PWA FR-1769
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DESIGN REPORT
FOR
RL10A-3-3 ROCKET ENGINE

CONTRACT NO. NAS8-15494

PRATT & WHITNEY AIRCRAFT
DEPENDABLE ENGINES

Approved by:

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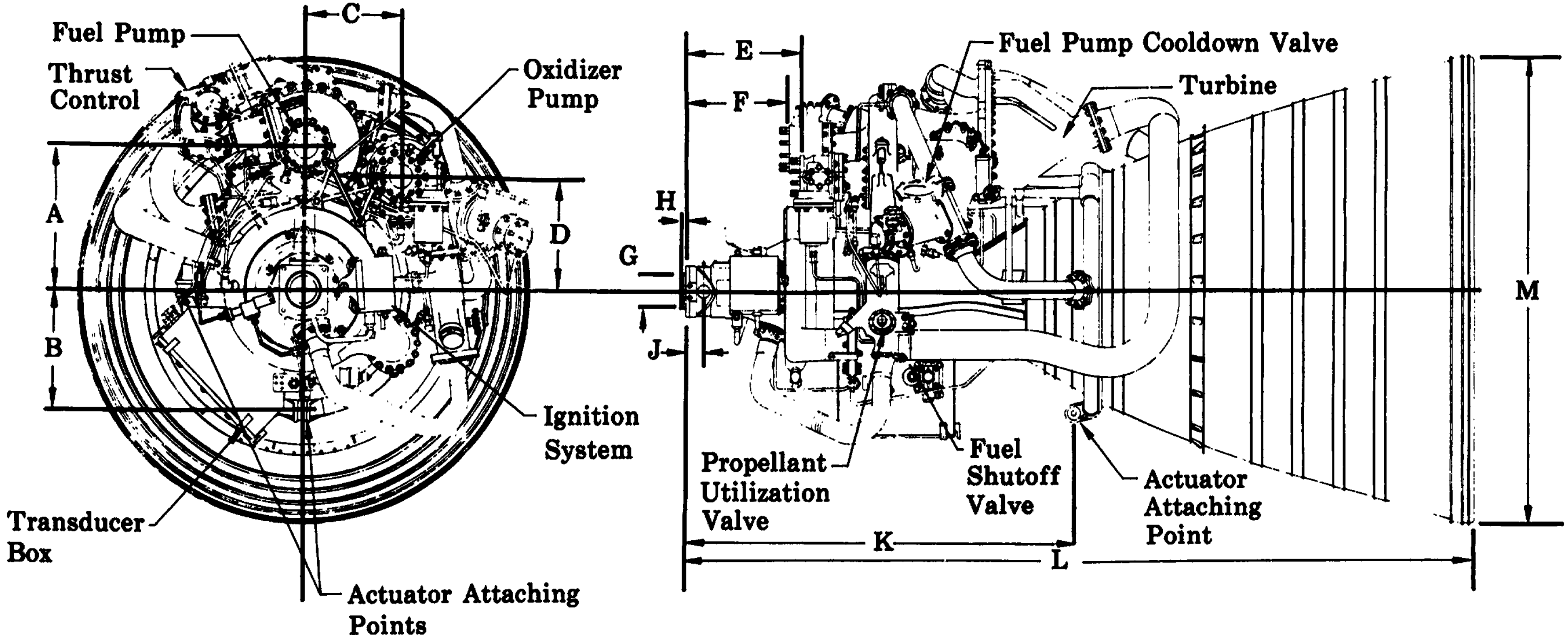
FLORIDA RESEARCH AND DEVELOPMENT CENTER

INTRODUCTION

The RL10A-3-3 rocket engine is a regeneratively cooled, turbopump-fed engine with a single chamber and a rated thrust of 15,000 lb at an altitude of 200,000 ft, and a nominal specific impulse of 444 sec. Propellants are liquid oxygen and liquid hydrogen injected at a nominal oxidizer-to-fuel mixture ratio of 5.0:1. Rated engine thrust is achieved at a nominal design chamber pressure of 400 psia with a nominal nozzle area ratio of 57:1. The engine can be used for multiengine installations on an interchangeable basis. The engine will be capable of making at least three starts during a single mission with a nominal running time of 450 sec during a single firing. The service life of the engine shall be an accumulated running time of 4000 sec. Nonfiring functional checks of the complete engine system shall not exceed 500 cycles or 30 turbopump rotating tests. Components having a service life in excess of 500 cycles shall be listed in the Service Manual.

SECTION II
INSTALLATION DRAWING

The installation drawing of the RL10A-3-3 engine assembly is shown in figure II-1.



A — 11.750	D — 9.419	G — 2.876	K — 32.874
B — 10.172	E — 9.603	H — 0.240	L — 70.10
C — 8.128	F — 8.738	J — 1.500	M — 39.54

Dimensions are Nominal in Inches at Room Temperature

Figure II-1. RL10A-3-3 Engine Installation

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SECTION III
ASSEMBLY DRAWING

The assembly drawing for the RL10A-3-3 engine assembly is shown in figure III-1.

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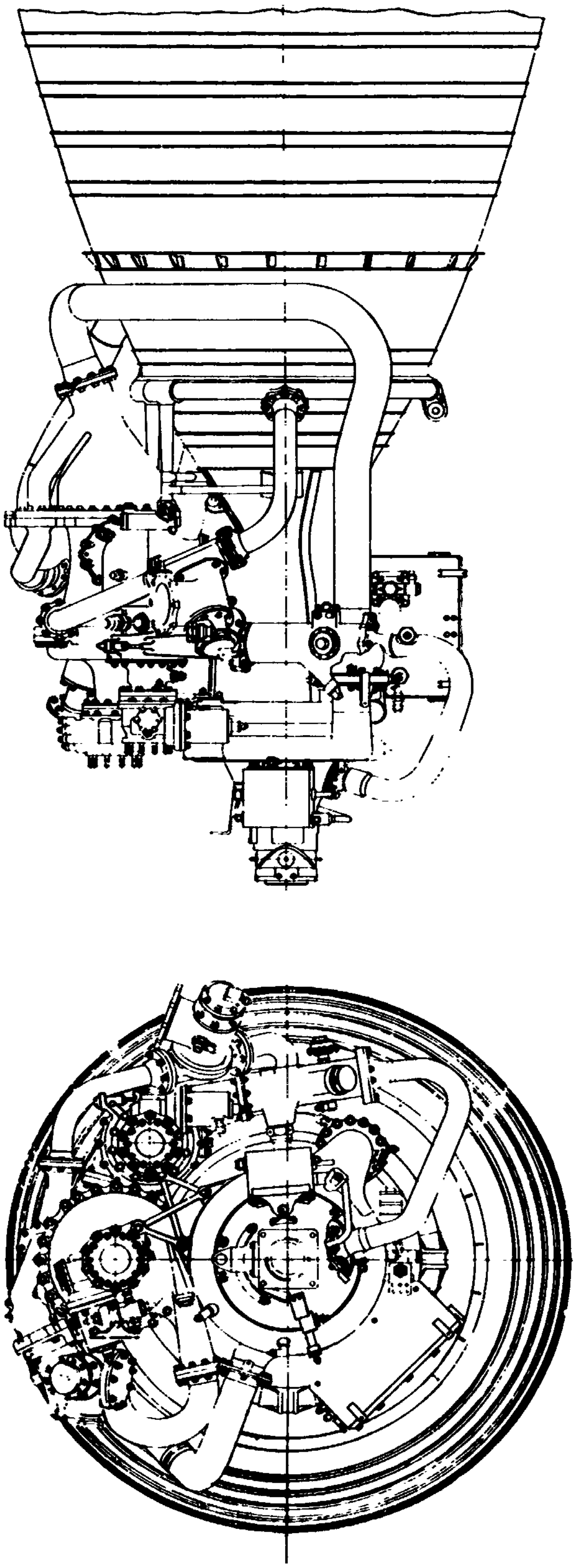

Figure III-1. RL10A-3-3 Engine Assembly

SECTION IV
WEIGHT BREAKDOWN

The weight breakdown of the RL10A-3-3 engine assembly is shown in table IV-1.

Table IV-1. RL10A-3-3 Assembly Weight Breakdown

Component	Weight, lb
Injector assembly	14.82
Thrust chamber	102.44
Turbopump	75.10
Turbopump mounts	3.78
Engine mount	10.75
Ignition system	7.10
Oxidizer inlet shutoff valve	5.55
Fuel inlet shutoff valve	5.81
Oxidizer flow control valve	6.92
Fuel cooldown valve interstage	7.03
Fuel cooldown valve downstream	6.26
Thrust control valve	5.30
Main fuel shutoff valve	3.41
Solenoid valves	7.68
Tube - oxidizer flow control valve to injector manifold	2.47
Tube - fuel pump to downstream cooldown valve	1.22
Tube - downstream cooldown valve to thrust chamber	1.55
Tube - thrust chamber to turbine	5.40
Tube - turbine to main fuel shutoff valve	8.40
Small lines	2.15
Connecting and miscellaneous hardware	6.65
Total basic engine weight (based on 3σ maximum) (Specification basic engine weight is 290.00 lb)	289.79
Nonchargeable weights	
Instrumentation	9.62
Hydraulic line brackets	.55
Nonflight items	1.23
Total engine weight	301.19

SECTION V
ANALYSIS OF STEADY-STATE AND TRANSIENT PERFORMANCE

A. STEADY-STATE PERFORMANCE

The steady-state performance characteristics of the RL10A-3-3 engine are given in table V-1.

Table V-1. Estimated RL10A-3-3 Engine Design Data

Parameter	Ratings		
Mixture ratio	4.4	5.0	5.6
Altitude, ft	200,000	200,000	200,000
Thrust, lb	14,720	15,000	15,220
Nominal specific impulse, sec	446	444	440
Fuel flow, lb/sec	6.11	5.63	5.24
Oxidizer flow, lb/sec	26.90	28.16	29.33
Chamber pressure (throat total), psia	383.7	385.2	385.3
Chamber pressure (injector face static), psia	392.8	394.6	395.0
Oxidizer Pump			
Inlet total pressure, psia	60.5	60.5	60.5
Inlet temperature, °R	175.3	175.3	175.3
Inlet density, lb/ft^3	68.8	68.8	68.8
Flow rate, gpm	175.5	183.7	191.3
Head rise, ft	1182	1123	1068
Speed, rpm	12,390	12,100	11,840
Efficiency, percent	61.9	63.2	64.3
Horsepower	93.5	90.9	88.6
Discharge pressure, psia	625.3	597.1	570.9
Fuel Pump			
Inlet total pressure, psia	30.0	30.0	30.0
Inlet temperature, °R	38.3	38.3	38.3
Inlet density, lb/ft^3	4.35	4.35	4.35
Discharge density, lb/ft^3	4.25	4.23	4.21
Flow rate, gpm	630.7	580.9	540.2
Fuel leakage, lb/sec	0.07	0.07	0.07
Head rise, ft	33,950	32,740	31,550

Table V-1. (Continued)

Fuel Pump (continued) Mixture Ratio	4.4	5.0	5.6
Speed, rpm	30,970	30,250	29,590
Efficiency, percent	55.9	54.7	53.6
Horsepower	635.5	574.7	524.1
Discharge pressure, psia	1030.9	991.3	952.6
Fuel pump downstream orifice and line pressure loss, psid	86.0	73.1	63.4
Fuel pump downstream orifice diameter, in.	0.683	0.683	0.683
Turbine			
Inlet total pressure, psia	722.3	698.1	676.5
Inlet total temperature, °R	316.5	353.9	386.6
Discharge static pressure, psia	498.5	496.3	492.2
Downstream total pressure, psia	495.9	493.1	488.5
Speed, rpm	30,970	30,250	29,590
Efficiency, percent	73.5	72.9	72.5
Horsepower	731.1	667.8	614.7
Turbine flow, lb/sec	5.99	5.35	4.87
Percent bypass flow	0.94	3.86	5.72
Effective area, in^2 (first stage)	1.169	1.169	1.169
Thrust control bypass area, in^2	0.0108	0.0454	0.0684
Thrust Chamber Assembly			
Chamber pressure (injector static), psia	392.8	394.6	395.0
Chamber pressure (throat total), psia	383.9	385.2	385.3
Fuel injector ΔP, psid	85.7	81.8	77.6
Oxidizer injector ΔP, psid	44.2	48.4	52.4
Fuel flow, lb/sec	6.04	5.56	5.17
Oxidizer flow, lb/sec	26.90	28.16	29.33
Chamber mixture ratio	4.45	5.06	5.67
c* efficiency, percent of shifting	98.9	98.6	98.3
c* (actual), ft/sec	7778	7626	7455

Table V-1. (Continued)

Thrust Chamber Assembly — Mixture Ratio	4.4	5.0	5.6
Combustion temperature (ideal), °R	5560	5829	6013
Gas constant (ideal), ft/°R	143.6	130.9	121.0
Specific heat ratio	1.216	1.210	1.206
Wall margin (minimum), °R	794	675	587
Characteristic length (L*), in.	38.7	38.7	38.7
Chamber area (injector end), in^2	83.4	83.4	83.4
Chamber throat diameter, in.	5.14	5.14	5.14
Chamber throat area, in^2	20.75	20.75	20.75
Discharge diamter ID, in.	38.8	38.8	38.8
Effective expansion ratio, A/A*	57.1	57.1	57.1
C_s (thrust coefficient efficiency), percent	98.1	98.0	97.9
Pressure Drop Summary			
Fuel			
Pump pressure rise, psid	1000.8	961.3	922.6
Downstream orifice and line, psid	86.0	73.1	63.4
Cooldown valve, psid	0.389	0.331	0.287
Jacket, psid	177.9	169.6	162.6
Gas line upstream of venturi, psid	3.33	3.23	3.13
Venturi, psid	40.9	47.0	46.7
Turbine (total to static), psid	223.8	201.8	184.3
Turbine discharge casing (static to total), psid	2.6	3.3	3.7
Gas line, turbine discharge to main fuel shutoff valve, psid	0.47	10.03	9.58
Main fuel shutoff valve, psid	6.96	6.66	6.35
Injector, psid	85.7	81.8	77.6
Oxidizer			
Pump pressure rise, psid	564.8	536.6	510.4
Mixture ratio control valve, psid	182.9	148.3	117.1
Liquid line, psid	5.39	5.90	6.40
Injector, psid	44.2	48.4	52.4

Table V-1. (Continued)

Temperature Change Summary	Mixture Ratio	4.4	5.0	5.6
Fuel				
Pump increase, °R		18.06	17.91	17.73
Jacket increase, °R		270.4	308.6	341.8
Turbine decrease, °R		21.8	22.4	23.0
Oxidizer				
Pump increase, °R		2.28	2.05	1.86

B. TRANSIENT PERFORMANCE

The transient performance characteristics of the RL10A-3-3 engine are shown in figures V-1 through V-3.

C. SEQUENCE OF ENGINE OPERATION

The design sequence of operation for the RL10A-3-3 engine is shown in figure V-4.

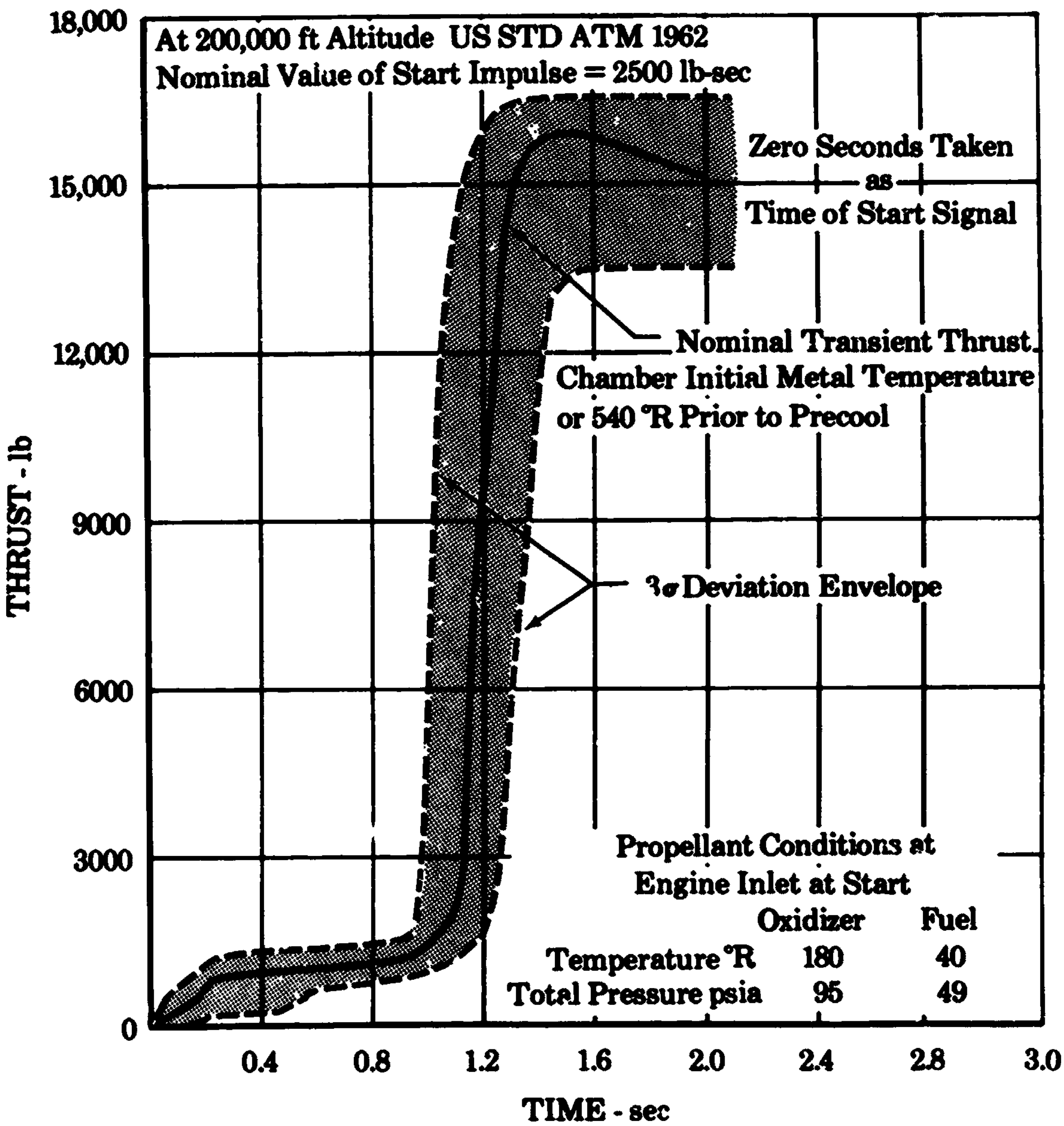

Figure V-1. Estimated Starting Transient Showing 3σ Deviation Envelope

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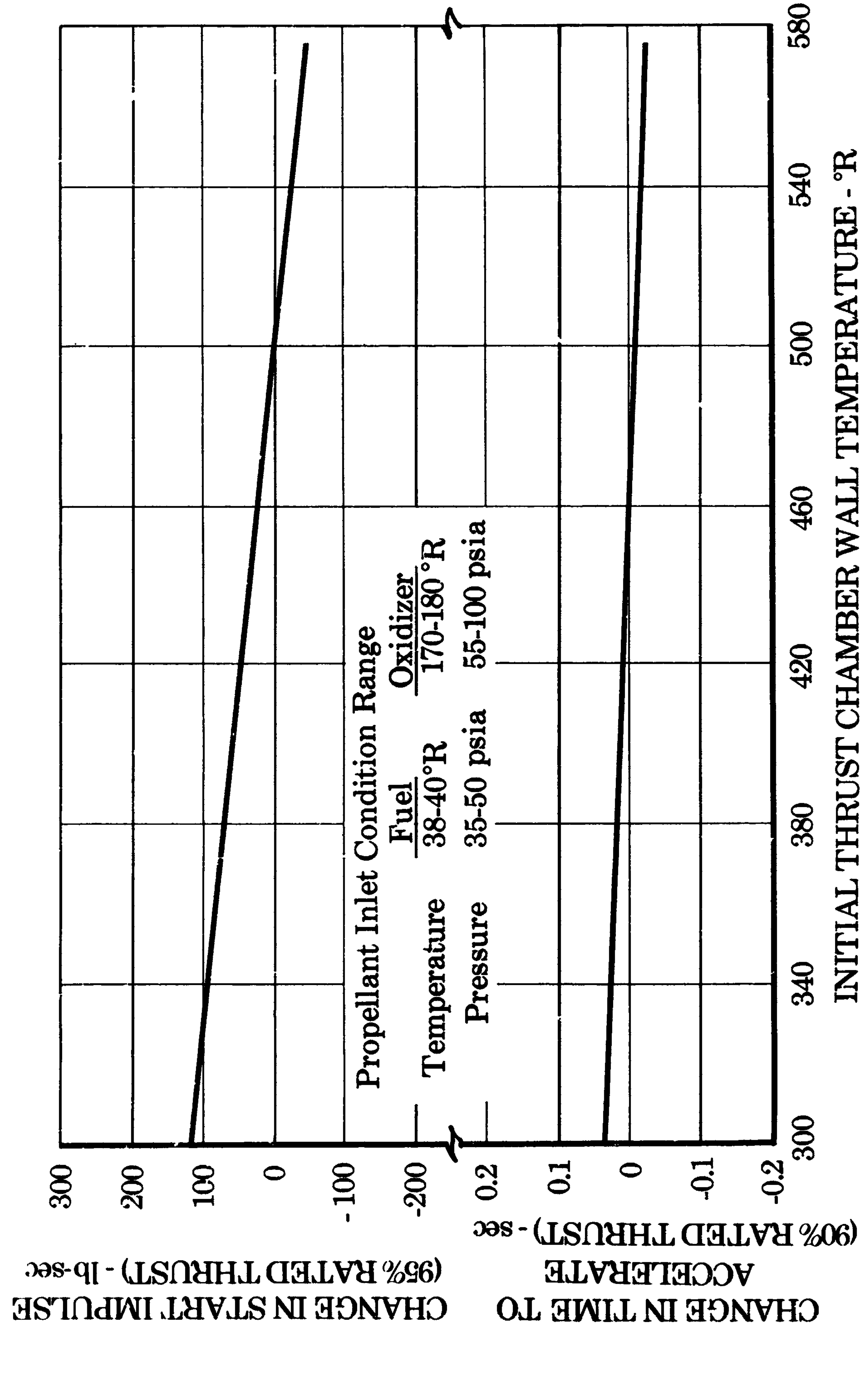

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Figure V-2. Estimated Effects of Initial Thrust Chamber Wall Temperatures

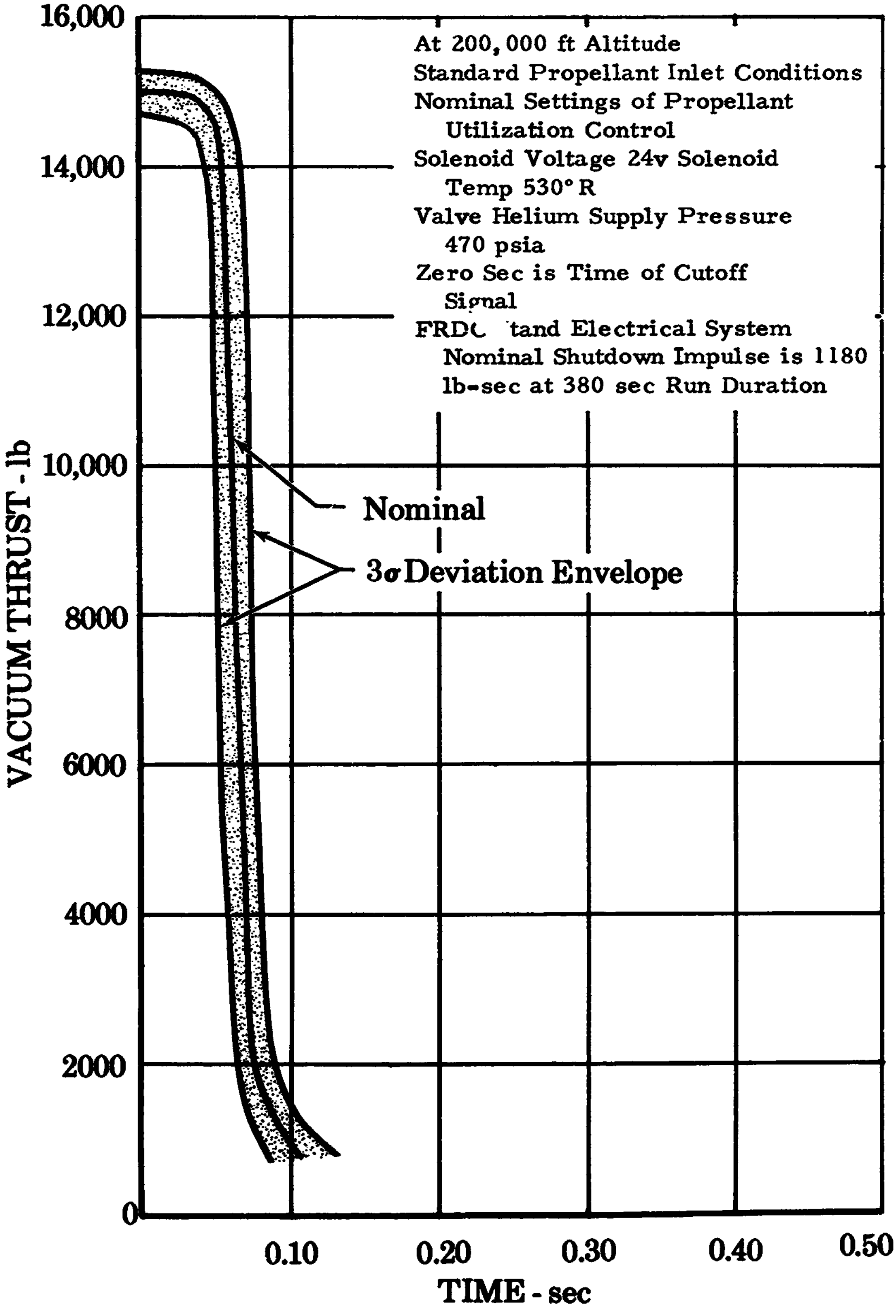

Figure V-3. Estimated Shutdown Transient Thrust vs Time

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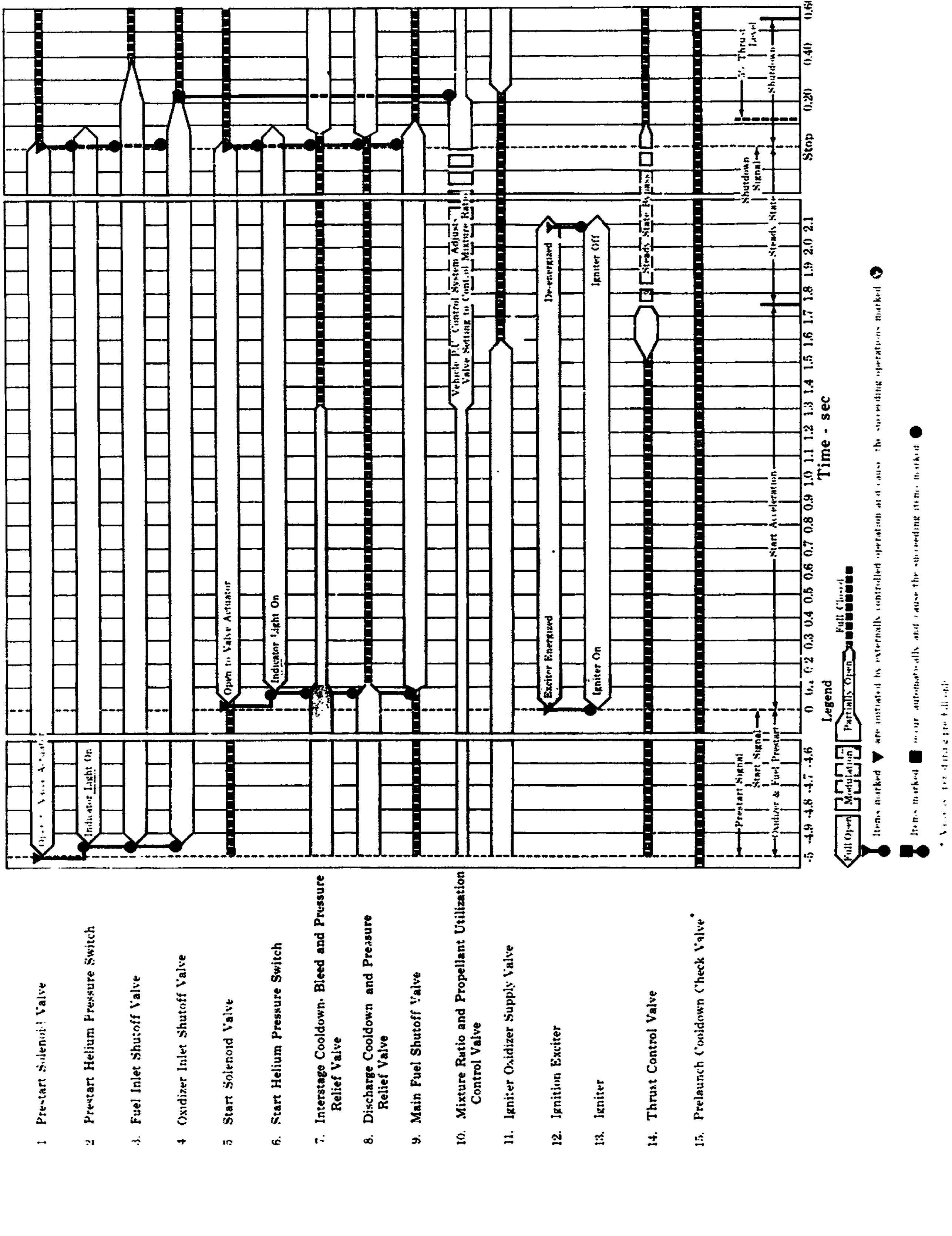

Figure V-4. Design Sequence of Engine Operation for RL10A-3-3 Engine

SECTION VI
SCHEMATIC DRAWING

The propellant flow schematic for the RL10A-3-3 engine assembly is shown in figure VI-1.

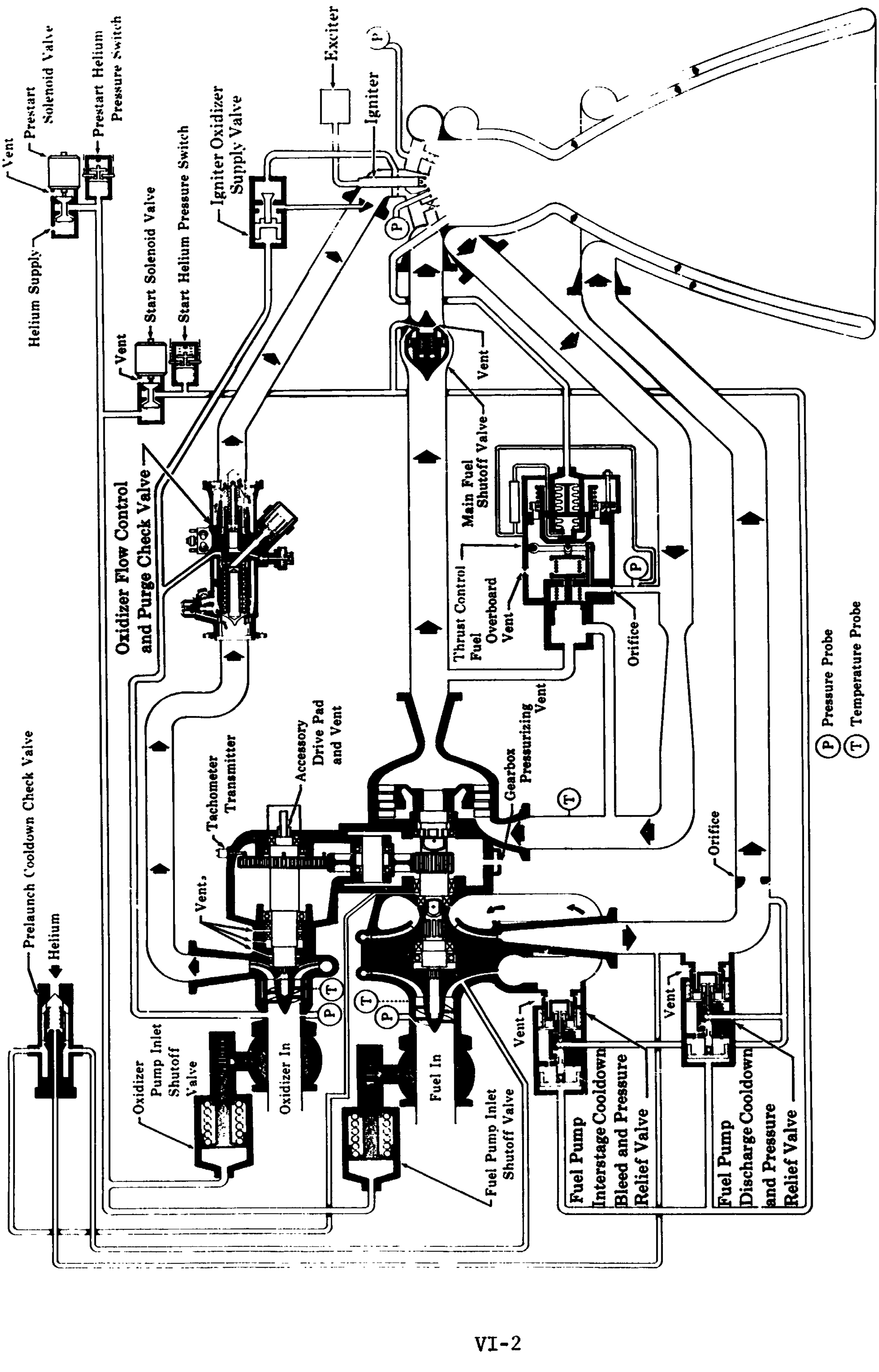

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Figure VI-1. Propellant Flow Schematic for RL10A-3-3 Engine

SECTION VII
MATERIALS GLOSSARY

The materials used in major engine components are listed in the following table.

Table VII-1. Materials Used in Major Engine Components

Component	Material	Type
Propellant Piping	Stainless steel tubing	PWA 770 (AISI 347)
Thrust Chamber Assembly		
Machined portion	Stainless steel forging	AMS 5646
Formed portion	Stainless steel sheet	AMS 5512
Reinforcing bands	Stainless steel sheet	AMS 5512
Porous injector face	Heat-resistant alloy wire	AMS 5794
Gimbal pintles	High-strength, stainless steel bar	AMS 5735
Gimbal pedestal and cone	Aluminum alloy forgings	AMS 4139
Brackets	Stainless steel sheet	AMS 5512
Turbopump		
Housings (all except*)	Aluminum alloy forgings	AMS 4130
Fuel pump gearbox housing*	Aluminum alloy casting	AMS 4215
Fuel impellers	Aluminum alloy forgings	AMS 4135
Oxidizer impellers	Stainless steel forging	AMS 5646
Turbine rotor	Aluminum alloy forging	AMS 4127
Shaft	High-strength, nickel alloy bar	AMS 5667
Gears	Carburizing steel	AMS 6260
Valves		
Housings		
Thrust control	Aluminum alloy casting	AMS 4215
Oxidizer flow control and pressure relief valve	Aluminum alloy forging	AMS 4127
Main fuel shutoff valve	Cast stainless steel	AMS 5362
Inlet valves	Aluminum casting	AMS 4217
Solenoid valves	Stainless steel forging	AMS 5646
Prelaunch cooldown check valve	Stainless steel bar	AMS 5646

Table VII-1. (Continued)

Component	Material	Type
Valves (continued)		
Cooldown valves	Aluminum bar and forging	AMS 4117 AMS 4127
Igniter oxidizer supply valve	High-strength stainless steel bar	AMS 5735
Springs	Stainless steel wire and nickel alloy wire	AMS 5688 AMS 5699
Bellows	Stainless steel sheet	AMS 5512 AMS 5525 PWA 767
	Copper Beryllium sheet	AMS 4532
Miscellaneous		
Fuel lines	Stainless steel tubing	AMS 5571
Gasket	Plastic	
	(sheet)	AMS 3651
	(film)	AMS 3652
Gaskets	Aluminum sheet	AMS 4001
Gaskets	Aluminum sheet	AMS 4025
Gaskets	Stainless steel sheet	AMS 5510
Plugs	Aluminum bar stock	AMS 4120
Flanges	Aluminum alloy forging	AMS 4127
Flanges	Stainless steel forging	AMS 5646
Cover	Aluminum casting	AMS 4027
Spring washers	Copper beryllium sheet	AMS 4532
Washers and clips	Stainless steel sheet	AMS 5510
Bracket	High-strength stainless steel sheet	AMS 5525
Tubes	Stainless steel tubing	AMS 5571
Rings and spacers	Stainless steel bar	AMS 5613
Bearings	Stainless steel bar and forging	AMS 5630
Plugs	Free machining stainless steel bar	AMS 5640
Miscellaneous small parts	Stainless steel bar and forgings	AMS 5646 AMS 5639
	Stainless steel forgings	AMS 5646

Table VII-1. (Continued)

Component	Material	Type
Miscellaneous (Continued)		
Nuts	Stainless steel bar and forgings	AMS 5735
Spacers, liners	High-strength, nickel alloy bar and forgings	AMS 5668
Safety wire	Nickel alloy wire	AMS 5685
Fasteners	High-strength, stainless steel bar	AMS 5735
Threaded inserts	Stainless steel wire	AMS 7245