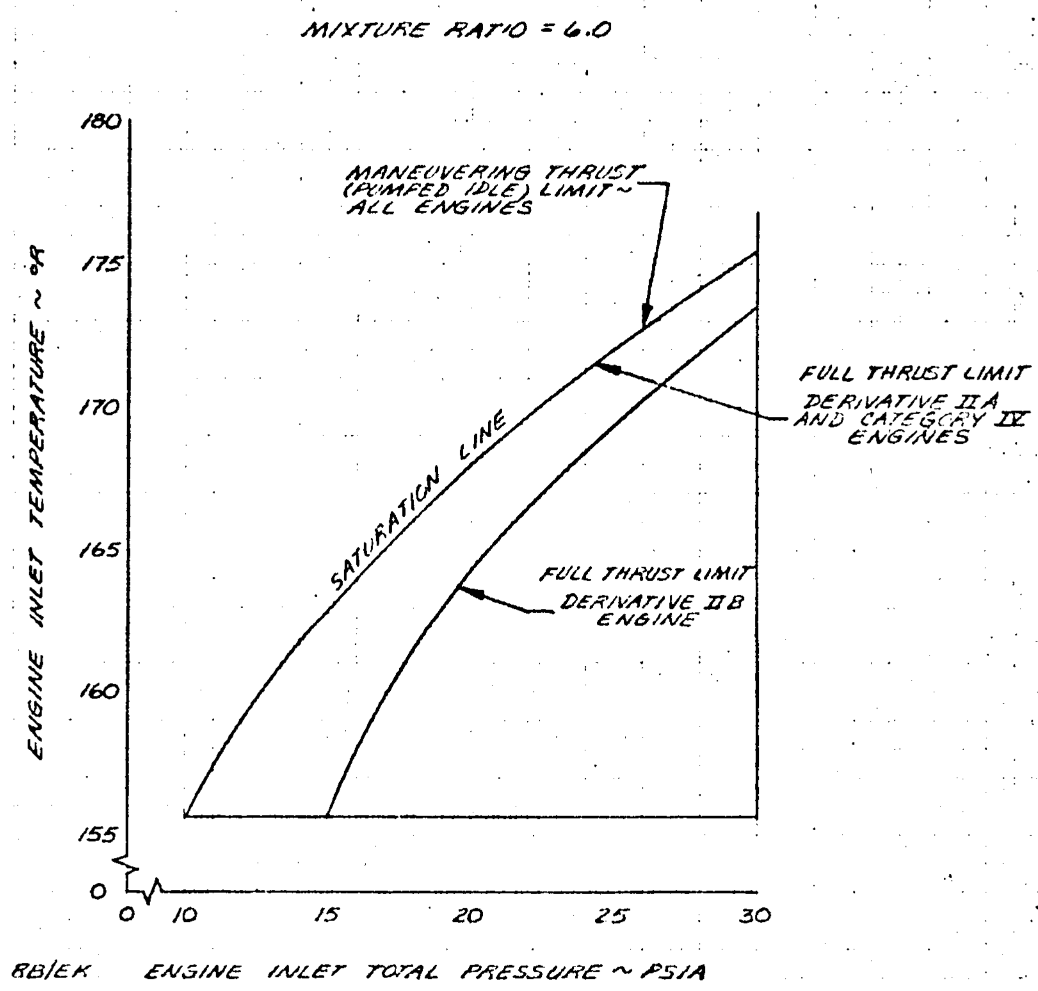

Figure E-7. Required Oxidizer Conditions at Engine Inlet, Derivatives IIA and IIB and Category IV Engines Maneuver and Full Thrust DF 96908

SECTION F
ENVIRONMENTAL CRITERIA

1. GENERAL

The RL10 derivative engines (Category I, Derivative IIA and IIB, and Category IV) will withstand the space environment as well as the environments induced while the Space Tug is stowed in the Space Shuttle orbiter cargo bay as specified in JSC 07700, Volume XIV, dated 13 April 1973.

1.1 Pressure Environment

The RL10 derivative engines will be unaffected by environmental pressures ranging from normal ground level ambient pressure to vacuum pressures encountered in the orbiter cargo bay and/or space environment.

1.2 Temperature Environment

The RL10 derivative engines will not suffer any detrimental effects in temperatures of 360°R to 660°R when in the Space Shuttle payload bay or in a space environment.

1.3 Acoustic Environment

The engines will withstand an estimated acoustic impingement of 147 db overall sound pressure level (0.0002 dynes/cm^2) over the frequency of 7 to 3000 Hz when in the Space Shuttle payload bay, per figure 10-4, JSC 07700, Volume XIV.

1.4 Humidity Environment

The derivative engines will not be adversely affected by the following:

Air humidity - 0 to 43 grains/lb of dry air
GN_2 humidity - 0 to 1 grain/lb of dry nitrogen

1.5 Shock Loads

The derivative engines are capable of withstanding the loads cited in Section G.

1.6 Vibration Environment

The engines will withstand externally imposed vibration environmental conditions from any source to the extent shown in the following paragraphs.

The vibration requirements listed below are for the RL10A-3-3 specification. Further study in this area will be required when the payload bay vibration requirements are defined. (Figure 10-1, JSC 07700, Volume XIV, to be supplied.)

1.6.1 Axial Direction

1.6.1.1 Sinusoidal Sweep Level

The sinusoidal sweep level in the axial direction is:

a. 10 to 16 Hz at 0.15 in. double amplitude

b. 16 to 480 Hz at 2 g peak or 570 lb actuator load, whichever occurs first

c. 480 to 1000 Hz at 0.00017 in. double amplitude

d. 1000 to 2000 Hz at 8.7 g peak

e. Sweep rate of 3 min/octave up and back

f. 10 to 100 Hz at 3 g peak or 570 lb actuator load, whichever occurs first, at a sweep rate of 6 sec/octave (up only).

1.6.1.2 Sinusoidal Dwell Level

The sinusoidal dwell level in the axial direction is:

a. 10 to 16 Hz at 0.073 in. double amplitude

b. 16 to 465 Hz at 1.0 g peak or 570 lb actuator load, whichever occurs first

c. 465 to 975 Hz ±0.00009 in. double amplitude

d. 975 to 2000 Hz at 4.35 g peak

e. 6 min dwell time per major resonance.

1.6.1.3 Random Motion Level

The random motion level in the axial direction has broadband random white noise over 20 to 2000 Hz bandwidth for 16 min at 0.031 g^2/Hz.

1.6.2 Lateral Direction

1.6.2.1 Sinusoidal Sweep Level

The sinusoidal sweep level in the lateral direction is as follows:

a. 10 to 12 Hz at 0.27 in. double amplitude or 570 lb actuator load, whichever occurs first

b. 12 to 500 Hz at 2 g peak or 570 lb actuator load, whichever occurs first

c. Sweep rate of 3 min/octave up and back

d. 10 to 100 Hz at 3 g peak or 570 lb actuator load, whichever occurs first, at a sweep rate of 5 sec/octave (up only).

1.6.2.2 Sinusoidal Dwell Level

The sinusoidal dwell level in the lateral direction is:

a. 5 to 500 Hz at 0.66 g peak or 570 lb actuator load, whichever occurs first

b. 16 min dwell time at each major resonance.

1.7 Contamination

Engine operation will be unaffected by TBD contamination levels.

1.8 Radio Frequency Environment

Electrical components for all RL10 derivative engines will not cause radio interference beyond the limits specified in MIL-I-6181. The interference limits specified in 3.2.2 of MIL-I-6181 for ignition components and other short duration interferences shall apply. This provides no limitation during the short duration transients while the solenoid and ignition systems are being switched "on" and "off", and there is a 20-db increase over the limit during the period while the ignition system is operating. These radio frequency requirements are from the RL10A-3-3 specification and further study in this area will be required upon definition of the radio frequency environment.

SECTION G
ENGINE LOAD CHARACTERISTICS

1. GENERAL

1.1 Allowable Gimbal Loads

The engine can be gimbaled through an angle about the engine geometric centerline (square pattern) while firing. The estimated maximum allowable loads due to gimbal actuation and the gimbal angle are shown in table G-1.

Table G-1. Estimated Maximum Allowable Loads Due to Gimbal Actuation and Degrees of Gimbal

	Engine			
	Category I	Derivative IIA	Derivative IIB	Category IV
Maximum allowable actuator load, lb	2640	2640	2640	2640
Maximum pitching acceleration, rad/sec^2	1	1	1	1
Maximum yawing acceleration, rad/sec^2	1	1	1	1
Gimbal angle, deg	±4	±4	±4	±4

The maximum allowable actuator shock load is 2640 lb with a minimum time interval of 2 sec between successive shocks for all engines.

1.2 Nonfiring Loads

1.2.1 Ground Handling Loads

The engines will withstand an estimated 4.0-g handling load applied in any direction while installed in their handling frame, and will withstand an estimated 3.0-g axial acceleration load in combination with a 2.8-g lateral acceleration load during ground handling without the handling frame installed, but with the engines supported at normal interfaces as defined on their installation drawings. The maximum handling load on a single gimbal actuator attach point shall not exceed 3.6 g.

1.2.2 Nonfiring Flight Loads and Landing Loads

The Category I, Derivative IIA and IIB, and Category IV engines will withstand the acceleration load conditions specified in table 4-1 of JSC 07700, Volume XIV during nonfiring flight, but the engines must be supported at normal interfaces as defined on their installation drawings. The maximum estimated load on a single gimbal actuator attach point shall not exceed 3.6 g.

SECTION II
WEIGHT CHARACTERISTICS

1. GENERAL

1.1 Engine Dry and Wet Weight

The estimated maximum dry weight of each category engine, and the estimated wet weight at normal operating conditions are shown in table II-1.

Table II-1. Maximum Engine Weight and Propellant Weight (Estimated)

Engine	Basic Dry Weight, lb	Propellant Weight, lb	Total Wet Weight, lb
Category I	301	8	309
Derivative IIA	513	14	527
Derivative IIB	474	8	482
Category IV	424	12	436

The standard equipment weight included in the engine dry weight consists of: (a) instrumentation kit, including pressure transducers, temperature and pressure probes, speed sensor, tubing and mounting provisions for transducers, (b) control solenoids, and (c) propellant tank pressurizing valves.

1.2 Items Not Considered in Engine Weight

The engine weight does not include the weight of the gimbal actuation arms and support system, equipment driven by the accessory drive, the propellant utilization motor and signal system, and nonpropulsive vents.

1.3 Center of Gravity

The estimated center of gravity for each engine is shown in table II-2 (refer to figure II-1).

Table II-2. Engine Center of Gravity Location

	Axial (x), Nozzle Retracted, in.	Axial (x), Nozzle Extended, in.	Horizontal (y), in.	Vertical (z), in.
Category I	N/A	26.0	4.5	1.5
Derivative IIA	25.6	37.6	1.5	2.8
Derivative IIB	26.1	39.2	1.0	2.2
Category IV	20.9	30.7	0	1.7

1.4 Gimbaled Moments of Inertia

Estimates of gimbaled moments of inertia are presented in table H-3. (Refer to previously shown figure H-1.)

Table H-3. Engine Gimbaled Moments of Inertia

Engine	I_{xx}, in.-lb-sec^2	I_{yy}, in.-lb-sec^2	I_{zz}, in.-lb-sec^2
Category I	112	725	703
Derivative IIA	505	3610	3585
Derivative IIB	480	3540	3520
Category IV	325	2275	2245

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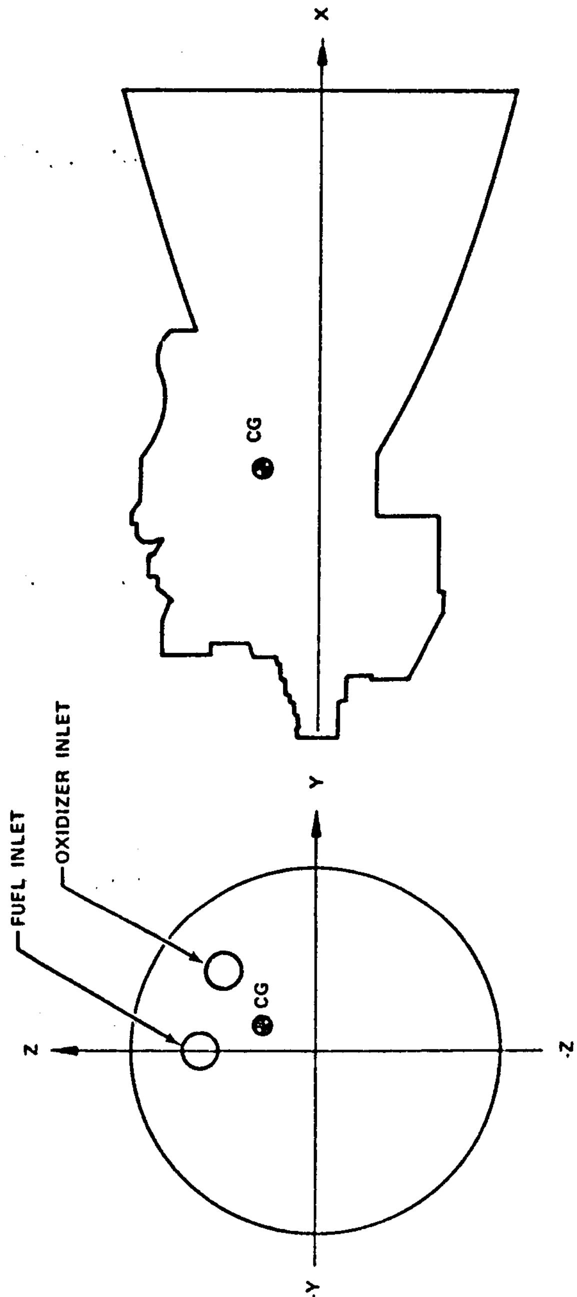

Figure H-1. Location of Engine Center of Gravity

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