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AFRPL-TR-70-40

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**THROTTLEABLE PRIMARY INJECTOR
FOR STAGED COMBUSTION ENGINE**

FINAL REPORT

Ronald A. Hankins

Michael Yankovich

Aerojet-General Corporation

TECHNICAL REPORT AFRPL-TR-70-40

June 1970

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AEROJET LIQUID ROCKET COMPANY

SACRAMENTO, CALIFORNIA • A DIVISION OF AEROJET-GENERAL

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FOREWORD

(U) This report describes the technical accomplishments of the Throtttable Primary Injector for Staged Combustion Engine Program of Project 3058, Contract F04611-69-C-0021. The period of performance for the technical effort was 1 November 1968 through 15 December 1969. The effort was directed toward demonstrating the throttling capability of a primary injector which would ultimately be incorporated into an advanced storable propellant space engine using the staged combustion cycle. Classified work related to this program was performed under Contracts AF 04(611)-10830⁽¹⁾ and F04611-68-C-0008⁽²⁾.

(U) All work was performed at the Liquid Rocket Company of Aerojet-General Corporation for the Air Force Rocket Propulsion Laboratory at Edwards, California. Mr. R. A. Hankins was the Aerojet program manager; Mr. M. Yankovich was the Project Engineer. Mr. C. D. Penn was the Air Force project engineer.

This technical report has been reviewed and is approved.

C. D. Penn
Project Engineer
Liquid Rocket Division
Air Force Rocket Propulsion Laboratory
Edwards, California 93523

-
- (1) Advanced Storable Rocket Engine - Storable, Phase I Final Report
AFRPL-TR-67-75, August 1967
- (2) Throttling and Scaling Study for Advanced Storable Engines, Report
AFRPL-TR-68-2, January 1968

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CONFIDENTIAL ABSTRACT

(U) This report summarizes the work performed under Contract F04611-69-C-0021, entitled "Throtttable Primary Injector for Staged Combustion Rocket Engine".

(U) The objective of this program was to demonstrate a throtttable primary injector for a storable space engine employing the staged combustion cycle. The program goal was to demonstrate throttling over a 10:1 range.

Specific accomplishments of the program were as follows:

(U) (1) Completed the detailed design of a flightweight modular primary injector for the storable space engine using the HIPERTHIN injector concept,

(C) (2) Demonstrated the injector over 90% of the desired throttling range (9K to 45K thrust),

(U) (3) Established critical design and fabrication parameters for the HIPERTHIN injector concept,

(C) (4) Demonstrated the performance of the HIPERTHIN injector through a chamber pressure range from 258 to 4390 psia and mixture ratio range from 10.7 to 27.0,

(C) (5) Demonstrated durability by conducting 87 tests with one injector in excess of 200 sec, with durations ranging from 10 sec at high thrust to 72 sec at low thrust,

(U) (6) Conducted supporting studies to provide additional design data in the areas of fluid flow and low frequency instability.

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LIST OF ABBREVIATIONS

$\dot{w}_f$ PC	Flow rate, fuel flowmeter, primary combustor
$\dot{w}_o$ PC	Flow rate, oxidizer flowmeter, primary combustor
PcPC	Pressure, chamber, primary combustor
Pc-H(P)	Pressure, high frequency Photocon
PFJ	Pressure, fuel injector manifold
PFJ-H(K)	Pressure, high frequency Kistler
PFJ-H(M)	Pressure, high frequency Microsystem
PFL	Pressure, fuel line
PFL-H(M)	Pressure, high frequency Microsystem
PFT	Pressure, fuel tank
POJ	Pressure, oxidizer injector manifold
POJ-H(K)	Pressure, high frequency Kistler
POJ-H(M)	Pressure, high frequency Microsystem
POL	Pressure, oxidizer line
POL-H(M)	Pressure, high frequency Microsystem
POT	Pressure, oxidizer tank
Pte	Pressure, turbine exit
Pti	Pressure, turbine inlet
TG	Temperature, gas side
TTI	Temperature, turbine inlet
SO/SF	Showerhead oxidizer/showerhead fuel
SO/IF	Showerhead oxidizer/impinging fuel
IO/IF	Impinging oxidizer/impinging fuel
DM	Dual manifold
MRPC	Mixture ratio Primary Combustor
MRSC	Mixture ratio Secondary Combustor
T_G	Temperature gas side
c^*	characteristic velocity
c^*_{TH}	characteristic velocity theoretical
η_c	combustion efficiency

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I. OBJECTIVE

(U) The objective of this program was to demonstrate a throttlable primary injector for a storable propellant (N_2O_4 /AeroZINE 50*) space engine employing the staged-combustion cycle. Aerojet's MIST engine concept, which is designed to operate at high chamber pressures and over a 10:1 throttling range from 5000 to 50,000 lb thrust, was designated as the engine to be used in establishing the operating parameters and overall design configuration for the injector. The HIPERTHIN, or platelet injector concept, was to be utilized for the basic design. The program goal was to demonstrate a full scale injector over the 10:1 throttling range with the performance, stability, and gas temperature distribution characteristics obtained to be compatible with the MIST engine requirements.

II. PROGRAM SUMMARY

(U) The program was initiated on 1 November 1968 and was concluded on 15 December 1969. The program milestone chart is shown in Figure 1.

(U) The program was performed in two phases. Phase I included the injector and supporting hardware design and a segment test program where candidate HIPERTHIN injector designs were evaluated. Phase II was an evaluation of clustered injectors, the design of which was based on the Phase I test program results.

(U) Primary injector design criteria were established by the MIST engine design and operating specification, as well as practical constraints imposed by the HIPERTHIN-type construction. The MIST engine description and operating

*AeroZINE 50 (A-50) is a trademark registered by Aerojet-General describing a mixture of 50 w% hydrazine and 50 w% unsymmetrical dimethylhydrazine.

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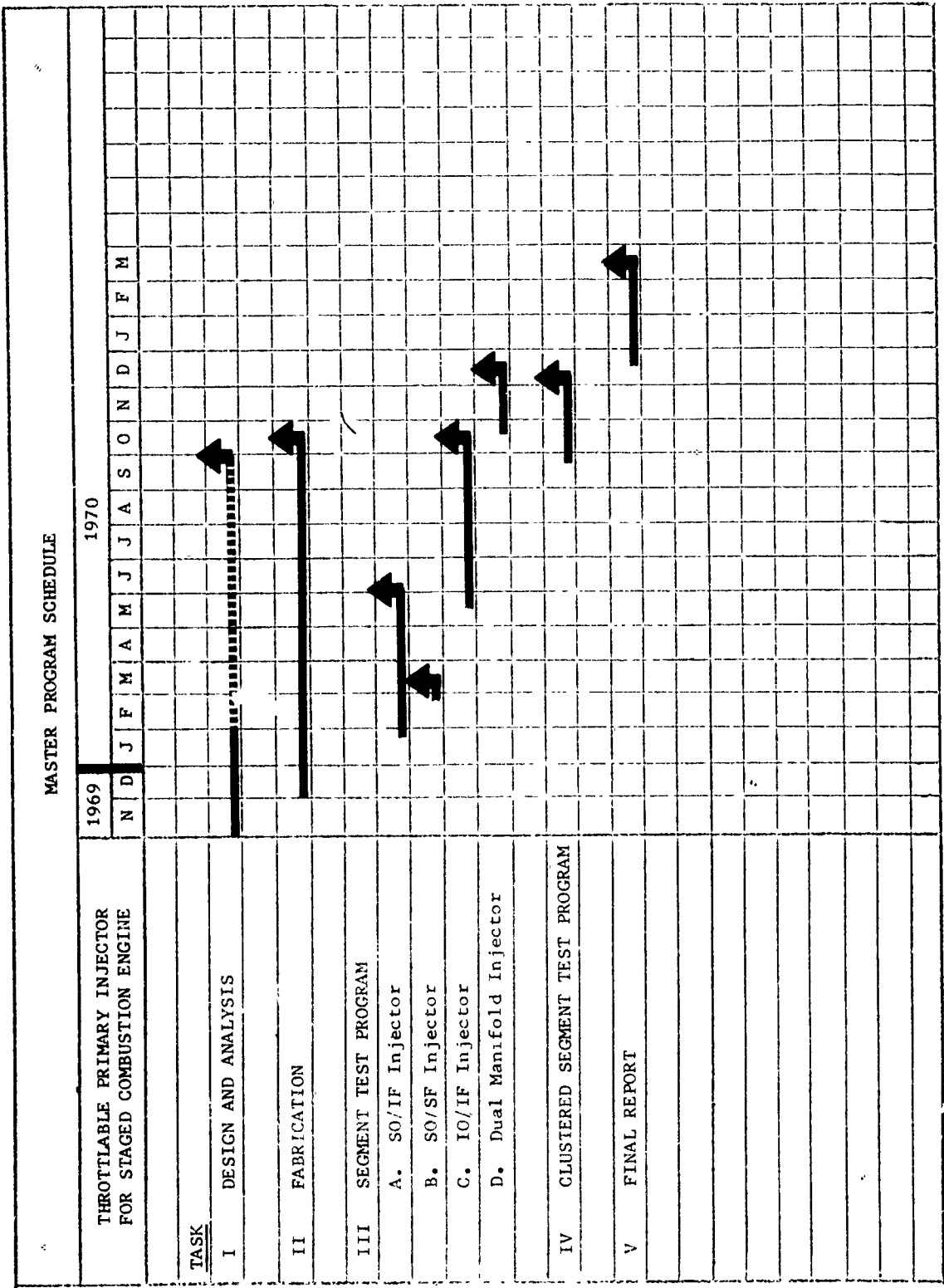


Figure 1. Program Milestone Chart

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II, Program Summary (cont.)

characteristics are described in detail in the appendix. Major primary combustor parameters, as defined by the engine power balance, are shown in Figure 2 over the thrust operating range. These relationships were established in part upon the results of a detailed performance analysis of the primary injector and combustion chamber.

A. PRIMARY INJECTOR DESIGN

(U) Early in the design phase of the program, several basically different HIPERTHIN injector configurations were studied with respect to pattern variation, versatility, ease of fabrication, cost, and packaging adaptability to the engine design. From this study, an injector of segmented design was selected. Ten identical segments or modules comprise the injector assembly; the segments are located circumferentially about the turbopump housing, in which the primary combustion chamber is located. Their location can be seen in Figure 3, a cut-away view of the MIST engine and in Figure A-1 of the Appendix, which is a photograph of the engine mockup. Selection of the modular approach allowed a single full scale segment to be used in the Phase I test program, thereby obviating the classic "subscale" approach with its attendant scaling problems. One of these injector segments, in the engine configuration, is shown in Figure 4.

(U) Four different HIPERTHIN injector patterns were designed, fabricated, and evaluated during the Phase I program. The first two patterns were evaluated concurrently during the initial part of the program, while the third and fourth patterns were iterations based upon test results. All injectors were of the same size and geometrical shape, having a rectangular face 1.75 inches in height by 2.00 inches in width. The injectors were of flight-weight design except for an added flange to provide bolt-on capability for development testing.

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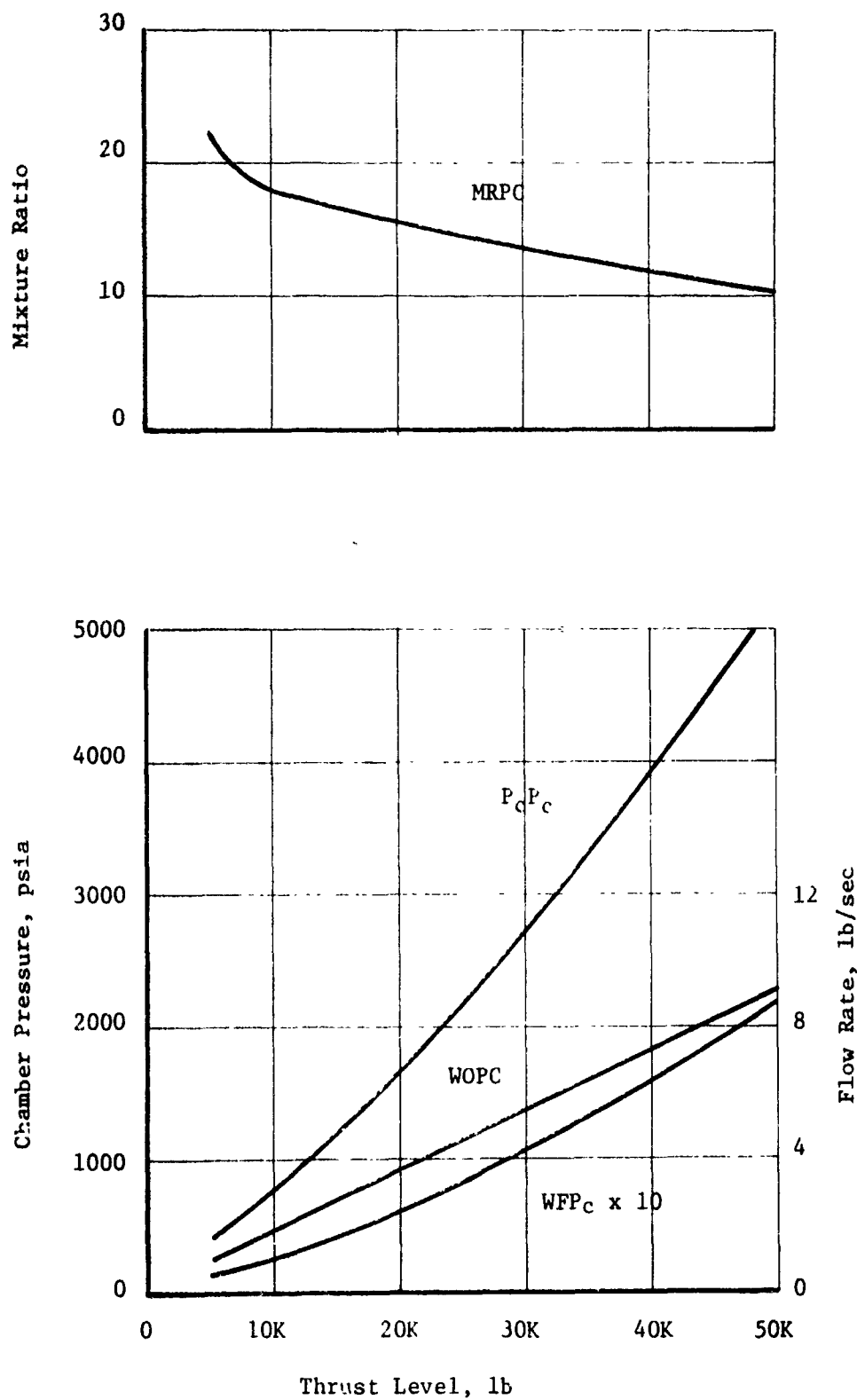
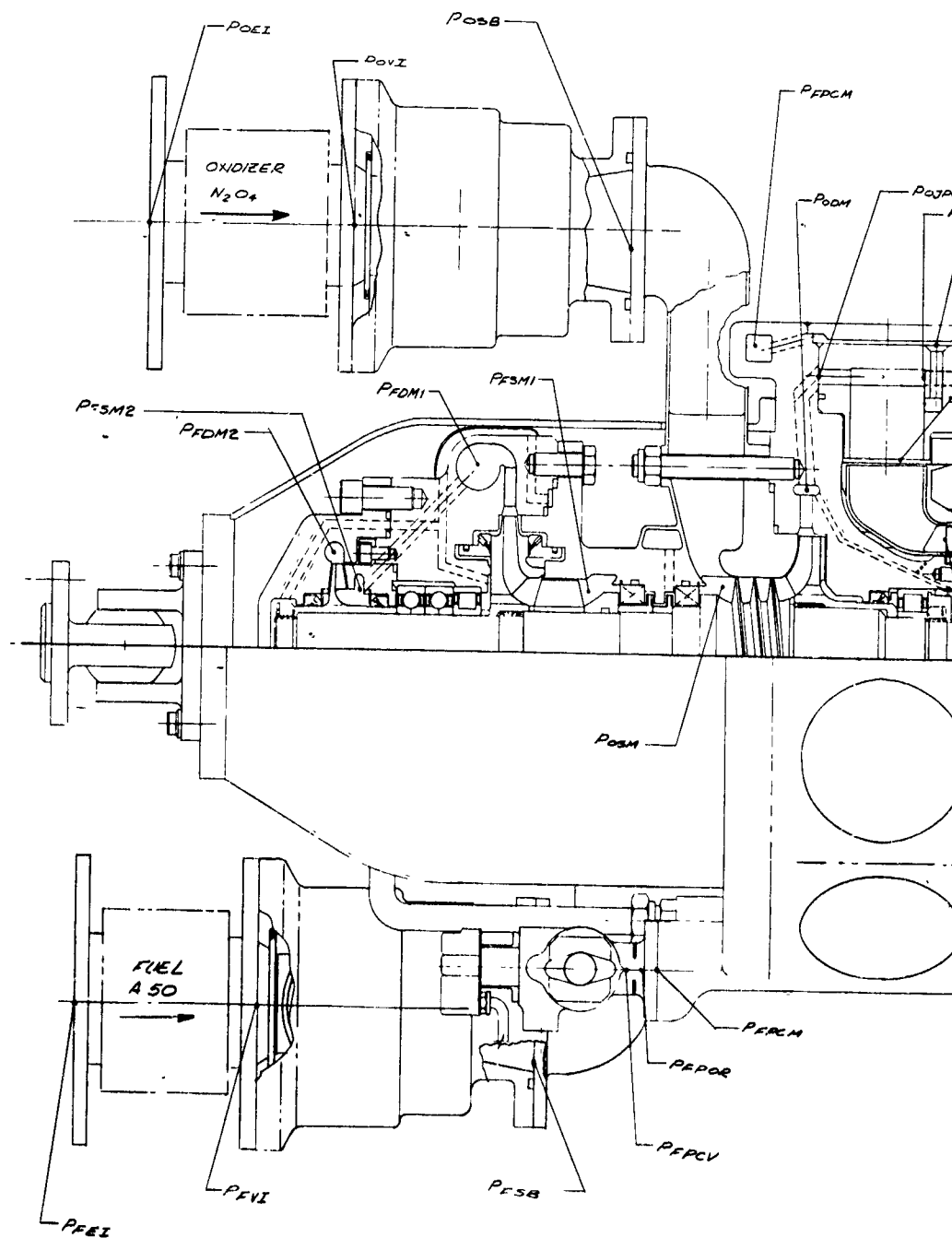
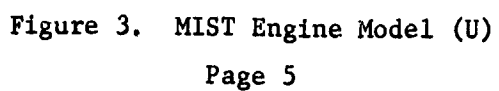


Figure 2. Primary Combustor Operating Parameters (2800 P_c Model)(U)

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Figure 4. Development Injector

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II, A, Primary Injector Design (cont.)

(C) The first injector pattern design featured both fuel and oxidizer showerhead orifices, while the second had the same oxidizer pattern but with impinging fuel orifices. Results of testing with these injector patterns disclosed that (1) the impinging fuel orifice design produced far smoother combustion than the showerhead pattern; and (2) higher circuit pressure drops were required to prevent low frequency oscillation at the lower thrust levels (below 18K). Based on this data, the third pattern was designed, in which the pressure drops in both circuits were increased. The oxidizer pattern was also converted to impinging orifice pairs in this redesign. During tests with this injector operation was excellent down to the 9K level, which represents over 90% of the intended throttling range. The fourth and final injector design retained the same face pattern as the third, but incorporated two fuel and two oxidizer circuits, with every other platelet being fed by an alternate manifold. In the lower throttling range, only one of the manifolds for each propellant would be used. Stable operation at the 5K and 7K levels was demonstrated with this injector configuration.

(C) The circuit pressure drops for the third and fourth patterns are higher than those currently used in the MIST engine models. For either of these injectors to be adopted into the engine, either the turbopump discharge pressure must be increased or the secondary chamber pressure reduced to 2400 psia. The latter would be the most probable course of action since it can be accomplished with a minimum redesign and does not significantly change engine performance or component packaging.

B. SEGMENT TEST PROGRAM

(C) The segment test program was initiated 27 January and concluded 12 December 1969. The program encompassed 176 tests, including basic injector

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II, B, Segment Test Program (cont.)

evaluation tests and acceptance tests for the Phase II test program. The test data and results of each test are summarized in Table I. The SO/IF* injector was the first pattern evaluated. In the first test series of 49 tests with this injector, operation was evaluated at conditions equivalent to a thrust range of 10-44K. Operation throughout this range was satisfactory with respect to performance and structural integrity of the injector. However, at thrust levels of 18K and lower, pressure oscillations were encountered, being $\pm 25\%$ of nominal chamber pressure and at frequencies of 260 Hz at the 10K level, and $\pm 12\%$ and 450 Hz at the 18K level. At all thrust levels above 18K, no organized pressure oscillations were present; in fact, operation was very smooth, with chamber pressure oscillations being below $\pm 1\%$. Tests were performed to determine if the oscillations were caused by coupling with the test stand feed system. It was determined that it was not, and that the unstable loop was between the combustion chamber and the injector feed manifolds.

(C) Thirty seven additional tests were then performed in which a resonator was attached to the combustion chamber in an attempt to suppress the oscillations. Using the resonator, stable operation was obtained at the 10K level; however, the resonator was highly selective as to the frequency it would damp, and since the combustion frequency changes with each thrust level, it was concluded that the best approach to eliminating the oscillations would be to redesign the injector, increasing circuit pressure drops to provide added injector "stiffness."

(C) Two tests were performed with the SO/SF injector, one at the 10K thrust level and one at 18K. In both tests combustion was very rough, with frequent intermittent "popping" in the combustion chamber, producing pressure

*Showerhead oxidizer/impinging fuel.

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TABLE I
TEST DATA SUMMARY - SEGMENT PROGRAM (U)

General Data				Measured Data										Performance Data					Remarks	
Test No.	S.S.	Lvr	Series	(1) Inj.	Pc psia	ωo lb/sec	ωf lb/sec	v̇r lb/sec	Poi psia	Pcj psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust		c* ft/sec	c*TH ft/sec	ηc		Stability (2)
														Nominal	ηc					
I	-101	-	SO/IF	701	1.96	0.110	2.070	13.3	786	803	-	-	-	-	10K	1255	2110	52.5	U-240	Initial checkout test
	-102	0.28	SO/IF	808	1.925	0.114	2.039	16.9	868	905	-	-	-	-	10K	1469	1790	82.0	U-240	MR survey
	-103	0.67	SO/IF	867	2.51	0.115	2.625	21.8	948	962	-	-	-	-	10K	1225	1480	82.6	U-240	MR survey
	-104	0.90	SO/IF	733	1.48	0.115	1.595	12.9	801	848	-	-	-	-	10K	1690	2160	78.2	U-240	MR survey
II	-105	1.35	SO/IF	1718	3.78	0.235	4.015	16.1	1848	1812	-	-	-	-	18K	1585	1855	85.5	S	Checkout test at 18K
	-106	1.36	SO/IF	1684	3.56	0.235	3.795	15.2	1814	1887	-	-	-	-	18K	1640	1930	84.9	S	MR survey
	-107	1.36	SO/IF	1655	3.34	0.235	3.575	14.2	1778	1856	-	-	-	-	18K	1710	2020	83.9	S	MR survey
	-108	9.36	SO/IF	1659	3.25	0.235	3.485	13.8	1785	1861	-	-	-	-	18K	1760	2060	85.3	Marginal	Long duration evaluation
	-109	2.10	SO/IF	1710	3.17	0.243	3.413	13.0	1804	1917	-	-	-	-	18K	1860	2140	86.8	S	Repeat Test 108 w/cavitating venturi
	-110	10.28	SO/IF	1704	3.27	0.241	3.511	13.6	1803	1900	-	-	-	-	18K	1800	2085	86.3	S	Duration demonstration
III	-111	0.66	SO/IF	2157	4.10	0.303	4.403	13.5	2290	2386	-	-	-	-	25K	1815	2095	88.2	S	Design MR demo. at 25K--blew gasket at 0.7 sec
	-112	-	SO/IF	Lost nozzle gasket	-	-	-	-	-	-	-	-	-	-	25K	-	-	-	S	Low MR demo. Blew gasket before steady-state
	-113	2.03	SO/IF	2097	5.53	0.301	3.831	11.7	2202	2333	-	-	-	-	25K	2020	2310	87.7	S	Repeat Test 112
	-114	2.04	SO/IF	2144	4.43	0.289	4.719	15.4	2300	2350	-	-	-	-	25K	1683	1920	87.7	S	High MR demonstration
IV	-115	2.00	SO/SF	1800	3.22	0.234	3.454	13.8	-	-	-	-	-	-	18K	-	-	-	U-48G	Showerhead pattern evaluation
V	-116	2.18	SO/IF	3221	5.52	0.444	5.964	12.4	3462	3595	-	-	-	-	37.5K	1990	2220	89.7	S	Design MR demonstration at 37.5K
	-117	9.63	SO/IF	3251	5.52	0.445	5.965	12.4	3489	3600	-	-	-	-	37.5K	2020	2220	91.0	S	Design MR duration demonstration
	-118	2.20	SO/IF	3245	5.10	0.450	5.550	11.3	3449	3603	-	-	-	-	37.5K	2165	2360	91.7	S	Low MR demonstration
VI	-119	2.10	SO/IF	3940	6.48	0.537	7.017	12.0	4246	4363	-	-	-	-	40K	2079	2270	91.6	S	Basic evaluation at 40K
	-120	2.10	SO/IF	4125	6.526	0.586	7.112	11.1	4440	4693	-	-	-	-	42K	2148	2400	89.6	S	Basic evaluation at 42K
	-121	2.10	SO/IF	4320	6.498	0.607	7.105	10.7	4640	4750	-	-	-	-	44K	2252	2460	91.5	S	Basic evaluation at 44K
	-122	2.20	SO/IF	Lost nozzle gasket	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	Instrumented chamber

(1) SO/IF: Showerhead oxid, tripping fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

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TABLE I (cont.)

General Data				Measured Data										Performance Data					Remarks																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
Test No.	Dur	Series	SI-30 Sec	Inj.	(1)	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc		Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	Pc	P

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

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TABLE I (cont.)

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Test No.	S.S.	Dur	Series	(1)	Pc	Wc	Wf	Wt	Fof	Pc	Ff	Ft	Ft	Ft	Ft	Ft	Ft	Ft		Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.

(2) Unstable tests show predominant frequency noted in chamber pressure.

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TABLE I (cont.)

General Data					Measured Data					Performance Data					Remarks													
Test S.S.	Dur	Series	SP-30	Sec	Int.	(1)	Pc	W _o	W _f	W _c	F _{ol}	P _{fj}	TC-1	TC-2		TC-3	Level	c ² TH	c ²	c ² TH	n _c	Stability	(2)					
							paia	lb/sec	lb/sec	lb/sec	MM	paia	paia	%		%	%	%	ft/sec	ft/sec	ft/sec	%	%	%				
XII	-167	1.65	SO/IF				765	1.910	0.104	2.014	18.4	-	-	250	295	230	10K	1400	1685	83.5			Stable	12-Hole reson, 0.625				
	-168	1.65	SO/IF				-	Not Gas Leak - No Valid Data										-	-	-	-	-	-	-	-	-	-	12-Hole reson, 0.625 in.; L*
	-169	1.65	SO/IF				750	1.920	0.102	2.022	18.7	-	-	300	345	340	10K	-	-	-	-	-	-	U-280	4-Hole resonator, 0.300 in.			
	-170	1.65	SO/IF				750	1.920	0.103	2.023	18.6	-	-	305	345	450	10K	-	-	-	-	-	-	U-280	4-Hole resonator; 0.250 in.			
	-171	1.65	SO/IF				745	1.89	0.103	1.993	18.3	-	-	315	345		10K	-	-	-	-	-	-	U-280	4-Hole resonator, 0.200 in.			
	-172	1.65	SO/IF				740	1.89	0.102	1.992	18.5	-	-	315	345	-	10K	-	-	-	-	-	-	U-280	4-Hole resonator, 0.150 in.			
	-173	1.65	SO/IF				745	1.89	0.103	1.993	18.3	-	-	275	350	-	10K	-	-	-	-	-	-	U-280	4-Hole resonator, 0.000 in.			
	-174	1.65	SO/IF				750	1.90	0.103	2.003	18.4	-	-	310	345	-	10K	-	-	-	-	-	-	U-280	4-Hole resonator, 0.400 in.			
	-175	1.65	SO/IF				750	1.90	0.103	2.003	18.4	-	-	285	345	326	10K	-	-	-	-	-	-	U-440	8-Hole resonator, 0.600 in.			
	-176	1.65	SO/IF				750	1.92	0.102	2.022	18.7	-	-	280	360	310	10K	-	-	-	-	-	-	U-440	8-Hole resonator, 0.500 in.			
	-177	1.65	SO/IF				750	1.92	0.102	2.022	18.7	-	-	285	355	305	10K	-	-	-	-	-	-	U-340	8-Hole resonator, 0.400 in.			
	-178	1.65	SO/IF				745	1.90	0.102	2.002	18.6	-	-	285	350	305	10K	-	-	-	-	-	-	U-340	8-Hole resonator, 0.450 in.			
	-179	1.65	SO/IF				745	1.90	0.102	2.002	18.6	-	-	278	346	325	10K	-	-	-	-	-	-	U-340	8-Hole resonator, 0.700 in.			
	-180	1.65	SO/IF				745	1.89	0.102	1.992	18.5	-	-	285	350	320	10K	-	-	-	-	-	-	U-340	8-Hole resonator, 0.800 in.			
	-181	1.65	SO/IF				694	1.89	0.102	1.992	18.5	-	-	276	350	290	10K	-	-	-	-	-	-	U-250	8-Hole resonator, 0.500 in.; L*			
	-182	1.65	SO/IF				710	1.89	0.102	1.992	18.5	-	-	260	345	321	10K	-	-	-	-	-	-	U-200	8-Hole resonator, 0.550 in.; L*			
	-183	1.65	SO/IF				730	1.84	0.102	1.942	18.0	-	-	250	450	310	10K	-	-	-	-	-	-	U-180	12-Hole resonator, 0.625 in.			
	-184	1.65	SO/IF				730	1.79	0.102	1.892	17.5	-	-	260	345	380	10K	-	-	-	-	-	-	U-200	12-Hole resonator, 0.525 in.			
	-185	1.65	SO/IF				720	1.79	0.102	1.892	17.5	-	-	250	370	330	10K	-	-	-	-	-	-	U-180	12-Hole resonator, 0.425 in.			
	-186	1.65	SO/IF				730	1.80	0.102	1.902	17.6	-	-	300	365	410	10K	-	-	-	-	-	-	U-200	12-Hole resonator, 0.800 in.			
	-187	1.65	SO/IF				760	1.80	0.102	1.902	17.6	-	-	255	300	330	10K	-	-	-	-	-	-	U-340	12-Hole resonator, 1.00 in.			

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TABLE I (cont.)

Test General Data			Measured Data										Performance Data				Remarks
No. S.S.	SP- Dur	Series 30	P _c psia	w _o lb/sec	w _f lb/sec	w _c lb/sec	P _o K.R. psia	P _f psia	TC-1 °F	TC-2 °F	Thrust Level	c* TH	Stability (2)				
	sec	Inj. (1)									lb	ft/sec	ft/sec				
XII	128	1.65 SO/IF	750	1.89	0.102	1.992	18.5	-	-	255	330	385	10K	-	-	U-320	12-Hole resonator, 0.625 in.
	189	1.65 SO/IF	750	1.89	0.102	1.992	18.5	-	-	295	340	350	10K	-	-	U-240	12-Hole resonator, 0.550 in.
	190	1.65 SO/IF	750	1.90	0.102	2.002	18.6	-	-	265	340	385	10K	-	-	U-320	12-Hole resonator, 0.800 in.
	191	1.65 SO/IF	750	1.90	0.102	2.002	18.6	-	-	260	330	385	10K	-	-	U-320	12-Hole resonator, 0.700 in.
	192	1.65 SO/IF	750	1.90	0.102	2.002	18.6	-	-	260	320	355	10K	-	-	U-320	12-Hole resonator, 0.650 in.
	193	1.65 SO/IF	750	1.90	0.102	2.002	18.6	-	-	270	335	350	10K	-	-	U-Random	12-Hole resonator, 0.600 in.
XIII	194	1.65 SO/IF	1090	2.58	0.151	2.731	17.1	-	-	345	450	670	14K	-	-	U-360	12-Hole resonator, 0.625 in.
	195	2.5 IO/IF-2	710+15%	1.92	0.091	2.01	21.1	792	806	254	-	-	10K	-	-	U-250	Modified IO/IF injector Eval. at 10K w/o L*
	196	2.5 IO/IF-2	797+14%	2.22	N.G.	2.30	-	902	909	267	-	-	12K	-	-	U-250	Eval. at 12K w/o L*
	197	2.5 IO/IF-2	884+13%	1.93	0.121	2.05	16.0	969	1016	304	-	-	10K	-	-	U-270	Low M.R. eval. w/o L*
	198	2.5 IO/IF-2	727+1%	1.92	0.091	2.01	21.1	807	824	260	-	-	10K	1335	1520	87.7	Stable L* eval. at 10K
	199	10.0 IO/IF-2	723+1%	1.89	0.090	1.98	21.0	806	824	265	-	-	10K	1350	1530	88.2	Stable 10K long duration w/L*
	200	2.5 IO/IF-2	1058+2.8%	2.54	0.140	2.68	18.1	1173	1203	325	-	-	14K	1460	1700	85.8	Marg. S 14K eval. w/o L*
	201	2.5 IO/IF-2	1125+2.2%	2.70	0.147	2.85	18.3	1234	1277	340	-	-	15K	1460	1690	86.4	Marg. S 15K eval. w/o L*
	202	2.5 IO/IF-2	330+15%	0.993	0.040	1.03	24.8	366	371	195	-	-	5K	-	-	U-110	5K eval. w/L*
	203	2.5 IO/IF-2	510+10%	1.42	0.063	1.46	22.5	561	569	225	-	-	7.5K	-	-	U-180	7.5K eval. w/L*
	204	2.5 IO/IF-2	711+1%	1.84	0.090	1.93	20.4	780	802	265	-	-	10K	1360	1580	86.0	Stable 10K eval. w/L*
	205	2.5 IO/IF-2	599+4.1%	1.62	0.075	1.70	21.6	659	672	240	-	-	8.5K	1300	1500	86.7	Marg. S 8.5K eval. w/L*
	206	10.0 IO/IF-2	618+1.6%	1.71	0.077	1.79	22.2	682	694	246	-	-	9K	1275	1470	86.7	Stable Long dur. eval. at 9K w/L*
	207	72.0 IO/IF-2	622+1.6%	1.74	0.078	1.82	22.2	685	701	324	317	333	9K	1260	1470	85.8	Stable 9K thrust demonstration test w/pulse, w/L*
	208	2.5 IO/IF-2	2274+1%	4.48	0.293	4.77	15.3	2550	2631	800	815	900	27K	1770	1920	92.1	Stable 25K checkout test, w/L*
	209	23.0 IO/IF-2	1800+1%	4.43	0.290	4.71	15.3	2073	2140	850	802	912	25K	-	-	Stable 25K thrust demonstration test w/pulse-gasket leak, w/L*	

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TABLE I (cont.)

Test General Data				Measured Data										Performance Data					Remarks
No.	S.S.	SP-Dur	Inf.	P _c	w _o	w _f	w _t	P _o	P _f	P _t	TC-1	TC-2	TC-3	c*	c* TH	Thrust			
Series	30	sec	(1)	psia	lb/sec	lb/sec	lb/sec	M.R.	psia	psia	°F	°F	°F	ft/sec	ft/sec	ft/sec	(2)		
210	2.5	IO/IF-2	2800+1X	6.95	0.530	7.480	13.1	-	-	981	-	11.0	35K	-	-	-	Stable		
211	10.5	IO/IF-2	2200+1X	7.05	0.545	7.648	13.0	-	-	1060	-	11.00	27K	-	-	-	Stable		
212	10.5	IO/IF-2	3810+1X	7.31	0.556	7.866	13.1	4482	4583	976	-	1139	42K	1795	2120	84.7	Stable		
213	4.40	IO/IF-2	1689	3.66	0.212	3.872	17.2	1936	1880	-	737	685	22K	1610	1760	91.5	Stable		
214	4.40	IO/IF-2	1695	3.66	0.216	3.876	16.9	1937	1883	-	752	701	22K	1618	1790	91.8	Stable		
215	4.40	IO/IF-2	1689	3.66	0.213	3.873	17.2	1928	1880	802	-	693	22K	1610	1760	91.5	Stable		
216	4.40	IO/IF-2	1692	3.66	0.215	3.875	17.0	1906	1883	755	-	739	22K	1615	1780	90.9	Stable		
217	4.40	IO/IF-2	1669	3.66	0.208	3.868	17.5	1883	1847	745	712	707	22K	1590	1740	91.5	Stable		
218	4.40	IO/IF-2	1703	3.70	0.216	3.916	17.1	1919	1925	-	716	701	22K	1610	1770	91.0	Stable		
220	4.56	IO/IF-2	1699	3.67	0.213	3.883	17.2	1956	1845	-	701	-	22K	1615	1760	91.8	Stable		
221	4.56	IO/IF-2	1706	3.68	0.216	3.896	17.0	1966	1858	-	710	-	22K	1620	1780	91.0	Stable		
222	4.56	IO/IF-2	1705	3.64	0.214	3.854	17.0	1936	1855	-	728	753	22K	1635	1780	92.0	Stable		
223	4.56	IO/IF-2	1710	3.64	0.215	3.855	16.9	1948	1855	-	735	747	22K	1640	1790	91.8	Stable		
224	4.56	IO/IF-2	1714	3.64	0.216	3.856	16.8	1894	1872	-	738	723	22K	1645	1800	91.5	Stable		
225	4.56	IO/IF-2	1695	3.72	0.212	3.932	17.5	1956	1858	-	680	697	22K	1595	1740	90.8	Stable		
226	4.23	IO/IF-2	1709	3.71	0.215	3.925	17.2	1951	2010	-	696	733	22K	1610	1760	91.5	Stable		
227	4.23	IO/IF-2		Invalid Data - Fuel Leak Injector Inlet Line										22K				Stable	
228	4.23	IO/IF-2		Invalid Data - Oxid. Leak Injector O-Ring Seal										22K				Stable	
229	4.24	IO/IF-2	1425	3.67	0.216	3.886	17.0	1661	1704	835	695	672	20K	1610	1780	90.5	Stable		
230	4.24	IO/IF-2	1417	3.68	0.214	3.894	17.2	1674	1592	774	724	698	20K	1590	1760	90.5	Stable		
231	4.24	IO/IF-2	1427	3.68	0.214	3.894	17.2	1669	1599	744	710	651	20K	1605	1760	91.2	Stable		

(1) SO/IF: Impinging oxid, showerhead fuel; SO/SF: showerhead oxid, showerhead fuel.
 (2) Unstable tests show predominant frequency noted in chamber pressure.

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TABLE I (cont.)

Test General Data				Measured Data										Performance Data					Remarks
No. S.S. CP-Dur Series 30	sec	(1) 10/IF-2	P _c psia	W _o lb/sec	W _f lb/sec	W _t lb/sec	P _o J M.R. psia	P _f psia	TC-1 °F	TC-2 °F	TC-3 °F	Level	c* ft/sec	c* TH ft/sec	η _c	Stability			
232 XIV	2.44	10/IF-2	1437	3.68	0.215	3.895	17.1	1669	1585	844	721	704	20K	1615	1770	91.3	Stable	SN 013	
233	4.24	10/IF-2	1423	3.66	0.214	3.874	17.1	1653	1573	716	729	693	20K	1605	1770	90.7	Stable	SN 014	
234	4.24	10/IF-2	1423	3.66	0.215	3.875	17.0	1680	1617	725	733	702	20K	1605	1780	90.2	Stable	SN 005	
235	4.24	10/IF-2	1427	3.61	0.215	3.825	16.8	1629	1601	-	740	696	20K	1630	1800	90.7	Stable	SN 006	
236	4.24	10/IF-2	1431	3.61	0.215	3.825	16.8	1672	1611	-	720	658	20K	1635	1800	91.0	Stable	SN 011; 0.144 in. dia. fuel orifice	
237	4.24	10/IF-2	1431	3.70	0.215	3.915	17.2	1664	1602	-	719	659	20K	1600	1760	91.0	Stable	SN 013; 0.120 in. dia. fuel orifice	
238	4.24	10/IF-2	1425	3.70	0.213	3.913	17.3	1650	1611	-	721	693	20K	1600	1760	91.0	Stable	SN 013; 0.092 in. dia. fuel orifice	
239	2.44	10/IF-2	1433	3.70	0.216	3.916	17.1	1678	1618	-	704	638	20K	1605	1770	90.7	Stable	SN 011	
240	2.44	10/IF-2	1439	3.68	0.215	3.895	17.1	1676	1618	-	712	685	20K	1615	1770	91.3	Stable	SN 013; 0.120 in. dia. fuel orifice	
241	2.44	10/IF-2	1426	3.68	0.215	3.895	17.1	1653	1593	-	698	672	20K	1605	1770	90.7	Stable	SN 015; 0.116 in. dia. fuel orifice	
242	2.44	10/IF-2	1433	3.68	0.215	3.895	17.1	1664	1619	-	710	685	20K	1610	1770	91.3	Stable	SN 015; 0.092 in. dia. fuel orifice	
243	2.44	10/IF-2	1432	3.67	0.216	3.886	16.9	1648	1620	-	710	672	20K	1615	1790	90.2	Stable	SN 006; 0.144 in. dia. fuel orifice; 0.454 in. dia. oxid. orifice	
244	2.44	10/IF-2	1429	3.64	0.215	3.855	16.9	1649	1614	-	710	672	20K	1610	1790	90.6	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.422 in. dia. oxid orif.	
245	2.44	10/IF-2	1427	3.67	0.213	3.883	17.1	1654	1608	-	734	688	20K	1610	1770	91.3	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.377 in. oxid. orif.	
246	2.44	10/IF-2	1430	3.72	0.215	3.935	17.3	1694	1630	-	674	636	20K	1610	1760	91.5	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.340 in. dia. oxid. orif.	
247	2.44	10/IF-2	1428	3.69	0.215	3.905	17.1	1684	1628	-	659	642	20K	1600	1770	90.5	Stable	SN 003; 0.343 in. dia. oxid orif.	
248	2.44	10/IF-2	1426	3.71	0.215	3.925	17.2	1670	1628	-	685	662	20K	1590	1760	90.5	Stable	SN 003; 0.377 in. dia. oxid. orif.	
249	2.36	10/IF-2	1395	3.68	0.215	3.895	17.1	1629	1644	827	755	531	20K	1570	1770	88.7	Stable	SN 010	
250	2.36	10/IF-2	1391	3.72	0.214	3.935	17.3	1572	1555	809	753	563	20K	1550	1760	88.2	Stable	SN 018	
251	2.36	10/IF-2	1391	3.68	0.219	3.899	16.8	1564	1568	816	803	475	20K	1565	1800	87.0	Stable	SN 019	
252	2.36	10/IF-2	1395	3.69	0.219	3.909	16.8	1583	1614	656	685	580	20K	1565	1800	87.0	Stable	SN 020	

(1) SO/IF; impinging oxid, showerhead fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

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TABLE I (cont.)

Test General Data					Measured Data										Performance Data					Remarks
No. S.S.	SP- Dur	Series	30 sec	Inst.	(1)	P _c	w _o	w _f	w _c	P _o	P _f	TC-1	TC-2	TC-3	Thrust Level	c* TH	c* TH	Stability (2)		
						psia	lb/sec	lb/sec	lb/sec	M.R.	psia	°F	°F	°F	°F	Nominal	ft/sec	ft/sec	%	
XIV																				
253	2.36	IO/IF-2				1396	3.72	0.219	2.939	17.0	184	1593	905	828	449	20K	1550	1780	87.2 Stable	SN 021
254	2.36	IO/IF-2				1399	3.73	0.219	3.949	17.0	1578	1568	850	790	524	20K	1550	1780	87.2 U-1120	SN 022; no turbine simulator orifice used
255	2.36	IO/IF-2				1390	3.66	0.213	3.873	17.2	1567	1551	837	812	458	20K	1570	1760	89.4 Stable	SN 023; no turbine simulator orifice used
256	1.26	IO/IF-2				1400	3.70	0.215	3.915	17.2	1568	1562	560	756	559	20K	1570	1760	89.4 U-1120	SN 024; no turbine simulator orifice used
257	2.15	IO/IF-2				1460	3.74	0.214	3.954	17.5	1690	1690	1653	1817	1939	20K	1615	1740	92.8 Stable	SN 012; fuel rich start and shutdown
258	2.15	IO/IF-2				1474	3.74	0.214	3.954	17.5	1716	1712	1771	1913	1985	20K	1630	1740	93.8 Stable	SN 017; fuel rich start and shutdown
259	2.30	IO/IF-2				1481	3.68	0.215	3.895	17.1	1725	1717	714	705	663	20K	1565	1770	94.2 Stable	SN 012
260	2.30	IO/IF-2				1480	3.69	0.214	3.904	17.2	1705	1691	658	710	713	20K	1660	1760	94.2 Stable	SN 018
261	2.30	IO/IF-2				1479	3.72	0.214	3.934	17.4	1699	1705	652	710	721	20K	1645	1750	94.0 Stable	SN 019
262	2.30	IO/IF-2				1488	3.68	0.214	3.894	17.2	1713	1727	649	718	738	20K	1670	1760	95.0 Stable	SN 020
263	2.30	IO/IF-2				1467	3.70	0.211	3.911	17.5	1701	1715	703	701	651	20K	1640	1740	94.3 Stable	SN 020
264	2.30	IO/IF-2				1472	3.70	0.214	3.914	17.3	1699	1692	680	710	682	20K	1650	1760	93.7 Stable	SN 023
XV																				
265	-	DM				-	-	-	-	No Steady State Data										SN 025; valve sequence reversed inadvertently
266	1.50	DM				258	1.00	0.035	1.035	28.6	320	324	219	226	218	5K	1090	1250	87.4 Stable	Single oxid and single fuel circuits
267	10.0	DM				262	1.00	0.037	1.037	27.0	321	328	234	234	221	5K	1105	1300	85.2 Stable	Same as Run 266
268	1.30	DM				390	1.29	0.58	1.348	22.2	477	492	281	287	283	7.5K	1265	1470	86.2 Stable	Same as Run 266
269	9.50	DM				390	1.29	0.057	1.347	22.6	480	492	282	285	280	7.5K	1265	1450	87.4 Stable	Same as Run 266
270	1.80	DM				279	0.974	0.039	1.013	25.0	334	345	241	245	236	5K	1200	1350	89.0 Stable	Single oxid and single fuel circuit
271	4.80	DM				280	0.975	0.040	1.015	24.4	336	347	238	251	238	5K	1210	1370	88.2 Stable	Same as Run 270
272	1.20	DM				280	0.974	0.040	1.014	24.4	-	-	232	242	236	5K	-	-	-	Single oxid and double fuel circuit
273	4.50	DM				285	0.974	0.038	1.013	25.0	-	-	250	244	227	5K	-	-	-	Double oxid and double fuel circuit
274	4.20	DM				284	0.974	0.039	1.013	25.0	-	-	250	244	231	5K	-	-	-	Double oxid and single fuel circuit
275	5.15	DM				373	1.20	0.052	1.252	23.0	-	-	285	285	272	6K	-	-	-	Same as Run 274
276	5.36	DM				411	1.33	0.058	1.388	22.9	-	-	286	289	277	7K	-	-	-	Same as Run 274

(1) SO/IF: Impinging oxid, showerhead fuel; SO/SP: showerhead oxid, showerhead fuel; DM: dual manifold.
 (2) Unstable tests show predominant frequency noted in chamber pressure.

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II, B, Segment Test Program (cont.)

spikes of up to 60% P_c overpressures. Based on the clearly superior operation of the SO/IF injector, no further testing was performed with the SO/SF injector.

(C) The IO/IF injector, which was designed on the basis of test results with the previous two patterns, was evaluated in a 24-test series. Operation was evaluated over a thrust range from 5 to 42K. At 9K and above, operation was stable and satisfactory in every respect. Low frequency pressure oscillations were encountered from 5 to 8.5K, ranging from $\pm 15\%$ P_c and 110 Hz at the 5K level to $\pm 4\%$ P_c and 200 Hz at the 8.5K level. Except for these relatively low amplitude oscillations, combustion was smooth and operation was satisfactory. Based on the fact that stable operation had been demonstrated for over 90% of the intended throttling range (Figure 5), the IO/IF injector was selected for Phase II testing. Concurrently with the Phase II program, the dual-manifold IO/IF injector was designed to increase the circuit pressure drops at the low thrust points. One injector module of this configuration was fabricated and tested; stable operation at the 5K and 7.5K level was demonstrated.

C. CLUSTERED SEGMENT TEST PROGRAM

(C) The objective of the clustered segment test program was to evaluate the operation of ten injector segments installed within a common housing simulating the primary combustor configuration of the MIST engine. A photograph of the housing is shown in Figure 6. The test program was initiated on 24 September 1969 and concluded on 3 December 1969, during which period 22 tests were conducted between the 10K and 37.5K operating points. The test data and results for each test are summarized in Table II. At the 10K thrust level, low frequency pressure oscillations of the type encountered in the segment test program were noted, a condition not unexpected. A continuous step throttling test was conducted at the 10K, 12K, and 15K thrust level to establish the lower limit of stable operation. Results showed

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DATA IS BASED ON TESTS SP-30-195 THRU -212

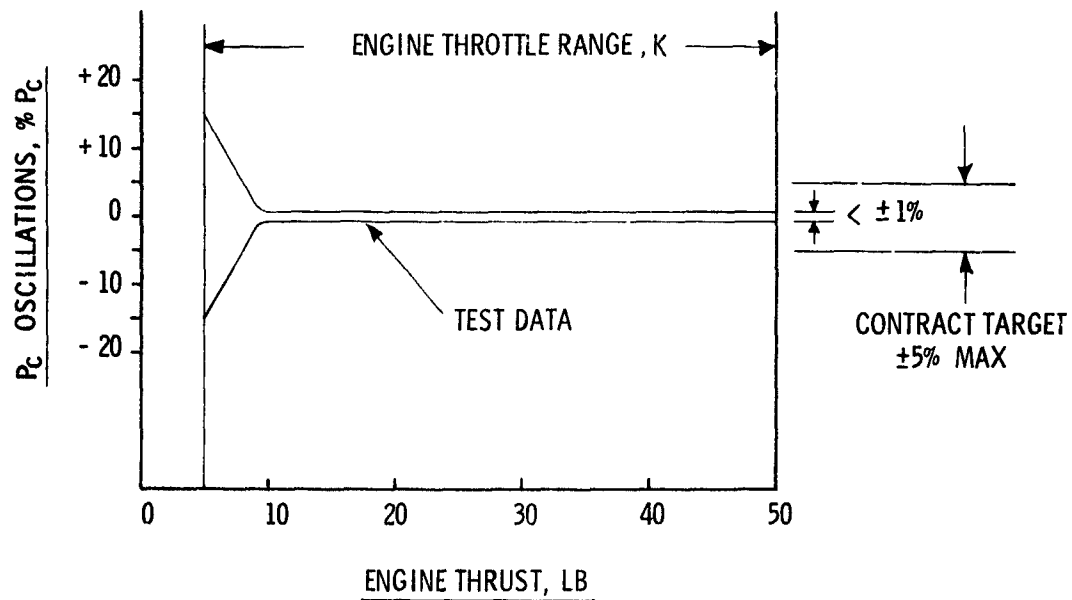


Figure 5. IO/IF Stability Range (U)

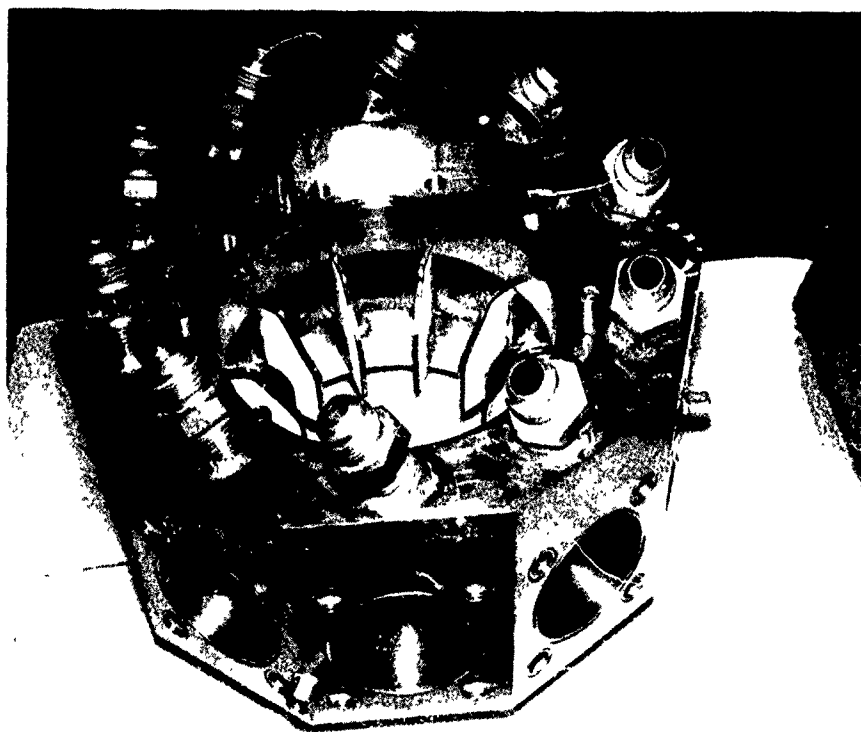


Figure 6. Cluster Injector Housing

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TABLE II
TEST DATA SUMMARY - CLUSTER PROGRAM (U)

TEST NO.	DATE	DURATION SEC.	THRUST LEVEL lbs.	CHAMBER PRESSURE PSIA	OXIDIZER FLOW RATE LB/SEC	FUEL FLOW RATE LB/SEC	MIXTURE RATIO O/F	C* FT/SEC	CLUSTERED SENSOR THERMOCOUPLES DATA									
									T0-1 °F	T0-2 °F	T0-3 °F	T0-4 °F	T0-5 °F	T0-6 °F	T0-7 °F	T0-8 °F	T0-9 °F	T0-10 °F
1298-101-01-001	9-24-69	.763	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-002	9-24-69	1.012	22K	1642	37.321	2.035	18.340	1544	(5)	-	-	(2)	-	-	-	-	-	-
-003	9-24-69	3.013	22K	1675	31.221	2.279	13.700	1845	1060	840	1010	(2)	-	-	-	-	-	-
-004	10-27-69	1.007	22K	1668	40.91	2.09	19.908	146.3	(5)	-	-	-	-	-	-	-	-	-
-005	10-28-69	1.064	22K	1716	38.07	2.18	17.454	1577.4	(5)	-	-	-	-	-	-	-	-	-
-006	11-10-69	.911	22K	1153	43.65	1.27	34.290	949.7	(5)	-	-	-	-	-	-	-	-	-
-007	11-10-69	1.107	22K	1723	42.16	2.13	13.796	1430.4	(5)	-	-	-	-	-	-	-	-	-
-008	11-11-69	1.511	22K	1692	39.07	2.17	18.020	1518.3	645	657	479	580	620	757	549	788	719	668
-009	11-11-69	2.010	22K	1698	40.25	2.14	18.024	1482.4	594	592	451	525	598	708	494	701	649	648
-010	11-12-69	1.252	22K	1693	37.84	2.21	17.135	1564.0	680	710	440	580	600	770	600	(6)	790	710
-011	11-12-69	2.006	22K	1722	40.35	2.17	18.582	1487.5	610	573	418	603	535	690	492	810	692	(6)
-012	11-12-69	3.007	22K	1728	40.84	2.17	18.835	1486.5	605	594	434	601	576	702	484	717	706	694
-013	11-12-69	5.005	22K	1722	43.65	2.17	20.617	1392.4	515	508	392	491	504	568	434	587	612	553
-014	11-13-69	9.998	22K	1716	41.61	2.14	19.408	1451.2	542	602	411	541	604	599	460	707	677	613
-015	11-14-69	2.004	10K	689	18.61	.87	21.314	1307.4	317	360	314	371	340	327	222	371	366	355
-016	11-17-69	2.999	15K	1089	26.8	1.40	19.2	1430.0	536	640	390	615	615	700	410	730	750	640
-017	11-19-69	3.005	15K	1079	30.37	1.32	23.010	1259.4	358	389	338	387	420	(6)	333	434	450	420
-018	11-19-69	9.298	15K	1092	28.19	1.36	20.721	1367.5	463	493	358	579	643	446	361	588	-	627
-019	12-02-69	.915	25K	1240	-	-	(3)	(3)	(5)	-	-	-	-	-	-	-	-	-
-020	12-02-69	3.002	25K	2004	45.92	2.60	17.758	1536.7	716	770	454	660	570	805	541	831	681	805
-021	12-02-69	1.402	37.5K	2347	56.68	4.61	12.299	2020.9	(5)	-	-	-	-	-	-	-	-	-
-022	12-03-69	1.809	37K	3267	57.84	4.46	12.963	1940.3	1170	1123	954	1094	943	1271	969	1332	(6)	(6)

- (1) Transient Test, No Steady State Data
(2) Only Three Thermocouples Employed
(3) Loss of Oxidizer Flowmeter Prevented Receipt of this Data
(4) Third step data summarized
(5) Test duration too short for valid temperature data
(6) Invalid Thermocouple

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II, C, Clustered Segment Test Program (cont.)

operation at the 12K level to be marginally stable, with completely smooth operation occurring at the 15K level. Operation at the 25K thrust level was excellent, with no anomalies occurring. The highest equivalent thrust level to which the assembly was tested was 37.5K. At this thrust minor erosion occurred in one of the ten combustion chambers; a posttest evaluation determined that the injector segment feeding the damaged portion of the chamber had an uneven mixture ratio profile across its face, which produced a localized area of hot gas that caused the erosion. Limitations of program funds precluded further testing in the program.

(C) Primary combustor performance was excellent at all thrust levels; in the clustered configuration, c^* values were in close agreement with those obtained in the segment program, usually slightly higher. Also, combustion was very smooth at all levels above the "chugging" threshold, with chamber pressure oscillations being $\pm 1\%$ of average chamber pressure.

III. CONCLUSIONS

(C) 1. The technology for a throttling primary injector using the HIPERTHIN injector concept was demonstrated.

(C) 2. The HIPERTHIN injector demonstrated excellent performance characteristics in a very short chamber length (3 inches). The delivered performance at all thrust levels was sufficiently high to provide the required energy for turbopump drive.

(C) 3. Three injector designs were identified as being suitable for use in an advanced storable propellant staged-combustion space engine such as the MIST engine: (a) The SO/IF injector is suitable for an engine operating at 2800 psia secondary chamber pressure and a required throttle ratio of 3:1;

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III, Conclusions (cont.)

(b) The IO/IF injector is suitable for an engine operating at 2400 psia secondary chamber pressure and a required throttle ratio of 5:1; (c) the IO/IF dual manifold injector will provide 10:1 throttle capability at a secondary chamber pressure of 2400 psia. This injector does require throttling valves in both the fuel and oxidizer circuits, a condition not required with the other two injectors.

(C) 4. Low frequency "chugging" instability at the low throttle range was the only major technical problem encountered during the program. The low frequency characteristics dictated the classification of injector operating ranges as listed in Item 3, above. In the stable operating range, combustion is very smooth, with chamber pressure oscillations averaging $\pm 1\%$ of the average value. Pulse testing demonstrated the dynamic stability of the primary injector. In no case did the pulse cause a combustion instability.

(U) 5. The basic injector design was shown to have excellent durability characteristics. Throughout the entire program, which encompassed 176 segment tests and 22 cluster tests, no structural failure or distortion occurred with any injector. During the segment program one injector was fired 87 times for a cumulative duration of over 200 seconds.

(C) 6. The planned throttling demonstration over the full thrust range (10K to 50K) with the clustered segment hardware was not made because of the hardware damage incurred during a test at the 37.5K level and because the funds remaining were insufficient to repair the hardware and continue testing. The cause of the damage was attributed to a mixture ratio maldistribution in one of the injectors. The adverse mixture ratio profile across its face resulted in a hot streak. Replacement of this injector with one having a proper mixture ratio profile should resolve the problem. Posttest flow testing of several injectors revealed that minor maldistribution was present in all injectors, although not to the extent of that of the injector which caused the problem. This could have resulted from either contamination or the net tolerance effects of the platelet stack. Both of these potential causes and means for their prevention should be thoroughly evaluated in any future design.

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IV. PRIMARY COMBUSTOR DESIGN

A. DESIGN CRITERIA AND REQUIREMENTS

(C) The primary injector design criteria and requirements were established by the MIST engine design and operating specification, discussed fully in the Appendix. Engine-imposed injector design criteria included operating conditions such as mixture ratios, flow rates, and pressures, as well as envelope constraints in diameter, height, thickness, and interface. The major primary combustor parameters, as defined from the engine power balance, are shown in Figures 2 and 7 over the operating thrust range. Figure 2 is for an engine operating at 2,800 psia chamber pressure, while Figure 7 is for one operating at 2,400 psia. Injectors compatible with both engine balance points were evaluated in the test program.

(C) The basic primary combustor assembly configuration was established by engine packaging considerations. An annular injector configuration flowing radially inward was shown to integrate best with the basic engine concept to produce a minimum-weight, neatly packaged engine design. The primary combustor gases turn 90° downward prior to entering the turbine, which is attached to the main axial shaft (see Figure 3). A design study in which injector diameter and height were evaluated with respect to combustion volume and shape, engine weight, and overall engine packaging resulted in the selection of a 7-in. inside diameter injector having a height of 1-3/4 in. The combustion chamber is relatively small, having a length of 3.00 in. (along the flow center line) and a total volume of 45.8 in.³. This design was analyzed to determine its expected performance by using a propellant vaporization model that has been used successfully in analyzing main thrust chamber performance. Results of this analysis are presented below.

(C) The primary combustion process proceeds as follows: First, all the fuel is burned with an amount of oxidizer required for near-complete combustion. The excess oxidizer is then vaporized by heat transfer from

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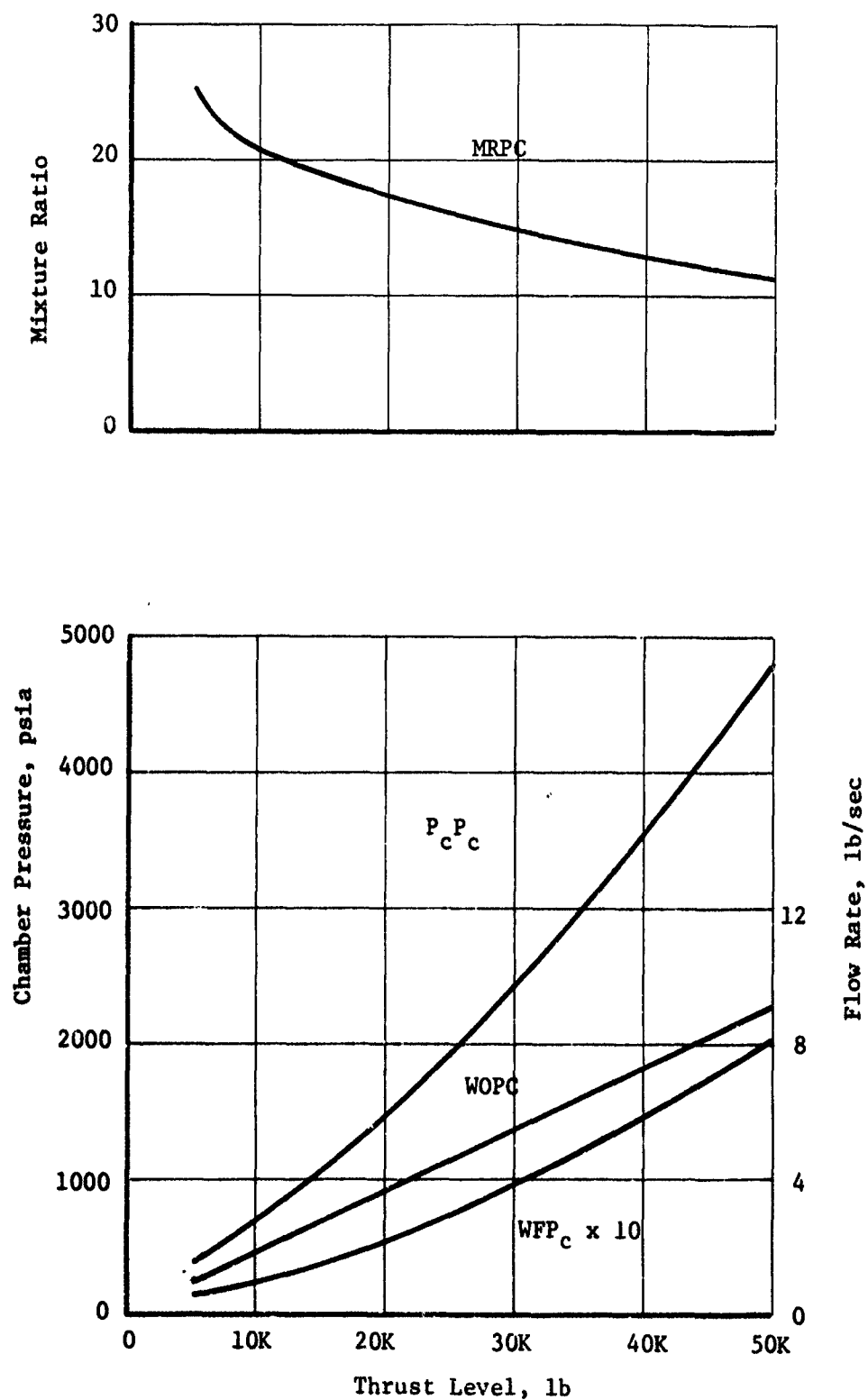


Figure 7. Primary Combustor Operating Parameter (2400 P_c Model)(U)

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IV, A, Design Criteria and Requirements (cont.)

the combustion products. The model predicts that the combustion part of the process is essentially completed by the time the gases exit the primary combustor; however, the oxidizer vaporization is not completed. Therefore, at the turbine inlet, the combustion products consist of a mixture of gases at a temperature corresponding to the mixture ratio of the gasified products, and unvaporized liquid oxidizer. The temperature of the gasified product is shown as a function of the mean path distance from the injector face in Figure 8. The equilibrium temperature is also shown. As the oxidizer vaporization progresses and the combustion gas temperature is reduced, the heat flux to the remaining oxidizer is decreased, and further oxidizer vaporization is obtained at a much slower rate. (The possible effect of residual oxidizer droplet impingement at the turbine inlet may result in droplet shattering, which could significantly increase droplet surface area available for vaporization. The resultant effect on gas temperature through the stator is indicated by the dashed lines in Figure 8.) The resultant characteristic curve shows that, after the first inch of chamber length, the vaporization rate is very low and significant changes in length are required to cause much change in gas temperature. Various injection patterns tend to locate the point at which the knee of the curve occurs, but have little effect downstream of the knee. Therefore, the amount of unvaporized oxidizer is primarily a function of mixture ratio, with pattern design and length being of secondary importance only to the extent that the length must be sufficient to assure operation below the knee of the curve. The effect of incomplete vaporization on predicted c^* efficiency at various thrust levels is shown in Figure 9. The reduced primary combustor efficiency at low thrust is compensated for by balancing to a lower mixture ratio and increasing gas temperature so that the proper power requirement is met.

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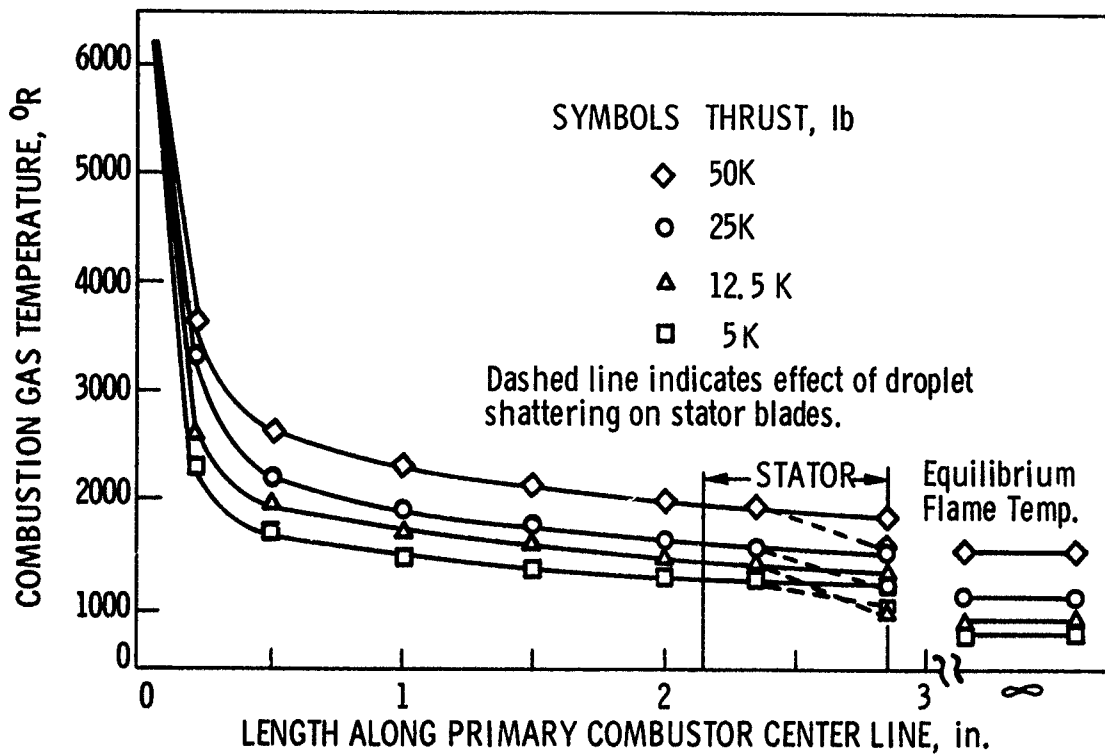


Figure 8. Gas Temperature vs Distance from Injector

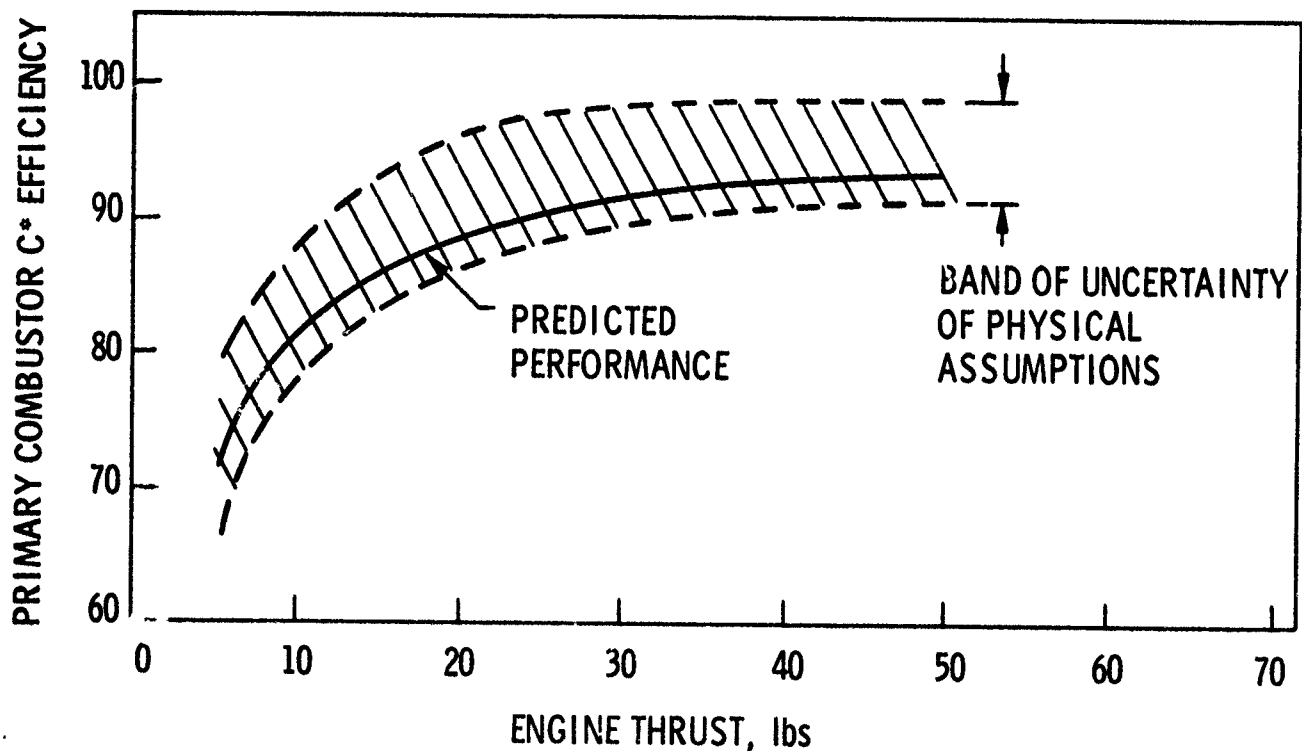


Figure 9. Predicted c^* Efficiency vs Thrust (U)

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IV, Primary Combustor Design (cont.)

B. INJECTOR DESIGN

1. Basic Design Approach

(U) Three basic injector configurations were studied in detail during the design study portion of the program. All used the HIPERTHIN injector concept, as dictated by the contract work statement. The first design, shown in Figure 10, was designated the annular ring injector. In this concept, disc-shaped platelets are stacked in the plane normal to propellant flow. The injector consists of multiple platelet sets that are stacked and then brazed into the injector body. Each platelet set consists of three platelets, one fuel platelet with an oxidizer platelet on either side. The resulting assembly is a one-piece unit with uniform propellant injection around the entire engine circumference.

(U) The second design considered, designated the segmented injector, is shown in Figure 11. This design consists of ten identical platelet segments that are brazed into a decagonal ring structure. The platelets of each segment are stacked in a plane parallel to propellant injection and sandwiched between two end plates. Individual segments are then individually brazed, after which they are machined to final dimensions. The completed segments are assembled onto the injector body (which contains the fuel manifold and is identical in design to that of the annular injector) and the entire assembly is brazed together in a second braze cycle. In this same cycle, the end plates of the individual segments are brazed together.

(U) The third injector approach investigated, called the modular injector, is similar to the segmented injector except that the individual injector segments are contained in cylindrical cartridges that are welded directly into the engine housing (see Figure 3 and Figure A-1 of the Appendix). An individual injector module is shown in Figure 12. Two metal piston rings (in one groove) provide a low leak path seal between the oxidizer manifold and the combustion chamber; the fuel manifold is isolated from the oxidizer

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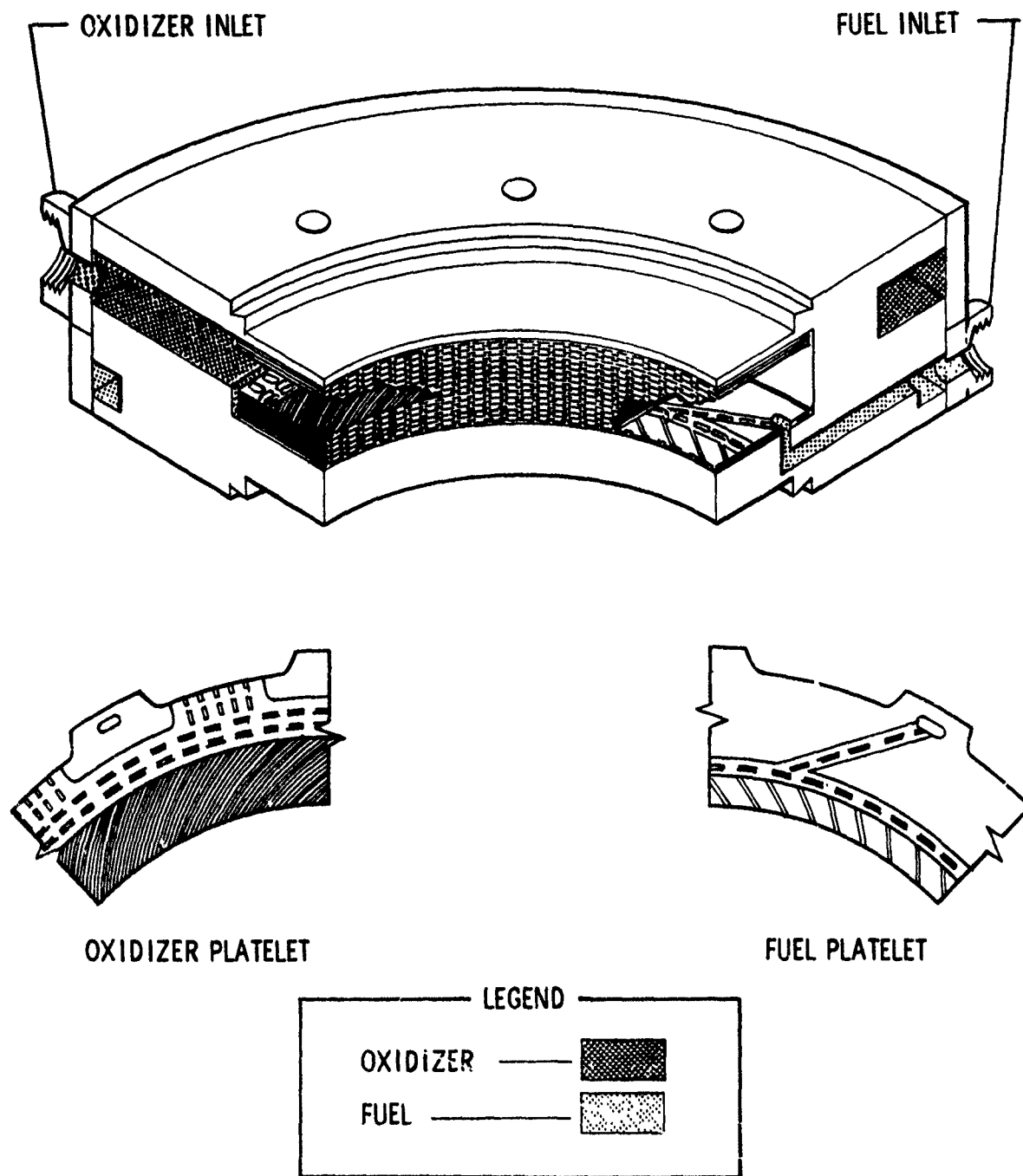


Figure 10. Annular Ring Injector

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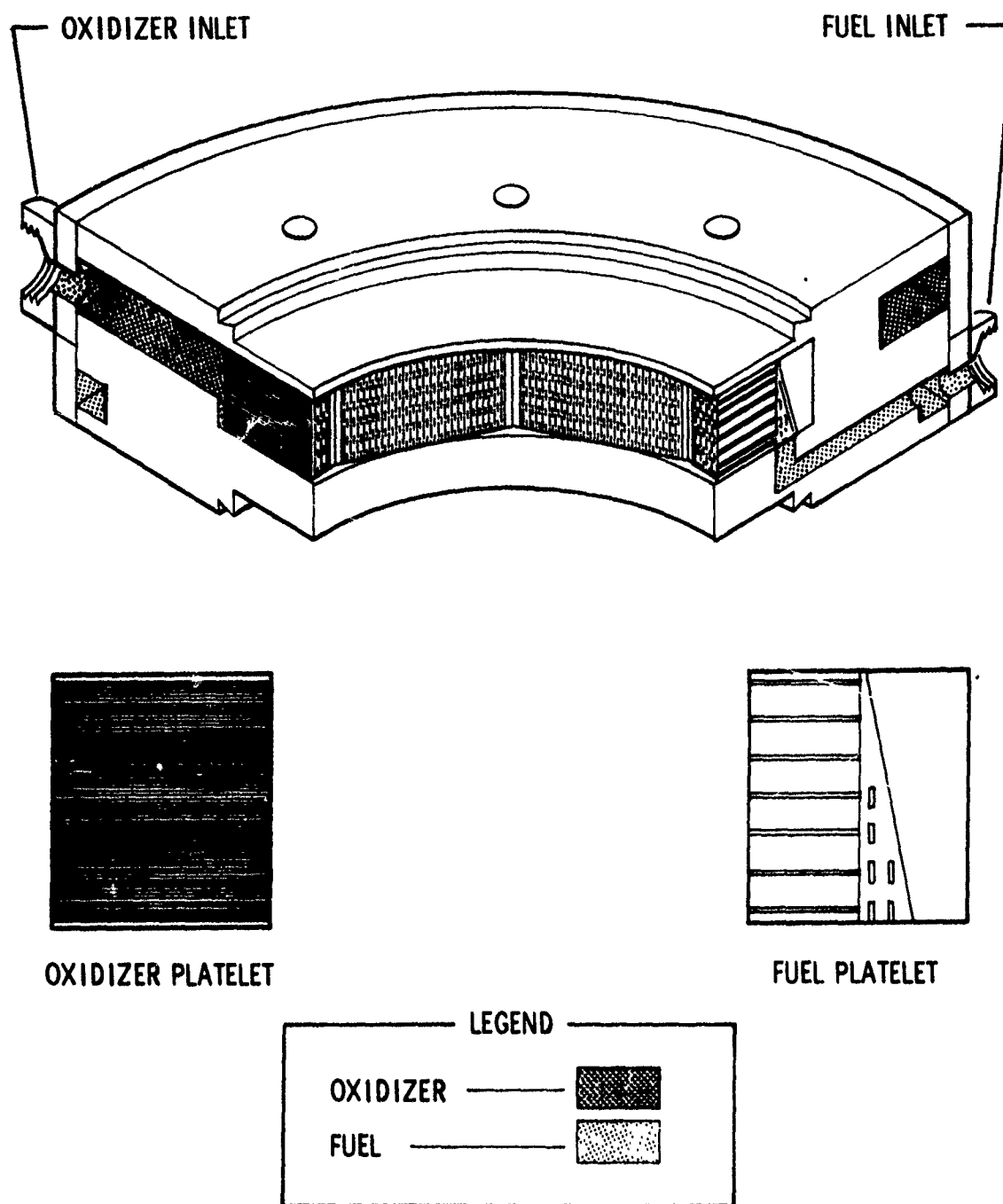


Figure 11. Segmented Injector

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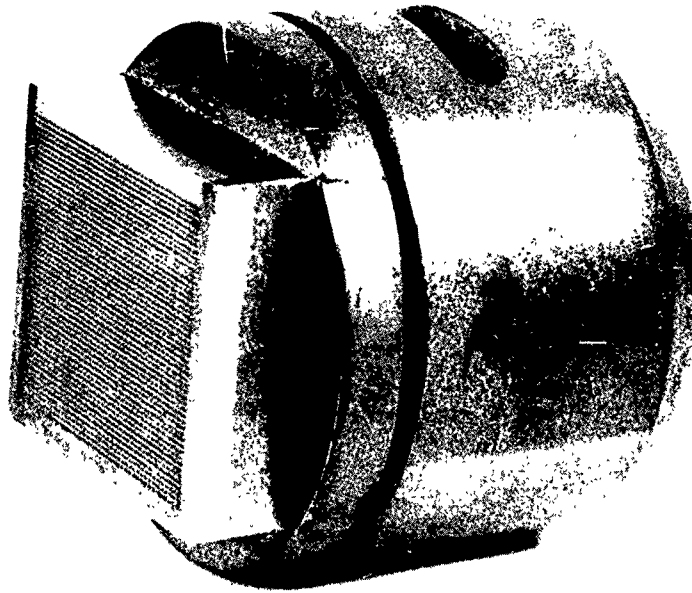


Figure 12. Modular Injector

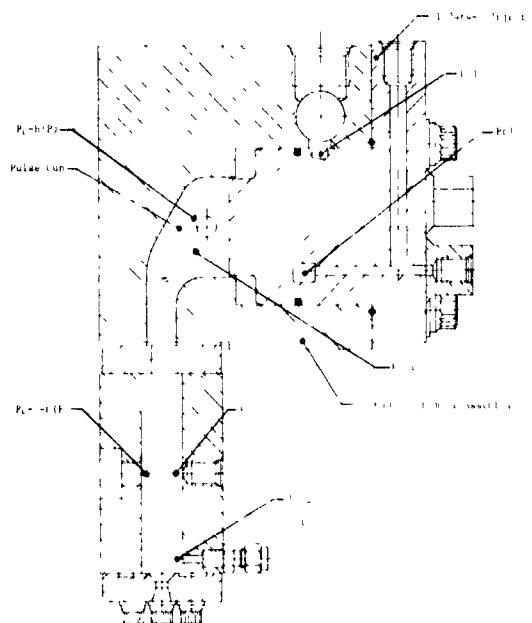


Figure 13. Segment Assembly

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IV, B, Injector Design (cont.)

manifold by the weldment of the module to the housing. The fuel is sealed to the outside by a cap welded to the housing, which also forms the back of the fuel manifold (see Figure 3).

(U) Each of the candidate injector designs has advantages relative to the other; all were considered capable of meeting the requirements of this program. The annular injector requires fewer platelets, and has greater pattern flexibility in that it contains an uninterrupted 360° surface (e.g., the pattern shown in Figure 10 could not be used in the other designs without significant edge effects). Also the entire injector assembly requires only one braze cycle. A disadvantage with this concept is the size of platelet required (approximately 11 in. O.D.) which is substantially larger than the platelet size normally used for injectors; this could present a state-of-the-art problem in fabrication techniques. Furthermore, since the injector is a one-piece unit, a fabrication problem could render the entire part, which represents a sizable cost investment, unusable. By comparison, the segmented injector uses platelets within the state-of-the-art size, involves multiple platelet components which are fabricated separately, and provides the flexibility of replacement of one or more segments if required by fabrication or test problems (e.g., an intropropellant task developing in one segment). This replacement would be accomplished by machining out the bad segment(s) and replacing it with a new one. Disadvantages of this concept are the relative pattern inflexibility and the requirement of two braze cycles in the fabrication process. The modular injector, the selected design concept, has the relative advantages of the segmented injector together with a significant additional advantage. This injector is the most cost effective during development; a large portion of the development can be accomplished with single modules using a low cost test facility. Furthermore, since the cost of a single module is substantially lower than that of a full injector, more patterns can be evaluated for the same total cost.

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IV, B, Injector Design (cont.)

2. Injector Module Design

(U) Four different HIPERTHIN injector patterns were designed, fabricated, and test-evaluated during the Phase I program. The first two patterns were designed and evaluated concurrently during the first part of the program, while the third and fourth patterns were iterations based upon test results. All injectors were of the same size and geometrical shape, having a rectangular face 1.75 in. in height by 2.0 in. wide. The injectors are of flightweight configuration except for an added flange to facilitate bolt-on capability for development ease. A typical injector is shown in Figure 4. Oxidizer enters the injector through the slot on the cylindrical portion of the injector; fuel enters through the port on top of the injector flange, passes down through the flange into a slot located below the platelet stack and normal to the injector face. The oxidizer is sealed from the combustion chamber by metal piston rings identical to those used in the flightweight engine design. The external oxidizer seal is a metal O-ring which is replaced by a weldment on the engine design. A cross section assembly of the injector installed in the test housing is shown in Figure 13. Each of the four injector patterns is discussed in the following paragraphs. Design parameters are summarized in Table III.

a. Showerhead Oxidizer - Showerhead Fuel Pattern (SO/SF)

(U) This pattern has showerhead orifices in both the oxidizer and fuel circuits. The metering platelets used are shown in Figure 14. As with all the injector patterns, the platelet stackup is made by alternating in sequence four sets of oxidizer metering and separator platelets with one set of fuel metering and separator platelets. The sequence is repeated beginning and ending with oxidizer platelet sets until 42 fuel platelet sets have been installed. The total number of injection orifices in the pattern

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TABLE III
INJECTOR PATTERN DESIGN DATA

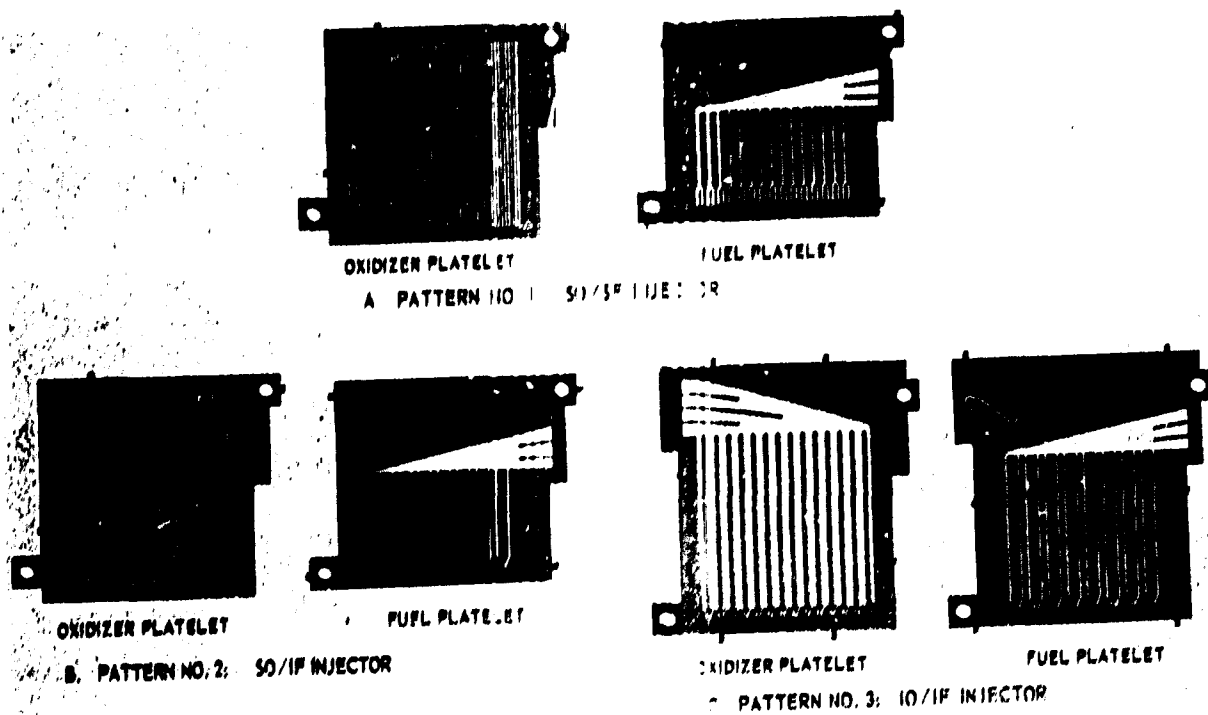
Injector Type	Feed Channel Dimensions (inches)		Channel Length (inches)		Orifice Dimensions (inches)		Injection Velocity (ft/sec)			
							5K Flow Rates		50K Flow Rates	
	Oxid	Fuel	Oxid	Fuel	Cxid	Fuel	Oxid Circuit	Fuel Circuit	Oxid Circuit	Fuel Circuit
SO/SF	.002x.015	.002x.015	1.5	.75	.002x.015	.002x.015	6.2	2.1	59	54.7
SO/IF	.002x.015	.002x.015	1.5	.75	.002x.015	.002x.013	6.2	2.8	59	73
IO/IF	.002x.030	.002x.015	1.46	1.44	.002x.010	.002x.013	8.3	2.8	79	73
IO/IF (Modified)	.002x.030	.002x.015	1.46	1.32	.002x.010	.002x.013	15.6	2.8	149	73
Dual Manifold	.002x.030	.002x.020	1.46	1.72	.002x.010	.002x.013	31.2 ⁽¹⁾	5.6 ⁽¹⁾	149	73
	Alt Plate	Alt Plate								
	.002x.015		1.46	1.32		.002x.013				

(1) Velocities shown are for single manifold operation. Velocities using both manifolds are the same as IO/IF (Modified) injector.

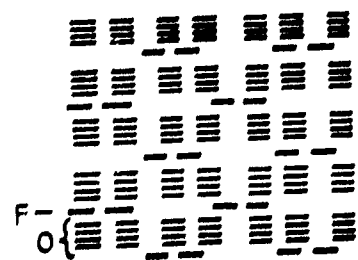
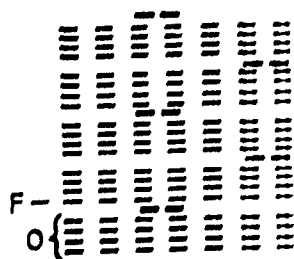
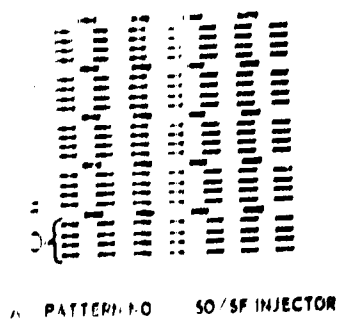
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F - FUEL
O - OXIDIZER



NOTE: APPROXIMATELY 1% OF TOTAL FACE SHOWN
FOR EACH PATTERN

Figure 14. Metering Platelets and Face Pattern Schematics

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IV, B, Injector Design (cont.)

are 8600 oxidizer and 1260 fuel. A schematic of the resulting face pattern is also shown in Figure 14. Circuit pressure drops as a function of thrust level are shown in Figure 15.

b. Showerhead Oxidizer - Impinging Fuel Pattern (SO/IF)

(U) This pattern uses the same showerhead oxidizer platelets as the SO/SF injector, but the fuel metering platelets incorporate impinging fuel orifices as shown in Figure 14. The total number of injection orifices in the pattern are 8600 oxidizer and 630 fuel. The 630 fuel orifices are comprised of alternating fuel metering platelets containing 7 and 8 impinging orifice pairs. The design circuit pressure drops are the same as those of the SO/SF (Figure 15).

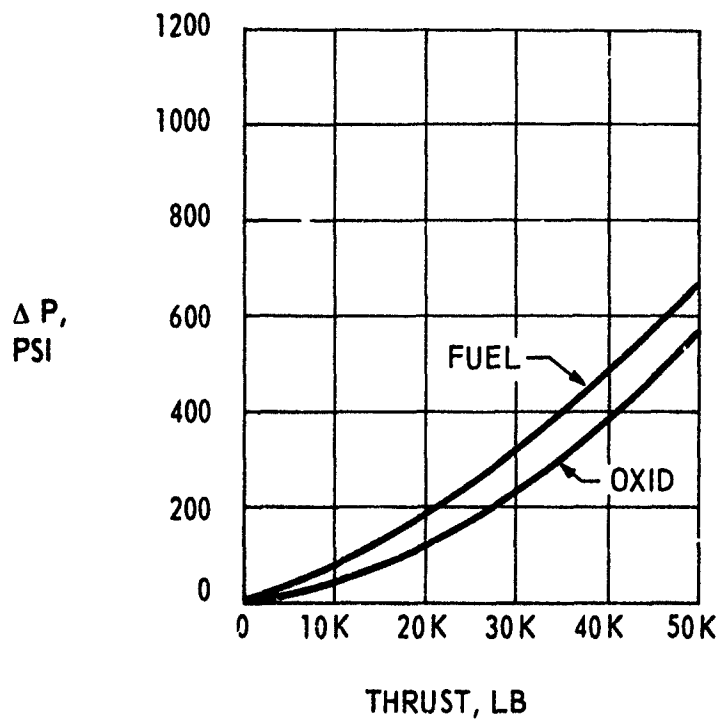
c. Impinging Oxidizer - Impinging Fuel (IO/IF)

(C) Data obtained from tests conducted on the SO/SF and SO/IF injectors disclosed that: (1) the SO/IF injector produced far smoother combustion than the SO/SF injector, (2) higher circuit pressure drops were required to prevent low frequency oscillations from occurring at the lower thrust levels, and (3) the chamber walls were grossly overcooled. Based on this information, the IO/IF orifice pattern was designed. The oxidizer pattern was converted from 50 showerheads to 14 impinging pairs (because of the relatively smooth operation of the impinging fuel pattern of the SO/IF injector), and the pressure drop in both circuits was substantially increased. The circuit pressure drops are shown in Figure 15. The additional pressure drop was obtained by lengthening the flow passages in the fuel metering platelet, and by redesigning the oxidizer metering platelet to incorporate impinging orifices at the face plane, similar to that of the fuel metering platelet. The platelets and face pattern are shown in Figure 14.

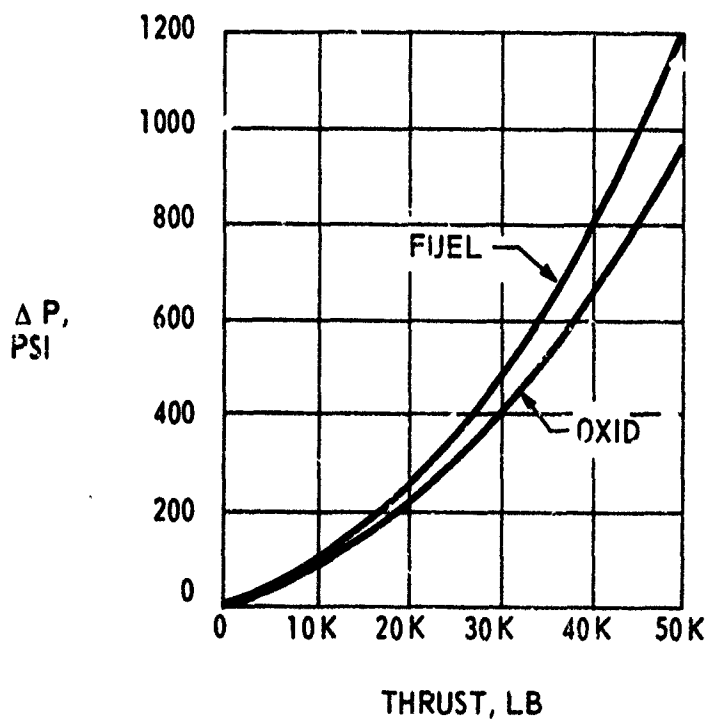
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A. SO/SF AND SO/IF INJECTORS



B. IO/IF INJECTOR

Figure 15. Design Pressure Drop vs Thrust

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IV, B, Injector Design (cont.)

(U) To reduce the overcooled chamber condition, the stacking sequence was revised and an additional fuel platelet set was added. In this design the beginning and ending platelet sets consist of two oxidizer sets instead of the previous four. The remaining sequence of four oxidizer metering and separator platelet sets alternating with one fuel metering and separator platelet set continues until 43 fuel platelet sets have been installed. The pattern contains 4816 oxidizer and 646 fuel orifices.

d. Dual Manifold IO/IF Injector

(C) Test data with the IO/IF injector showed that the unit was within the contract specifications from the 9K thrust level up to 45K thrust. However, between 5K and 9K low frequency chamber pressure oscillations were noted in increasing amplitude from $\pm 4\% P_c$ at the 8.5K thrust level to $\pm 15\% P_c$ at the 5K thrust level. These oscillations were identified as a classic chugging mode, resulting from insufficient injector pressure drop at the low thrust levels. To stabilize operation at throttled conditions, a dual-manifold injector was designed and test-evaluated. In this design, two fuel and two oxidizer circuits were incorporated; during engine operation at the low thrust levels one set of circuits would be valved closed, thus forcing all the propellant through the remaining circuits, increasing the circuit pressure drops.

(U) The 8-pair fuel metering platelets were redesigned to increase the channel length, thereby facilitating a separate fuel plenum beneath the assembled platelet stack. The new fuel plenum was fed through the original fuel inlet at the top of the injector flange. The alternating 7-pair platelet plenum was plumbed through a thin wall tube and fed through the injector fuel pressure port (P_{fJ}). The oxidizer platelets were redesigned so that the plenums of one-half the platelets opened up during machining 0.080 inch prior to the remaining half. The two types of platelets were

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IV, B, Injector Design (cont.)

alternated on assembly to obtain symmetry of injection. After testing the single-manifold modules, the oxidizer circuit was machined the remaining 0.080 inch to open the second oxidizer circuit. The remainder of the test program was conducted with both oxidizer circuits open.

(U) The single-manifold mode contained 2408 oxidizer orifices and 352 fuel orifices. The dual manifold injector components are identical to the IO/IF injector except for the displacement of the fuel plenum on the 8-pair platelet. The rise in pressure drop due to the displaced plenum was balanced by enlarging the channel dimension feeding the orifices. The design variation between the single circuit injector and the dual manifold injector is shown schematically in Figure 16. The face pattern schematic depicted in the figure is identical for both injectors.

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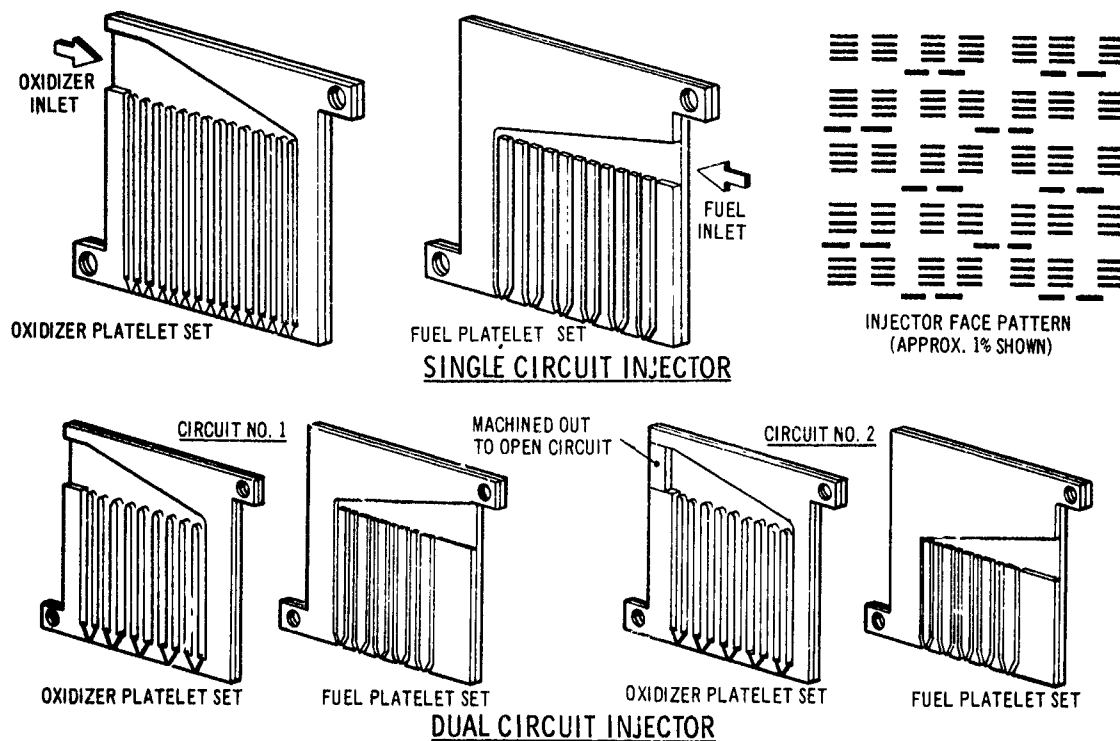


Figure 16. Comparison of Single-Manifold and Dual Manifold Metering Platelets

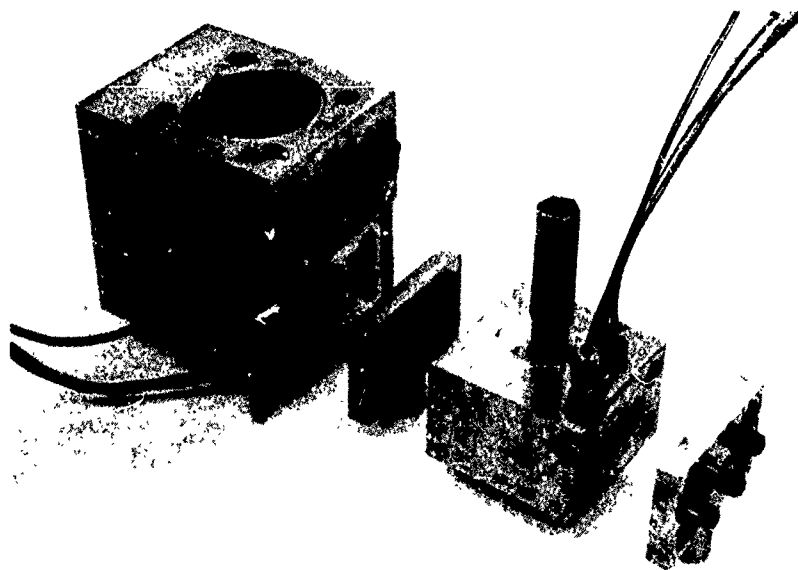


Figure 17. Combustion Chamber Housing Assembly

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IV, Primary Combustor Design (cont.)

C. COMBUSTION CHAMBER DESIGN

(U) The combustion chamber designs used for the injector evaluations are discussed in this section. Two basic configurations were designed, one with a single combustion chamber for use in the segment test program, and one with all ten segments arranged as in the engine for the clustered segment test program.

1. Segment Program Combustor

(U) The combustion chamber housing, shown in Figures 13 and 17, is designed with two mirror-image halves into which the internal combustion contour is machined prior to brazing the halves together. It is fabricated from CRES 347 material. Chromel-alumel thermocouples are brazed integrally into the joint to measure gas-side wall temperatures down the chamber wall. The segment housing contour differs slightly from the clustered housing, which precisely matches the engine configuration. The engine configuration consists of 10 segments located circumferentially about the engine centerline; this results in the chamber walls converging at an 18° half-angle as they move towards the center of the engine. The combustion chamber (downstream of the injector interface) makes a 90° turn and terminates at the turbine stator vanes in a curved, trapezoidal shape. The segment housing, for ease of fabrication, was designed with parallel walls and terminates in a rectangular shape. This difference results in a volume of 5.50 in.^3 for the segment housing, compared to 4.58 in.^3 for a one-tenth segment of the engine configuration. The L^* (mean distance from the injector face to the turbine simulator plate) was maintained at the engine dimension of 3.00 in.

(U) A close-tolerance cylindrical interface is provided to feed oxidizer from the chamber housing into the injector. This interface is sealed

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IV, C, Combustion Chamber Design (cont.)

to the outside by a metal "O" ring, and sealed to the combustion zone by two piston rings. Instrumentation capability, in addition to the wall profile thermocouples, includes ports for a Photocon 307 high frequency pressure transducer, a Taber low frequency pressure transducer, and an AGC Model V pulse generator. Instrumentation locations are shown in Figure 13.

(U) A sonic throat consisting of a multihole converging - diverging nozzle fabricated from a 0.5-in.-thick stainless steel plate is attached to the aft end of the combustion chamber housing. A photo of the sonic nozzle plate is included in Figure 17. The design discharge coefficient of the nozzle (C_D) used in the test program to calculate c^* performance was 0.75.

(U) In the latter portion of the segment test program, a chamber extension attached to the main chamber housing was evaluated. This extension, shown in Figure 17, was designed to provide the proportional segment volume and length between the turbine and secondary injector, and thus more closely simulate the engine configuration. The extension volume is 5.9 in.³, with a chamber length of 3.5 in. A turbine simulator plate, fabricated from a 0.5-in.-thick metal plate with three drilled holes, was installed between the combustion chamber and the extension. The turbine simulator plate is shown in Figure 17. The connotation "turbine simulator" is a misnomer in the sense that the plate does not extract work from the primary gas, and therefore cannot effect the same pressure drop on the test hardware that the turbine does on the engine. However, both the turbine simulator plate and the turbine are subsonic devices and are placed in the same relative location, and do provide acoustic similarity.

2. Clustered Segment Program Combustor

(U) The clustered segment combustor is composed of an assembly of three parts; the injector housing, the forward combustion chamber housing,

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IV, C, Combustion Chamber Design (cont.)

and the aft combustion chamber housing. All are fabricated from CRES 347 material. A schematic of the assembled unit is shown in Figure 18. Photographs of the component parts are shown in Figure 19. The combustion chamber is composed of the forward housing which forms the inner chamber contour, and the aft housing, which forms the outer chamber contour. The forward housing includes a high frequency Photocon port, standard Taber port, a pulse gun port, and mounting holes for the turbine simulator orifice. The injector housing includes the interfaces for the ten injector assemblies and the oxidizer inlet ports for each injector. The injectors are inserted into cylindrical ports machined radially from the outside of the housing ring. The injectors are sealed on the cylindrical portion to isolate the oxidizer circuits from the combustion chamber. Metal O-rings seal the oxidizer circuit on the outside. At the base of the cylindrical section a transition is made to a rectangular window. This window forms the interface for the rectangular portion of the injector modules. Conoseal joints are used to interface the forward and aft chamber housings.

(U) The combustion chamber volume is separated into ten equal parts by means of baffles which extend from the injector housing down to the turbine simulator plate. The baffles are 1/8-in. thick and are indexed by means of slots in the chamber housing (see Figure 19). During the test program two design modifications were made on the baffle assembly. The first modification was implemented to eliminate the gap between the baffle and the injector housing for the purpose of further isolating adjacent combustion compartments. Slots were designed into the injector housing and the baffle plates were extended into the slots. The second design modification was incorporated when the injector housing eroded during a test at the baffle interface. To eliminate the discontinuity between the housing and baffle, the interface was redesigned to provide a welded joint instead of the slotted one. Figure 19 shows the final configuration.

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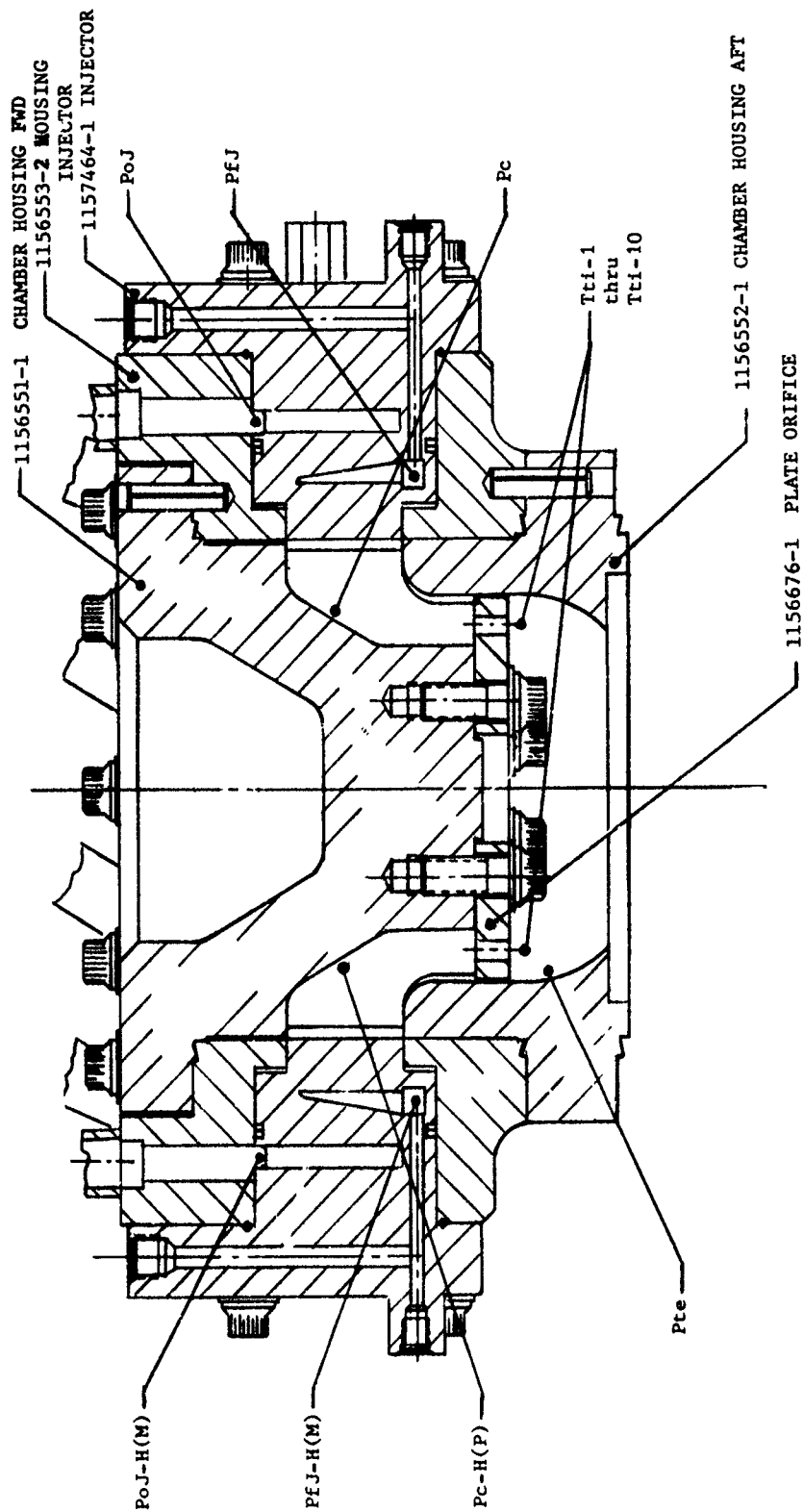


Figure 18. Cluster Assembly

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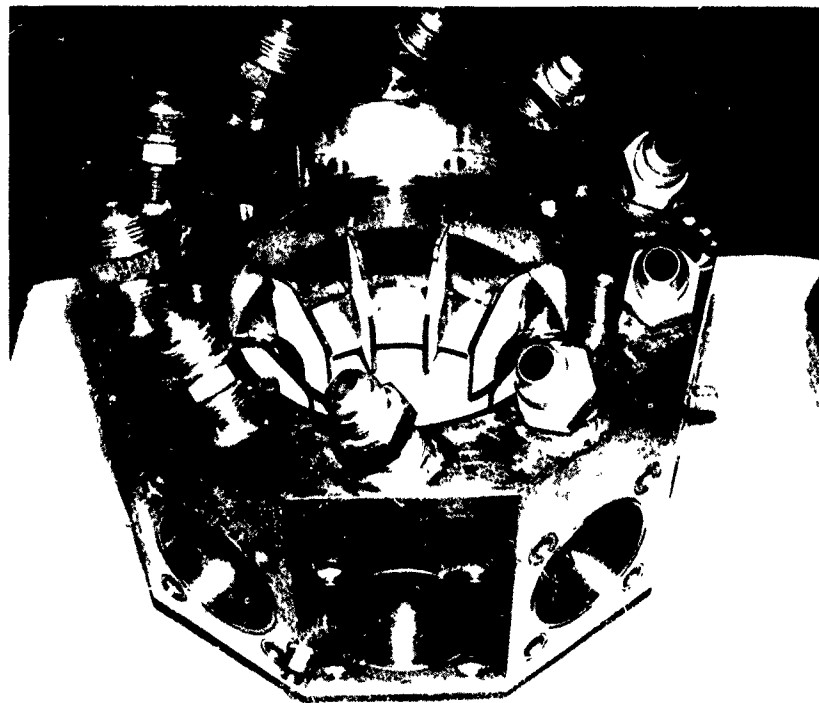
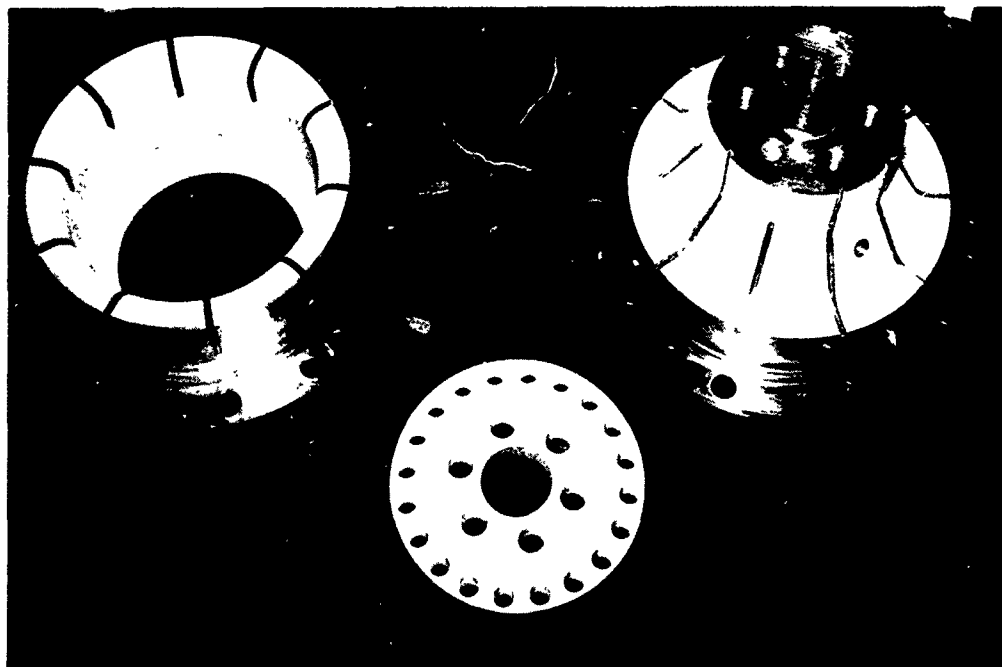


Figure 19. Cluster Assembly Components

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V. COMPONENT FABRICATION

(U) The major items of hardware fabricated during the program, together with part numbers and number of each part built are shown in Table IV. No significant fabrication problems were encountered during the program, although two injector design deficiencies were discovered during the early phase of fabrication. Fabrication of the first injector disclosed that the fuel platelet plenum was not adequately supported and sagged during the braze cycle. Fabrication of the second injector pointed out a marginal tolerance condition between the fuel manifold and the fuel plenums of the injector platelets. This condition permitted braze alloy to enter the fuel plenum during the second braze cycle. These problems were corrected on subsequent units.

(U) The fabrication of the injector consists of five basic operations: the photo-chemical etching of the platelets; the platelet stacking and subassembly brazing; electrical discharge machining of the propellant inlet plenums and machining, grinding and fitting the brazed subassembly to the injector manifold; the manifold platelet stack brazing; and the final machining to finish dimensions. Two leak check operations are performed during the fabrication sequence. The first leak check is made prior to brazing the platelet subassembly to the manifold. This insures that no leakage occurs between the oxidizer and fuel platelets. The second leak check is performed prior to electrical discharge machining the injector face to open the orifices, which is part of the final machining process. The fuel passages are pressurized to insure that no leakage occurs between the fuel and oxidizer circuits; and from the fuel circuit to the outside of the injector.

(U) The material used to fabricate all injector components was 347 Stainless Steel. The platelets were nickel-flashed and the metering platelets were copper plated over the nickel flash to provide the first braze alloy. Oxygen-free high conductivity copper foil was used to braze the end plates to the platelet stack. For the final braze Niore foil and powder were used.

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TABLE IV

HARDWARE FABRICATION SUMMARY

FABRICATION SUMMARY

<u>Number</u>	<u>Nomenclature</u>	<u>Quantity</u>
1156340-1	Segment Chamber	2
1158936-1	Chamber Extension	1
1157383-9	Resonator	1
1156551-1	Chamber Housing Forward	2
1156552-1	Chamber Housing Aft	2
1156553-2	Chamber Housing Main Body	2
1156230-1	Injector (SO/SF)	3
1156230-2	Injector (SO/IF)	4
1157236-1	Injector (IO/IF)	2
1157464-1	Injector (IO/IF)	24
1157464-1M	Injector Dual Manifold (IO/IF)	1

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V, Component Fabrication (cont.)

(U) It is significant to note that the fabrication of the 24 IO/IF injectors in the Phase II production run was completed with no difficulties and that all injectors were acceptable units for the clustered segment test program. These units were acceptance test fired at the 20K thrust level. The flow data obtained during this test series are included in Table I.

(C) The durability of the injector was demonstrated during the program when a total of 199 tests were conducted for a total duration of 664.3 sec. There was no structural failure or distortion in any injector. During the segment program one injector was fired 87 times for a total duration of 202.8 seconds; chamber pressure ranged from 700 psia to 4390 psia; mixture ratio ranged from 10.7 to 21.8; and the unit was pulsed with a 15-grain charge at the 9K, 25K, and 44K levels. No mechanical failure was noted during the entire series.

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VI. SEGMENT TEST PROGRAM

A. SUMMARY

(U) The objectives of the segment test program were to: (1) evaluate injector design variations of full scale injector modules at several thrust levels over the 10:1 throttling range, (2) conduct demonstration tests of long duration at full thrust, minimum thrust, and at points in between, and (3) evaluate the dynamic stability characteristics of the selected injector design by shocking the chamber with a pulse gun. For the demonstration tests, the success criteria for acceptable combustion stability characteristics was that the chamber pressure oscillations during steady-state operation should not exceed $\pm 5.0\%$ of the average chamber pressure value and not be divergent with time. Also, the effect of measured temperature distribution on engine operation was to be analytically evaluated, with corrections incorporated if found necessary.

(U) The test program was initiated on 27 January 1969 and concluded on 12 December 1969, during which period 176 tests were conducted. The test conditions, objectives and results for the cluster test program are summarized in Table V. The test data summary is shown in Table I. Four different injector designs were evaluated during the program, including the SO/IF, SO/SF, IO/IF, and dual-manifold IO/IF configurations.

(C) The SO/IF and SO/SF injectors were evaluated in parallel during the first portion of the test program. The test data showed that the combustion characteristics with the SO/IF injector were far smoother than with the SO/SF injector, as can be seen on representative oscillograph traces from similar tests, shown in Figure 20. As a result, testing was discontinued with the SO/SF injector, while the SO/IF injector was evaluated in depth, with a total of 87 tests performed with that design. Low frequency "chugging" type oscillations were encountered below the 18K thrust level; efforts to

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TABLE V
TEST CONDITIONS AND OBJECTIVES - SEGMENT PROGRAM

Test Series	Run No. SP-30	Test Objective	Test Results
I	101-104	10K Data Point; Test Stand Checkout and MR Survey; SO/IF Injector	No hardware damage; all tests unstable 240 Hz; MR range 12.9 to 21.8.
II	105-110	18K Data Point; Injector Evaluation and MR Survey; SO/IF Injector	No hardware damage; all tests stable; MR range 13.0 to 16.1; long duration test - 10.28 seconds steady state.
III	111-114	25K Data Point; Injector Evaluation and MR Survey; SO/IF Injector	No hardware damage; all tests stable; MR range 11.7 to 15.4.
IV	115 and 131	18K Data Point and 10K Data Point Injector Evaluation; SO/SF Injector	No hardware damage; unstable - 480 Hz at 18K point; unstable - 320 Hz at 10K point.
V	116-118	37.5K Data Point; Injector Evaluation; SO/IF Injector	No hardware damage; all tests stable; long duration test 9.63 seconds steady state.
VI	119-126	44K Data Point; Injector Evaluation; stability evaluation; long duration demonstration; SO/IF injector	No hardware damage; all tests stable; 15 grain pulse charge attenuated; long duration test 9.60 seconds steady state.
VII	127	25K Data Point; Stability Evaluation; SO/IF Injector	No hardware damage; test stable; 15 grain pulse charge attenuated.
VIII	128-141	10K Data Point and 18K Data Point; Test facility coupling characteristics evaluation; SO/IF Injector	No hardware damage; all tests unstable - 320 Hz to 500 Hz; varied line resonant frequencies by changing venturis and line orifices; test hardware sympathetic to all frequencies in range noted above.

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TABLE V (cont.)

<u>Test Series</u>	<u>Run No. SP-30</u>	<u>Test Objective</u>	<u>Test Results</u>
IX	142-148	10K, 14K, 18K, 25K Data Point; Stability Evaluation with Chamber L* section; SO/IF Injector.	No hardware damage; 10K and 14K points unstable - 250 and 340 Hz; 18K and 25K points stable.
X	149-151	18K Data Point, Turbulator Evaluation; SO/IF Injector.	No hardware damage; all tests unstable; no significant change in temperature profile due to turbulence devices.
XI	152-157	10K, 12K, 14K, 18K Data Points; Injector Evaluation; IO/IF Injector.	Injector separator plates collapsed in the plenum area; 10K test unstable - 240 Hz; 12K marginally stable - 260 Hz; 14K marginally stable - 400 Hz; 18K test stable; new injector required to resume injector development testing.
XII	158-194	10K Data Point; Stability Evaluation with resonator; SO/IF Injector.	No hardware damage; resonator cavity varied from 0.0 in. to 0.4 in. stroke on 4 hole resonator; 0.4 in. to 0.8 in. stroke on 8 hole resonator, 0.425 to 1.00 in. stroke on 12 hole resonator; no noticeable improvement in stability with this resonator design.
XIII	195-212	5K through 42K data points; Demonstration tests and stability evaluation at 9K, 25K and 42K; IO/IF modified design injector.	No hardware damage; 9K test duration 72.0 seconds, 25K test duration 23.0 seconds, 42K test duration 10.5 seconds; 10K and 12K tests unstable W/O L* section; 14K, 15K tests marginally stable

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TABLE V (cont.)

<u>Test Series</u>	<u>Run No.</u> <u>SP-30</u>	<u>Test Objective</u>	<u>Test Results</u>
XIII (cont.)			W/O L* section; all tests 9K and above stable with L* section; 8.5K marginally stable with L* section; 5K and 7.5K unstable with L* at 110 Hz and 180 Hz respectively; all three pulse tests attenuated the 15 grain charge within 40 milliseconds.
XIV	213-264	20K Data Point; Injector acceptance test and balance tests for Clustered Segment Test Program.	Minor erosion sustained on injectors and chamber housing while testing S/N 022 and S/N 024 injectors, tested W/O turbine simulator orifice; high frequency (1120 Hz) oscillations with amplitudes of ± 150 psi occurred on both tests.
XV	265-276	5K, 6K, 7K, 7.5K Data Points; Injector Evaluation; Dual Manifold Injector.	5K and 7.5K test stable with single circuits flowing; unit unstable when both fuel and/or both oxidizer circuits flowing; no appreciable improvement in stability by dual manifolding only one circuit.

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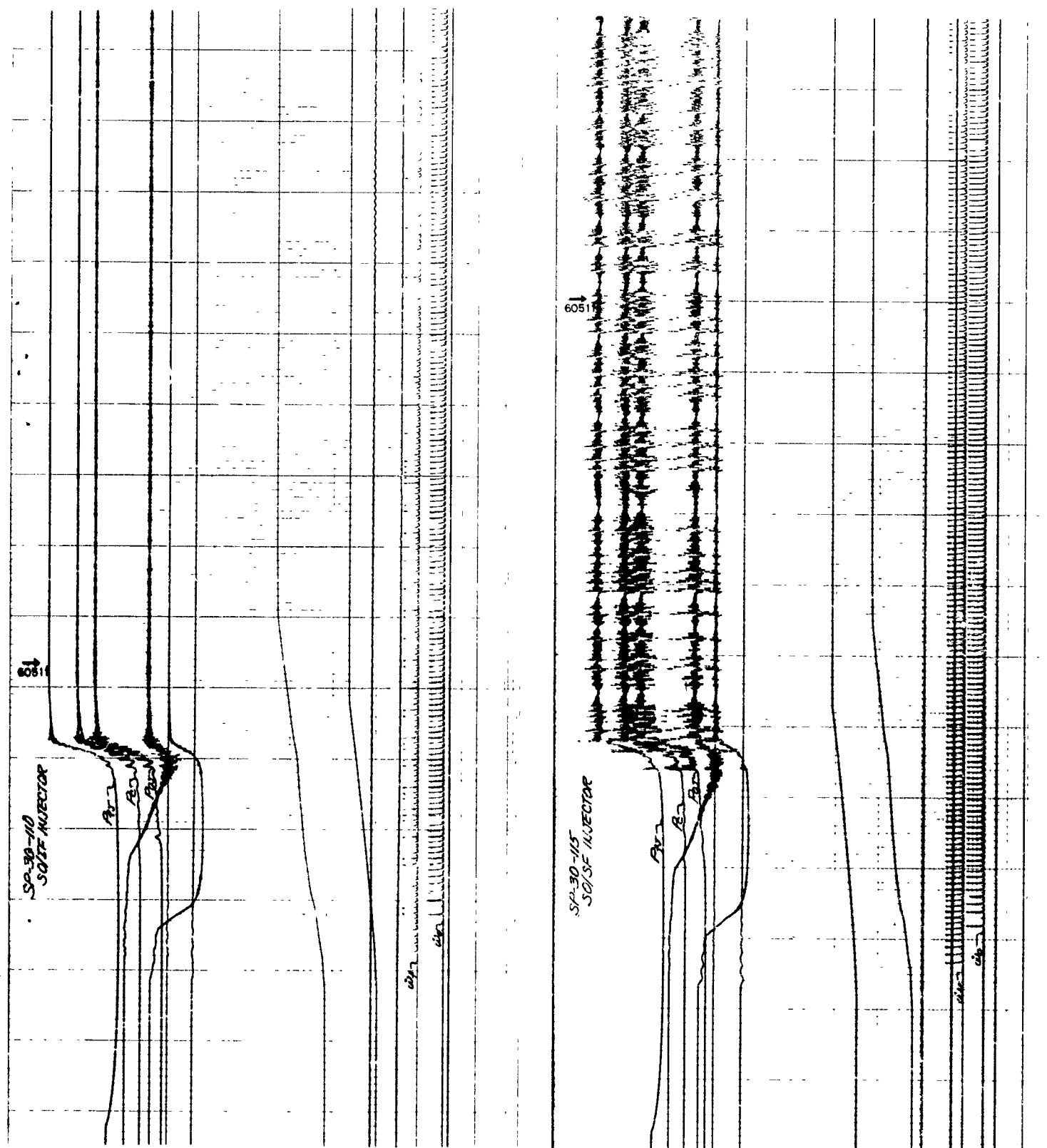


Figure 20. Oscillograph, Runs SP-30-110 and 115

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VI, A, Summary (cont.)

stabilize the operation at the low levels with an acoustic resonator were generally unsuccessful. It was concluded that the injector circuit pressure drops would have to be increased to widen the stable operating range.

(C) The test program was resumed with the IO/IF injector, which incorporated increased circuit stiffnesses as well as other design changes suggested by evaluation of data from tests with previous injectors. The operating characteristics of this injector were clearly superior to the earlier designs. Operation was extremely smooth at all equivalent thrust levels above 8.5K, with chamber pressure oscillations being $\leq \pm 1\%$ of average chamber pressure. Performance and gas temperature distribution were also acceptable. The test unit was pulsed with a 15-grain charge during operation at the 9K, 25K and 42K thrust levels. The unit proved dynamically stable in each test. Following the momentary pressure overshoot resulting from the pulse charge, operation returned to normal within 20 millisecc. A typical pulse trace is shown in Figure 21.

(C) In the thrust range between 5 and 8.5K, an organized low frequency "chugging" instability occurred again, due to insufficient pressure drop through the injector orifices. Because of the otherwise excellent results with this injector, authorization was received to proceed into the Phase II clustered segment test program with the IO/IF injector. Subsequently, 24 additional units of that design were fabricated and acceptance test fired for Phase II testing.

(C) Concurrently with the Phase II program, the dual-manifold IO/IF injector was designed to increase the circuit pressure drops at the low throttle points while not increasing the pressure drops at full thrust flows. One injector module of this configuration was fabricated and tested. Stable operation at the 5K level was demonstrated.

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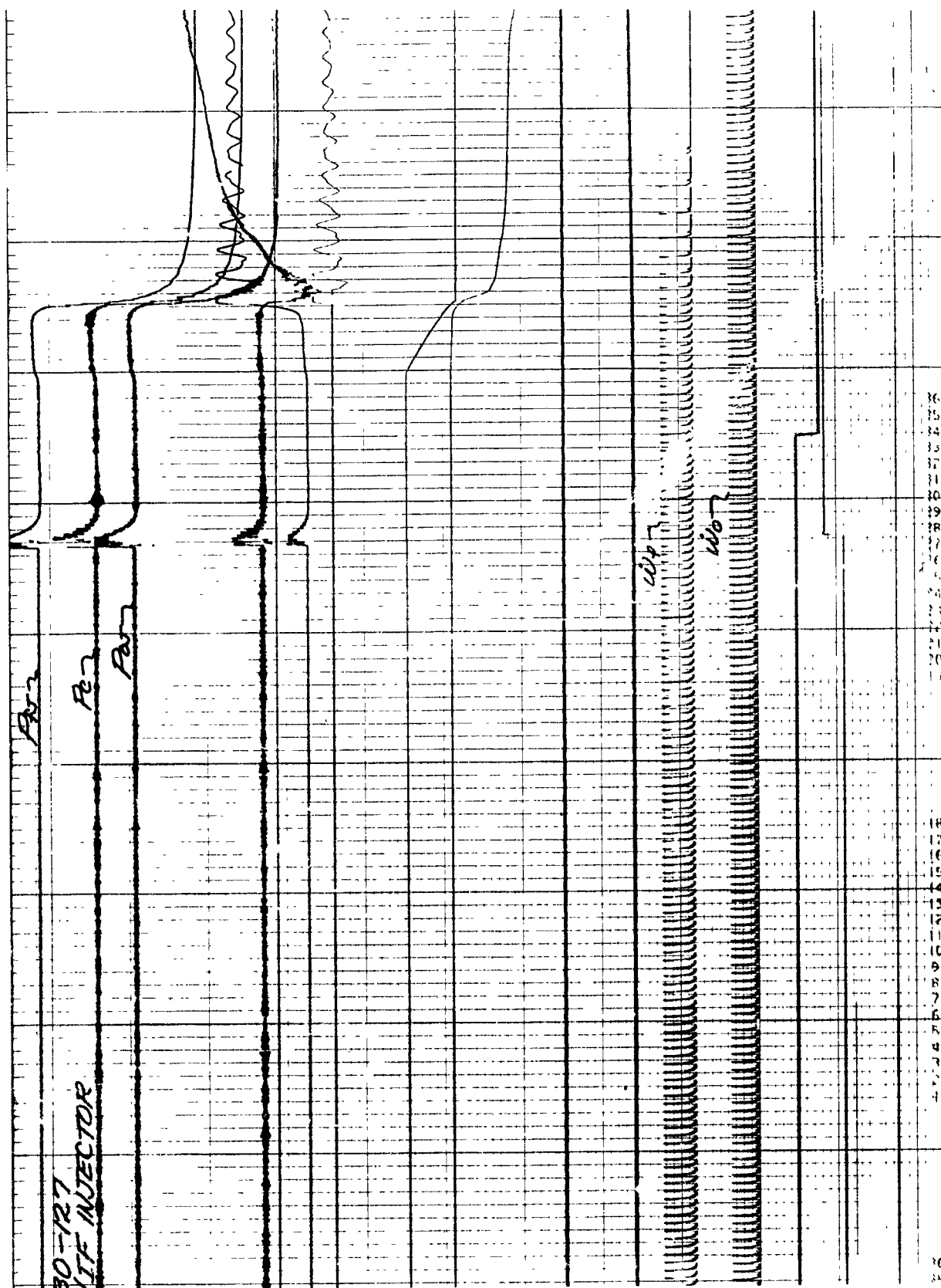


Figure 21. Oscilloscope Record SP-30-127

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VI, A, Summary (cont.)

(U) A description of the test setup and instrumentation is given in Section VI,B. The detailed test program performed is discussed in Section VI,C. The evaluation of the test data, including performance and stability, is discussed in Section VI,D.

B. TEST SETUP

(C) The segment test program was conducted in Aerojet's Physics Laboratory, Test Bay 6. A photograph of the test installation is shown in Figure 22; the flow schematic is given in Figure 23. Both oxidizer and fuel propellants were supplied to the test unit from high pressure storage tanks pressurized with nitrogen gas. Cavitating venturis installed in the propellant feed lines to the injector were used for flow rate control. (During the low frequency instability evaluation portion of the program, several tests were performed with the venturis removed to determine if changing the feed system configuration would change the basic stability characteristics of the system. It was concluded the venturis were not the controlling factor in the instability).

(U) The test instrumentation consisted of Taber transducers for pressure measurement, Potter turbine-type flowmeters for flow measurement, and 1/8 in. chromel-alumel (C-A) thermocouples for temperature measurement. In addition, high frequency pressure instrumentation included a flush-mounted Photocon 307 transducer in the combustion chamber, and flush-mounted Kistler 601A transducers on the oxidizer and fuel propellant lines just upstream of the injector. The gas temperature profile exiting the chamber was measured by high response, 0.040 in. dia, C-A thermocouples. The chamber also contained a gun port to allow stability evaluation by pulsing the chamber during selected tests with a 15-grain charge.

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Figure 22. Physics Lab Test Installation

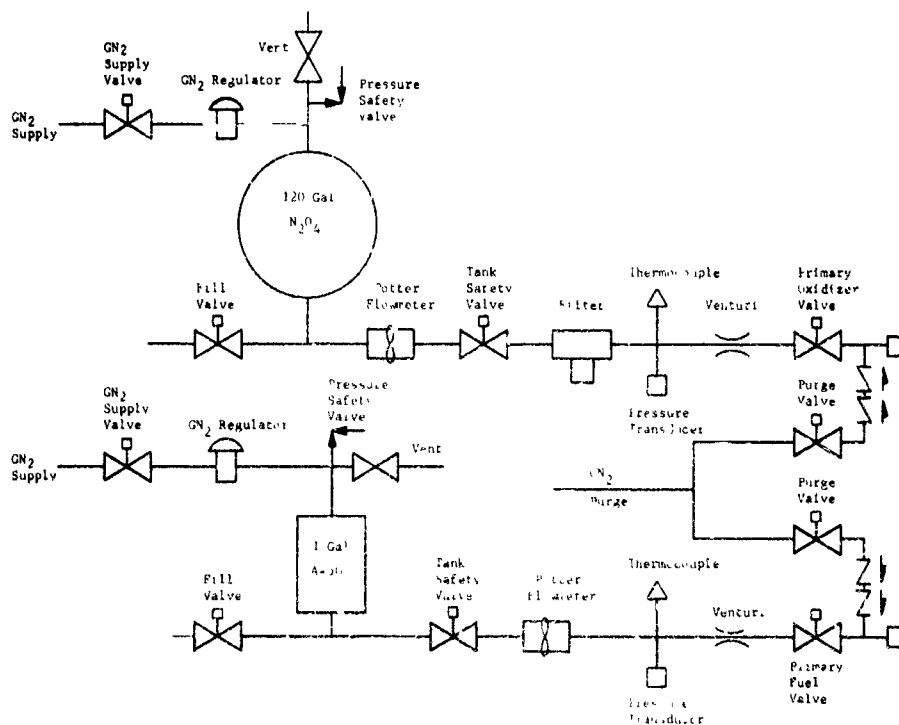


Figure 23. Flow Schematic - Physics Lab Testing

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VI, Segment Test Program (cont.)

C. DETAILED TEST PROGRAM

(U) The detailed test program performed with each of the four injector designs are discussed in this section. A summary is first given for the evaluation performed with each injector type, followed by a discussion of each test series performed during the evaluation. The test series designation refers to the chronological test sequence of all injectors, and is therefore not necessarily sequential within each specific injector evaluation.

1. SO/IF Injector Evaluation

a. Summary

(C) The segment test program was initiated on 27 January 1969 using the SO/IF injector. In the first test series of 49 tests, injector operation was evaluated at conditions equivalent to a thrust range of 10 - 44K. Operation throughout this range was satisfactory with respect to performance and structural integrity of the injector. However, at thrust levels of 18K and lower, pressure oscillations of $\pm 25\%$ of nominal chamber pressure at 260 cps at the 10K level, decreasing to $\pm 12\%$ at 450 cps at the 18K level, were encountered. At all thrust levels above 18K, no organized pressure oscillations were present. In fact, operation was very smooth, with chamber pressure oscillations being below $\pm 1\%$. Tests were performed to determine if the oscillations were caused by coupling with the test stand feed system. It was determined that they were not, and that the unstable loop was between the combustion chamber and injector feed manifolds.

(C) Thirty seven additional tests were then performed in which a resonator was attached to the combustion chamber in an attempt to suppress the oscillations. Using the resonator, stable operation was obtained

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VI, C, Detailed Test Program (cont.)

at the 10K level; however, the resonator was highly selective to the unstable frequency it would damp, and since the combustion frequency changes with each thrust level, it was concluded that the best approach for eliminating the oscillations would be an injector redesigned with high circuit pressure drops to increase the injector stiffness.

b. Test Series I (SP-30-101 through 104)

(C) The primary test objective of this series was to define the injector operating characteristics at the 10K thrust flow rates. Injector mixture ratio was intentionally varied during this series, with data points obtained for mixture ratios from 12.9 to 21.8. The test durations ranged from 0.28 to 0.90 sec of steady state. The unit was unstable at all mixture ratios, with chamber pressure oscillating at 250 psi peak-to-peak at 240 Hz.

c. Test Series II (SP-30-105 through 110)

(C) Test series II was conducted at the 18K level to determine if the increased injector stiffness resulting from the higher flow rates was sufficient to stabilize combustion. Test durations ranged from 1.35 to 10.28 sec of steady state and six mixture ratio data points were obtained between 13.0 and 16.1. All tests in this series were stable tests, with the exception of test SP-30-108, during which chamber pressure began to oscillate at 500 Hz with amplitudes up to 180 psi peak-to-peak. The oscillations occurred first at 2.91 sec into the test, but recovery was effected after 0.470 sec, with stable operation continuing for 4.48 sec. The oscillation reoccurred at that point and was sustained for the remaining 1.50 seconds of the run. Based on these tests, it was concluded that stable operation at the 18K thrust level was marginal. The measured oxidizer and fuel pressure drops were 126 and 202 psi, respectively.

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VI, C, Detailed Test Program (cont.)

d. Test Series III (SP-30-111 through 114)

(C) This series of four tests was conducted at the 25K operating point at approximately 2100 psi chamber pressure. Mixture ratio was varied from 11.7 to 15.4. The tests were stable and satisfactory in all respects.

e. Test Series V (SP-30-116 through 118)

(C) The objective of this series was to obtain data at the 37K operating point. Three tests were conducted from 2.18 to 9.63 sec duration at chamber pressures between 3221 and 3251 psia. The tests were stable and satisfactory in all respects.

f. Test Series VI (SP-30-119 through 126)

(C) This series was designed to evaluate the operating characteristics in the 40 to 50K range. The upper thrust limit to which the injector could be tested was 45K, due to the pressure supply capability of the test facility. During this series, three satisfactory long-duration runs (9.2, 9.6 and 9.6 sec) were conducted, which demonstrated the stability and structural adequacy of the design. Also during this series, the unit was pulsed with a 15-grain charge at a steady state chamber pressure of 4376 psia. The pulse charge produced an 820 psi spike in chamber pressure; the perturbation was completely attenuated in 0.020 sec.

g. Test Series VII (SP-30-127)

(C) This test was a pulse test at the 25K point to evaluate the stability characteristics at an intermediate throttle point. The test was 19.2 seconds in duration with the 15-grain pulse initiated at a steady state

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VI, C, Detailed Test Program (cont.)

chamber pressure of 2285 psi, just prior to shutdown. A 650 psi spike was noted following the pulse, which was attenuated in 0.020 sec.

h. Test Series VIII (SP-30-128 through 142)

(C) Having demonstrated the adequacy of the design over the high range throttling, this series was designed to evaluate, and eliminate if possible, the oscillations noted at the throttle points below 18K. During this series 14 tests were conducted, two at 10K and twelve at 18K. All tests conducted during this series were unstable. Variations of test setup, designed to evaluate the influence of the test facility components on the instability, included moving the venturis to a new location to change system resonances, and replacing the venturis with orifices. No effect was noted on the combustion characteristics other than slight changes in frequency. Attention was turned to the injector and an additional 100 psi orifice was placed in the oxidizer inlet to attempt to isolate the oxidizer circuit. An increase in nozzle area to increase the injector pressure drop while maintaining chamber pressure was also investigated. Neither modification had any marked effect on combustion. The oxidizer inlet to the chamber, in the region where it transitions from round to rectangular shape, was modified to streamline the transition geometry; it was thought that the original configuration, which contained a sharp discontinuity, could induce cyclic flow separation from the wall (flutter) and thus act as a fluid oscillator. No improvement was noted.

i. Test Series IX (SP-30-143 through 148)

(C) Test series IX was an evaluation of an L* extension added to the combustion chamber. This extension was designed to more nearly simulate the chamber conditions of the engine, which has a subsonic turbine at the location of the sonic nozzle of the test chamber. The sonic nozzle was replaced by an orifice, and an extension added, sized to provide the equivalent volume (for one segment) from the turbine to the secondary

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VI, C, Detailed Test Program (cont.)

injector face. This change provided consistent stable operation at the 18K thrust level, but the unit remained unstable at lower thrust levels. Following an evaluation at 25K, the L* extension was removed and the test repeated to verify stable operation of the basic configuration at the 25K level. Operation was stable. It was concluded that, while the L* extension did provide stable operation at 18K, the chance of obtaining stable operation down to the 5K level by combustion volume changes was remote.

j. Test Series X (SP-30-149 through 151)

(C) This series was performed to determine if turbulators installed in the combustion chamber would improve the stability range of the system, since the analysis indicated that forced mixing would tend to increase the heat transfer rate and gas temperatures. The tests were performed at the 18K thrust level, previously established as the marginal operating range. Three turbulator concepts were evaluated, including (1) a series of three splash plates, (2) a multi-hole orifice plate, and (3) a double row of triangular bars. Figure 24 is a photograph showing the posttest condition of the turbulators. No damage, except minor sagging, was noted on any of the turbulators. Their presence in the chamber reduced the chamber volume and changed the effective chamber dimensions which establish the chamber acoustics; as a result the combustion frequencies varied significantly (1100, 460 and 970 cps for the three designs, respectively). However, operation remained unstable in all cases, and no further testing with the turbulators was performed.

k. Test Series XII (SP-30-158 through 194)

(C) This test series was performed to determine if an Helmholtz resonator attached to the combustion chamber would damp the unstable oscillations and improve the stable throttling range of the injector. The resonator was designed with an adjustable volume feature;

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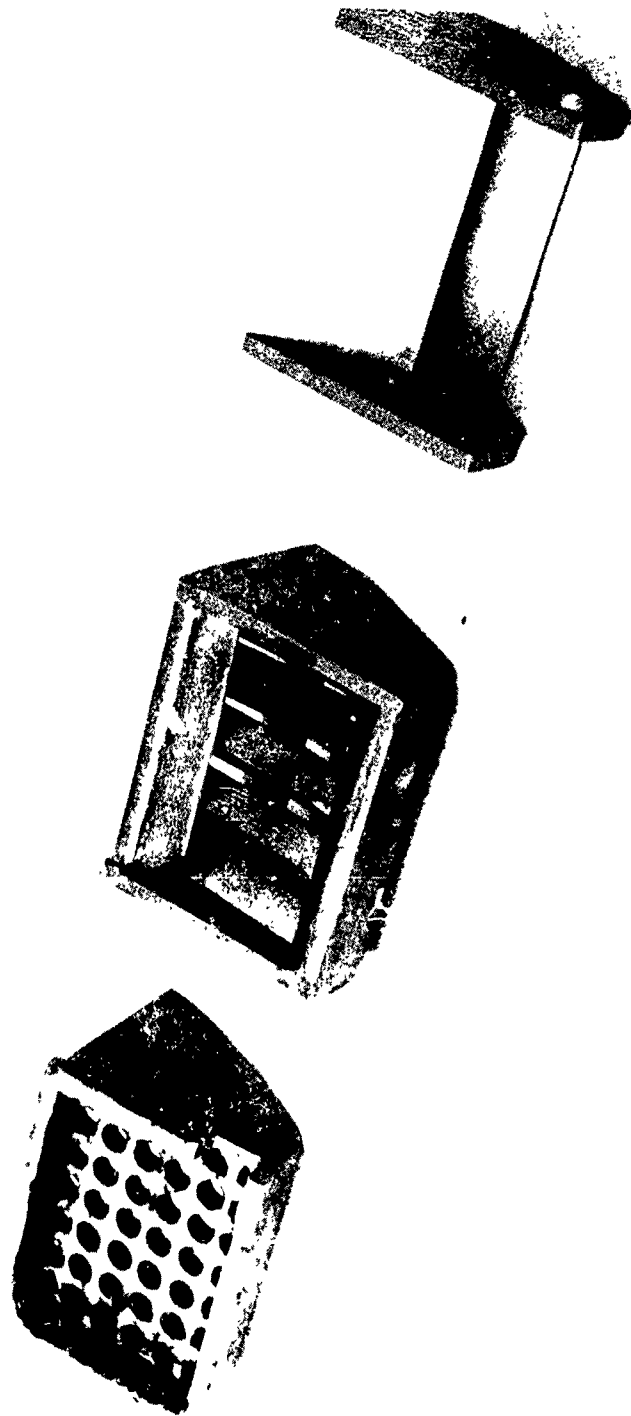


Figure 24. Turbulator

(Fig. 24)

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VI, C, Detailed Test Program (cont.)

the basic testing approach was to vary the volume setting in an attempt to obtain stable operation. All tests--with the exception of one--were conducted at the 10K level, a throttle point which had always produced unstable operation. Stable operation was achieved during three tests. However, later in the test series, operation was unstable at the same resonator volume settings. The resonator design and test results are discussed in Section VI,D,3. The test data obtained with the test resonator showed that it was not probable that a resonator of reasonable size would be effective in damping the unstable oscillations.

(C) Up to this point in the test program, three different approaches had been pursued with the SO/IF injector in attempts to eliminate the low frequency oscillations at the lower throttle levels: (1) test system changes; (2) turbulators, and (3) the resonator. None of these attempts significantly changed the throttling range capability of the injector. It was concluded that the injector circuit pressure drops would have to be increased to effect a significant improvement in the throttling range. On this basis, no additional testing was performed with the SO/IF injector; direction was focused on the IO/IF injector, which had been designed with increased circuit pressure drops.

2. SO/SF Injector Evaluation Test Series IV (SP-30-115 and -131)

(C) Two tests were performed with the SO/SF injector, one at the 10K thrust level and one at 18K. In both tests operation was very rough, with frequent intermittent "popping" in the combustion chamber which caused pressure spikes of up to 60% P_c overpressure. The oscillograph trace of the 18K test is shown in Figure 20. Based on the clearly superior operation of the SO/IF injector, no further testing was performed with the SO/SF injector.

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VI, C, Detailed Test Program (cont.)

3. IO/IF Injector Evaluation

a. Summary

(C) The IO/IF injector, which was designed with higher circuit pressure drops on the basis of test results with the SO/IF and SO/SF patterns, was evaluated in two development test series totaling 24 tests. Operation was evaluated over a thrust range from 5-42K and included tests both with and without the chamber L* extension installed. Without the extension, operation was marginally stable in the 12-14K range. With the chamber extension installed, operation was stable at 9K and above, and operation was satisfactory in every respect. Low frequency pressure oscillations were encountered in the 5 to 8.5K thrust range, ranging from $\pm 15\%$ and 110 Hz at 5K to $\pm 4\%$ and 200 Hz at 8.5K. Except for these relatively low amplitude oscillations, combustion was smooth and operation was satisfactory.

(C) Based on the fact that stable operation was demonstrated for over 90% of the intended throttling range, Phase I development testing was concluded with the IO/IF injector selected for Phase II testing. Subsequently, 24 of these injectors were fabricated and acceptance test fired in Test Series XIV for use in the Phase II cluster program.

b. Test Series XI (SP-30-152 through -157)

(C) The IO/IF injector was tested over the range of 10-18K thrust in this series of six tests. Operation was stable at 18K, unstable at 10K, and marginally stable in the 12-14K range. These tests were all conducted without the chamber extension installed. Inspection of the test records showed a "pop" in the propellant circuits just before ignition, indicative of an inter-propellant leak. Subsequent water testing with the

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VI, C, Detailed Test Program (cont.)

injector confirmed the leak, and determined its location as being in the vicinity of the fuel manifold. The leak must have developed during testing or just prior to testing during a routine acid flush operation, since the injector had previously passed an interchannel leak test.

(C) Operation with this injector was substantially improved over the original injector design, which was marginally stable at 18K. Because of the interpropellant leak, which was determined to be non-repairable, the test series was concluded until a new injector could be fabricated.

c. Test Series XIII (SP-30-195-212)

(C) Test evaluation of the IO/IF injector was resumed with a new unit during this 18-test series. Tests were performed over the equivalent thrust range of 5-42K. The initial tests were made without the chamber extension. In this configuration, operation was marginally stable in the 14-15K thrust range, and unstable at 10K. With the extension added, operation at 9K and above was stable and satisfactory in every respect. Low frequency pressure oscillations were encountered between 5 and 8.5K, ranging from $\pm 15\% P_c$ and 110 Hz at 5K to $\pm 4\%$ and 200 Hz at 8.5K.

(C) Demonstration tests included a 72-sec test at 9K, and a 23-sec test at 25K, and a 10-sec test at 42K. Each of these tests included a pulse from a 15-grain charge during the steady-state portion of the run; attenuation was complete in all cases within 0.040 sec

d. Test Series XIV (SP-30-213 through 264)

(C) This series was performed to qualify injectors for the clustered segment test program. Twenty four injectors were test-fired

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VI, C, Detailed Test Program (cont.)

during the series, all at the 20K thrust level. The series was designed to identify the base point circuit pressure drops and to balance, by means of propellant inlet orifices, a group of 10 injectors for clustered testing. Performance, structural integrity, and erosion-free operation were also demonstrated during the series.

4. Dual-Manifold IO/IF Injector Evaluation; Test Series XV (SP-30-265 through 276)

(C) This test series was designed to evaluate the dual manifold injector, the last of the 25 injectors committed to the test program. Eleven tests were conducted to define the operating characteristics using the following manifold combinations: first, one fuel circuit and one oxidizer circuit; second, both fuel circuits and one oxidizer circuit; third, both fuel circuits and both oxidizer circuits and; fourth, one fuel circuit and both oxidizer circuits.

(C) Five tests were conducted at the 5K thrust point with durations ranging from 1.50 to 10.0 sec of steady state operation, and chamber pressure ranging from 258 to 280 psia. Only one fuel and one oxidizer circuits were opened for this group of tests, and stable combustion was noted on all tests. Two tests were conducted at the 7.5K point with stable combustion resulting.

(C) The second fuel circuit was then opened and a test was conducted at the 5K point with a single oxidizer circuit and double fuel circuits. The result was unstable combustion at 87 Hz and 106 psi peak-to-peak oscillations at a chamber pressure of 280 psia.

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VI, C, Detailed Test Program (cont.)

(C) The second oxidizer circuit was machined open and a test performed using both oxidizer and both fuel circuits. (This configuration is identical to the IO/IF injector design except that the fuel circuit is fed from two separate inlets). This configuration was also unstable. Oscillations of 124 psi and 63 Hz were noted.

(C) The third configuration (both oxidizer circuits and single fuel circuit) was evaluated through a thrust range of 5K, 6K and 7K. This configuration lends itself most readily to the MIST engine design, since only minor modification to the engine design would be required to dual manifold the fuel circuit. Chamber pressures for the tests were 284, 373 and 411 psia, respectively. Unstable combustion resulted at all three points with frequencies of 54, 95 and 115 Hz recorded; and amplitudes of 122, 103, and 77 psi noted in chamber pressure.

(C) It was concluded from this testing that to achieve the full 10:1 throttling range, the primary injector would have to incorporate dual manifolds in both the fuel and oxidizer circuits. At the lower thrust levels, only one circuit for each propellant would be opened, duplicating the conditions for the first tests in this series. The impact of this configuration on the overall engine design is discussed in the appendix.

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VI, Segment Test Program (cont.)

D. TEST DATA ANALYSIS

1. Performance

(C) Performance of the segment primary combustor was evaluated with respect to characteristic exhaust velocity and hot gas temperature variation. Characteristic exhaust velocity performance was analyzed on all stable tests conducted during the primary combustor segment test program. This evaluation encompassed a total of 97 tests on three injectors over a chamber pressure operating range of 258 to 4390 psia and a mixture ratio range of 10.7 to 27. Achieved performance characteristically followed partial equilibrium theoretical performance with the actual combustion efficiencies following predicted trends with chamber pressure and mixture ratio as previously discussed in Section IV,A. A complete summary of the performance test data appears in Table I. The following discussions define the method of analysis used in these evaluations as well as detailed discussions of the performance of each of the HIPERTHIN injector concepts tested as functions of mixture ratio and chamber pressure. Temperature discussion follows this discussion.

(U) HIPERTHIN injector performance was evaluated in terms of characteristic exhaust velocity since the tests were conducted without thrust measurements thereby precluding use of the ICRPG approved method⁽¹⁾ using energy release efficiency.

(U) The basic procedure involved calculating characteristic exhaust velocity by:

$$c^* = P_c A_t \dot{g}/\dot{w}_t$$

(1) J. L. Pieper, ICRPG Liquid Propellant Thrust Chamber Performance Evaluation Manual, Chemical Propulsion Information Agency, Report 178, September 1968.

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VI, D, Test Data Analysis (cont.)

where:

P_c = Chamber pressure as measured on PCPC-1 and equated to stagnation conditions using isentropic subsonic compressible flow equations, in psia.

A_t = Throat area as measured in square inches and corrected for nozzle flow coefficients (C_d), which is discussed in later paragraphs.

g = Acceleration of gravity in ft/sec^2 (32.174 ft/sec^2).

$\dot{w}_t$ = Total combustor flow rate as measured in lb per second of propellant by a rotor flow meter located in the propellant feed system.

(U) Theoretical performance was derived using partial equilibrium theory previously presented in the Integrated Components Program Final Report, AFRPL-TR-65-150 Volume III, Section V, "Thermochemical Analysis." This technique assumes that endothermic heating of the nitric oxide (2NO) occurs in sufficiently short periods of time (stay time) to prohibit exothermic decomposition into $N_2 + O_2$ which delivers equilibrium temperatures and characteristic exhaust velocity.

(U) Nozzle throat flow coefficients (C_d) were calculated using two dimensional compressible flow theory taking into account entrance diameter ratio, entrance angle, land width at the throat, and the radius of curvature at the sonic throat. For the nominal four-hole nozzle geometry of the segment tester, a flow coefficient of 0.75 was derived ($C_d = 0.75$) which thermodynamically reduces the measured throat area to 75% of its geometric value. On some tests the throat area was increased, which has the effect of reducing the flow coefficient due to reduced entrance to throat radius ratio and increased throat land width. These corrections were made to the nominal value for all tests in this category.

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VI, D, Test Data Analysis (cont.)

(U) The performance data was classified into three groups pertaining to the three injector designs tested. A total of 97 test data points make up this data package as summarized in Table VI.

a. SO/IF Injector

(C) This injector was the initial injector to be tested in the program and the design incorporated 8600 showerhead oxidizer elements and 315 fuel 90° included angle doublet elements. Element pattern arrays were uniform with the exception of the outermost four rows which had no fuel orifices, producing a small oxidizer film barrier for chamber wall cooling. A total of 28 stable performance tests make up the data package on this injector. These tests were conducted at 10 to 44K equivalent thrust, at chamber pressures of 701 to 4390 psia, and at mixture ratios of 10.7 to 21.8.

(C) The resulting characteristic exhaustic velocity performance correlates well with mixture ratio, as can be seen in Figure 25. The resulting performance efficiencies range from 93% at a mixture ratio of 10.5 to 81% at a mixture ratio of 22. This trend, in percentage of optimum performance, can also be equated to chamber pressure since all low mixture ratio tests were performed at high chamber pressures, while the high mixture ratio tests were conducted at low chamber pressures. These combinations were required to meet engine operating balance points for the staged combustion MIST engine.

(C) Defining this performance in terms of percentage and equating it to operating chamber pressure (thrust level) results in the curve of Figure 26. The predicted line previously defined during design analysis is described in Section IV,A. Interpreting the results clearly defines the endothermic heating process of the oxidizer and how this process is affected

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TABLE VI

PERFORMANCE DATA SUMMARY TEST POINTS (U)

PERFORMANCE DATA RANGE

Injector	No. of Performance Data Tests	Thrust Range lbsf	MR Range O/F	P _c Range psia
Showerhead Oxidizer/ Impinging Fuel	28	10 to 44K	10.7 to 21.8	701 - 4390
Impinging Oxidizer/ Impinging Fuel	63	8.5 to	13.1 to 22.2	599 - 3818
Dual Manifold Impinging Oxidizer/ Impinging Fuel	6	5 to 7.5	22.2 to 27	258 - 390

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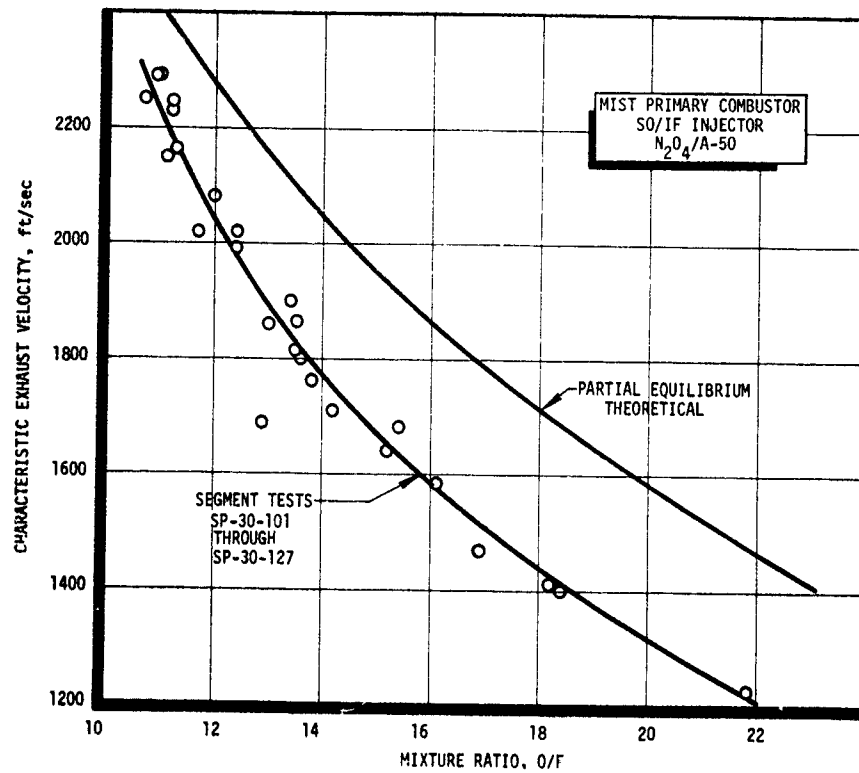


Figure 25. c^* vs MR (SO/IF) (U)

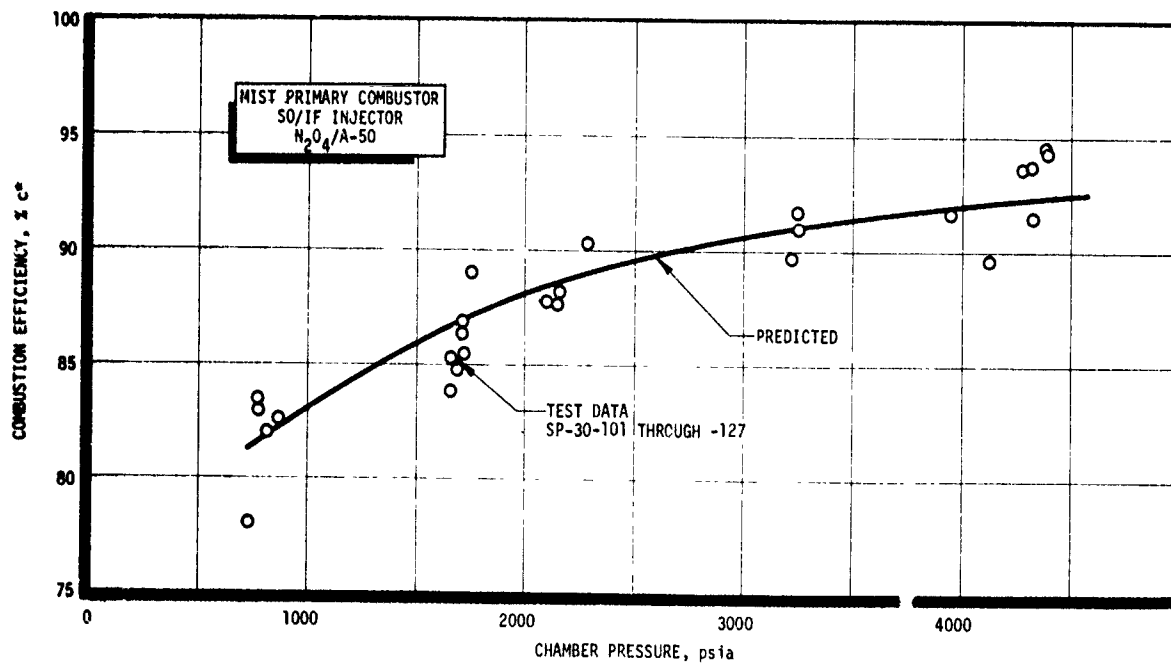


Figure 26. Combustion Efficiency vs P_c (U)

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VI, D, Test Data Analysis (cont.)

by increased chamber pressure and quantity of fuel corresponding to lower mixture ratios. A lower mixture ratio balance allows more fuel and oxidizer to be reacted stoichiometrically ($MR_s = 2.1$) enabling a greater quantity of heat to be transferred to the remaining oxidizer. Increases in P_c are also beneficial since they increase the heat transfer rates between the stoichiometric gases and the excess oxidizer, thereby increasing combustor efficiency still further.

(C) It can therefore be concluded the showerhead oxidizer injector with impinging fuel doublets performed as predicted with excellent performance agreement for the conditions at which it was operated.

b. IO/IF Injector

(C) This injector was introduced into the segment test program in an effort to improve stability at low thrust. The injector differed from the showerhead oxidizer design in two ways: the oxidizer circuit had a higher pressure drop, and the 8600 showerhead elements were replaced with 2408 oxidizer 90° impinging doublets.

(C) A total of 63 performance data tests were conducted on this HIPERTHIN injector at thrust levels of 8.5 to 42K. The corresponding mixture ratio range was 13.1 to 22.2. Detailed performance data tabulations appear in Table I.

(C) The resulting characteristic exhaust velocity performance is in direct agreement with the showerhead oxidizer injector performance as analytically predicted. A comparison of the two injectors performance is shown in Figure 27. The data trends indicate slightly higher performance at high mixture ratios resulting from the increased atomization of the higher

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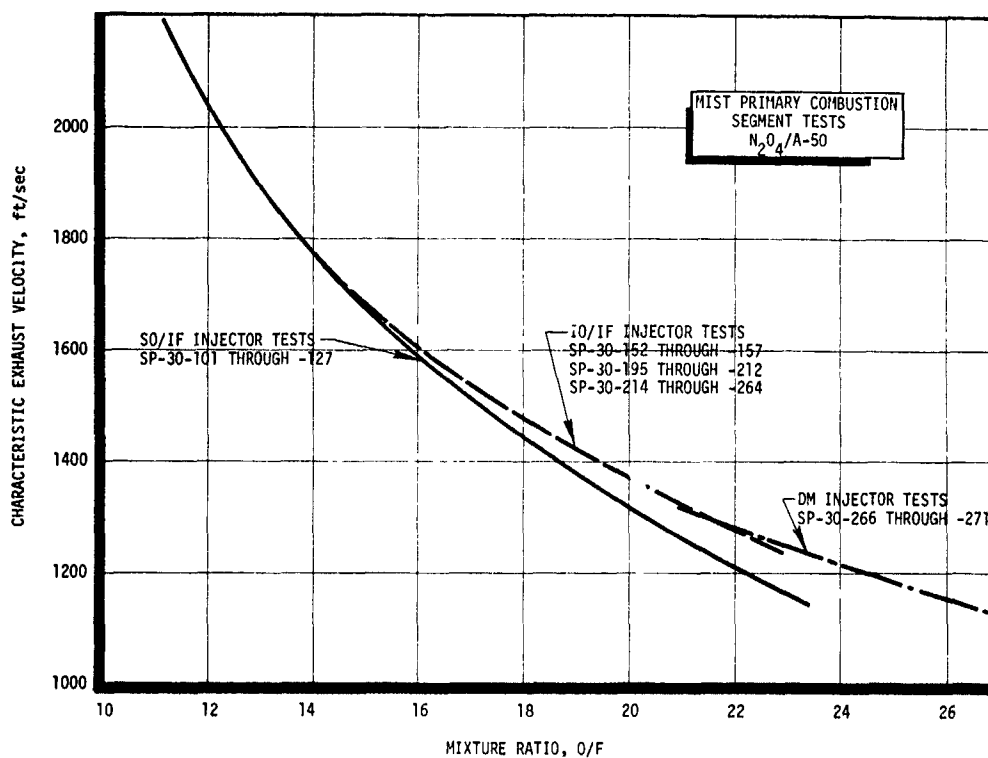


Figure 27. c^* vs MR (IO/IF vs SO/IF vs DM) (U)

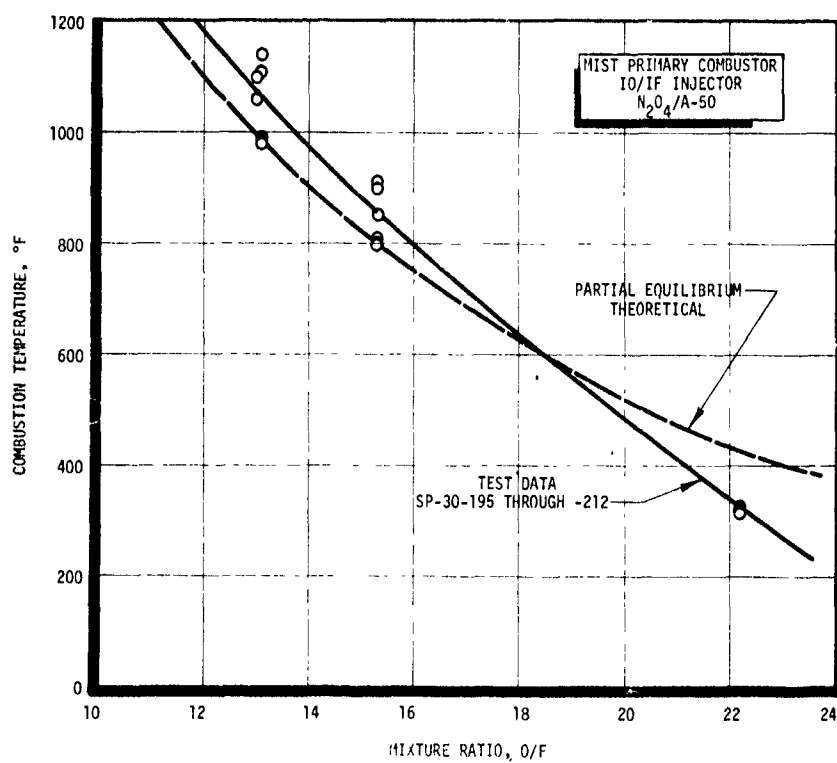


Figure 28. Combustion Temperature vs MR, Segment Tests

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VI, D, Test Data Analysis (cont.)

ΔP doublet elements. At low mixture ratio (below 16) the variation between the two injectors is well within the data scatter. It is therefore concluded that the impinging oxidizer injector is a superior performing unit since it delivers approximately 5% higher performance at high mixture ratios of 22, and equal performance below a mixture ratio of 16. Again it must be emphasized the high mixture tests were performed at low chamber pressures where it is increasingly difficult to obtain high performance due to the endothermic oxidizer heating process.

c. Dual Manifold Injector

(C) A third injector was evaluated during the program in an effort to improve the low-thrust stability of the combustor. This injector utilized two parallel oxidizer and fuel circuits to allow increased injection pressure drop at low thrusts. Six data point tests were conducted on this injector defining comparable high mixture ratio performance with the impinging oxidizer injector design. This injector was tested from 5K to 7.5K thrust at mixture ratios of from 22 to 27.

(C) Performance comparisons with the showerhead oxidizer, impinging oxidizer and dual manifold injectors are shown in Figure 27. As noted in the illustration, this injector performs as well as, or better than, the impinging design over its tested MR range. This characteristic results due to the increased atomization capability of the higher velocity doublet elements producing more doublet momentum exchange. For this reason the dual manifold design delivers improved performance. Since the observed data trends are in excellent agreement with theoretical predictions it is concluded that high pressure/low MR performance of this injector would be identical to that of the impinging-oxidizer injector. Therefore, the general curve of performance for the impinging-oxidizer injector is considered indicative of performance for the dual manifold design.

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VI, D, Test Data Analysis (cont.)

d. Temperature Distribution

(U) Temperature data as measured on the three thermocouples located just upstream of the sonic back pressure throat are also presented in the data summary, Table I. The actual temperature distribution for the accepted injector, the impinging oxidizer/impinging fuel, is presented as a function of mixture ratio in Figure 28. These data are in close agreement with theoretical over the entire test range. As previously presented, the theoretical data is generated using the partial equilibrium dissociation model which assumes endothermic heating of the oxidizer. The figure indicates recorded temperature data slightly higher than theoretical at mixture ratios below 18 and slightly lower above this value. In all cases the data is within 100°F of the theoretical values, showing excellent temperature distribution.

2. Primary Combustor Stability Characteristics

(C) Early in the test program, the data showed low frequency coupling between the combustion chamber and the propellant injection circuits. This condition was experienced with both the SO/IF and SO/SF injectors. The test records showed that the oscillations were initiated in the combustion chamber, and coupled first with oxidizer circuit; the fuel circuit coupling was generally noted several hundred milliseconds after the oxidizer had already coupled. The frequency of the coupling was 240 to 250 Hz at the 10K level, with amplitudes up to $\pm 50\%$ of average chamber pressure.

(C) A study was conducted to determine the possible causes of the oscillatory behavior seen in the propellant feedlines and the combustion chamber. Pressure data was recorded at the venturi inlets, injector inlets (3-in. upstream in the propellant lines), the injector manifolds, and the combustion chamber. Low response Taber transducers were located everywhere except at the

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VI, D, Test Data Analysis (cont.)

injector inlets and the combustion chamber. High response Kistler Model 601A transducers were used on both the fuel and oxidizer circuit; a Photocon 307 was flush-mounted in the chamber.

(C) The observed frequencies were compared with the theoretical combustion frequencies to determine if a direct correlation existed. The calculated combustion chamber frequencies were determined from the following formula:

$$\text{Frequency} = \frac{\text{acoustic velocity}}{2 \times \text{characteristic length}}$$

where the characteristic lengths represented the chamber's transverse dimensions (1.7 and 2.0 in.) and an injector to nozzle mean length of 3.0 in. The acoustic velocities were calculated from chemical equilibrium properties and are listed in Table VII as functions of the mixture ratio. A propellant line analysis was also made to determine the general range of frequencies possible in the fuel and oxidizer circuits. The termination (boundary) points of the lines were assumed to be the cavitating venturis and the injector inlet. Using both closed end and open end "organ pipe" theory, the fundamental frequencies of oscillation were calculated to be 1300 and 2600 Hz in the fuel circuit and 625 and 1250 Hz in the oxidizer circuit. The fact that the high response Kistler pressure transducers were flush mounted eliminated the possibility of transducer resonances excited by random flow perturbations.

(C) The pressure oscillations observed during the test program all have frequencies below the fundamental values calculated to exist in the feed line between the venturi and injector inlet, as well as the computed fundamental combustion frequencies. The oscillations recorded are therefore functions of a lumped nature associated with the feed system inertance (line length, cross-sectional area, propellant mass flow), an injector resistance characterized by $\frac{\Delta P}{P_c}$, capacitive and resistive combustion chamber affects (c^* , L^* , etc.) and a suitable characteristic time lag or phase relationship.

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TABLE VII

FUNDAMENTAL MODE FREQUENCY FOR VARIOUS MR's

<u>Characteristic Chamber Length (in.)</u>	<u>M.R.</u>	<u>Acoustic Velocity (ft/sec)</u>	<u>Frequency (Hz)</u>
1.7	13.3	1600	5600
	21.8	1178	4160
2.0	13.3	1600	4800
	21.8	1178	3540
3.0	13.3	1600	3200
	21.8	1178	2400

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VI, D, Test Data Analysis (cont.)

(C) The injector circuit pressure drops were increased with the injector redesign to the IO/IF configuration to improve the system stable operating range. With this new injector, the system did not oscillate at the 18K level. Operation became marginal, however, at the 14 - 15K level, with organized frequency patterns intermittantly appearing during a test. With the chamber extension added to the system, no organized oscillations occurred down to the 8.5K point. The amplitudes of the chamber pressure oscillations at that point were $\pm 4\% P_c$, increasing to $\pm 15\% P_c$ at the 5K point. With the subsequent dual-manifold injector, which further increased the injector circuit pressure drop at the low throttle levels, stable operation was demonstrated at the 5K thrust level.

(U) It should be noted that the sonic nozzle used during the test program does not simulate the resistance characteristics of the subsonic turbine assembly used in the full scale engine. The turbine will have a greater damping effect on chamber oscillations, possibly eliminating them altogether; further, the turbine will alter the engine's low frequency response since it forms an integral part of the system.

(C) At all thrust levels above those where the low frequency oscillations occurred, the primary combustor proved to be extremely stable. Chamber pressure was extremely smooth, averaging $\leq \pm 1\%$ of average chamber pressure. The assembly was pulsed at the 9K, 25K, and 42K thrust levels with a 15-grain charge; in each instance the momentary disturbance and overpressure was completely attenuated in 0.040 sec or less.

3. Acoustic Resonator Evaluation

(C) An acoustic resonator attached to the preburner chamber was evaluated as a device for suppressing the low frequency oscillations experienced with the SO/IF injector at low throttle ratios. This resonator was an adaptation

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VI, D, Test Data Analysis (cont.)

of the simple Helmholtz resonator, which is analogous to a spring-mass mechanical damping device. In principle the resonator consists of a rigid enclosed volume, connected to the external medium, i.e., the combustion gases in the chamber, through a small opening of a specific diameter and length. The gases in the opening are considered to move as a unit, and as such are analogous to a mass element of a mechanical oscillator. The alternate compression and expansion of the gas in the enclosed volume is the stiffness element. Finally, the radiation of sound at the opening, which leads to dissipation of acoustic energy, is analogous to the resistance element. This resonator can be "tuned" to damp a specific oscillatory frequency by simply varying its geometric parameters, providing the properties of the gases in the resonator are fixed. The controlling equation is:

$$f_o = \frac{c}{2\pi} \sqrt{\frac{A_o}{l_{eff} V}}$$

where:

- l_{eff} = $l + 0.85 d_o (1 - 0.7 \sqrt{\sigma})$
- A_o = Area of opening, $\pi d_o^2/4$, in.²
- c = Speed of sound of gases in resonator, in./sec
- d_o = Diameter of opening, in.
- f_o = Resonant frequency of resonator, Hz
- l = Length of opening of resonator, in.
- l_{eff} = Effective length of opening accounting for end effects, in.
- V = Volume of resonator cavity, in.³, $A \cdot L$ or $\pi D^2/4 \cdot L$
- σ = Fracture of resonator frontal area occupied by A_o/A
- A = Area of resonator normal to opening, in.²
- L = Length of resonator, in.
- D = Diameter of resonator, if of circular cross section, in.

(U) The relationship between the length and diameter of the opening, the volume of the cavity, and the resonant frequency of the resonator can thus be seen. For example, as the cavity volume decreases, the diameter must decrease or the length of the opening must increase to maintain a constant resonant frequency.

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VI, D, Test Data Analysis (cont.)

(U) The one geometric parameter that is not included in this relationship is the number of resonator elements which are required to successfully damp a given oscillation. Some experience with larger engines has lead to the preliminary conclusions that the total open area of the Helmholtz resonator must exceed 7% of the active injector area. The application of this criteria to a primary combustor of this nature was of uncertain validity and was therefore used only as a starting point. The resonator designed for this program included a ratio of resonator to injector area range of 2 to 25% by virtue of a design feature which allowed the cavity volume to be adjusted as the number of resonator openings was changed from test to test.

(C) The unstable frequencies experienced in the injector test program varied from approximately 200 - 500 Hz over the thrust range from 10-18K, with corresponding combustion temperatures of 280° to 1000°R. The higher temperatures occurred at the higher thrust levels because the injector was operated at lower mixture ratios. The combustion frequency, which also increased with increasing thrust level, was the result of changed acoustics at the different thrust levels. The resonator design was based upon analyses to determine the required relationship between the passage length, diameter, and resonant volume, as well as practical constraints imposed by the engine design. Obviously, if a resonator was to be used in the engine, it must be compatible with the engine design and of a reasonable size. It was determined that up to eight holes of 1/4 in. dia could be drilled into the upper portion of secondary injector flange joining each primary combustor segment, with a resonator cavity located circumferentially around the engine just below the turbopump housing. The passage length required for such an installation is 3.0 in. This formed the basis for the resonator design, shown in Figure 29. It consists of twelve 3-in.-long, 1/4 in. holes leading to a resonant cavity 3-in. in diameter, the length of which is adjustable by means of a screw-adjusted piston. The resonator is designed to attach to the chamber in the existing pulse gun port.

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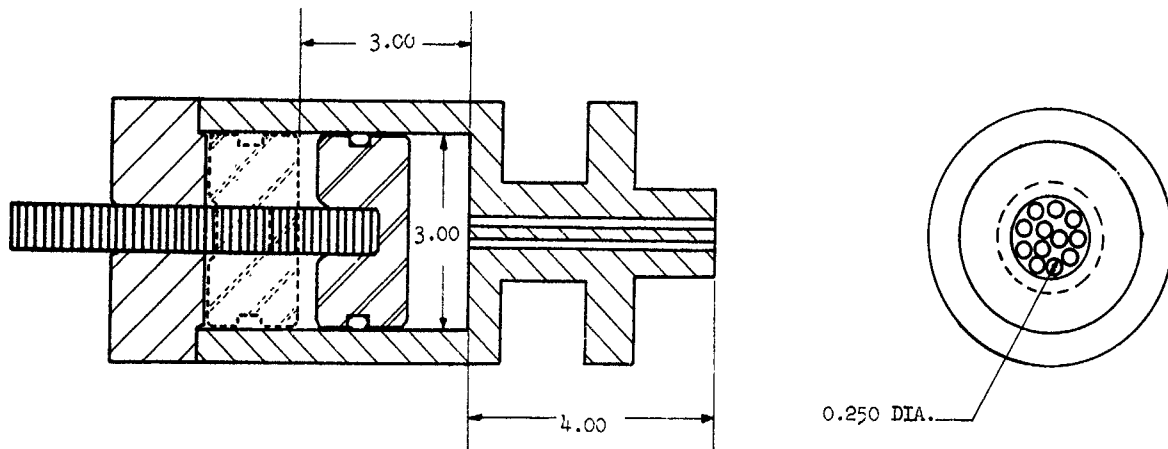


Figure 29. Resonator Design

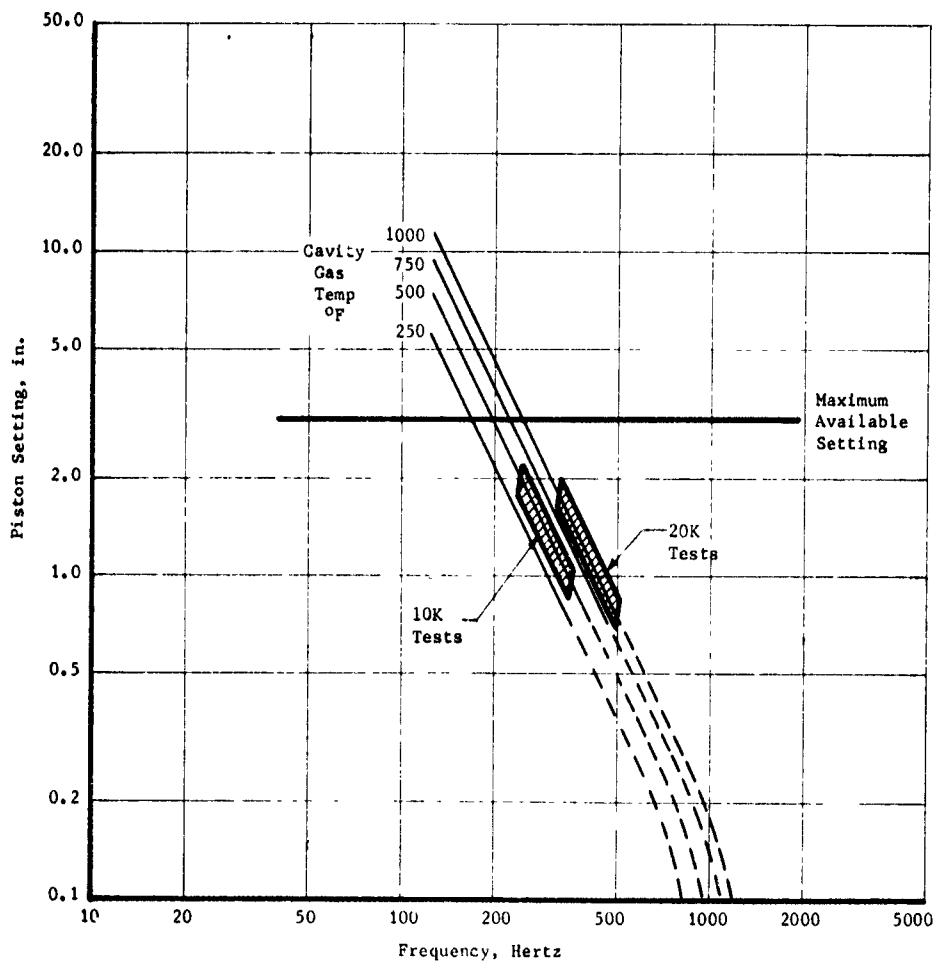


Figure 30. Resonator Piston Stroke vs Frequency

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VI, D, Test Data Analysis (cont.)

(U) Twelve holes were used instead of eight to provide peripheral data for establishing the required size of the resonator. The testing approach was to first establish stable operation with the 12-hole configuration, and then to progressively close off holes (and at the same time proportionally reducing the resonator volume) until the lower operating limit was reached. Required resonant cavity volume settings for the twelve-hole configuration were calculated using the Helmholtz resonator equation based on the observed combustion temperatures and frequencies during the test program. These results are shown in terms of piston stroke in Figure 30.

(U) The Helmholtz equation applies to this type of device, provided that the maximum dimension is limited to one-eighth of a wavelength of the pressure oscillation. Beyond these dimensions, the resonator approaches a "quarter-wave resonator". In this region, the Helmholtz resonance equation is no longer valid for predicting the necessary cavity volume. The solid lines on Figure 30 indicate the necessary piston setting (distance from piston face to the end of the cavity) for varying gas conditions and frequency. The dashed lines indicate extrapolations of these operating curves beyond applicability of the Helmholtz equation. As such, they are only estimates of the expected operating conditions. The vertical asymptotes are the resonant frequencies of the resonator with the acoustic cavity volume completely closed by the piston. These frequencies are determined by considering the resonator as twelve quarter-wave resonators rather than twelve Helmholtz resonators.

(C) The resonator was evaluated in tests SP-30-158 through -194. In the first 11 tests, the piston stroke was varied between 1.00 and 0.625 in. Stable operation was achieved at settings of 0.625 and 0.650 in.; however the cavity volume proved very sensitive, with unstable operation occurring at a setting of 0.600 in., a 4% change. With stable operation achieved,

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VI, D, Test Data Analysis (cont.)

8 of the 12 holes were closed off, and the 4-hole configuration evaluated. Piston stroke was varied between 0 and 0.4 in. in six increments; operation was unstable in all cases. An 8-hole configuration was next evaluated, with similar results. Testing with the 12-hole resonator was then resumed with an attempt to repeat the previously stable test at the 0.625 in. setting. Operation was unstable. The stroke setting was then incrementally varied between 0.425 in. and 1.00 in.; the unit continued to be unstable throughout this range. This concluded the resonator test series.

(C) It was concluded that the resonator cavity volume was insufficient to stabilize the system. The limited success achieved with the 12-hole configuration indicates a marginal condition. Furthermore, the demonstrated criticality of the cavity volume for producing stable operation precludes the effective use of this resonator over the relatively wide thrust range in which it must operate with the MIST engine (5K - 18K). Each specific thrust level has a different combustion temperature and attendant combustion frequency; therefore, an effective resonator must have a broad tolerance on required cavity volume if it is to be effective. Theoretically, the resonator size could be increased to produce this result; however, a larger resonator cannot be integrated into the existing engine design without major packaging change (8-hole configuration maximum possible with existing design).

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VII. CLUSTERED SEGMENT TEST PROGRAM

A. SUMMARY

(U) The objective of the clustered segment test program was to evaluate the operation of ten injector segments installed within a common housing simulating the primary combustor configuration of the MIST engine. The testing approach was to evaluate injector operation at several discrete equivalent thrust level operating points between 5K and 50K, with a program goal of demonstrating continuous step throttling over the full 10:1 range.

(C) The test program was initiated on 24 September 1969 and concluded on 3 December 1969, during which period 22 tests were conducted between the 10K and 37.5K operating points. Test data and results are summarized in Table II. At the 10K thrust level, low frequency pressure oscillations of the type encountered in the segment test program were noted, a condition not unexpected. A continuous step throttling test was conducted at the 10K, 12K, and 15K thrust level to establish the lower limit of stable operation. Results showed operation at the 12K level to be marginally stable, with completely smooth operation occurring at the 15K level. Operation at the 25K thrust level was excellent, with no anomalies occurring. The highest equivalent thrust level to which the assembly was tested was 37.5K. At this thrust, minor erosion occurred in one of the ten combustion chambers. A posttest evaluation determined that the injector segment feeding the damaged portion of the chamber had an uneven mixture ratio profile across its face area, which produced a local gas hot enough to cause erosion. Limitations of program funds precluded further testing in the program.

(C) Primary combustor performance was excellent at all thrust levels; in the clustered configuration, c^* values were in close agreement with those obtained in the segment program, usually slightly higher. Also, combustion was very smooth at all levels above the "chugging" threshold, with chamber pressure oscillations being $\pm 1\%$ of average chamber pressure.

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VII, A, Summary (cont.)

(U) A discussion of the test facility and setup used in the clustered segment test program is given in Section VII,B. The detailed test program is discussed in Section VII,C. An evaluation of the test data including performance, stability, and the special investigation performed to determine the injector mixture ratio profile is presented in Section VII,D.

B. TEST SETUP

(U) The clustered segment test program was conducted in the H-3 test facility at Aerojet's Sacramento facility. The test system consisted of propellant pressure intensifiers to deliver high pressure (6300 psia) N_2O_4 and A-50 propellant, a computer controlled servo-mechanical flow control system for transient and steady-state pressure control, primary combustor test hardware, an exhaust gas water scrubber emission control system, and necessary controls and instrumentation to operate the system remotely from a control room located some 100 yards from the test facility. A photograph showing the test hardware installation is given in Figure 31.

(U) The propellant pressure intensifier system is shown schematically in Figure 32. This system consists of single-stroke positive displacement pumps having a 5 to 1 compression ratio. The low-pressure side utilizes compressed nitrogen gas supplied through the flow control system from a high pressure (3000 psia) nitrogen cascade. The 5 to 1 area ratio on the piston allows the prescribed compression ratio to be obtained. The high pressure propellants are then fed through a series of lines and valves to the test hardware.

(U) Pressure control is maintained by servo-operated flow control valves at the intensifier gas side entrance. Four-in. and 2-in. poppet valves are arranged in parallel to give flexibility to the test operation. Servo control is established through a closed loop feedback system using a

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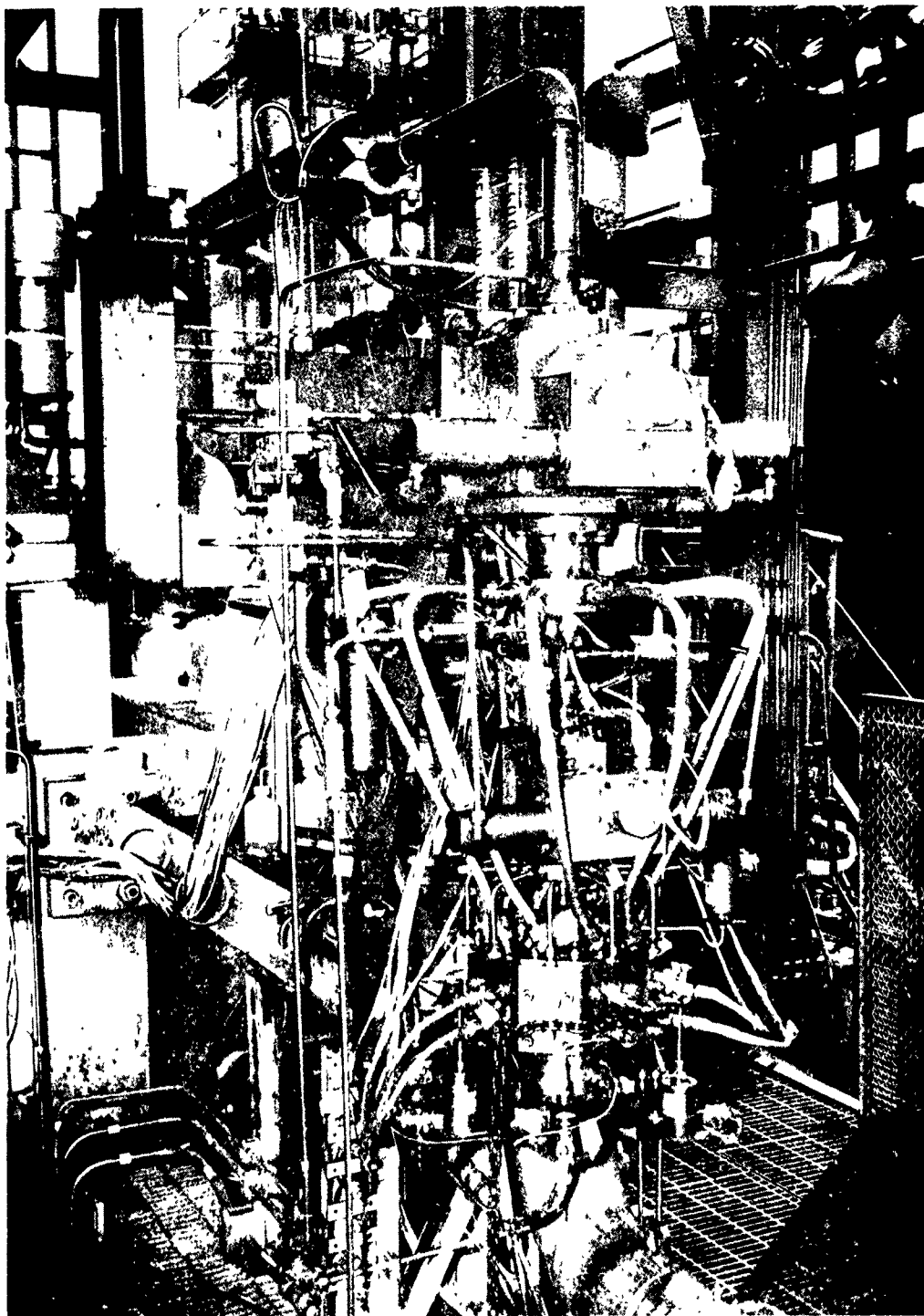


Figure 2-10-8 Test Installation

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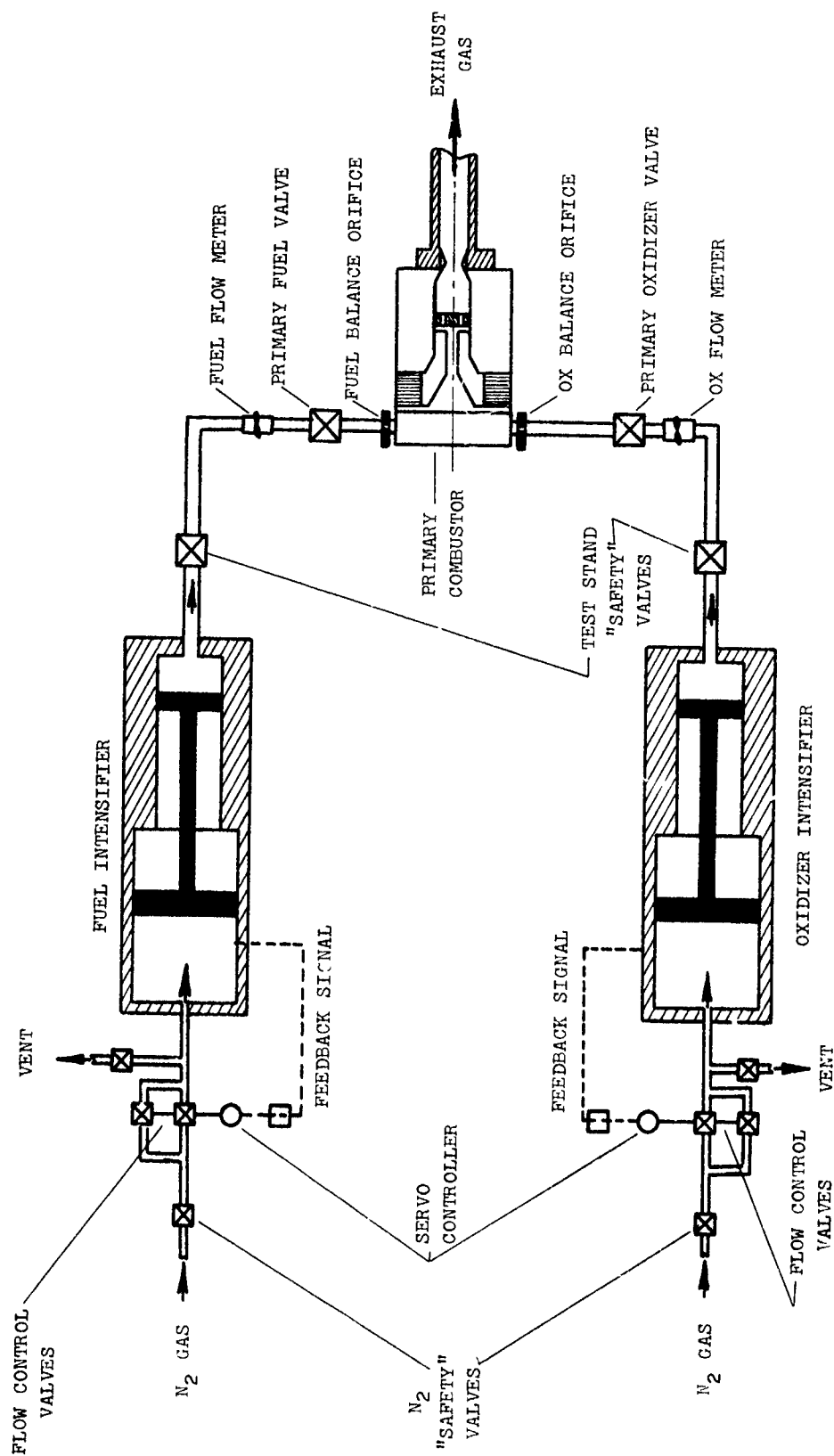


Figure 32. Intensifier Schematic (H-3)

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VII, B, Test Setup (cont.)

Pace TR-48 analog computer. This feedback control system continuously monitors the intensifier pressure and compares it to pre-programmed pressure versus time relationship, making corrections with the flow control valves as necessary. This system maintains pressure control for start and shutdown transients, steady-state operation, and continuous throttle feed system pressure changes.

(U) The operating control system consisted of a series of in-line valves for flow sequencing, pressure venting, and propellant pushback feed line draining. These valves were operated remotely from the control room at the test firing console and their operation monitored in the TR-48 computer for malfunction detection. In addition, several other malfunction detection systems are employed. Propellant phasing valves opening rates were checked against a prescribed position at a given time. Propellant overpressure was monitored for shutdown to prevent damage to critical components. The pressure intensifier piston position was monitored to prevent oxidizer propellant exhaustion to the combustor, a condition which would produce an adverse mixture ratio shift. Mixture ratio was monitored through a comparator in the computer which was programmed to terminate the test in the event an adverse mixture ratio developed.

(U) Thermocouples placed at the turbine simulator exit to each compartment were continuously monitored to indicate adverse temperatures in any of the 10 combustors. Temperature limits used were 1500°F for the low thrust tests and 1800°F for the high thrust tests. A combustion stability monitor was used to identify undesirable frequencies and amplitudes in the combustor. A fuel-to-oxidizer feed system pressure comparator was incorporated to insure that the fuel and oxidizer intensifiers were operating properly. All the malfunction devices were patched into the normal shutdown signal sequence in the event any of the functions were beyond pre-programmed limits.

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VII, B, Test Setup (cont.)

(U) Standard test instrumentation included Taber transducers for pressure measurement, chromel-alumel thermocouples for temperature measurement, and Potter turbine - type meters for flow control. In addition, the test hardware was monitored with special instrumentation, the locations of which can be seen in Figure 18. An external view of the instrumentation ports and bosses can be seen in Figure 33. The propellant manifold pressures of four of the ten injector segments were instrumented, two with standard Taber transducers and two with high frequency Microsystems transducers. Chamber pressure was measured by one Taber transducer and one flush mounted, high frequency Photocon 307. Microsystems high frequency transducers were also located in the propellant feed system to obtain data on feed system coupling effects. Combustion chamber temperature in each chamber segment was measured by 0.040-in.-dia chromel-alumel thermocouples. These ten thermocouples were located just downstream of the turbine simulator plate opposite the flow orifices. Data from these thermocouples were used to establish the combustion temperature spread between compartments.

C. DETAILED TEST PROGRAM

(U) The test program consisted of five test series, which defined the combustor's operating characteristics at low, intermediate, and high throttle points. Each of the test series are discussed in chronological order in this section; consolidated performance and stability discussions for the entire program are presented in the following section. The test conditions, objectives, and results for the clustered segment test program are summarized in Table VIII. The data summary for all tests is given in Table II.

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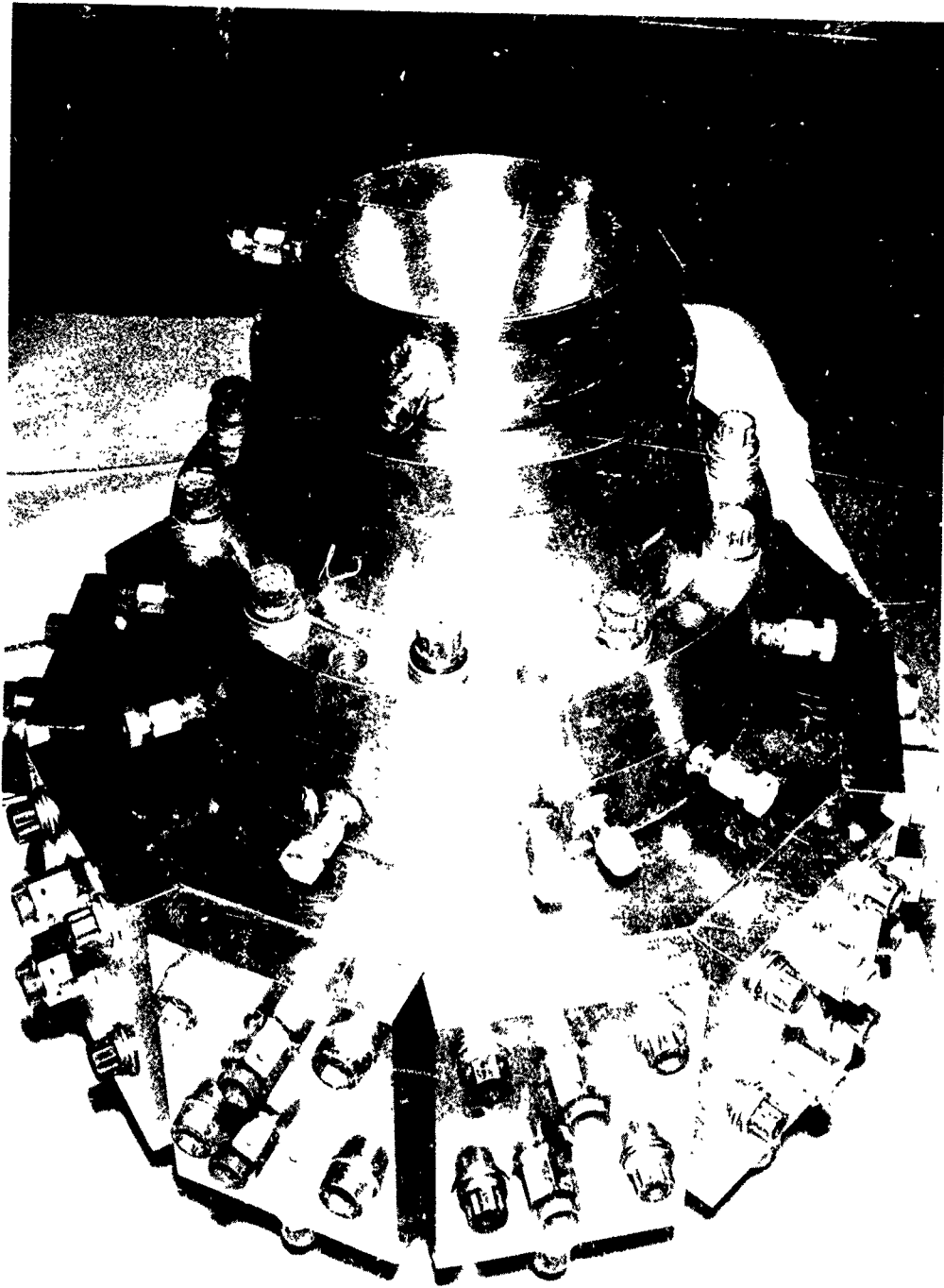


Figure 33. Test Hardware Assembly

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TABLE VIII
TEST CONDITIONS AND OBJECTIVES - CLUSTER PROGRAM (U)

SERIES	TEST	TEST CONDITIONS				DURATION sec.	OBJECTIVE	RESULTS
		THRUST LEVEL lbs _f	CHAMBER PRESSURE psia	MIXTURE RATIO O/F				
I	1008-D01-01							
	001	22K	1000	30.0		.763	Start transient, controls and feed system checkout to intermediate chamber pressure.	Satisfactory checkout, no hardware damage.
	002	22K	1642	18.3		1.012	Check system balance, performance and stability on minimum duration test.	Satisfactory test, no hardware damage all systems performed as desired.
	003	22K	1675	13.7		3.013	Performance demonstration for extended duration.	System completed prescribed duration. Gross damage sustained to all hot gas system hardware.
	004	22K	1668	19.9		1.007	Combustor checkout at mixture ratio below exothermic ignition temperature.	Satisfactory modified system checkout test. No hardware damage.
II	005	22K	1716	17.4		1.064	System checkout to duration at which combustor erosion was evidenced on Test 003.	Erroneous mixture ratio shutdown at 1.07 seconds. Slight erosion evidenced at baffle insert point between injectors.
	006	22K	1153	24.3		.911	System checkout with welded baffle configuration.	Shutdown at .91 seconds due to incorrect MR setting. No damage.
	007	22K	1723	19.8		1.107	Repeat Test 006	Satisfactory test, no hardware damage.
	008	20K	1692	18.0		1.511	Repeat Test 005	Satisfactory test, no hardware damage.
	009	22K	1698	18.8		2.010	Extended duration performance demonstration.	Satisfactory performance test, completely stable, no hardware damage.
	010	22K	1693	17.1		1.252	Extended duration mechanical integrity check.	Premature shutdown at 1.25 seconds due to primary combustor fuel valve micro switch breakage. No hardware damage.
	011	22K	1709	18.5		2.000	Repeat Test 010	Maximum TTI shutdown at 2.0 seconds. Inspection revealed TTI-10 had failed mechanically. No hardware damage.
	012	22K	1728	18.8		3.007	Repeat Test 010	Completed scheduled duration with no hardware damage.

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TABLE VIII (cont.)

SERIES	TEST	TEST CONDITIONS				DURATION sec.	OBJECTIVE	RESULTS
		THRUST LEVEL lbf	CHAMBER PRESSURE psia	MIXTURE RATIO O/F				
III	1298-101-01							
	013	22K	1722	20.6		5.005	System demonstration at 5 second duration.	Completed scheduled duration with no hardware damage.
	014	22K	1716	19.4		9.998	Full duration demonstration at 22K thrust level.	Satisfactory test. No hardware damage. Excellent performance and completely stable.
	015	10K	649	21.3		2.004	System checkout at 10K thrust level.	Completed scheduled duration. Low frequency chugging instability evidenced beyond acceptable limits. No hardware damage.
	016	10K 11K 15K	660 860 1090	23.0 22.0 21.0		2.999	Three thrust level step throttle test to define minimum stability limit. (10K, 12K & 15K)	Low frequency instability eliminate between 12 & 15K. No hardware damage.
IV	017	15K	1079	22.7		3.005	Minimum throttle demonstration at 15K thrust.	Satisfactory test completely stable. No hardware damage.
	018	15K	1092	20.7		9.298	Full duration demonstration and minimum throttle operation.	TTI shutdown c 9.28 seconds. hardware inspection denoted slight burning off injector face on side walls in compartments 9 and 10.
	019	25K	1290	--		0.915	System checkout at 25K with outboard fuel orifice modification to injectors.	Ergonomic MR shutdown at .91 seconds due to low gain from oxidizer flow meter. No hardware damage.
	020	25K	2004	17.7		3.002	Repeat Test 019	Satisfactory 25K demonstration test. no hardware damage, completely stable.
	021	37.5K	3347	12.3		1.402	System checkout at 37.5K thrust level.	Premature shutdown at 1.4 seconds due to transient mixture ratio excursions as sensed on oxidizer to fuel feed pressure comparator. hardware inspection revealed slight erosion at 5 turbine simulator orifices.
	022	37K	3267	12.9		1.809	Repeat Test 21	TTI shutdown at 1.809 seconds indicating excessive temperature in compartments 9 & 10. Severe throat erosion noted.

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VII, C, Detailed Test Program (cont.)

1. Test Series I - 20K Thrust Level Evaluation, Tests 1298-D01-OJ-001 through 003

(U) The 20K thrust operating point was selected for the initial test series because of the extensive data accumulated in this range during the segment test program. Prior to commencement of the test firings, flow control system checkout tests were performed to obtain desirable flow control characteristics in both the low and high pressure ranges.

(C) The first test 1298-D01-OJ-001, was a partial transient test up to 1000 psia chamber pressure to define the start transient characteristics. Satisfactory operation was obtained with only minor changes required in the starting sequence. Test 002 completed the start transient checkout series, with the system ramped to the steady-state balance point. The primary combustor operated at 1680 psia chamber at a mixture ratio of 14. With start, shutdown, and engine balance verified, the test duration was increased to 3 sec for Test 003. Posttest hardware inspection revealed extensive erosion in the hot gas system and between injector elements. Photographs of the damaged hardware are shown in Figures 34, 35, and 36. The injector faces were not eroded; however, the injectors sustained damage from adjacent burning metal. Test record review indicated satisfactory engine operation up to 1.7 sec after FS_1 , at which point burning initiated with subsequent chamber pressure decay due to the eroding throat nozzle. Careful examination of the data, together with a review of the high speed color movies, showed no anomalies of any kind prior to failure. Test hardware review disclosed two distinct areas of burning. The most intense erosion was noted just upstream of the sonic throat, proceeding through the throat and through the elbow just downstream of the sonic throat, proceeding through the throat and through the elbow just downstream of the divergent section, as can be seen in Figure 36. The condition of this area indicated material oxidation and exothermic decomposition of the steel which then continued through the downstream elbow.

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Figure 34. Injector Housing Post 1298-D01-OJ-003



Figure 35. Chamber Aft Post 1298-D01-OJ-003

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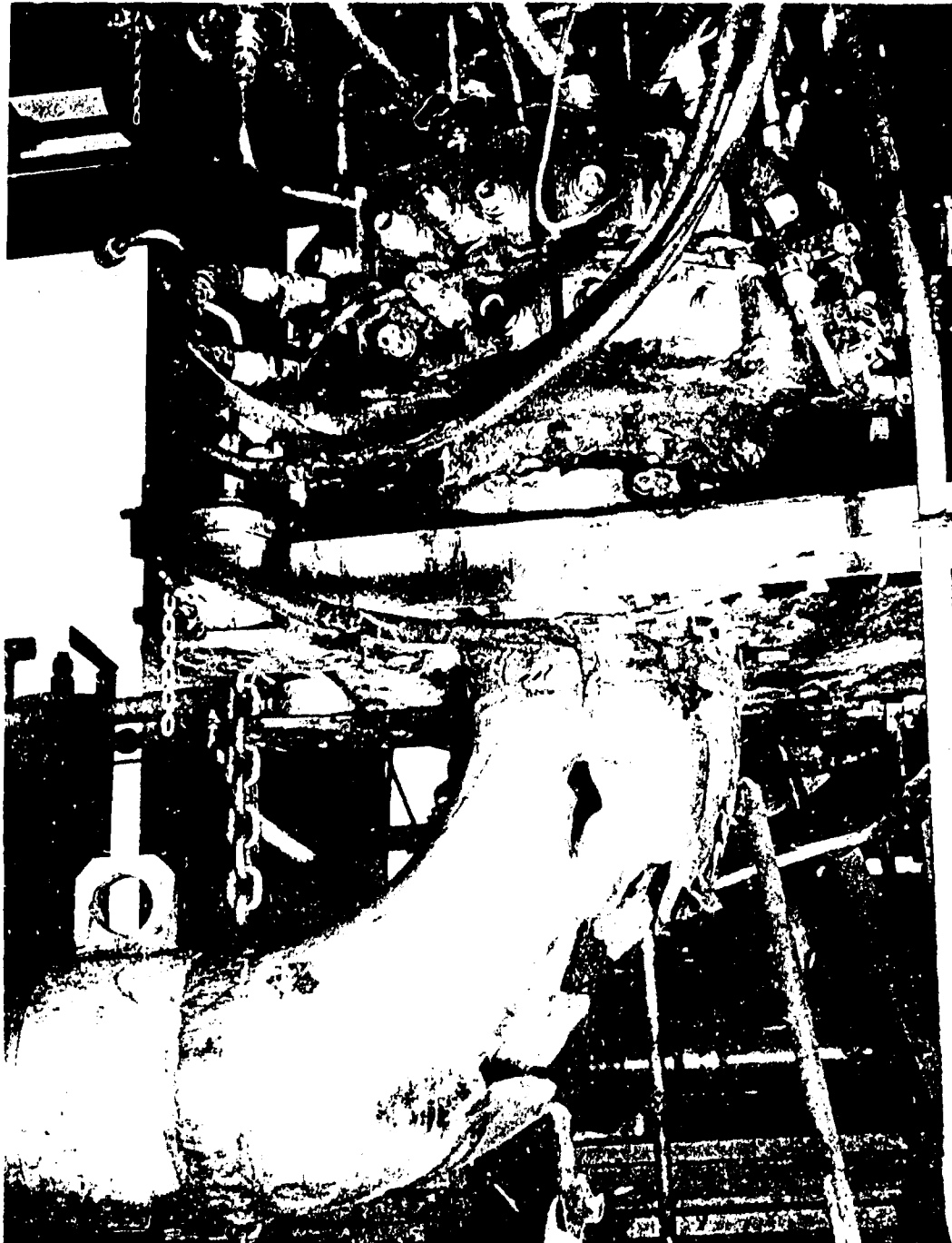


Figure 36. External Test Setup Post 1298-D01-OJ-003

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VII, C, Detailed Test Program (cont.)

(C) The other burned area, shown in Figure 34, was in the baffle area between the injector segments. Erosion in this area was localized; no gross exothermic burning of the steel had taken place. Cross flow between chamber compartments at the plane of the injector face was postulated as the source of the problem. The primary design was such that the baffles separating compartments are indexed into the upper and lower chamber housings, but not attached to the wall of the injector housing. This left a small gap between compartments at the injector face plane, and it was postulated that any chamber pressure unbalance between compartments could draw unburned quantities of fuel into this area and set up hot recirculation zones. It was also postulated that the problem in the baffle area initiated the burning in the lower portion of the chamber, where there were large recirculation zones due to the irregular shape of the flow passages in that area (see Figure 37).

(C) Prior to resuming the test program, the primary combustor housing design was modified so that the baffles extended into slots machined in the injector housing, thus eliminating the gaps between the chamber sections. Also, a new filler ring was incorporated, which was contoured to provide a smooth transition through the hot gas circuit downstream of the turbine simulator plate. Finally, to further minimize recirculation possibilities, the elbow downstream of the nozzle was replaced by a straight duct leading to a water scrubber system for neutralizing the oxidizer-rich exhaust gases prior to releasing them to the atmosphere. The revised system configurations are shown in Figure 38.

2. Test Series II - 20K Thrust Level Evaluation with Modified System Design, Tests 1298-D01-OJ-004 through 014

(C) The test program resumed with Test 004, performed at the same operating conditions as Test 003 except for a higher mixture ratio balance. The test was scheduled for 1.0-sec duration to a steady-state mixture ratio of 20. Programmed duration was achieved and no hardware damage occurred.

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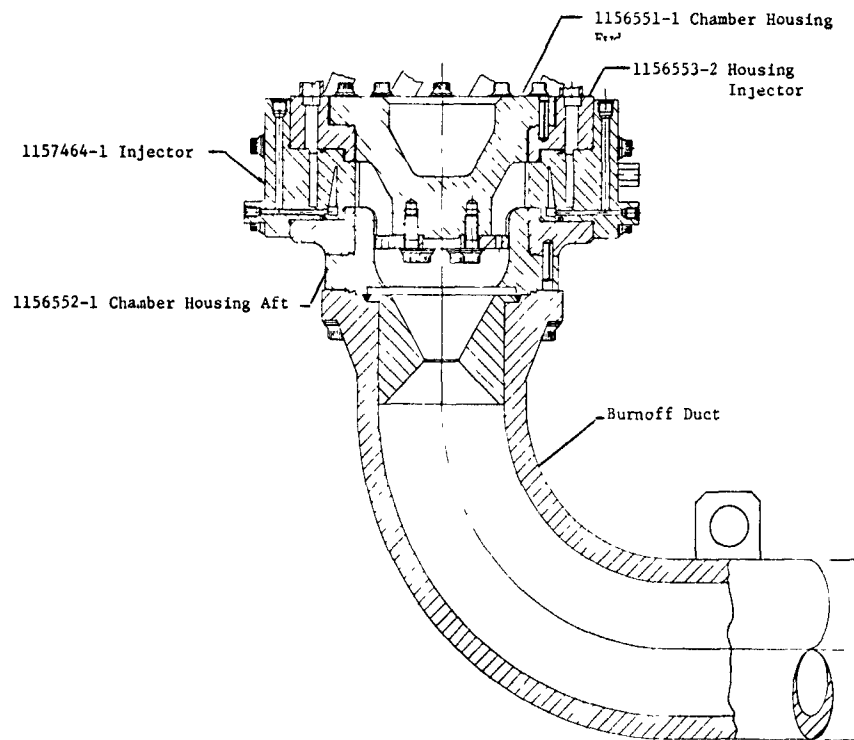


Figure 37. Initial Test Hardware Schematic

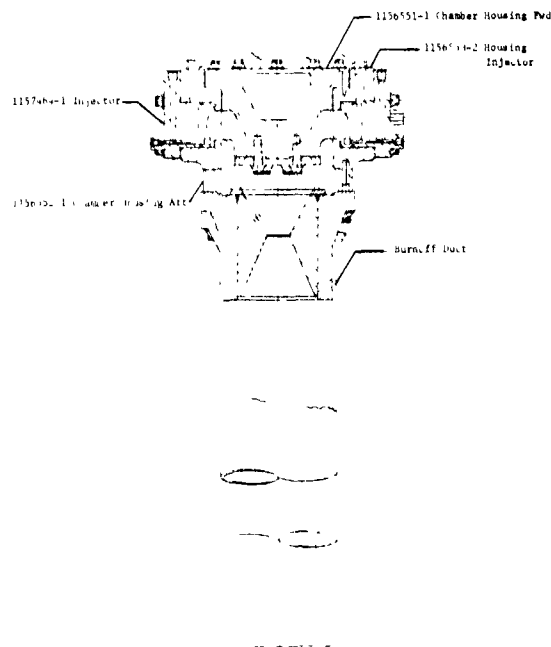


Figure 38. Modified Test Hardware Schematic

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VII, C, Detailed Test Program (cont.)

Test 005 was programmed for 1.5 sec duration; the test was terminated prematurely at 1.07 sec by an erroneous signal received from one of the malfunction shutdown circuits. Posttest hardware inspection showed slight erosion of the injector housing at the point where the baffles were inserted into the housing. The cause was attributed to recirculation about the discontinuity at the baffle-housing interface. This discontinuity was eliminated prior to the next test by welding the baffles directly into the housing. Also, thermocouples were installed to measure the gas temperature between the baffle and the housing just downstream of the welded joint.

(C) Tests 006 to 014 were then performed, with test durations incrementally increased during the series. The final two tests were 5 and 10 sec duration, respectively. Posttest analysis of the test records and hardware showed no anomalies. Operation was smooth with excellent combustion performance obtained. The thermocouples installed in the housing prior to the series showed no adverse temperature excursions where burning had occurred on prior tests. The pressure, flow and temperature characteristics during Tests -014 are shown in Figure 39.

3. Test Series III - 10K - 15K Thrust Level Evaluation, Tests 1298-001-OJ-015 through -018

(C) Combustor operation at the low throttle levels was evaluated in this test series. The initial test point was programmed for a chamber pressure of 700 psia and mixture ratio of 23, which corresponds to the 10K engine throttle point. The test completed the programmed 2.0 sec duration; no hardware damage occurred. A record review showed an organized low frequency chugging mode in the chamber of 250 Hz at an amplitude of 210 psi peak to peak. This condition was not unexpected, since this throttle level was very close to the lower stable operating range limit established in the segment test program.

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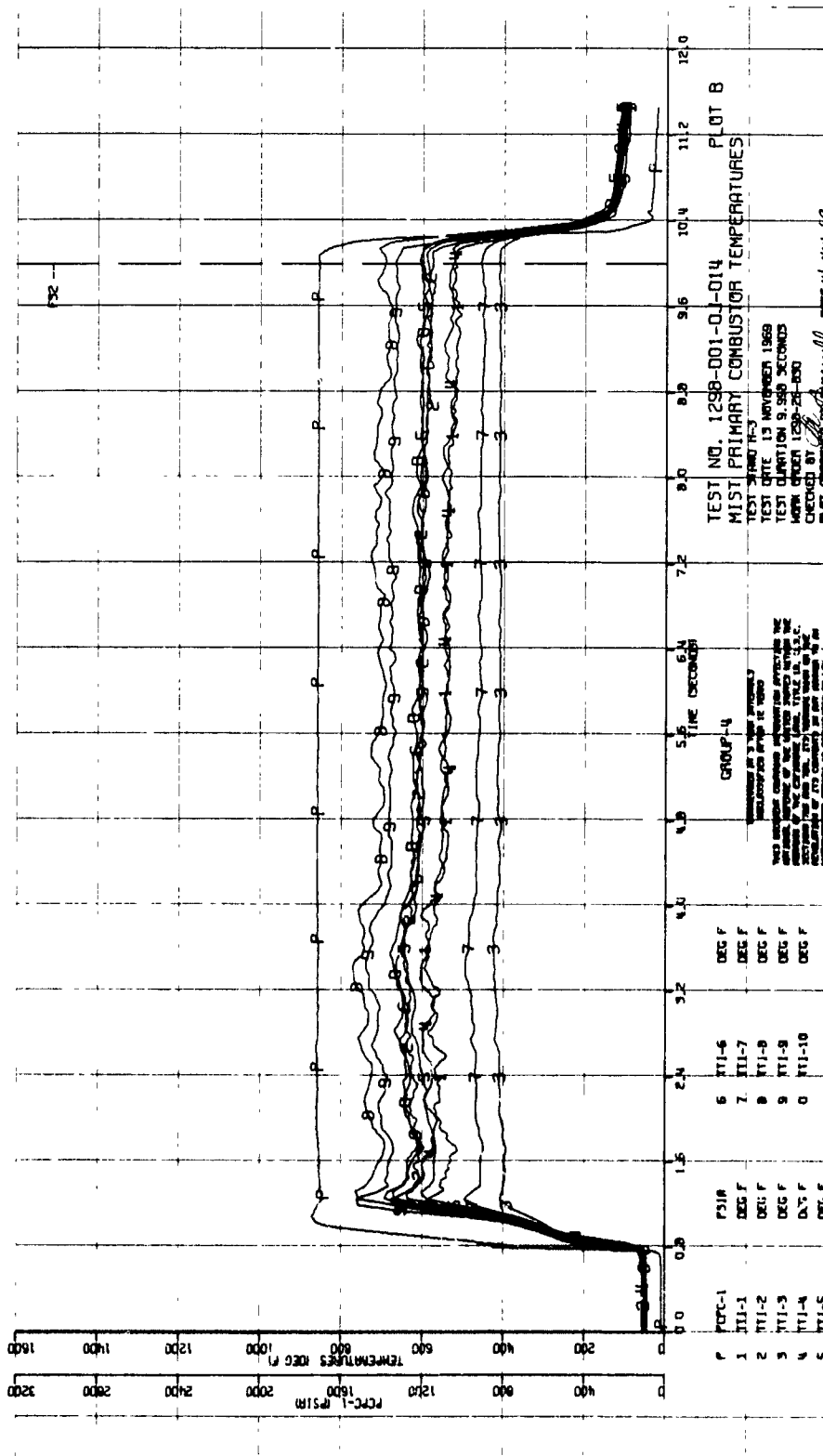


Figure 39. ADR Plot Test 1298-D01-OJ-014 (U)
(Sheet 2 of 2)

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VII, C, Detailed Test Program (cont.)

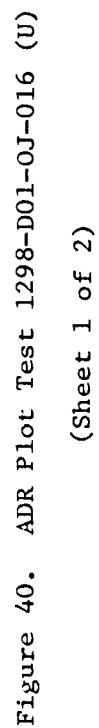
(C) The next test (016) was programmed to ramp the intensifier in step changes at 1.0 sec intervals from 10K to 12K to 15K thrust levels to determine the lower stable operating limit for the cluster hardware. The 3-sec test was satisfactorily completed, with data points obtained at 660, 860, and 1090 psia chamber pressure. No hardware damage was sustained on the test. The three step operation is shown in Figure 40, which gives the pressures, flow rates and mixture ratios throughout the test.

(C) The results of this step-throttle test indicated the combustor attained stable operation between the 12 and 15K thrust levels, with some attenuation noted on the 12K step. The following test (017) was a 3-sec duration evaluation test of the primary combustor operating at the 15K point. Chamber pressure was 1079 psia and mixture ratio 22.7. The next test (018) was a scheduled 10-sec-duration demonstration test at the same balance point. The test was terminated at 9.28 sec by a malfunction detection system which sensed a temperature greater than 1500°F in compartments 9 and 10. Detailed hardware inspection indicated slight erosion on the baffles just downstream of the injector face between compartments 9 and 10. (Injector SN 018 was located in compartment 9, and SN 023 was in compartment 10.)

(C) It was concluded that due to the discrete differences in chamber geometry between the segment and cluster (i.e., converging sidewalls) additional film cooling was required along the cluster chamber wall to provide a cool boundary against the metal parts. Since no injector - chamber compatibility problem had been evidenced throughout the entire segment test program, no film cooling circuit had been designed into the clustered segment hardware. The slight differences in the combustor geometry between the two systems and minor discontinuities at the chamber-baffle joint evidently set up recirculation patterns which allowed uncombusted fuel to reach the wall. To rectify this situation, film cooling was introduced by welding closed

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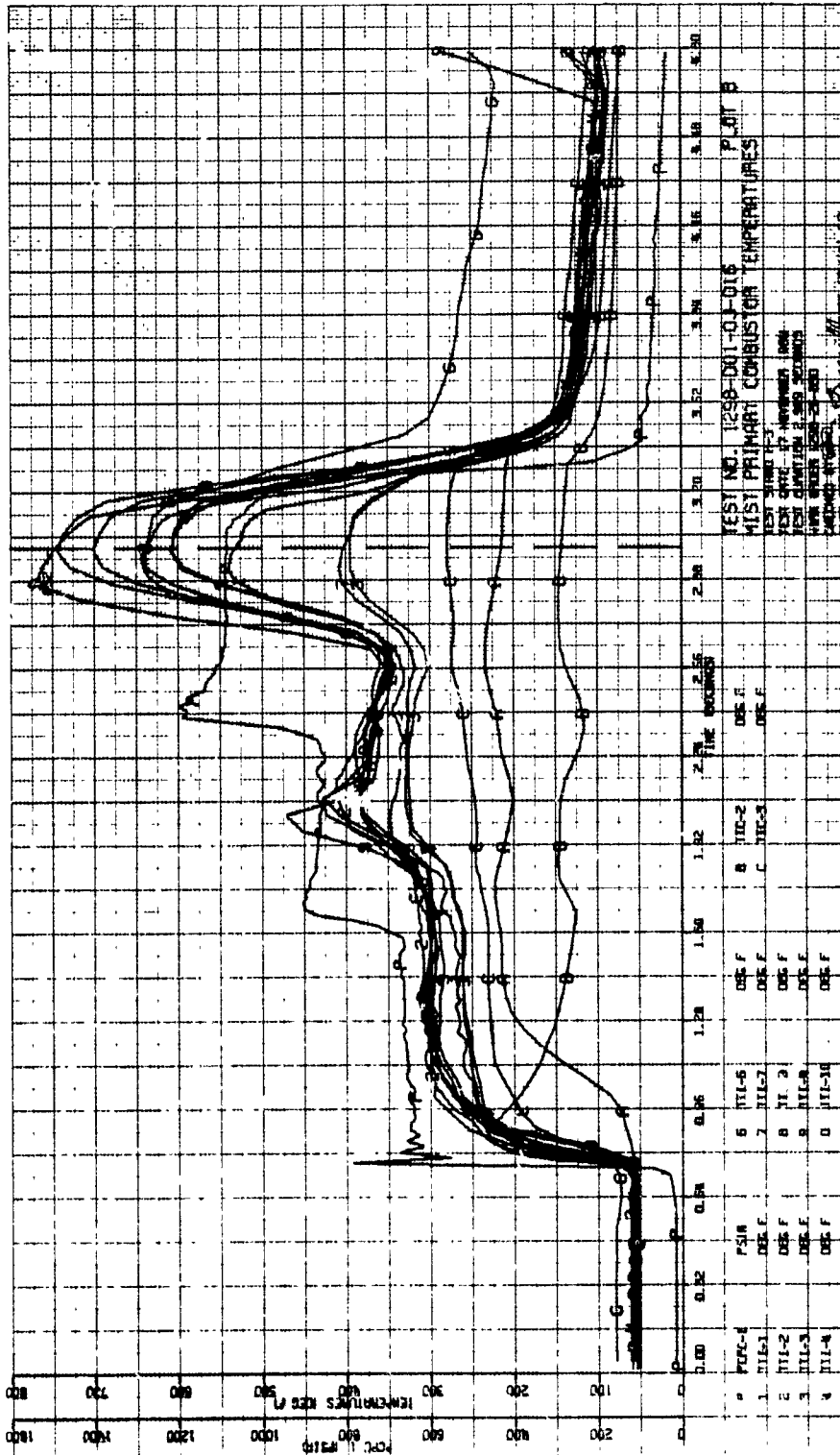


Figure 40. ADR Plot Test 1928-D01-OJ-016 (U)
(Sheet 2 of 2)

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VII, C, Detailed Test Program (cont.)

the outermost row of the fuel orifices on all 10 injectors, which produced an oxidizer-rich boundary along the side walls.

4. Test Series IV - 25K Thrust Level Evaluation Tests 1298-D01-OJ-019 and -020

(C) Using the modified injectors, Tests -019 and -020 were performed at the 25K thrust level. Test durations were 0.9 sec and 3.0 sec, steady chamber pressure during the longer test was 2004 psia; mixture ratio was 17.8. Data and hardware review showed the operation was satisfactory in all respects. The primary combustor operating characteristics during the test are shown in Figure 41.

5. Test Series V - 37.5K Thrust Level Evaluation, Tests 1298-D01-OJ-021 and -022

(C) With the satisfactory demonstration at the 25K thrust level completed, the test program proceeded to evaluate operation at the 37.5K thrust level. Engine balance was set for 3350 psia chamber pressure and 12.3 mixture ratio. Two tests were conducted, with durations of 1.4 and 1.8 sec. The first test (-021) was terminated prematurely at 1.4 sec by the fuel-to-oxidizer pressure comparison shutdown device. This device compares oxidizer and fuel pressures measured during the test with preset allowable limits programmed into the computer. Analysis of the test records showed that during the last portion of the transient, there was a momentary fuel-rich condition in the chamber. Postfire hardware inspection indicated very minor erosion on five of the orifices in the turbine simulator plate; the cause of erosion was attributed to the off-mixture ratio transient conditions. The transient was programmed to correct the problem in preparation for the next test.

(C) Test 022 was programmed for a scheduled duration of 3.0 sec; the test was terminated at 1.809 sec by the high temperature shutdown device.

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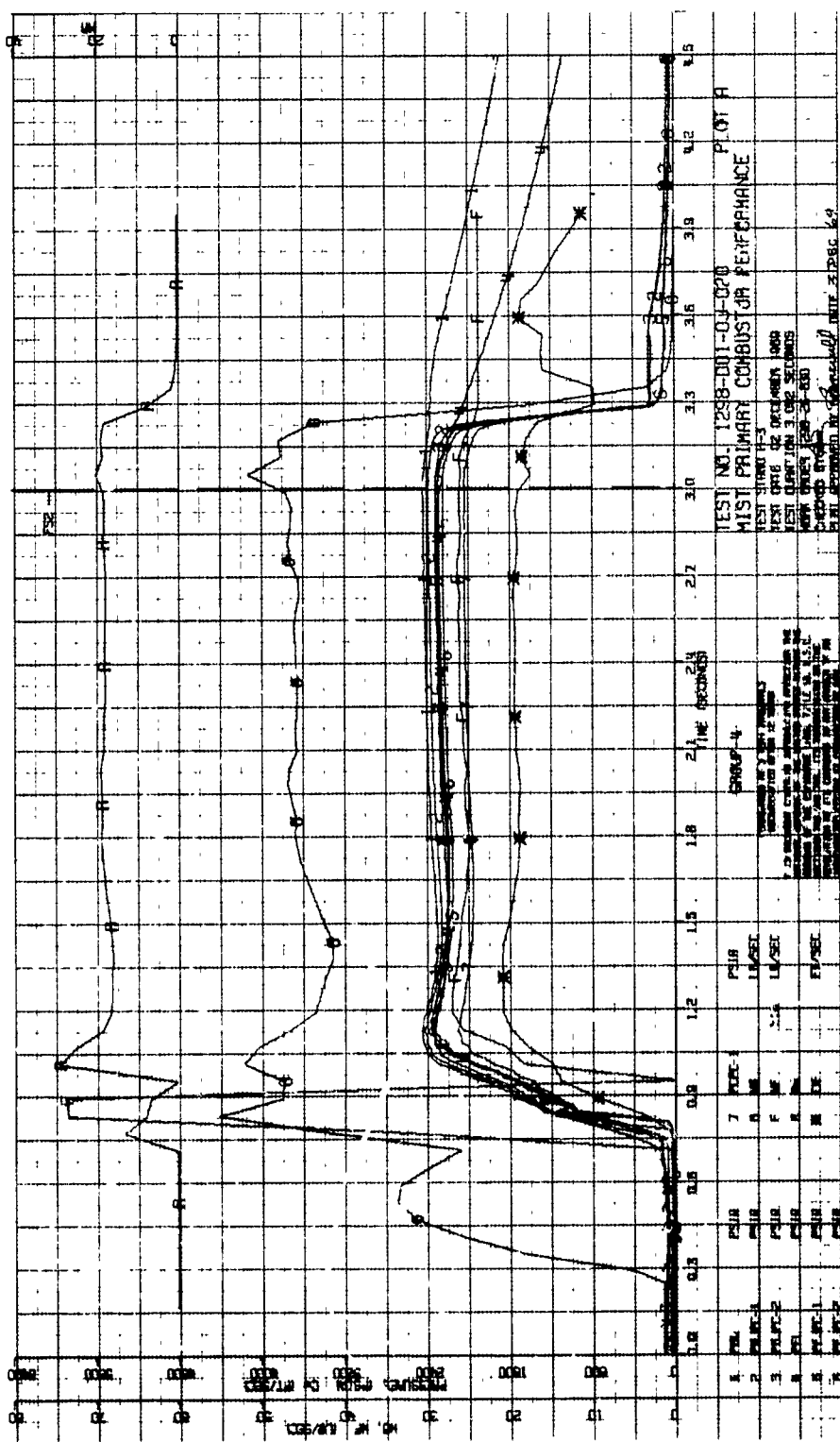


Figure 41. ADR Plot Test 1298-D01-OJ-020 (U)
(Sheet 1 of 2)

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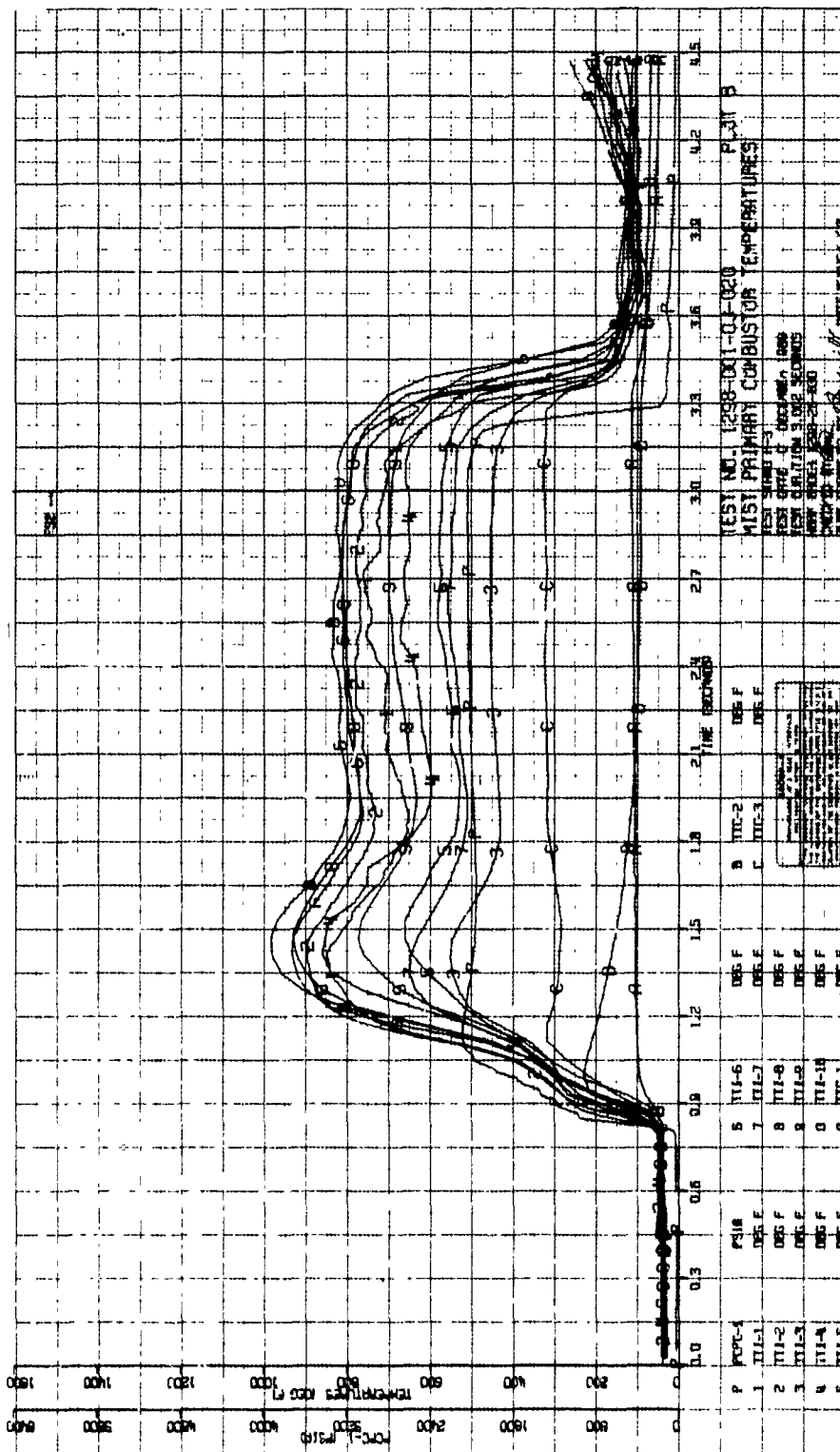


Figure 41. ADR Plot Test 1298-D01-0J-020 (U)
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VII, C, Detailed Test Program (cont.)

Posttest inspection revealed that the outer chamber wall in compartment 10 was eroded downstream of the bottom edge of the injector. The erosion progressed down the chamber wall and through the baffle separating compartments 9 and 10. Photographs showing the damaged areas are given in Figures 42 and 43. The damage occurred in precisely the same circumferential location as previously experienced in Test 018. This fact made the injector feeding the damaged compartment (SN 023) a primary suspect as the cause of the problem. The injector was subsequently removed and its mixture ratio distribution evaluated by cold flow testing along with several other injectors selected at random. The results of this special investigation are discussed in full in Section VII,D,3. It was determined that injector -023 did, in fact, have an uneven mixture ratio profile and that a fuel rich zone was located on the side of the injector where the erosion occurred. It was therefore concluded that the injector was the cause of the problem.

(U) The other injectors also exhibited some maldistribution, but not nearly as severe as that of SN-023. The cause of the maldistribution could be either contamination or the combined tolerance effects of the platelet stack. During the electrical discharge machining operation of the propellant manifolds, some of the removed material is in "flake" form, which can drop into the passages. Subsequent back-flushing may not be 100% successful in removing all particles. In more recent injector designs, special flow paths have been designed into the platelets to allow back-flowing of oil through the propellant manifolds during machining, which precludes contamination from entering the manifold. Such a circuit would be designed into a future MIST injector design. With respect to the combined tolerance effects, the MIST injector is susceptible to some maldistribution from this source because of its very small passage sizes, i.e., 0.002 x 0.010 in. and 0.002 x 0.015 for the oxidizer and fuel circuits, respectively. These small passages were required because the design was based upon laminar flow through part of the throttling range. As determined by the test program, no benefit with respect to stability was derived from the

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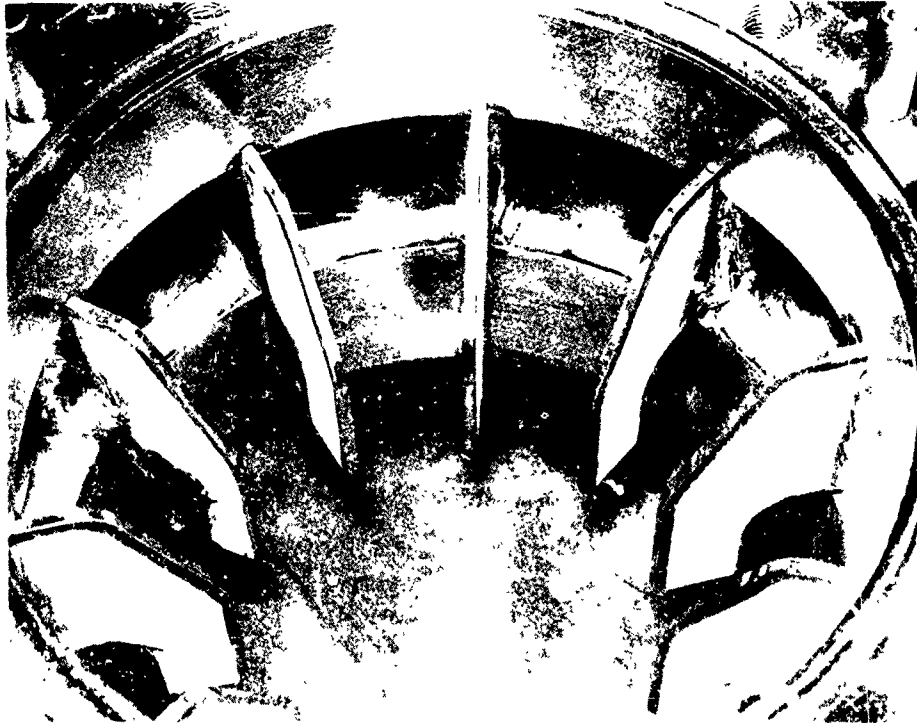


Figure 42. Injector Housing Post 1298-D01-OJ-022



Figure 43. Fuel Atomizer Post 1293-D01-OJ-022

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VII, C, Detailed Test Program (cont.)

laminar flow feature (the IO/IF injector, which was the final selected injector, was fully turbulent in the oxidizer circuit); therefore, the passages need not be so small. In future injectors, maintaining passages with a minimum dimension of 0.005 in. are recommended, which should minimize any maldistribution from passage dimension tolerance effects.

(C) The clustered segment test program was concluded at this point because of funding limitations. The only unfulfilled objective of the program was the demonstration at the 50K thrust level. Based upon the successful segment test program results and the overall clustered test program results, it is believed that, following correction of the mixture ratio distribution problem with the injector, this demonstration can successfully be made.

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VII, Clustered Segment Test Program (cont.)

D. TEST DATA ANALYSIS

1. Performance

(U) Performance analysis of the MIST clustered primary combustor was analyzed with respect to two combustion characteristics. The most definitive parameter is the characteristic exhaust velocity as measured in total by the sonic throat located just downstream of the merging of the segment gases as they exit from each set of turbine simulator nozzles. The second parameter which describes the performance of the clustered assembly are the hot gas temperature measurements taken just downstream of the turbine simulator nozzle in line with each compartment.

(C) The characteristic exhaust velocity performance is in excellent agreement with the data generated during the segment program. This characteristic is shown in Figure 44 with the data points from the 22-test clustered program located just above the impinging oxidizer/impinging fuel injector segment performance. This performance data is calculated using the same technique described in Section VI,D,1. Flow rates were again recorded through the use of "Potter" rotor-type flowmeters. Chamber pressure was measured in one segment of the combustion chamber while propellant manifold pressures were averaged between two segment injector readings. The geometric throat area was corrected for entrance conditions of angle, diameter ratio, and clustered geometry to give representative aerodynamic flow area.

(C) Examination of the data in Figure 44 shows performance of the clustered segments to be generally higher than the single segments over the entire thrust range. This performance increase is believed to be not necessarily a result of higher performance in the clustered version, but rather reflective of differences in the assessment of the two throat geometry flow coefficients.

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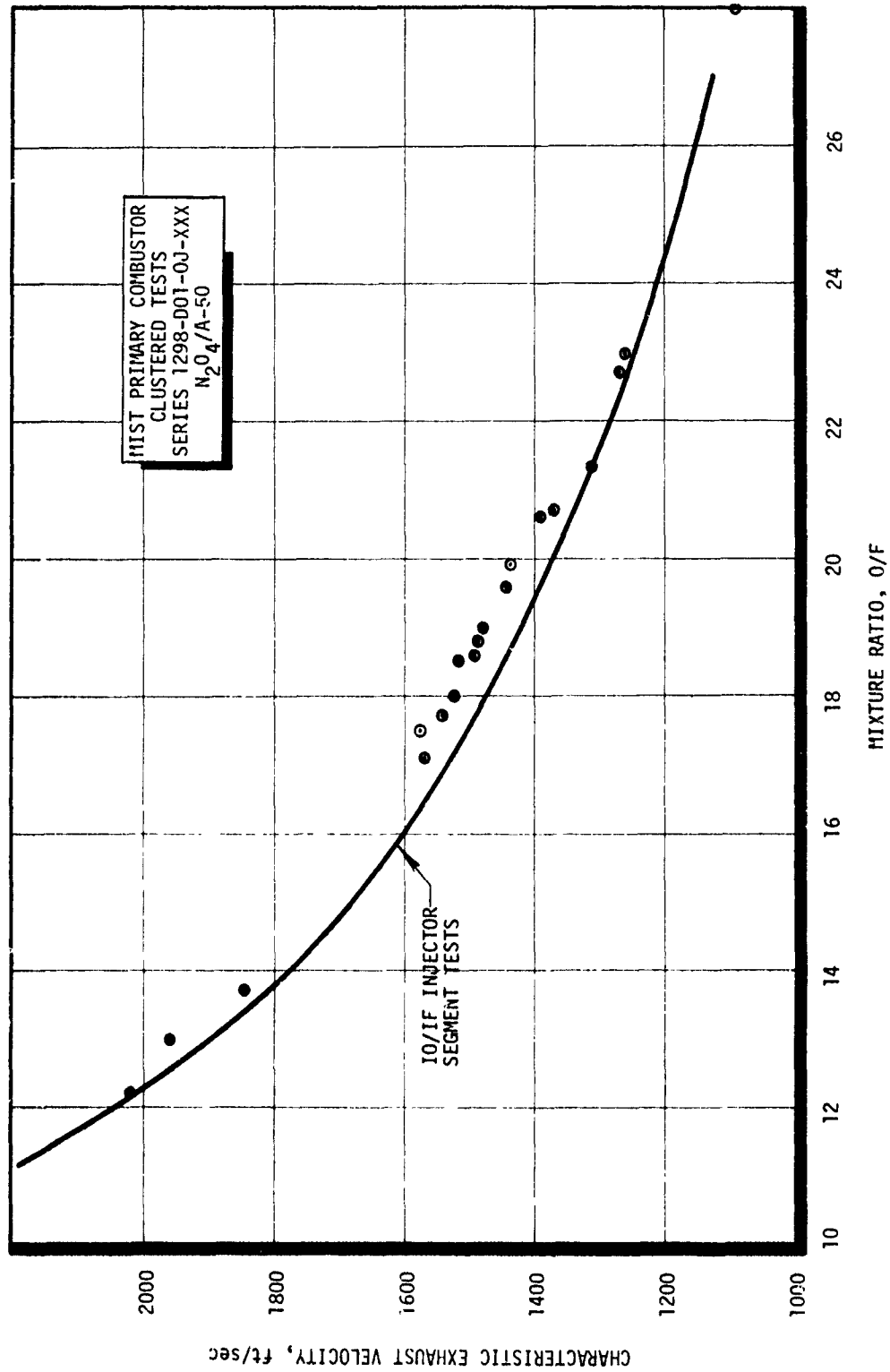


Figure 44. c^* vs MR, Cluster Tests (U)

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VII, D, Test Data Analysis (cont.)

(U) The temperature data for the ten thermocouple readings on each of the 22 tests is included in Table II. An analysis of all valid data is summarized in Table IX. Given are the test number, mixture ratio, theoretical temperature for the test conditions, average measured temperature and maximum temperature spread between thermocouples. Generally, the temperature variation was less than 200°F, well within acceptable engine turbine variation limits. Not included in the results of Table IX are the temperatures indicated by TTI-3 and TTI-7 for Tests -008 through -022 and by TTI-5 for Tests -020 through -022. These thermocouples constantly indicated temperatures substantially below the normal spread. It could be postulated that the injectors opposite these locations were balanced to a higher mixture ratio, thereby producing a lower temperature. However, analysis of the data of Tests -003 through -008 (transient tests) showed that up until Test -008, thermocouples TTI-3 and TTI-5 were not reading low. The precise reason for the sudden change in readings of these particular thermocouples has not been determined; no hardware, instrumentation changes, or changes in test procedure were made at this time. Similarly, up until Test -020, TTI-5 was reading normally. It was concluded that these changes must have been caused by an instrumentation shift, and that the indicated values do not reflect the true temperatures.

(C) It is therefore concluded that the MIST clustered primary combustor performance is both acceptable from an engine operation standpoint and is in excellent agreement with the segment data generated during the segment development portion of the program. Also, it can be concluded that the combustor appears to operate as predicted with good nominal performance although minor chemical incompatibilities were noted on the high thrust testing of the clustered assem'. This phenomenon is described in detail in Section VII,D,3.

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TABLE IX

TEMPERATURE SUMMARY - CLUSTER PROGRAM

<u>Test No.</u>	<u>Mixture Ratio</u>	<u>Theoretical Partial Equilibrium Temp, °F</u>	<u>Average Recorded Temperature, °F</u>	<u>Temperature Spread, °F</u>
1298-D01-OJ-001	(1)	-	(2)	-
-002	18.3	580	(2)	-
-003	13.7	900	970 ⁽³⁾	220
-004	19.9	507	(2)	-
-005	17.5	630	(2)	-
-006	(1)	-	(2)	-
-007	19.8	510	(2)	-
-008	18.0	600	678	208
-009	18.8	550	622	183
-010	17.1	660	691	210
-011	18.6	563	645	275
-012	18.8	550	645	141
-013	20.6	475	548	108
-014	19.4	525	611	166
-015	21.3	450	351	54
-016	19.2	535	654	214
-017	23.0	390	402	76
-018	20.7	470	548	180
-019	(4)	-	(2)	-
-020	17.6	620	753	150
-021	12.3	1000	(2)	-
-022	13.0	950	1198	238

- (1) Test duration too short to reach steady-state mixture ratio.
(2) Test duration too short for steady-state temperature data.
(3) Only three thermocouples used.
(4) Oxidizer flowmeter malfunction - no valid data.

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VII, D, Test Data Analysis (cont.)

2. Stability Characteristics

(C) The test data analysis of the cluster tests showed that the stability characteristics for the cluster assembly were generally the same as for the segment assembly with a somewhat closer correlation obtained with segment tests in which the chamber extension was not installed. This is reflected in the comparison of several thrust points noted below. For comparison, only IO/IF pattern injectors were used.

Thrust Level	Segment Program				Cluster Program	
	w/o Chamber Extension		w/Chamber Extension		Frequency (Hz)	Amplitude (% P _C)
	Frequency (Hz)	Amplitude (% P _C)	Frequency (Hz)	Amplitude (% P _C)		
10K	250	+15.0	Random	+1.0	210	+15.0
12K	250	+14.0			210	+ 9.5
15K	280	+ 2.2			Random	+ 1.2
25K			Random	+1.0	Random	+ 1.0

(U) The segment test setup was substantially different from the cluster test setup; i.e., the propellant feed line lengths varied substantially, no venturis were used in the cluster testing, 10 parallel circuits were employed on the cluster as compared to one on the segment, and there were variations in hardware configuration.

(C) The resulting similarity in level and frequency of the unstable ranges in the two test programs tends to confirm the conclusion that the predominant factor affecting stability is the loop between P_{OJ} and P_C (the "lump" parameter described in Section VI).

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VII, D, Test Data Analysis (cont.)

3. Special Investigation of Injector SN 23 Following Test 1298-D01-OJ-022

(C) In Test 1298-D01-OJ-022, chamber wall erosion downstream of injector SN 23 was noted. It was postulated that a locally low mixture ratio could have generated this burning. In order to verify this hypothesis, SN 23 injector and others were cold flowed with trichloroethylene and water under simulated firing conditions. The following paragraphs describe the cold flow testing and interpret the resultant data.

(U) The injector flow fixture and collector (Figure 45) comprise an injector mounting fixture, a flow collection head, and a collection bottle array with interconnecting plumbing. A pneumatically driven deflection plate covers the collection head and prevents liquids from entering the collection bottles during flow startup and shutdown transients. The collection head comprises 100 3/16-in. stainless tubes arranged in a 10 x 10 matrix. The collection tube ends on the inlet side are swaged square and sharpened to ensure maximum recovery of the test fluids. The test fluids are routed through the collection head into individual sample bottles via Tygon tubing. The amount of fluid accumulated in each bottle is measured with a graduated cylinder.

(C) The injectors were positioned symmetrically over the collection head and one inch above it. Trichloroethylene was used as simulant for the N_2O_4 and water simulated the A-50. Test durations were 25 sec, with the water flow rate at 0.19 lb/sec and trichloroethylene flow rate at 2.9 lb/sec. These flows correspond to oxidizer and fuel propellant flows of 3.7 and 0.235 lb/sec, respectively, which corresponds to the 20K thrust operating point. The resulting data, consisting of 100 water and trichloroethylene volumetric measurements, were reduced to engineering terms with the aid of a computer program.

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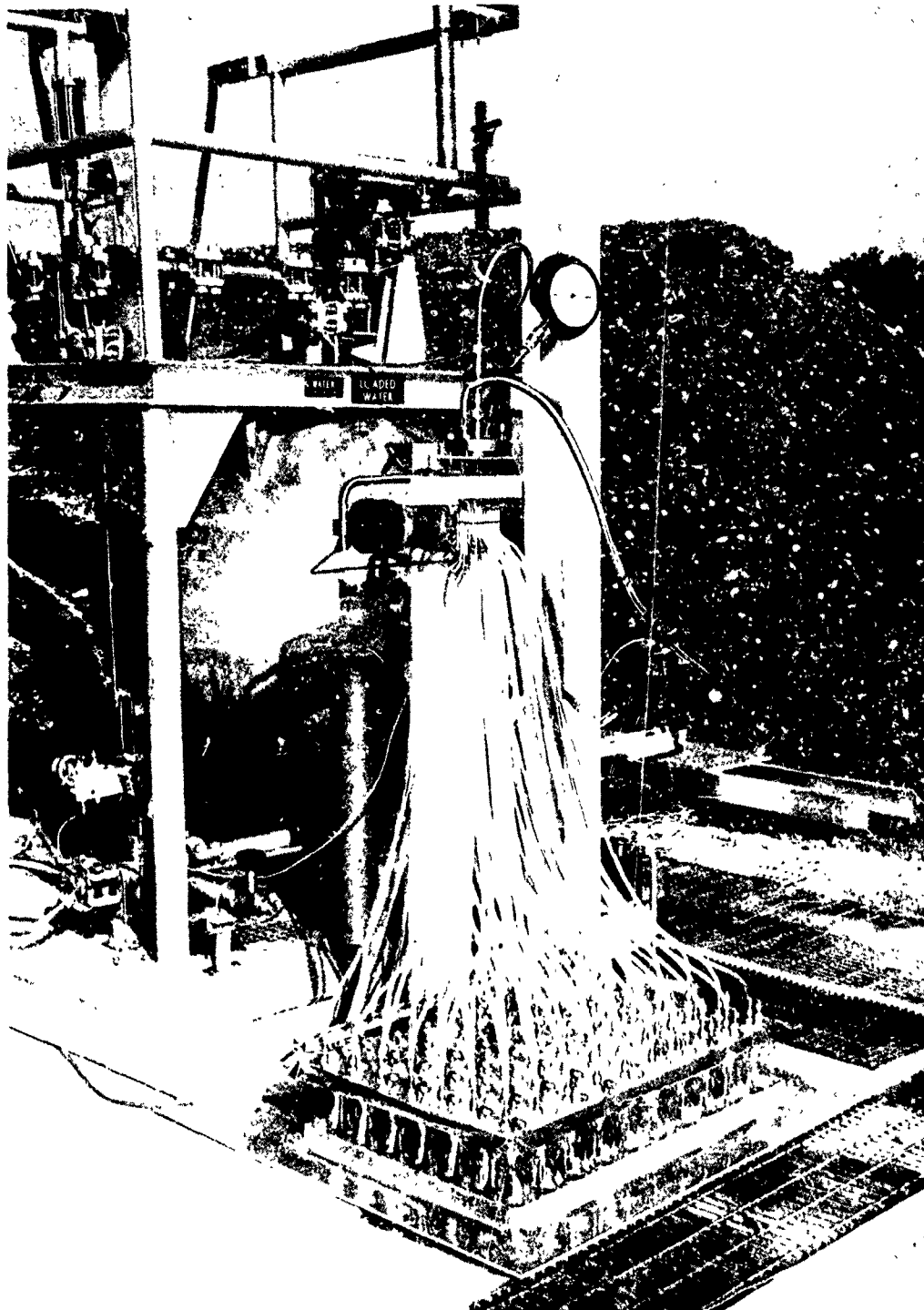


Figure 43. Injector Flow Fixture

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VII, D, Test Data Analysis (cont.)

(C) The resulting mixture ratio data, corrected to propellant values, are presented for three injectors tested in Table X with a graphical presentation in Figure 46. The data are tabulated as if the injector were above the page, flowing toward the page, with the oxidizer inlet to the left margin. The orientation of Figure 45 is similar except the oxidizer inlet is as noted.

(C) Inspection of Figure 46 reveals some qualitatively similar characteristics. The mixture ratio gradient is oxidizer rich at the boundaries and fuel rich in the center. The majority of the excess oxidizer is located at the top and bottom of the injector with the top being defined as the oxidizer inlet. This zone is generated by the outside row of oxidizer doublets, the location of which is indicated in the figure. In fact, at the edge of the collector, nearly all the flow was oxidizer. At the left and right of the injector, this distribution is not evident. However, it is likely that some oxidizer was not collected at these boundaries, as the oxidizer injection point was very close to the edge of the collector.

(C) Inspecting the individual differences between injectors, it can be concluded that injectors SN 8 and SN 23 had some potential for streaking the chambers. Injector SN 9, however, has a more uniform mixture ratio profile and would not generate hot zones in the resulting combustion gases. One important difference between injectors SN 8 and 23 should be noted, however. The low mixture ratio zone of injector SN 8 is positioned in the center of the injector and is surrounded by the bulk of the remaining high mixture ratio products. It is unlikely, then, that this hotter core would reach the chamber walls. It should also be noted that these distributions will be flattened by turbulent mixing as the products proceed down the chamber. Injection SN 23 had a fuel-rich core located toward the bottom of the injector. Between this core and the chamber wall is distributed approximately 1.5% of the total flow. It is likely, then, that turbulent mixing would not significantly dilute this low mixture zone and the potential for burning the lower chamber wall existed. The burning noted in Test -022 was probably generated by this mechanism.

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NOTE: Direction of flow is toward paper

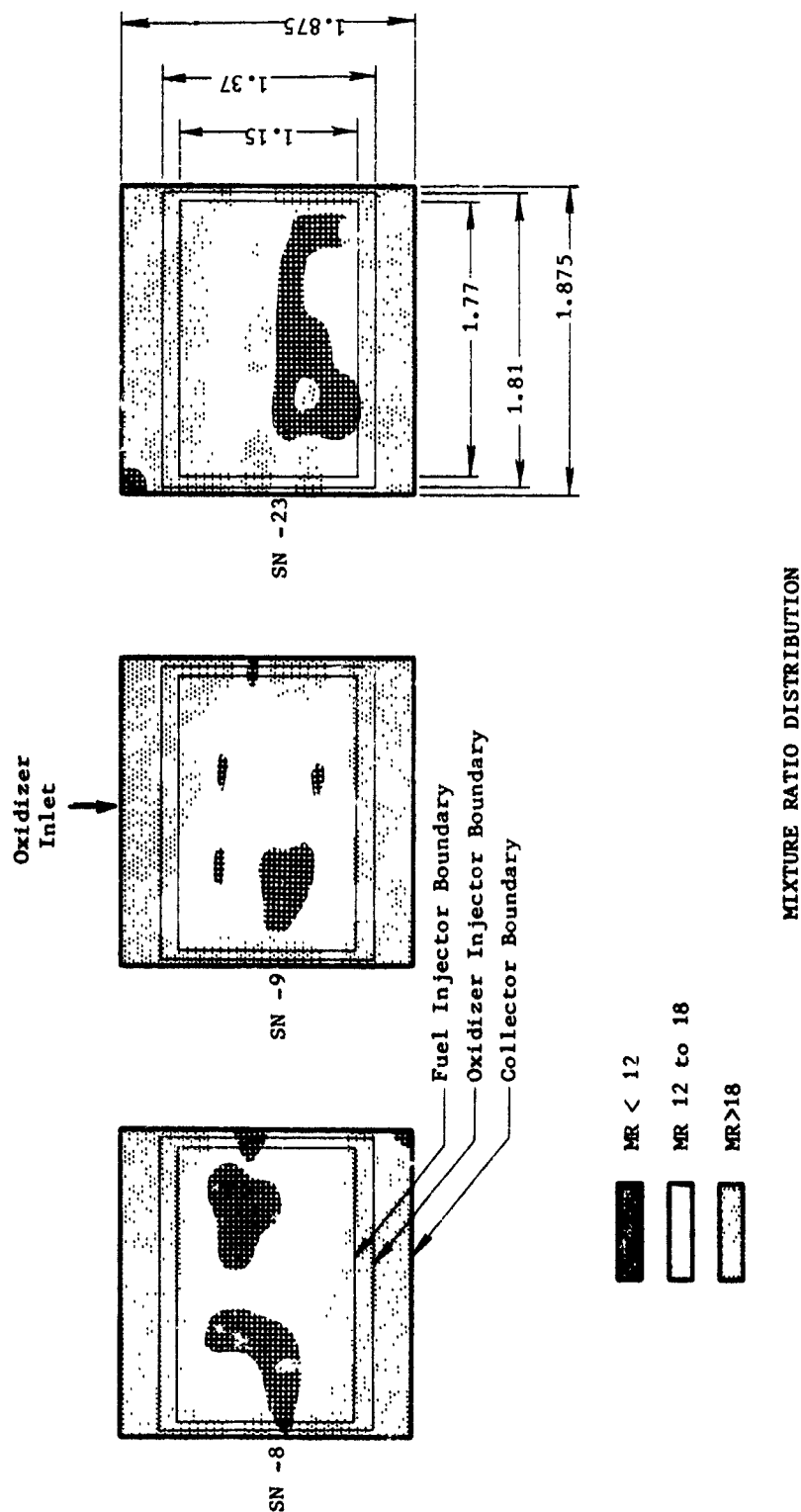


Figure 46. Water Flow Graphical Data

TABLE X

WATER FLOW TABULAR DATA
INJECTOR SN 8

57.60	29.54	23.60	14.93	10.88	17.53	14.08	15.20	47.20	9.60
128.00	29.67	11.68	10.08	12.40	12.62	16.27	13.87	57.50	28.80
46.40	28.34	16.00	10.72	9.80	9.42	13.60	15.20	36.80	24.00
107.20	38.40	15.11	10.72	10.20	8.53	16.60	15.60	20.00	999.00
999.00	51.20	16.16	11.20	13.49	12.44	17.83	16.80	44.00	35.20
129.60	19.73	16.00	12.80	14.86	15.09	16.00	18.93	52.00	43.20
48.00	40.00	16.36	14.04	11.67	14.86	15.68	18.93	73.50	999.00
36.80	32.00	15.42	10.67	10.67	9.02	13.87	12.34	70.44	999.00
99.20	30.77	16.46	16.46	13.87	17.14	8.74	14.60	86.40	999.00
999.00	27.20	42.00	16.40	32.96	11.84	44.00	25.60	46.40	800.00

FUEL INJECTOR
BOUNDARY

OXIDIZER INJECTOR
BOUNDARY

OXIDIZER INLET



COLLECTOR
BOUNDARY

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TABLE X (cont.)

INJECTOR SN 9

48.00	35.60	52.62	75.73	11.73	30.40	29.60	16.00	36.80	92.80
40.00	82.40	23.37	14.58	12.48	13.00	12.62	19.43	25.87	48.00
23.20	50.40	14.67	13.80	12.60	12.98	12.07	19.20	17.80	46.40
60.80	14.40	19.73	11.40	12.48	12.80	13.44	17.00	44.80	999.00
70.40	18.80	18.00	11.56	12.40	12.80	10.24	15.20	97.60	41.60
999.00	35.20	16.71	13.51	9.80	12.44	12.09	17.20	56.00	24.00
999.00	60.00	16.71	11.32	12.80	12.32	12.34	16.40	69.60	17.60
59.20	30.13	15.13	11.20	13.40	9.60	16.46	15.64	71.20	27.20
83.20	15.67	16.00	12.98	15.77	9.73	15.64	17.83	16.80	19.20
104.00	18.67	19.73	23.52	18.70	23.20	31.20	13.87	50.67	60.80

FUEL INJECTOR
BOUNDARY

OXIDIZER INJECTOR
BOUNDARY

OXIDIZER INLET

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TABLE X (cont.)

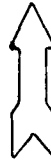
INJECTOR SN 23

30.40	67.40	14.00	31.20	17.69	44.40	27.66	25.00	30.40	22.40
25.07	14.40	38.80	17.14	20.00	13.39	9.71	12.68	49.60	70.40
68.00	64.80	29.87	14.18	16.23	17.52	12.75	11.78	24.00	19.20
37.60	198.40	21.33	13.28	16.53	10.55	13.88	11.65	7.54	19.20
52.80	278.40	25.60	14.93	18.93	11.31	15.27	14.78	34.00	64.00
36.80	67.48	27.52	13.71	18.67	11.59	12.75	12.87	126.40	48.00
21.60	102.40	42.67	12.44	17.33	11.13	11.30	12.57	18.40	160.00
25.60	24.00	19.20	16.82	16.00	9.12	23.20	10.62	44.80	160.00
41.60	26.29	24.00	16.40	21.16	11.33	9.10	11.68	35.20	320.00
5.71	31.40	18.40	18.13	20.57	13.31	33.42	16.80	11.73	320.00

FUEL INJECTOR
BOUNDARY

OXIDIZER INJECTOR
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OXIDIZER INLET



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APPENDIX

MIST ENGINE DESCRIPTION

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Appendix

I. DESIGN POINT

(C) The MIST engine is shown in Figure A-1. It is designed for 50,000, lb thrust and 10:1 throttling. Engine characteristics are shown below.

	Nominal Design Point	Throttle 2:1	Throttle 10:1
Thrust, lb	50,000	25,000	5,000
Specific impulse, sec (vac)	337	334	315
Specific impulse efficiency	91.8	91.0	86.0
Mixture ratio	2.41	2.4	2.41
Nozzle area ratio	300	300	300
Minimum suction pressure, psia			
Oxidizer	(22)*	35	4
Fuel	(11)*	14	2
Thrust chamber pressure, psia	2,800	1,400	285
Engine weight, lb	403(442)*	Same	Same
() * with boost pumps			

II. PHYSICAL DESCRIPTION

(U) A cross section of the MIST engine (exclusive of boost pumps) is shown in Figure A-2. The engine consists of a turbopump assembly, a thrust chamber assembly, and fuel and oxidizer suction valves. The MIST engine with boost pumps for low suction pressure capability is shown in Figure A-3 (two sheets). The turbopump assembly includes the main pumps, the turbine, the primary injector and combustor, and the primary combustor fuel control valve. The thrust chamber assembly includes the secondary combustor, nozzle, secondary injector, and the secondary combustor fuel valve.

(U) The turbopump is oriented with its shaft axis in line with the thrust vector. The turbopump is mounted on top of the thrust chamber, with the engine

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Appendix

I. DESIGN POINT

(C) The MIST engine is shown in Figure A-1. It is designed for 50,000, lb thrust and 10:1 throttling. Engine characteristics are shown below.

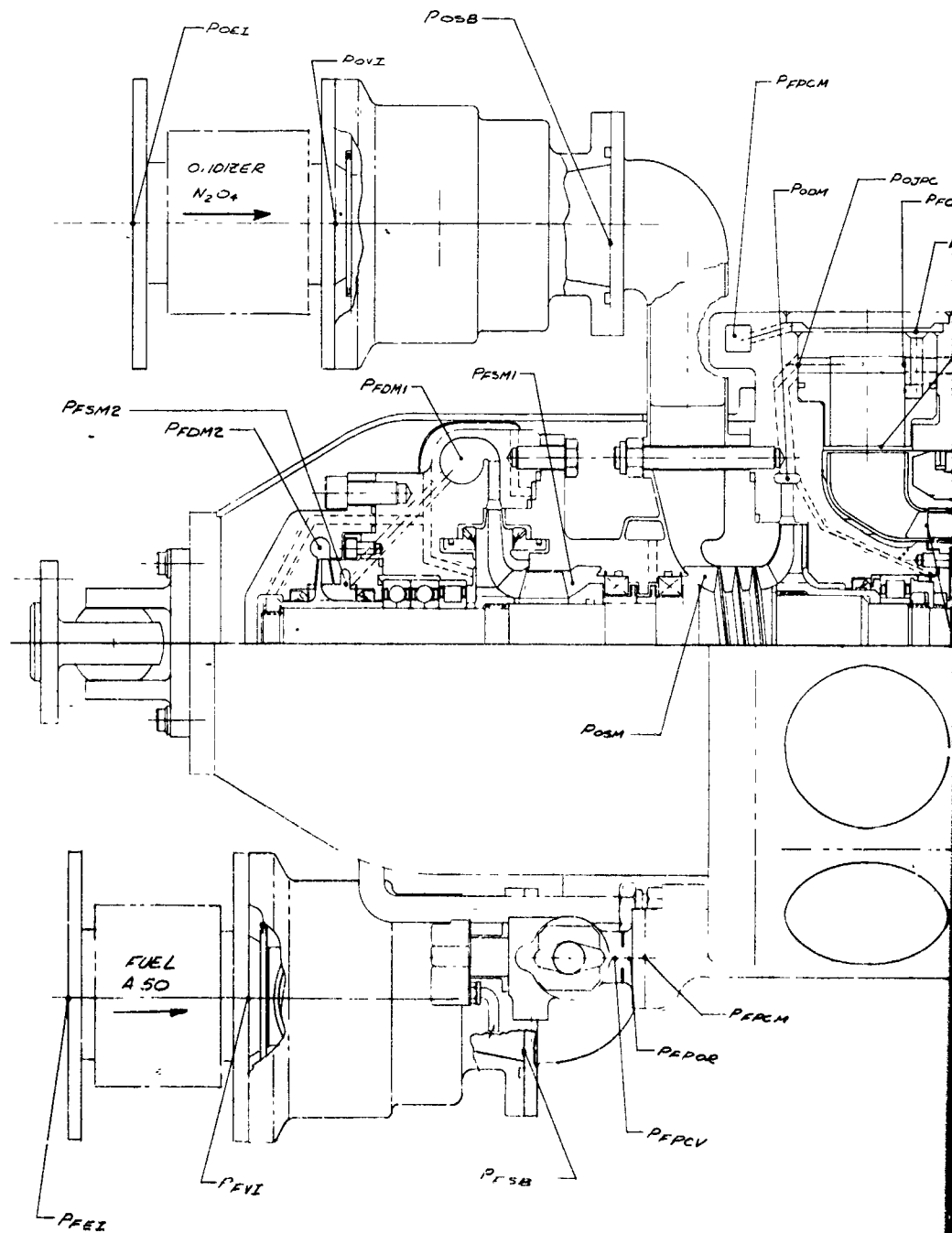
	Nominal Design Point	Throttle 2:1	Throttle 10:1
Thrust, lb	50,000	25,000	5,000
Specific impulse, sec (vac)	337	334	315
Specific impulse efficiency	91.8	91.0	86.0
Mixture ratio	2.41	2.4	2.41
Nozzle area ratio	300	300	300
Minimum suction pressure, psia			
Oxidizer	(22)*	35	4
Fuel	(11)*	14	2
Thrust chamber pressure, psia	2,800	1,400	285
Engine weight, lb	403(442)*	Same	Same
() * with boost pumps			

II. PHYSICAL DESCRIPTION

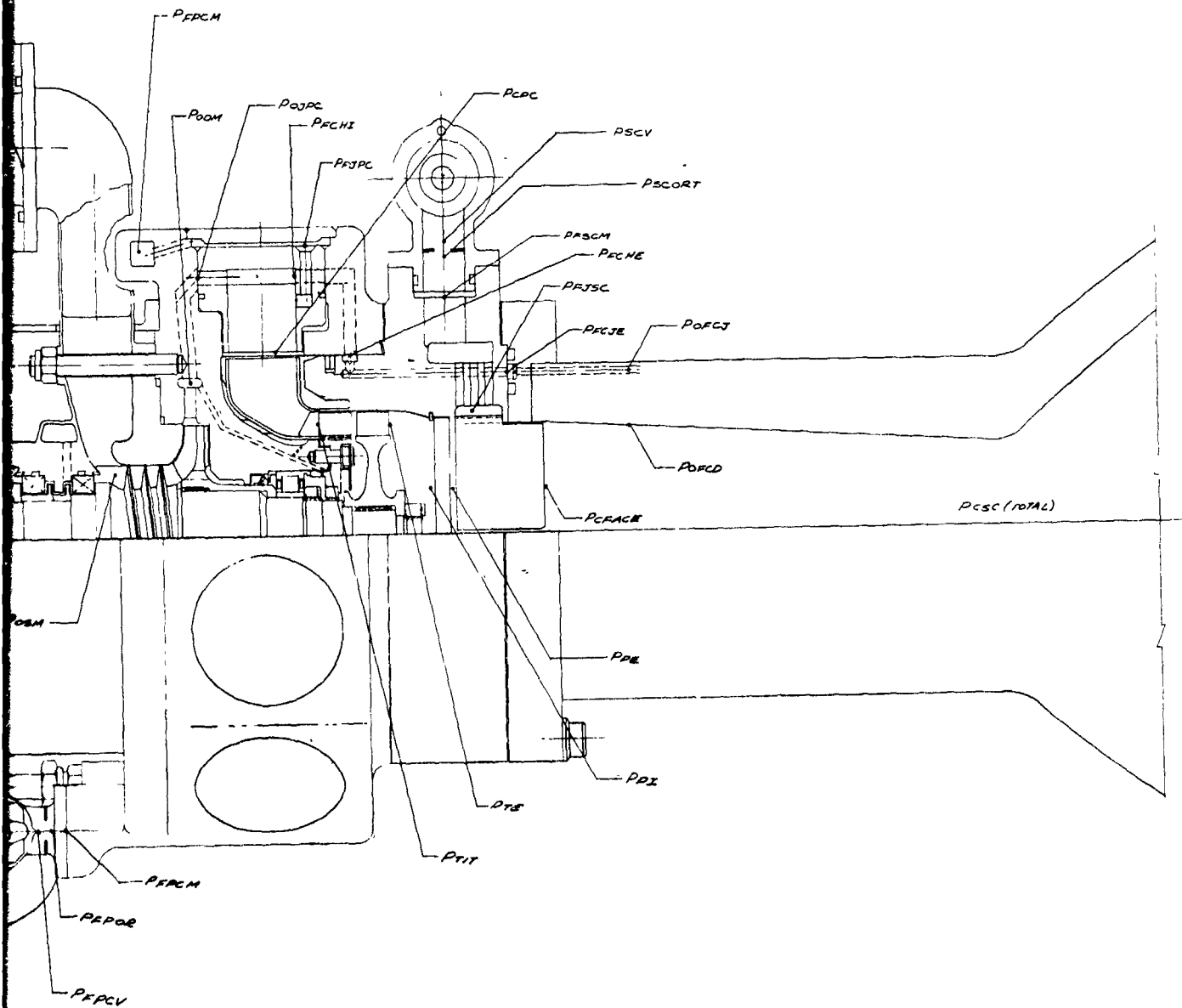
(U) A cross section of the MIST engine (exclusive of boost pumps) is shown in Figure A-2. The engine consists of a turbopump assembly, a thrust chamber assembly, and fuel and oxidizer suction valves. The MIST engine with boost pumps for low suction pressure capability is shown in Figure A-3 (two sheets). The turbopump assembly includes the main pumps, the turbine, the primary injector and combustor, and the primary combustor fuel control valve. The thrust chamber assembly includes the secondary combustor, nozzle, secondary injector, and the secondary combustor fuel valve.

(U) The turbopump is oriented with its shaft axis in line with the thrust vector. The turbopump is mounted on top of the thrust chamber, with the engine

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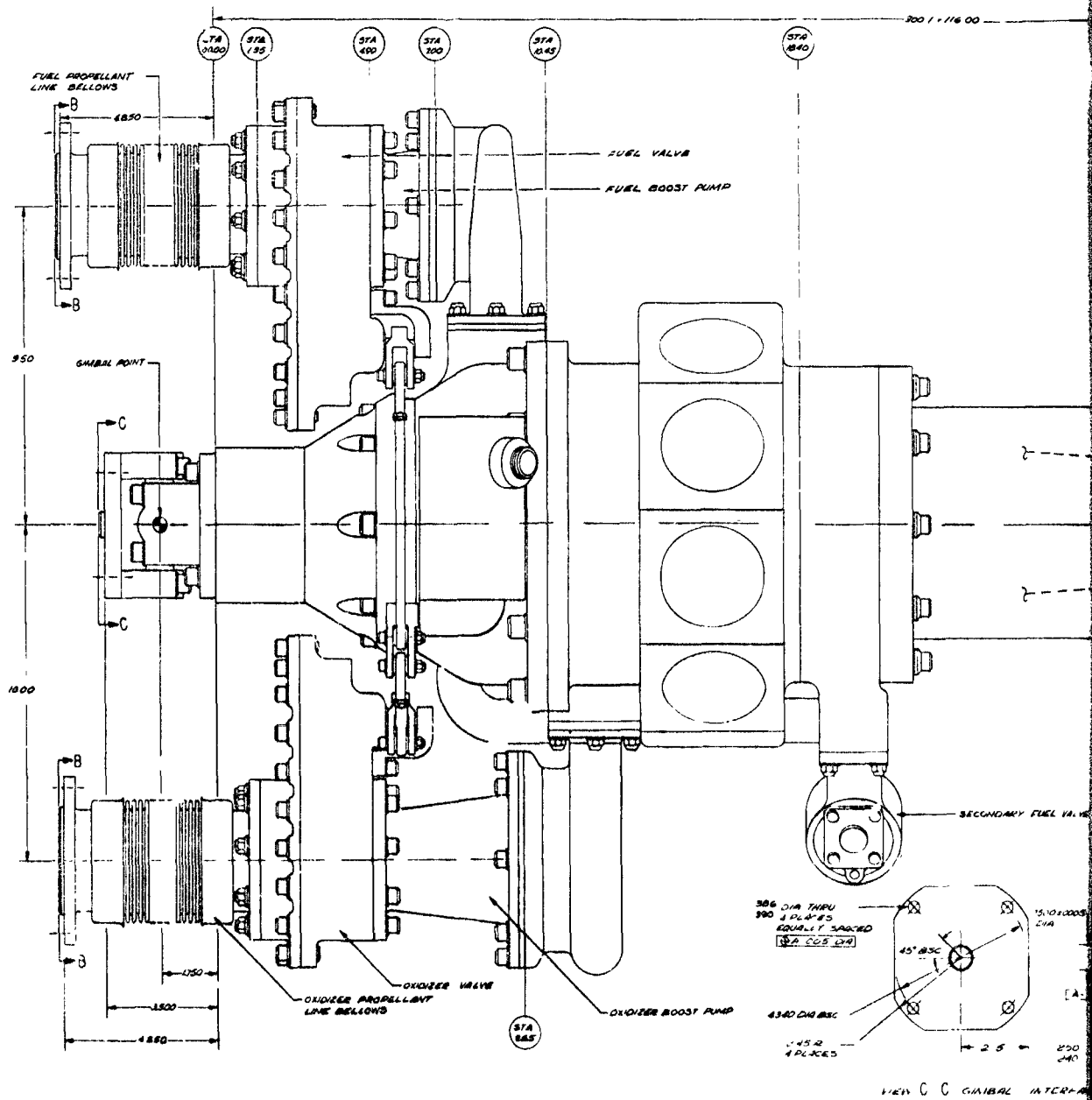


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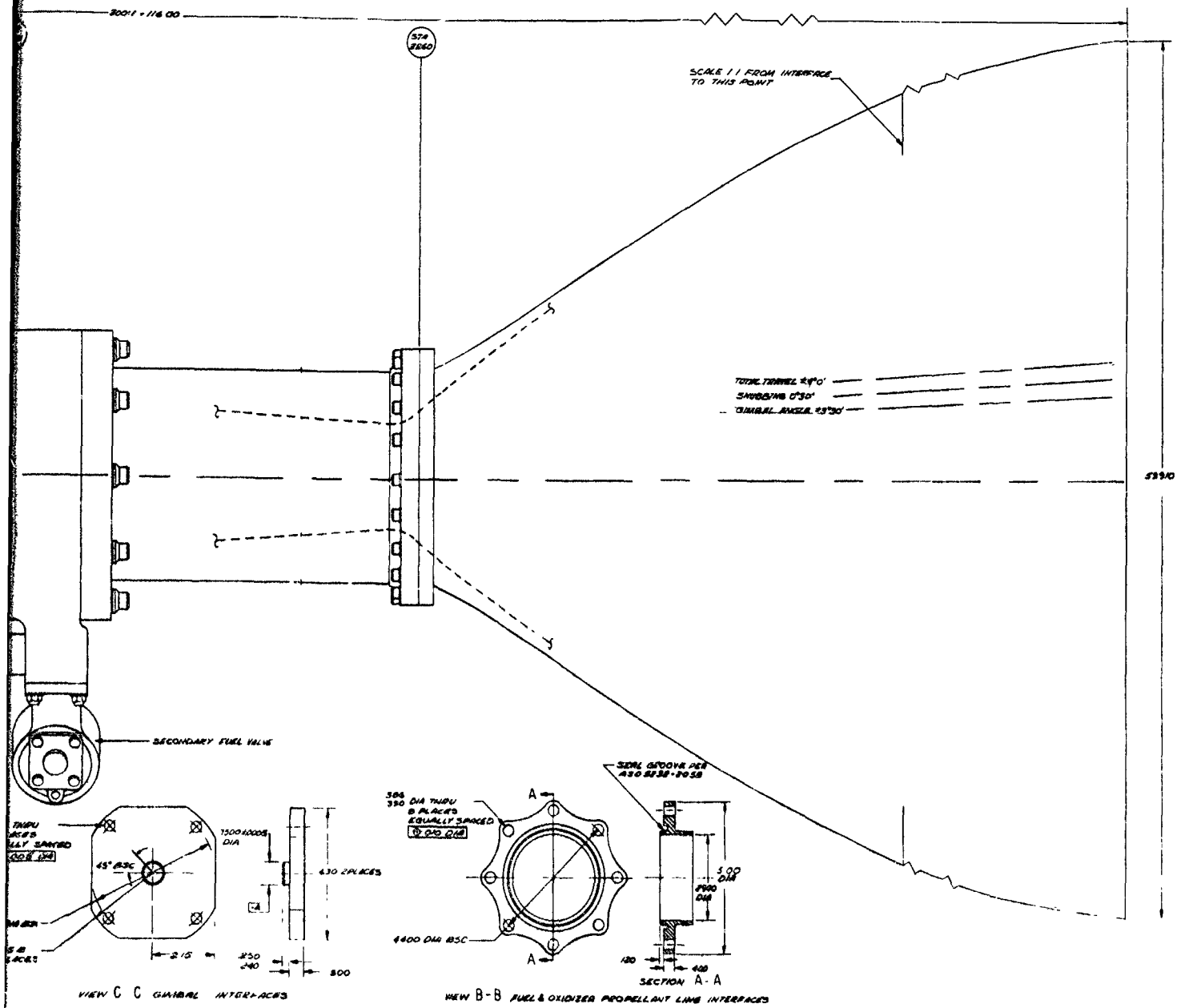
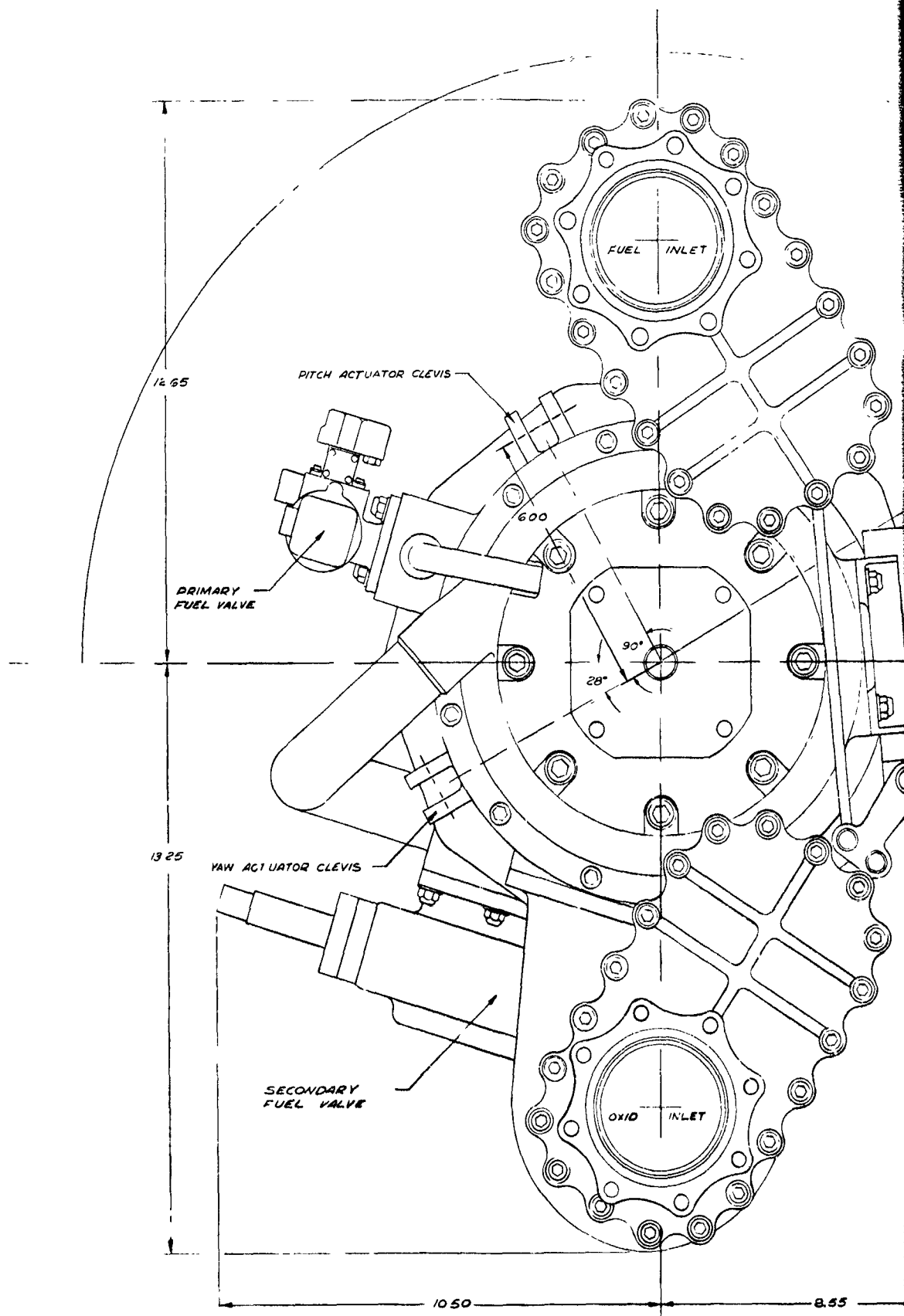


Figure A-3. Cross Section - MIST Engine with Boost Pumps (Sheet 1 of 2)

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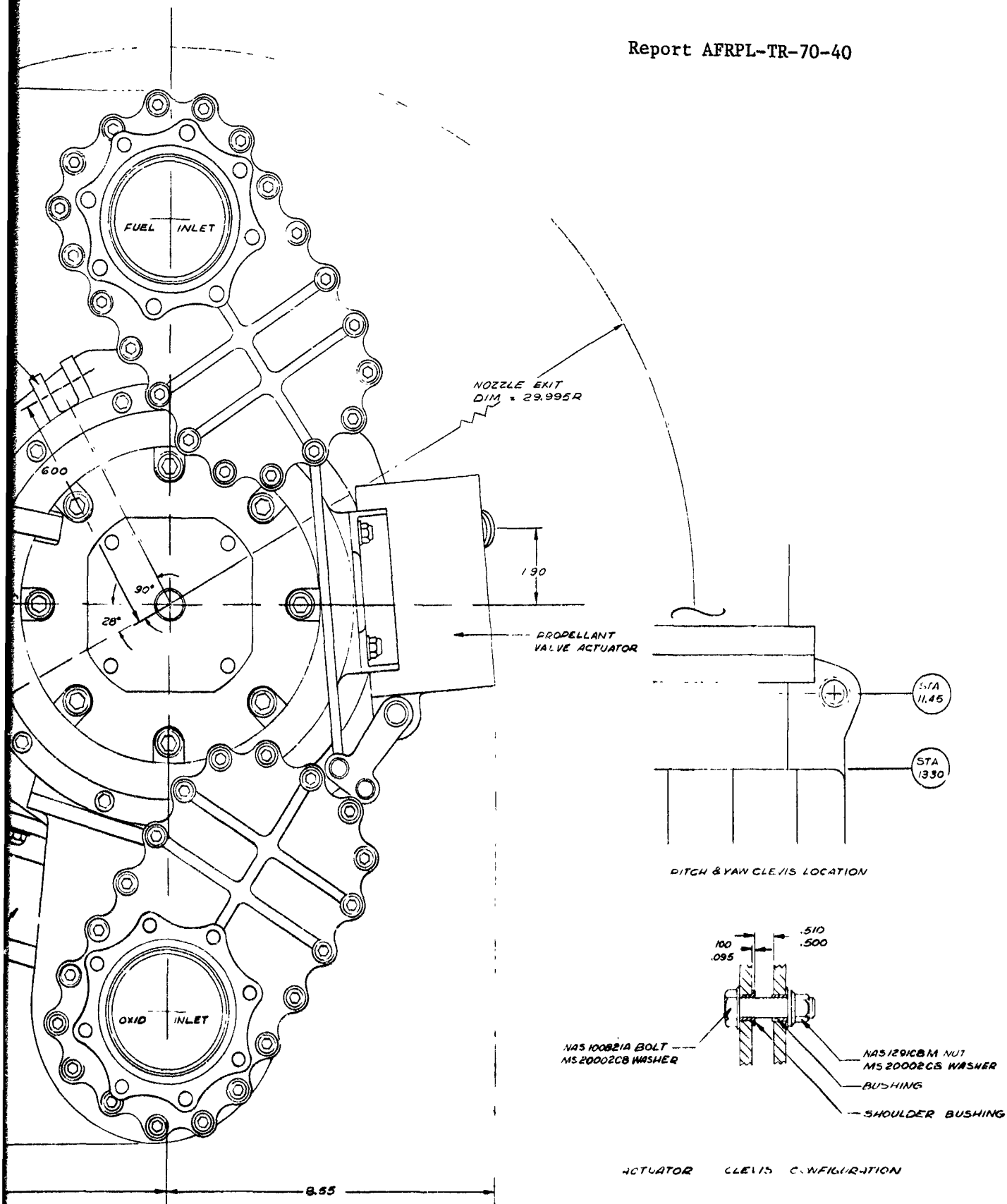


Figure A-3. Cross Section - MIST Engine with Boost Pump
(Sheet 2 of 2)

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Appendix

II, Physical Description (cont.)

thrust transmitted through the turbopump to the gimbal which is mounted to the airframe. The turbine exhaust gas discharges directly into the thrust chamber injector.

(C) The primary combustor incorporates a platelet type injector, wherein fuel and oxidizer are introduced between metal plates through photoetched flow passages formed on the surface of each plate. The secondary combustor injector is of the axial platelet type; the fuel is introduced through photoetched platelet pairs and the oxidizer-rich turbine exhaust gas passes over the exterior surface of the platelets.

(U) The secondary combustor (thrust chamber), including the chamber and throat section, together with a portion of the nozzle, is transpiration cooled using platelet washers for metering the required amounts of oxidizer through the thrust chamber wall. The nozzle extension is cooled by a carryover of the transpiration coolant and radiation and is similar in design to the radiation-cooled nozzle of the Apollo engine.

(U) The turbopump shaft is supported in the housing by propellant-lubricated rolling contact bearings. The turbine is on the lower end of the shaft; the single-stage oxidizer pump is on the center of the shaft, with the two-stage fuel pump on the top end of the shaft. Shrouded pump impellers with large running clearances are used to preclude pump rubbing. An interpropellant vented cavity seal is located between the suction sides of the oxidizer pump and first stage fuel pump to separate the propellants.

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Appendix

III. OPERATION

A. STEADY STATE

(C) The engine cycle is shown schematically in Figure A-4. Detailed engine operating parameters over its throttling range are presented in Table A-1. Symbols used in Table A-I are defined in Table A-II. For descriptive purposes operation at the 50,000 lb thrust is used. Except for pressure and speeds, the dynamics of operation are identical at other thrust conditions. Propellants enter the engine through the suction valves. All of the oxidizer (N_2O_4) is then pumped to a pressure of 5700 psia in the main oxidizer pump with most of it continuing to the primary combustor injector. The fuel is pumped to a pressure of 5100 psia in the first stage fuel pump. A portion of this fuel (20%) then enters the second stage fuel pump where it is pumped to 6800 psia and passes through the primary combustor fuel control valve to the primary injector. The oxidizer and fuel enter the primary combustor where they ignite hypergolically at a mixture ratio of 10.4 to form a hot gas of 1400°F and 5200 psi chamber pressure. This oxidizer-rich gas then passes through the turbine and is then exhausted into the thrust chamber. The major portion of the fuel flow from the first stage pump is ducted through the secondary combustor fuel control valve to the main injector where it is injected into the thrust chamber. This fuel burns with the oxidizer-rich turbine exhaust in the thrust chamber at the 2800 psia chamber pressure.

(U) If boost pumps are used, they are driven by hydraulic turbines which use 10% of the respective propellant bled from the main pump discharge. This drive fluid is then exhausted into the boost pump discharge. In the main turbopump, oxidizer for bearing coolant is bled from the pump discharge, passed through the oxidizer bearings, and discharged into the turbine inlet where it provides some turbine cooling. High pressure fuel is used to cool the fuel pump bearings. Secondary combustor transpiration coolant, N_2O_4 , is tapped from the oxidizer circuit at the primary injector.

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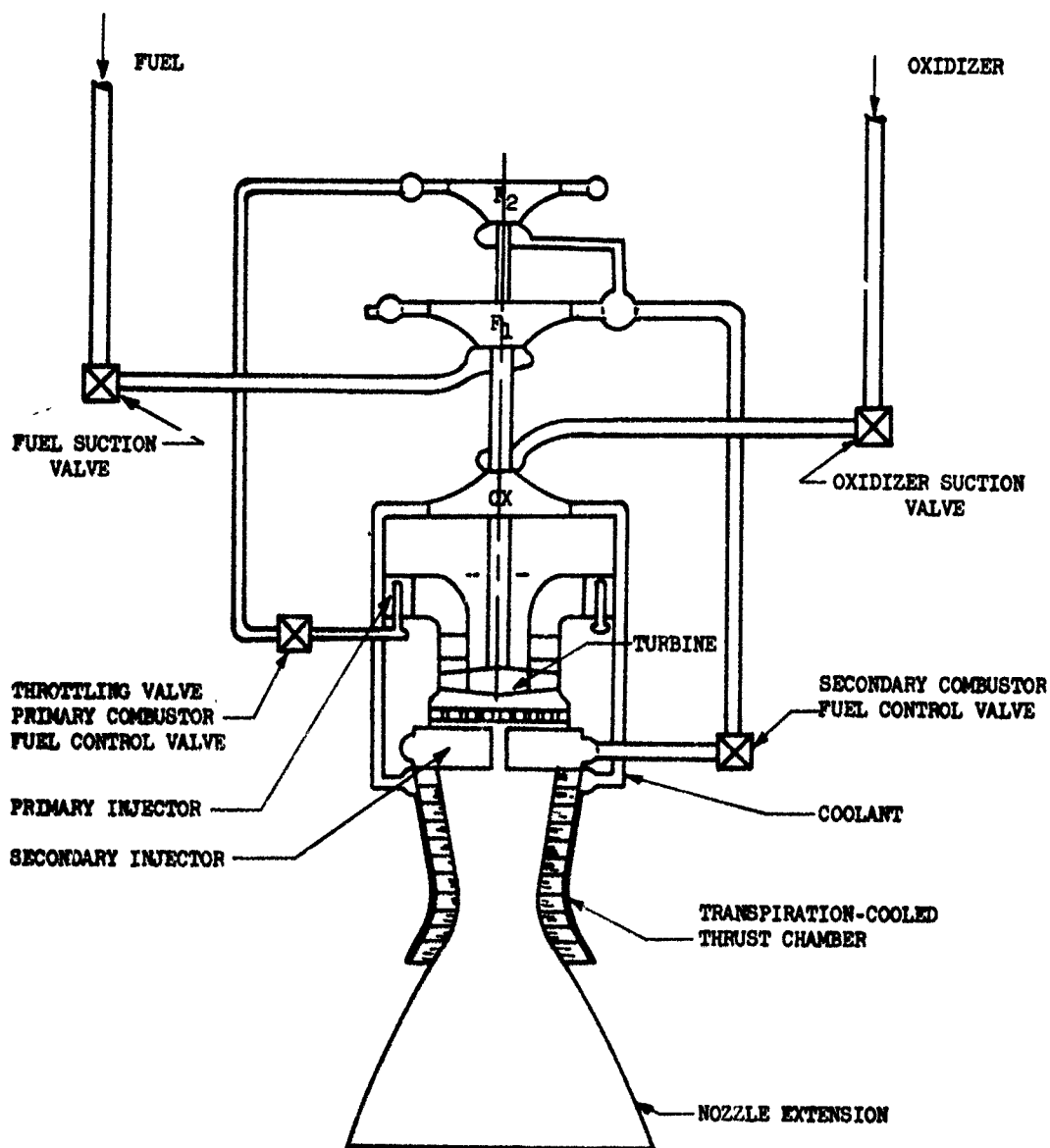


Figure A-4. Engine Schematic (U)

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TABLE A-I
ENGINE PARAMETERS, INITIAL (U)

PAGE	1	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124	
PCSC	2799.99960	2097.65666	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492	
MR-ENG	2.41572	2.42792	2.44005	2.43467	2.42444	2.36551	2.37181	2.74724	
IS	336.00557	336.03625	333.25032	331.69607	329.43365	325.46622	321.50514	306.40238	
W-ENG	147.06269	111.57786	75.00069	60.29098	45.52401	30.72453	23.32918	16.32664	
WOT	104.64036	79.02541	53.19829	42.73104	32.22763	21.59539	16.41040	11.97025	
WFT	43.31662	32.54659	21.80206	17.54956	13.29406	9.12932	6.91900	4.35715	
NT	36999.60107	30176.49805	22967.35547	19749.37646	16441.24097	12886.99866	10891.94800	8622.70764	
RPT	1.67215	1.55822	1.42933	1.37759	1.32559	1.27284	1.24376	1.20871	
POEIT	51.02575	51.49659	51.63836	51.93886	52.01765	52.07493	52.09465	52.10726	
TOEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	
PREIT	21.75524	22.45058	22.95727	23.10511	23.22274	23.30826	23.34149	23.36916	
YFEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	
ATSC	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229	
ATT	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757	
ATtr	1.57563	1.53420	1.49902	1.47589	1.44547	1.40098	1.37347	1.33586	
ATDBP	.02765	.02765	.02765	.02765	.02765	.02765	.02765	.02765	
ATFDP	.01280	.01280	.01280	.01280	.01280	.01280	.01280	.01280	
KWFSCV	1.89585	1.89585	1.89585	1.89585	1.89585	1.89585	1.89585	1.89585	
KWFPCV	.50030	.25797	.16838	.14555	.12449	.10270	.09163	.08149	
CSFOR	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	
CMFOR	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	
CMOOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
COMTOR	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	
CFATOR	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	
CFECT	192701.97461	193506.48047	194722.60938	195389.59375	196313.13477	197626.90820	198627.05273	200152.40820	
DOFCOR	.25583	.25583	.25583	.25583	.25583	.25583	.25583	.25583	
KWOBY	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
KWBY	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
CTIME	4.59170	8.49660	7.82000	6.47700	6.87650	6.61470	7.84380	2.97500	
CASE 1	NDM BAL 50K 4-3-69								
CASE 2	THROTTL W/ FPCV, F=37500								
CASE 3	THROTTL W/ FPCV, F=25000								
CASE 4	THROTTL W/ FPCV, F=20000								
CASE 5	THROTTL W/ FPCV, F=15000								
CASE 6	THROTTL W/ FPCV, F=10000								
CASE 7	THROTTL W/ FPCV, F=7500								
CASE 8	THROTTL W/ FPCV, F=5000								

CASE 1
CASE 2
CASE 3
CASE 4
CASE 5
CASE 6
CASE 7
CASE 8

NDM BAL 50K 4-3-69
THROTTLE W/ FPCV, F=37500
THROTTLE W/ FPCV, F=25000
THROTTLE W/ FPCV, F=20000
THROTTLE W/ FPCV, F=15000
THROTTLE W/ FPCV, F=10000
THROTTLE W/ FPCV, F=7500
THROTTLE W/ FPCV, F=5000

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TABLE A-I (cont.)

PAGE	2	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124	
POSTB	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	
POSTB	46.16808	46.99314	51.04378	51.04378	52.11952	52.11952	52.11952	52.11952	
POSTB	40.68841	45.62797	49.62797	50.73302	51.59979	52.29797	52.29797	52.29797	
POSTB	145.54107	126.41642	102.85377	92.96816	82.99013	73.02516	67.06360	62.38967	
POSTM	135.20481	120.40010	100.03030	91.10299	81.79189	72.50135	67.54735	62.21523	
POSTM	128.51244	116.52212	98.22409	89.91581	81.09789	72.17438	67.35164	62.10801	
POSTM	5678.55737	3897.67178	2336.55689	1787.00163	1280.33464	826.26543	611.34128	404.47927	
POSTM	5661.65131	3886.47754	2332.55483	1784.37918	1279.31663	826.19556	611.53693	404.81832	
POSTM	5446.71991	3579.94571	2329.09018	1782.39340	1278.01111	825.19520	611.18785	404.63346	
PFT	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	
PFTB	14.04590	18.18697	21.20452	22.08497	22.78552	23.29484	23.49273	23.55782	
PFTB	5.87490	13.49235	19.04311	20.66270	21.95136	22.88825	23.25226	23.55539	
PFTB	83.55895	71.84718	56.60793	50.07616	43.43273	36.82240	33.50067	30.20750	
PFTB	76.31833	67.68612	54.68453	48.81477	42.89048	36.85864	33.26444	30.11473	
PFTB	67.91231	62.87632	52.47662	47.35470	41.83322	36.03990	33.03630	30.00887	
PFTB	5135.84387	3531.91768	2104.50824	1599.66646	1134.91560	718.52898	522.25422	333.53614	
PFTB	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130	
PFTB	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130	
PFTB	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.94207	482.05486	317.97361	
PFTB	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.94207	482.05486	317.97361	
PFTB	5070.03559	3494.04678	2037.07230	1588.20117	1128.20099	714.97482	520.32830	332.82227	
PFTB	5069.62292	3493.84415	2086.99005	1588.14909	1128.17099	714.96002	520.31908	332.81747	
PFTB	6783.81042	4723.39929	2827.90866	2148.59815	1521.22769	956.74412	695.18646	442.83855	
PFTB	6690.97443	4679.62054	2909.30145	2136.93512	1514.62633	955.65185	693.35930	442.87576	
PFTB	6259.57428	4475.92688	2730.46854	2088.16199	1487.28947	942.60142	685.38762	438.02097	
PFTB	5915.58417	3936.31119	2325.60370	1789.53341	1292.15045	834.52796	616.29827	404.77417	
PFTB	5909.50714	3533.79346	2374.60146	1789.19174	1291.93935	834.44840	616.25780	404.75877	
PCPC	5190.95974	3597.55630	2196.55225	1485.20627	1218.93098	788.56866	583.22816	384.12576	
PCPC	5049.89966	3490.79633	2127.13469	1639.81248	1185.71046	767.37338	567.37952	373.88782	
PCPC	3031.84540	2252.36416	1432.05974	1192.89618	896.39140	603.87495	456.91117	309.59784	
PCPC	3020.00020	2245.15240	1438.20470	1190.05440	894.47915	602.77700	456.18209	309.16123	
PCPC	3020.14005	2245.10295	1438.12440	1190.03214	894.45525	602.71902	456.09369	309.09309	
PCPC	2931.84850	2190.83707	1459.00121	1168.93823	880.25053	594.27000	450.13311	305.42107	
PCPC	2800.00000	2165.08371	1445.18140	1156.91188	873.49461	590.24858	447.29484	303.67186	
PCPC	2799.99960	2097.65866	1400.15629	1122.82104	846.29224	571.86706	433.36518	294.21492	
PCPC	.42596	.32010	.21433	.17155	.12880	.09470	.06424	.04020	
CASE 1	NOM BAL SOK	4-3-69							
CASE 2	THROTILE W/ FPCV	F=37500							
CASE 3	THROTILE W/ FPCV	F=25000							
CASE 4	THROTILE W/ FPCV	F=20000							
CASE 5	THROTILE W/ FPCV	F=15000							
CASE 6	THROTILE W/ FPCV	F=10000							
CASE 7	THROTILE W/ FPCV	F=7500							
CASE 8	THROTILE W/ FPCV	F=5000							

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TABLE A-I (cont.)

PAGE	CASE 3	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
P	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124	
DP/PSF	.07976	.06520	.04767	.04002	.03181	.02341	.01833	.01112	
DP/PPC	.09343	.08314	.06865	.05056	.04831	.03841	.03433	.02433	
DP/PPF	.13844	.09347	.06323	.06171	.05998	.05805	.05667	.05371	
PCSC	2799.99960	2097.65866	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492	
MRSC	2.20000	2.20888	2.21865	2.21258	2.20118	2.13944	2.14111	2.49228	
AE/AT	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794	
ETAC	.99188	.98967	.98756	.98666	.98573	.98424	.98341	.98316	
ETAN	.92697	.92396	.91861	.91487	.90899	.89791	.88754	.86847	
CASC	5663.70313	5626.87305	5597.35156	5574.74481	5563.83972	5570.63324	5559.67273	5393.40002	
CF	1.92012	1.92143	1.91898	1.91435	1.90502	1.87978	1.86056	1.82782	
WGJSC	104.04743	77.55334	51.57234	41.20716	30.90544	20.54246	15.53569	11.30450	
WJSC	34.56004	26.89136	18.60042	15.17180	11.64895	8.11872	6.17990	3.91216	
WFC	9.35002	7.15936	4.82747	3.90144	2.97028	2.06366	1.59597	1.11062	
WFC/WT	.06319	.06390	.06437	.06472	.06525	.06717	.06841	.06802	
DPFJSC	168.06671	103.53839	50.94221	34.4525	20.76068	10.40594	6.21493	2.58714	
DPJSC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
WJPC	91.13517	68.62238	46.02486	36.86686	27.62097	18.31919	13.78734	10.02634	
WJPC	8.75658	5.65724	3.20164	2.37775	1.64512	1.01061	.72110	.44499	
MRPC	10.40762	12.13002	14.37540	15.50491	16.83223	18.12694	19.11988	22.53152	
YIT	1400.10164	1219.46159	1175.66423	1165.96980	1164.45190	1187.39537	1205.10089	1181.92430	
KGIT	1.25221	1.24711	1.24098	1.23996	1.24149	1.24654	1.25272	1.25853	
RGIT	47.59236	45.01923	42.25354	41.08126	39.87002	38.95803	38.16378	37.04282	
CAPC	236.29641	227.19951	217.59354	212.27901	204.96897	196.46922	189.17519	160.82987	
MOB	2562.78541	2325.73523	2084.05545	1983.56655	1879.70274	1789.12054	1728.12715	1533.81288	
MOB	168.79651	127.36484	84.62177	67.29646	49.96876	33.28850	24.70594	15.72145	
MON	201.00394	150.78547	96.84434	75.77663	55.30142	35.84579	26.35249	17.09461	
MON	8978.73022	6110.26855	3613.36777	2738.28061	1934.09029	1215.56755	876.64743	551.55984	
MFH1	13226.17834	9027.58044	5323.09955	4020.35272	2826.96634	1761.13057	1262.08604	782.09409	
MFH2	4905.43347	3405.86746	2004.49904	1504.23953	1046.87180	644.63547	460.66193	288.59128	
NPSMOB	45.92397	50.47866	53.78460	54.75663	55.51878	56.07274	56.26349	56.38548	
NPSMFB	29.08461	39.71678	47.46400	49.72441	51.52294	52.83051	53.33854	53.76159	
NPSMOM	186.86927	163.56992	131.30132	117.11486	102.30433	87.50762	79.63420	71.23844	
NPSMFM	188.25339	166.21330	132.93567	117.89203	102.22940	86.30369	78.19633	70.09695	
NPSMFB	28.54422	31.37634	33.43210	34.03657	34.51053	34.85502	34.97365	35.04951	
NPSMFB	11.33037	15.07269	18.49116	19.37188	20.07264	20.56211	20.78006	20.94490	
NPSMOM	115.84853	101.48799	81.50263	72.71025	63.52596	54.34547	49.46045	44.25490	
NPSMFM	72.99051	64.51433	51.65218	45.82580	39.75379	33.57486	30.42736	27.28084	

CASE 1
CASE 2
CASE 3
CASE 4
CASE 5
CASE 6
CASE 7
CASE 8

NOM BAL SOK 4-3-69
TMRITILE W/ PCV, F=37500
TMRITILE W/ PCV, F=25000
TMRITILE W/ PCV, F=20000
TMRITILE W/ PCV, F=15000
TMRITILE W/ PCV, F=10000
TMRITILE W/ PCV, F=7500
TMRITILE W/ PCV, F=5000

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TABLE A-I (cont.)

PAGE	CASE 4	CASE 1	CASE 2	CASE 3	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.92124
ETA-T	.72417	.70721	.65587	.62273	.57649	.50854	.46192	.40911
WTI	99.89175	74.27962	49.22050	39.24461	29.32960	19.32960	14.50844	10.47133
U/C-GT	.48399	.45312	.38519	.35100	.30996	.25847	.22723	.19475
SMPT	5665.54967	2988.63614	1250.23013	789.37869	445.19677	207.92380	122.49430	57.96613
SMQW	3095.91207	1633.72458	686.19165	434.16777	245.35813	114.67516	67.92716	33.44826
SMQW1	2287.13550	1199.00391	457.19525	312.91241	175.63265	81.59637	47.53383	21.01070
SMQW2	300.64079	158.61094	68.86947	42.65581	24.42165	11.71639	7.07982	3.82670
APT	1.67215	1.52582	1.42933	1.37759	1.32959	1.27376	1.23735	1.20871
POSTM	135.20481	120.40010	100.30300	91.10299	81.79188	72.50135	67.54735	62.21523
PODTR	5701.51709	3911.09134	2342.95496	1791.15221	1282.76683	827.41385	612.02927	404.86644
MDMNC	9979.33948	6109.60181	3613.36871	2738.28226	1934.09071	1215.59002	876.64919	581.56396
QDSM	580.61271	441.62129	301.44349	248.36477	186.81782	128.22523	99.19727	73.41608
MDM/N2	-5 65591913	-5 67092492	-5 68100372	-5 70205547	-5 71549671	-5 73194095	-5 73894940	-5 74183711
Q/DUM	.99988	.93290	.83994	.78840	.72401	.63399	.58030	.54251
ETA-OM	.60999	.59804	.57481	.55820	.53346	.49243	.46386	.43874
NSO	966.51167	917.87294	851.69246	815.67533	770.52401	708.84920	673.34261	649.14590
SOM	17640.02100	13667.14148	10235.97607	8672.13123	6986.11047	5100.54175	4069.51727	3013.11398
DQSM	84.27197	69.33470	69.38507	69.40175	69.41692	69.42933	69.43778	69.45599
PFSTM1	76.31833	67.69612	54.69453	48.81477	42.69048	36.45864	33.28444	30.11473
PFDTM1	5204.85425	3571.55325	2122.77673	1611.69969	1141.98445	721.69334	524.30166	334.80968
MFNMC1	13226.32520	9027.58484	5323.09961	4020.35275	2826.96637	1761.13058	1262.08606	792.09409
QFSM1	406.64429	310.04911	212.47947	173.44744	134.03779	94.86620	73.82770	49.41988
MF1/N2	-5 96615121	-5 99136570	-4 10179646	-4 10307596	-4 10450668	-4 10604446	-4 10638437	-4 10518933
Q/QDF1	1.09549	1.02412	.92617	.87539	.81261	.73375	.67562	.57128
ETAFM1	.53190	.52859	.51564	.50534	.49443	.48469	.44478	.41766
NSF-1	604.95779	573.72725	534.87350	515.15665	490.97324	461.78433	441.97585	409.87395
SFM1	14681.13000	11478.61213	9514.42834	7270.03015	5920.77527	4432.99982	3559.07886	2502.25952
DdFM1	55.83237	55.89242	55.95123	55.97423	55.99706	56.02055	56.03254	56.04297
PFSTM2	5070.03558	3494.24678	2087.07230	1588.20117	1128.20099	714.97482	520.32830	332.82227
PFDTM2	6980.67706	4820.06427	2867.11068	2173.52573	1535.52271	965.79538	699.57442	445.12442
MFNMC2	4905.43347	3405.86746	2004.40904	1504.23953	1046.87180	644.63547	460.66193	288.59128
QFSM2	96.95612	67.95642	43.29627	34.45867	26.15241	18.37136	14.45793	10.46224
MF2/N2	-5 75833011	-5 37401589	-5 37331390	-5 38566499	-5 36727931	-5 38815986	-5 38830340	-5 38814668
Q/QDF2	1.08706	.93420	.78544	.72361	.65986	.59138	.55202	.50334
ETAFM2	.35922	.33269	.29464	.27584	.25446	.22943	.21407	.19435
NSF-2	621.55087	557.97322	502.28653	479.97099	456.84664	431.75451	417.02493	398.33066
NT	36999.60107	30176.45805	22667.35547	19749.37646	16481.24097	12886.99866	10891.94800	8622.70764

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NOM BAL 50K 4-3-69
THROTTLE W/ FPCV, F=37500
THROTTLE W/ FPCV, F=25000
THROTTLE W/ FPCV, F=20000
THROTTLE W/ FPCV, F=15000
THROTTLE W/ FPCV, F=10000
THROTTLE W/ FPCV, F=7500
THROTTLE W/ FPCV, F=5000

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F	50012-21436	37492-86035	24994-00391	19994-96362	14997-14026	9999-79663	7500-45233	5002-52124	
NT08	12060-08008	9910-92163	7553-14008	6538-32922	5456-39355	4288-56812	3624-14210	2856-83514	
W08	104-64036	79-02541	53-19829	42-73104	32-22763	21-59539	16-41040	11-97025	
Y08	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	
POSTB	46-16808	46-95314	51-04378	51-64674	52-11952	52-46316	52-58149	52-65716	
POB7B	748-59799	128-16010	103-64404	93-47804	83-18015	73-15541	67-93881	62-42969	
MOBNC	165-69230	127-60765	84-66467	67-31367	49-97422	33-28965	24-70633	15-72154	
Q08	524-69964	396-24397	266-73639	214-25191	161-58719	108-27737	82-28020	60-01763	
MOB/N2	-5 1139201	-5 12991201	-5 1480453	-5 15745981	-5 16785512	-5 18100257	-5 1810368	-5 19263030	
Q/000B	1-16201	1-06782	94320	87520	79095	67433	60637	56110	
ETA08	59786	61975	60909	59012	55738	50034	46133	42986	
SHPOB	52-44305	29-52639	13-43804	8-66001	5-25304	2-61231	1-59790	79600	
S08	15659-87219	10417-81677	6211-37030	4754-59808	3410-29102	2177-85803	1600-27667	1075-62622	
PT10B	3906-83594	2689-93500	1620-16797	1243-21922	895-61680	564-00416	436-94977	294-35874	
DPT08	3763-29486	2563-51855	1517-31419	1150-25105	812-72667	510-57899	368-58617	231-96706	
Y110B	101-10693	94-32657	86-45785	66-37250	84-42132	82-64503	81-64768	80-28546	
Y10B	10-85083	8-92025	6-83858	5-94685	4-99313	3-95519	3-35783	2-66323	
CTA10B	44923	44811	44626	44522	44395	44241	44154	44046	
N1F8	14180-32434	11636-53592	8838-54150	7638-40338	6360-75812	4980-03906	4194-20209	3284-49274	
TF8	43-31682	32-54859	21-80206	17-54956	13-29406	9-12932	6-91900	4-35715	
PF8	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	
PF0TB	14-04590	18-16657	21-20452	22-08497	22-78552	23-29484	23-49273	23-65752	
MF8NC	92-35020	76-89815	58-93340	51-06640	44-33021	37-25992	33-75939	30-31738	
MF8	201-49904	150-73983	96-84611	75-77705	55-30149	35-84580	26-35260	17-09461	
QF8	346-54838	250-35393	174-41670	140-39590	106-35164	73-03378	55-35132	34-85674	
MF8/N2	-5 1020760	-5 11132182	-5 12397125	-5 12987708	-5 13668444	-5 14453490	-5 14980444	-5 15846111	
Q/00F8	1-08444	59297	87566	81561	74193	65076	58561	47092	
ETA0F8	62796	62833	59956	57620	54177	49196	45300	38011	
SHPF8	25-20966	14-19410	6-40287	4-19628	2-46728	1-20943	73182	35628	
SF8	21078-16821	11869-18555	6455-25775	4933-53424	3411-08624	2171-91721	1581-04678	976-71943	
PT1F8	3807-28156	2616-50314	1556-93089	1185-54143	842-19587	534-79593	390-36483	251-46733	
DPT1F8	3723-72260	2544-65594	1502-32295	1135-46526	798-76314	497-97346	356-86416	221-25983	
Y11F8	107-14187	58-59249	91-06706	88-34954	85-78525	83-33206	82-11070	80-85474	
N1F8	3-91124	3-23228	2-48286	2-15835	1-81017	1-42926	1-20994	95276	
ETA1F8	37096	36963	36755	36649	36518	36365	36272	36173	
W0T5	2-04618	1-62318	1-17309	98261	78540	61796	53214	44455	
W0BY	1-07141	83184	58537	48698	38782	29339	24413	19192	
WFBY	1-03608	81870	59734	49276	39613	30131	25098	19670	
WFRYS	3-36019	2-83186	2-20459	1-92442	1-61975	1-28290	1-06842	86130	

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NOM BAL 50K 4-3-69
THROTTLER W/ FPCV. F=37500
THROTTLER W/ FPCV. F=25000
THROTTLER W/ FPCV. F=20000
THROTTLER W/ FPCV. F=15000
THROTTLER W/ FPCV. F=10000
THROTTLER W/ FPCV. F=7500
THROTTLER W/ FPCV. F=5000

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F	50012-21436	37492-66035	24994-00391	19994-96362	14997-14026	9990-79663	7500-45233	5002-52124	
POT	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	
OPDE1	16-44482	9-11209	3-78942	2-22437	2-22437	10529	200186	39827	
POEIT	51-02575	51-49659	51-63836	51-93886	52-01765	52-07493	52-09465	52-10726	
POE1	35-05518	42-38791	47-71058	49-27563	50-50277	51-39471	51-70186	51-89827	
OPD58	-5-63323	-3-46006	-1-91701	-1-45740	-1-09702	-83507	-74487	-68719	
PO578	46-16808	48-99314	51-04378	51-64874	52-11952	52-46316	52-58149	52-68716	
POS8	40-66841	45-66791	49-62758	50-73302	51-59979	52-22379	52-44673	52-58546	
POD78	148-59799	128-16010	103-64404	93-47804	83-18015	73-15541	67-93681	62-43969	
POD8	145-54107	126-41642	102-85377	92-96816	82-99013	73-02516	67-86360	62-38967	
OPDSM	17-02863	9-89430	4-62969	3-05235	1-79223	65079	51196	28166	
POSTM	135-20481	120-42010	100-03030	91-10299	81-79188	72-50135	67-54735	62-21523	
PSM	128-51244	116-52212	98-22409	89-91581	81-69789	72-17438	67-35164	62-10801	
POD7M	5701-51709	3911-09134	2342-95496	1791-15221	1282-76683	827-41385	612-02927	404-88644	
PODM	5678-55737	3897-67178	2336-65659	1787-00163	1280-33464	826-26543	611-34128	404-47927	
DPOM	20-46783	11-45361	4-98917	3-12178	1-68965	67709	35264	16851	
POHT	5675-95276	3896-64538	2336-65646	1787-26007	1280-76285	826-78592	611-87162	404-99538	
POH	5661-65131	3896-47754	2332-95483	1784-67918	1279-41563	826-19556	611-53495	404-61832	
DPQORF	14-93140	8-53183	3-86465	2-48578	1-40552	61636	34940	18486	
POJPC	5675-95276	3896-64538	2336-65646	1787-26007	1280-76285	826-78592	611-87162	404-99538	
POJPC	5646-71991	3879-94571	2329-09018	1782-39340	1278-01111	625-57920	611-18755	404-63346	
OPDPC	455-76117	282-38940	142-53793	97-18713	59-18013	36-91054	27-95939	20-50770	
PCPC	5190-95874	3597-55630	2186-55225	1685-20627	1218-83098	788-66866	593-22816	384-12576	
TOT	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	
DROT	89-51039	89-51039	89-51039	89-51039	89-51039	89-51039	89-51039	89-51039	
WOT	104-64036	79-02541	53-19829	42-73104	32-22763	21-59539	16-41040	11-97025	
WOSM	115-49118	87-94566	60-03687	48-67789	37-22075	25-55097	19-76823	14-63348	
TODM	101-10693	94-32657	88-45785	86-37250	84-42132	82-64503	81-64768	80-28546	
DQDDM	91-57873	90-85628	90-21813	89-99314	89-79204	89-61235	89-53961	89-50108	
WQFC	91-13517	68-62238	46-02486	36-86586	27-69097	16-31919	13-78734	10-02634	
WQFC	9-35002	7-12936	4-82747	3-90144	2-97028	2-06366	1-59597	1-11062	
WTOB	10-85083	8-92025	6-83858	5-94585	4-99313	3-95319	3-35783	2-63233	
WTS	2-10749	1-65054	1-17275	97974	78395	59470	49312	38863	
TQJPC	103-95350	96-08595	89-34118	86-97283	84-78528	82-66700	81-81347	80-40558	
DQJPC	90-99968	90-49996	90-03992	89-87428	89-71996	89-56796	89-50655	89-47722	
REDJPC	6719-86176	4799-82550	3078-22818	2427-50638	1797-29466	1174-17178	877-64201	632-40393	
REFJSC	36213-98340	25719-69946	16361-19995	12948-75916	9667-19912	5565-67834	4950-01215	3085-40170	

CASE 1
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NON BAL SOK 4-3-69
THROTTLE W/ FPCV. F=37500
THROTTLE W/ FPCV. F=25000
THROTTLE W/ FPCV. F=20000
THROTTLE W/ FPCV. F=15000
THROTTLE W/ FPCV. F=10000
THROTTLE W/ FPCV. F=7500
THROTTLE W/ FPCV. F=5000

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TABLE A-I (cont.)

PAGE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012-21436	37492-06035	24994-00391	14994-96362	14997-14025	9999-79663	7500-45233	5002-52124
PFT	23-00000	23-00000	23-00000	23-00000	23-00000	23-00000	23-00000	23-00000
D#E1	9-41550	5-24446	2-20433	1-31729	-61150	-09837	-10100	-26702
D#E1T	21-75524	22-45058	22-95727	23-10511	23-22274	23-30826	23-34149	23-36916
D#E1T	13-58350	17-75554	20-79867	21-68271	22-38850	22-90163	23-10100	23-28702
D#F5B	7-70860	4-26319	1-75256	1-02001	-43714	-01338	-15126	-28837
D#F5B	14-04590	18-18697	21-20452	22-08497	22-78552	23-29484	23-49273	23-65752
D#F5B	5-87490	13-49235	19-04311	20-66270	21-95136	22-88825	23-25226	23-55539
D#F5B	92-35020	76-89815	59-93340	51-60640	44-33021	37-25992	33-75939	30-31738
D#F5B	83-55695	71-64718	56-60793	50-07616	43-43273	36-82246	33-50067	30-20750
D#F5B	21-00696	21-00696	21-00696	21-00696	21-00696	21-00696	21-00696	21-00696
D#F5B	76-31833	67-69612	58-69853	48-81477	42-69048	36-45664	33-28444	30-11473
D#F5B	67-91231	62-87632	52-47662	47-33470	41-83322	36-03630	33-03630	30-08867
D#F5B	5204-65425	3571-55325	2122-77673	1611-69969	1141-98445	721-65334	524-30166	334-50968
D#F5B	5135-84387	3531-91788	2104-50824	1594-66646	1134-91560	718-22898	522-25422	333-63614
D#F5B	900-26923	544-02621	259-79826	172-68219	101-64490	49-20655	28-55066	11-13745
D#F5B	4304-92139	3027-64993	1463-00653	1439-02991	1040-34386	672-48781	495-75135	323-31229
D#F5B	4242-94507	2990-18460	1845-10246	1427-12230	1033-32628	669-04014	493-76570	322-52130
D#F5B	-00000	-00000	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	4304-92139	3027-64993	1863-00653	1410-02991	1040-34386	672-48781	495-75135	323-31229
D#F5B	4242-94507	2990-18460	1845-10246	1427-12230	1033-32628	669-04014	493-76570	322-52130
D#F5B	372-34891	224-77448	107-22556	71-23007	41-88982	20-22807	11-71083	4-54769
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000	-00000	-00000	-00000	-00000	-00000
D#F5B	3932-71283	2802-92551	1755-79259	1367-80496	998-45582	652-25015	484-04065	318-76461
D#F5B	3670-59616	2602-92551	1737-87691	1355-89223	991-43646	648-84207	482-05486	317-97361
D#F5B	3970-59616	2765-40912	-00000					

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TABLE A-I (cont.)

PAGE	CASE 8	CASE 1	CASE 7	CASE 3	CASE 5	CASE 6	CASE 7	CASE 8
F	50012-21436	37492-86035	24994-00391	19994-96362	14997-14024	9999-79663	7500-45233	5002-52124
PFDTM1	5204-85425	3571-55325	2125-77673	1611-69969	1141-98445	721-69334	524-30166	334-50968
PFDM1	5135-84387	3531-91788	2104-50824	1599-66646	1134-91560	718-23898	522-25422	333-63614
DFFSM2	66-22095	36-07373	17-51919	11-51736	6-74461	3-27896	1-93513	81868
PFSTM2	5070-03058	3494-04578	2087-07230	1588-20117	1128-20099	714-97482	520-32830	332-82227
PFSTM2	5069-62292	3493-84415	2086-99005	1588-14909	1128-17099	714-96002	520-31908	332-81747
PFDTM2	6980-67706	4820-06427	2867-11868	2173-55273	1535-53271	985-79538	699-37442	445-12442
PFDM2	6783-61042	4723-39929	2627-90066	2149-69815	1521-22769	959-74412	695-12646	442-83855
DFPACL	92-10547	45-03687	16-08578	11-34351	6-40701	3-01244	1-76441	77939
PFPCRT	6887-95074	4776-31189	2848-51581	2-61-76443	1528-92191	982-71325	697-74731	444-36164
PFPCRT	6690-97443	4679-62054	2809-30145	2136-92512	1514-62633	955-66185	693-35930	442-07576
DFPPOS	431-40015	203-69366	78-83292	48-77313	27-33685	13-06043	7-57188	4-08479
PFPCVT	6362-77753	4518-93500	2744-23035	2095-74945	1490-91995	943-57789	686-08451	438-28625
PFPCV	6259-57428	4475-92888	2730-48854	2088-16199	1487-28947	942-60142	685-38762	438-02097
DFPFCV	343-99011	539-61565	408-86484	298-52858	195-13902	108-07346	65-08935	33-24680
PFPCVT	6019-00366	3979-46060	2335-35935	1797-23460	1295-78522	935-95812	616-99545	405-03950
DFPCM	5915-58417	3936-31119	2325-60370	1789-63341	1292-15045	834-52796	616-29827	404-77417
DFPCM	6-07703	2-51773	-80222	-44167	-21111	-07956	-04047	-01840
PFJPC	5909-57422	3933-62144	2324-81046	1789-19667	1291-94171	834-44930	616-25826	404-75894
DFJPC	5900-50714	3933-79346	2324-80148	1789-19174	1291-93935	834-44840	616-25780	404-75877
DFJPC	718-54840	336-23715	139-24924	103-98547	73-10837	45-77974	33-02964	20-53301
PCPC	5190-55074	3597-55630	2186-55225	1685-20627	1218-83098	788-66866	523-22816	384-12576
TFSM2	107-14137	98-59249	91-06705	88-34954	85-78525	83-13206	82-11070	80-85474
DFSM2	56-08727	56-06399	56-03980	56-03279	56-02819	56-02881	56-03120	56-03603
WFSM2	12-11677	8-48910	5-48623	4-30217	3-26487	2-29351	1-80952	1-30629
TFDM2	123-25920	111-14205	99-88475	95-59744	91-41651	87-30747	85-20690	83-08076
DFDM2	55-93329	55-91336	55-90528	55-91175	55-92528	55-94928	55-96619	55-98720
WFJPC	8-75658	5-65724	3-20164	2-37775	1-64512	1-01061	72110	44499
WFRTS	8-75658	5-65724	3-20164	2-37775	1-64512	1-01061	72110	44499
TFJPC	131-78693	116-98545	103-11553	97-91363	92-91802	88-14769	85-74055	83-34069
DFJPC	55-32563	55-49869	55-67501	55-74660	55-81818	55-88937	55-92684	55-96853
REFJPC	5003-36780	2933-60421	1503-63565	1073-52443	714-28022	422-22259	295-39222	178-82657

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CASE 1
CASE 2
CASE 3
CASE 4
CASE 5
CASE 6
CASE 7
CASE 8

NOM 9AL 50K 4-3-69
THROTTLE W/ PFCV, F=37500
THROTTLE W/ PFCV, F=25000
THROTTLE W/ PFCV, F=20000
THROTTLE W/ PFCV, F=15000
THROTTLE W/ PFCV, F=10000
THROTTLE W/ PFCV, F=7500
THROTTLE W/ PFCV, F=5000

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TABLE A-I (cont.)

PAGE	9	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012-21436	37492-56035	24994-00391	15994-90362	14997-14026	9999-79663	7500-45233	5002-52124	
POPC	5190-95874	3597-55630	2196-55225	1695-20627	1218-83096	789-66866	583-22616	384-12576	
POPC	141-05908	97-75998	59-41736	45-73179	33-12051	21-84864	15-84864	10-43823	
PTIT	5049-69966	3499-79633	2127-13489	1639-41248	1185-71046	767-23738	567-37952	373-68752	
PTET	3031-84540	2252-36816	1492-05974	1192-85618	894-39140	603-87495	456-91117	309-59784	
OTE	7020-00000	2245-15240	1488-20470	1190-05440	994-87815	602-77700	456-18209	309-16123	
DPITX	-114005	.05145	.08029	.02226	.02290	.05798	.08820	.06814	
PPIT	3031-84540	2252-36816	1492-05974	1192-85618	894-39140	603-87495	456-91117	309-59784	
PPI	3020-14005	2245-10095	1486-12440	1190-03214	894-45525	602-71902	456-09389	309-09309	
DPPI	89-29355	54-26369	29-12320	21-09390	14-20472	8-44901	5-96078	3-67202	
PPET	2943-00494	2194-28418	1463-01497	1171-95406	882-21795	595-44241	450-96120	305-93191	
PPE	2931-04650	2190-03707	1459-00121	1168-93823	880-25053	594-27000	450-13311	305-42107	
DPJMG	41-84850	28-75334	13-83971	10-02635	6-75593	4-02142	2-83827	1-74920	
PCFACE	2890-00000	2165-02371	1445-18150	1158-91184	873-49461	590-24858	447-29484	303-67188	
PCSC	2799-99960	2097-65866	1400-15628	1122-82104	846-29224	571-86706	433-36518	294-21492	
PESC	.42596	.32010	.21433	.17155	.12880	.08470	.06424	.04020	
TPC	1400-10164	1154-01673	916-72253	822-14769	727-31473	646-87016	595-19215	503-27549	
WPC	99-82175	74-27962	49-22650	39-24461	29-33609	19-32080	14-50844	10-47133	
TTIT	1400-10164	1218-46159	1175-66423	1165-06990	1164-45190	1187-39537	1205-10089	1181-92430	
TTET	1267-62222	1057-41878	852-52657	770-03288	686-59409	616-75777	570-64542	484-34471	
TJMG	1240-13786	1066-71042	864-92714	782-10553	697-67340	626-62718	578-76796	487-72290	
WJMG	104-04743	77-55334	51-57234	41-20716	30-90544	20-54246	15-53569	11-30450	
PDITM	5701-51709	3911-09134	2342-95496	1791-15221	1282-76683	827-41385	612-02927	404-85644	
POFCL	5658-08954	3896-21817	2331-66772	1783-87985	1278-64499	825-58634	610-98864	404-31076	
DPFCL	1277-75122	751-89819	349-31291	229-42733	133-66604	65-21451	39-23078	19-15996	
POJFCT	4380-33832	3134-32892	1982-33481	1554-35252	1144-95895	760-37383	571-75786	385-15081	
POJFC	4380-33832	3134-32892	1982-33481	1554-35252	1144-95895	760-37383	571-75786	385-15081	
DPJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
POFCD	4380-33832	3134-32892	1982-33481	1554-35252	1144-95895	760-37383	571-75786	385-15081	
WDFC	2-35502	7-12936	4-82747	3-90144	2-97028	2-06366	1-59597	1-11062	
TOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
DPJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	

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CASE 1
CASE 2
CASE 3
CASE 4
CASE 5
CASE 6
CASE 7
CASE 8

WPM BAL 50K 4-3-69
THROTTLE W/ FPCV, F=37500
THROTTLE W/ FPCV, F=75000
THROTTLE W/ FPCV, F=20000
THROTTLE W/ FPCV, F=15000
THROTTLE W/ FPCV, F=10000
THROTTLE W/ FPCV, F=7500
THROTTLE W/ FPCV, F=5000

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TABLE A-I (cont.)

PAGE 10	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012-21436	37492-04035	24994-00391	19994-96362	14997-14026	9999-79663	7500-45233	5002-52124
WFC/WT	06319	06390	06437	06472	06525	06717	06841	06802
WFC	9-35002	7-12936	4-82747	3-90144	2-97026	2-06366	1-59597	1-11062
WFCI	5658-08954	3886-21817	2331-66772	1763-67985	1276-64499	925-58634	610-98864	404-31076
WFCDO	4380-33832	3134-32692	1982-35481	1554-35252	1144-95895	760-37383	571-75769	385-15081
WFC	91-19613	90-63428	93-11629	89-92861	89-75352	89-59380	89-52882	89-49563
WFCI	1-41029	1-0527	0-68956	0-54712	0-40708	0-27502	0-20986	0-14336
WFC2	2-09126	1-56965	1-03674	0-26333	0-61822	0-42100	0-32161	0-22049
WFC3	1-99226	1-51191	1-01572	0-61704	0-61815	0-42605	0-32774	0-22648
WFC4	0-94191	0-72154	0-99178	0-39870	0-30456	0-21215	0-16422	0-11432
WFC5	0-93313	0-72049	0-99706	0-40564	0-31241	0-21961	0-17093	0-11977
WFC6	0-74160	0-57751	0-40366	0-33177	0-25779	0-18307	0-14359	0-10125
WFC7	0-54046	0-40065	0-28321	0-23448	0-18369	0-13172	0-10379	0-07185
WFC8	0-26708	0-21150	0-13164	0-12638	0-09993	0-07246	0-05781	0-04129
WFC9	0-22692	0-16306	0-13495	0-11420	0-09207	0-06838	0-05915	0-04047
WFC10	0-23510	0-18023	0-12294	0-09973	0-07638	0-05361	0-04176	0-02933
PCPC	5190-95874	3597-55630	2186-55225	1685-20637	1218-63098	788-66866	583-22816	384-12576
PTT	5049-99966	3499-79633	2127-13489	1639-41248	1185-71046	767-23738	567-37952	373-69752
PTE	3020-00000	2245-15240	1488-20470	1190-05480	894-47815	602-77700	456-18209	309-16123
WPT	1-57215	1-55882	1-42933	1-37759	1-32559	1-27284	1-24376	1-20871
WPC	10-40762	12-13002	14-37540	15-50491	16-63223	18-12694	19-11968	22-53152
WPC	1400-10164	1154-61873	916-72233	922-14769	727-31473	646-87016	595-19215	503-27549
WPC	47-59236	45-01923	42-25354	41-08126	39-87002	38-85803	38-16378	33-04282
WPC	1-25221	1-24711	1-24098	1-23996	1-24149	1-24684	1-25272	1-25858
WPC	2562-78549	2325-73523	2062-05545	1983-66655	1879-70274	1799-12034	1728-12715	1533-81288
WPC	0-00000	0-04618	0-18324	0-24158	0-30387	0-36882	0-40782	0-48758
WPC	10-40762	11-52373	11-55809	11-51761	11-41363	11-11071	10-91446	11-05808
WPC	1400-10164	1219-46159	1175-66423	1165-96980	1164-45190	1167-39537	1205-10089	1181-92430
WPC	47-59236	45-99496	46-27354	46-46309	46-75576	47-40097	47-81301	47-59564
WPC	1-25221	1-25007	1-25410	1-25568	1-25753	1-26034	1-26202	1-26176
WPC	1-64757	1-64176	1-63102	1-62985	1-62970	1-63466	1-63466	1-63560
WPC	1667-82895	1452-92343	1295-35309	1227-71542	1156-84329	1087-33424	1045-16733	966-72054
WPC	0-48399	0-45312	0-38519	0-35100	0-36	0-25847	0-22723	0-19475
WPC	1267-62222	1057-41878	852-52657	770-03288	686-55	616-75777	570-64542	484-34471

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CASE 1
CASE 2
CASE 3
CASE 4
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CASE 6
CASE 7
CASE 8

MON BAL 50K 4-3-69
THROTTLE W/ PFCV. F=37500
THROTTLE W/ PFCV. F=25000
THROTTLE W/ PFCV. F=20000
THROTTLE W/ PFCV. F=15000
THROTTLE W/ PFCV. F=10000
THROTTLE W/ PFCV. F=7500
THROTTLE W/ PFCV. F=5000

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TABLE A-II

Engine Parameter Symbols

UNITS: LB, PSI, PSIA, SEC, LB/SEC, RPM, °F, IN², LB/FT³

F	THRUST
PCSC	SECONDARY COMBUSTOR CHAMBER PRESSURE, TOTAL AT THROAT
MR-ENG	ENGINE MIXTURE RATIO
IS	SPECIFIC IMPULSE
W-ENG	ENGINE PROPELLANT FLOW RATE
WOT	ENGINE OXIDIZER FLOW RATE
WFT	ENGINE FUEL FLOW RATE
NT	TURBINE SPEED
TTIT	TURBINE INLET TEMPERATURE - TOTAL
RPT	TURBINE PRESSURE RATIO - TOTAL TO STATIC
POEIT	ENGINE INLET PRESSURE, OXIDIZER-TOTAL
TOEIT	OXIDIZER TEMPERATURE AT INLET
PFEIT	ENGINE INLET PRESSURE, FUEL-TOTAL
TFEIT	FUEL TEMPERATURE AT INLET
ATSC	SECONDARY COMBUSTOR THROAT AREA
ATT	TURBINE AREA
ATT*	TURBINE CHARACTERISTIC AREA
ATOBP	OXIDIZER BOOST PUMP TURBINE AREA
ATFBP	FUEL BOOST PUMP TURBINE AREA
KWFSCV	SECONDARY COMBUSTOR FUEL VALVE ADMITTANCE, IN-LB ^{1/2} /SEC
KWFPCV	PRIMARY COMBUSTOR FUEL VALVE ADMITTANCE, IN-LB ^{1/2} /SEC
CSFOR	SECONDARY FUEL ORIFICE RESISTANCE SEC ² /FT ⁵
CPFOR	PRIMARY FUEL ORIFICE RESISTANCE SEC ² /FT ⁵
CPOOR	PRIMARY OXIDIZER ORIFICE RESISTANCE SEC ² /FT ⁵
COBTOR	OXIDIZER BOOST PUMP TURBINE ORIFICE RESISTANCE SEC ² /FT ⁵
CFBTOR	FUEL BOOST PUMP TURBINE ORIFICE RESISTANCE SEC ² /FT ⁵
KOFCT	TURBULANT ADMITTANCE FILM COOLING - SEC. COMB.
COFCL	LAMINAR RESISTANCE FILM COOLING CIRCUIT, LB-SEC/FT ⁵
KWOBY	ADMITTANCE OXIDIZER PUMP BYPASS IN-LB ^{1/2} /SEC
KWFBY	ADMITTANCE FUEL PUMP BYPASS IN-LB ^{1/2} /SEC
COFCT	TURBULENT RESISTANCE FILM COOLING CIRCUIT, LB-SEC/FT ⁵
DOFCOR	EQUIVALENT DIAMETER, FILM COOLING ORIFICE, IN.

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TABLE A-II (cont.)

UNITS: LB/PSIA

F	THRUST
POT	OXIDIZER TANK PRESSURE AT OUTLET
POSTB	OXIDIZER PRESSURE BOOST PUMP SUCTION-TOTAL
POSB	OXIDIZER PRESSURE BOOST PUMP SUCTION-STATIC
PODB	OXIDIZER PRESSURE BOOST PUMP DISCHARGE-STATIC
POSTM	OXIDIZER PRESSURE MAIN PUMP SUCTION-TOTAL
POSM	OXIDIZER PRESSURE MAIN PUMP SUCTION-STATIC
PODM	OXIDIZER PRESSURE BOOST PUMP DISCHARGE-STATIC
POH	OXIDIZER PRESSURE HOUSING-STATIC
POJPC	OXIDIZER PRESSURE PRIMARY INJECTOR INLET-STATIC
PFT	FUEL TANK PRESSURE AT OUTLET
PFSTB	FUEL PRESSURE BOOST PUMP SUCTION-TOTAL
PFSB	FUEL PRESSURE BOOST PUMP SUCTION-STATIC
PFDB	FUEL PRESSURE BOOST PUMP DISCHARGE-STATIC
PFSTM1	FUEL PRESSURE MAIN PUMP 1 SUCTION-TOTAL
PFSM1	FUEL PRESSURE MAIN PUMP 1 SUCTION-STATIC
PFDM1	FUEL PRESSURE MAIN PUMP 1 DISCHARGE-STATIC
PSCOR	FUEL PRESSURE SECONDARY COMBUSTOR ORIFICE IN-STATIC
PSCV	FUEL PRESSURE SECONDARY COMBUSTOR VALVE IN-STATIC
PFSCM	FUEL PRESSURE SECONDARY INJECTOR MANIFOLD IN-STATIC
PFJSC	FUEL PRESSURE SECONDARY INJECTOR IN-STATIC
PFSTM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-TOTAL
PFSM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-STATIC
PFDM2	FUEL PRESSURE MAIN PUMP 2 DISCHARGE-STATIC
PFPOR	FUEL PRESSURE PRIMARY COMBUSTOR ORIFICE IN-STATIC
PFPCV	FUEL PRESSURE PRIMARY COMBUSTOR VALVE IN-STATIC
PFPCM	FUEL PRESSURE PRIMARY INJECTOR MANIFOLD IN-STATIC
PFJPC	FUEL PRESSURE PRIMARY INJECTOR IN-STATIC
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE
PTIT	TURBINE INLET PRESSURE-TOTAL
PTET	TURBINE EXIT PRESSURE-TOTAL
PTE	TURBINE EXIT PRESSURE-STATIC
PPI	DISTRIBUTION PLATE PRESSURE AT INLET
PPE	DISTRIBUTION PLATE PRESSURE AT EXIT
PCFACE	SECONDARY COMBUSTOR FACE PRESSURE
PCSC	SECONDARY COMBUSTOR PLENUM PRESSURE
PESC	NOZZLE EXIT PRESSURE

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TABLE A-II (cont.)

UNITS: LB, LB/SEC, °F, PSI, RPM, LBS/FT³, FT

F	THRUST
DP/PSF	(PFJSCT-PCFACE)/PCFACE
DP/PPO	(POJPCT-PCPC)/PCPC
DP/PPF	(PFJPCT-PCPC)/PCPC
PCSC	SECONDARY COMBUSTOR CHAMBER PRESSURE - TOTAL
MRSC	SECONDARY COMBUSTOR MIXTURE RATIO
AE/AT	AREA EXIT/AREA THROAT
ETAC	SECONDARY INJECTOR COMB. EFF.
ETAN	NOZZLE EFFICIENCY, %
C*SC	SECONDARY COMBUSTOR CHARACTERISTIC VELOCITY
CF	NOZZLE COEFFICIENT
WGJSC	GAS FLOW RATE, SECONDARY COMB.
WFJSC	FUEL FLOW RATE, SECONDARY COMB.
WOFC	OXIDIZER COOLANT FLOW RATE
WFC/WT	COOLANT/TOTAL PROPELLANT FLOW RATE
DPFJSC	ΔP , FUEL SECONDARY INJECTOR PFJSC-PCFACE
DPOFC	ΔP , OXIDIZER FILM COOLANT CIRCUIT POHT-POFCD
WOJPC	OXIDIZER FLOW RATE, PRIMARY COMBUSTOR
WFJPC	FUEL FLOW RATE, PRIMARY COMBUSTOR
MRPC	PRIMARY COMBUSTOR MIXTURE RATIO
TTIT	TURBINE INLET TEMPERATURE-TOTAL
KGPC	SPECIFIC HEAT RATIO, TURBINE GAS
RGPC	GAS CONSTANT, TURBINE GAS, FT/°R
C*PC	PRIMARY COMBUSTOR GAS C*, THEORETICAL AT MRPC, FT/SEC
HOB	OXIDIZER BOOST PUMP HEAD, RISE TOTAL
HFB	FUEL BOOST PUMP HEAD RISE TOTAL
HOM	OXIDIZER MAIN PUMP HEAD RISE TOTAL
HFM1	FUEL 1 MAIN PUMP HEAD RISE TOTAL
HFM2	FUEL 2 MAIN PUMP HEAD RISE TOTAL
NPSHOB	OXIDIZER BOOST PUMP NPSH - TOTAL
NPSHFB	FUEL BOOST PUMP NPSH - TOTAL
NPSHOM	OXIDIZER MAIN PUMP NPSH - TOTAL
NPSHFM	FUEL MAIN PUMP NPSH - TOTAL
NPSPOB	OXIDIZER BOOST PUMP NPSP - TOTAL
NPSPFB	FUEL BOOST PUMP NPSP - TOTAL
NPSPOM	OXIDIZER MAIN PUMP NPSP - TOTAL
NPSPFM	FUEL MAIN PUMP NPSP - TOTAL

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TABLE A-II (cont.)

UNITS: LB, LB/SEC, RPM, °F, PSI, FT

F	THRUST
ETA-T	TURBINE EFFICIENCY
WTI	TURBINE WEIGHT FLOW
U/C-GT	TIP VELOCITY/SPOUTING VELOCITY, TURBINE
SHPT	TURBINE SHAFT HORSEPOWER
SHPOM	OXIDIZER PUMP SHAFT HORSEPOWER
SHPFM1	FUEL PUMP 1 SHAFT HORSEPOWER
SHPFM2	FUEL PUMP 2 SHAFT HORSEPOWER
RPT	TURBINE PRESSURE RATIO, TOTAL TO STATIC
POSTM	OXIDIZER PUMP SUCTION PRESSURE, TOTAL
PODTM	OXIDIZER PUMP DISCHARGE PRESSURE - TOTAL
HOMNC	OXIDIZER PUMP HEAD RISE, NONCAVITATING, TOTAL
QOSM	OXIDIZER PUMP VOLUME FLOW
HOM/N2	OXIDIZER PUMP/HEAD (SPEED) ²
Q/QDOM	OXIDIZER PUMP (Q/N)/(Q/N) _D
ETA-OM	OXIDIZER PUMP EFFICIENCY
NSO	OXIDIZER PUMP SPECIFIC SPEED
SOM	OXIDIZER PUMP SUCTION SPECIFIC SPEED
D*OSM	OXIDIZER PUMP DENSITY, SUCTION
PFSTM1	FUEL PUMP 1 SUCTION PRESSURE - TOTAL
PFDTM1	FUEL PUMP 1 DISCHARGE PRESSURE - TOTAL
HFMNC1	FUEL PUMP 1 HEAD RISE, NONCAVITATING - TOTAL
QFSM1	FUEL PUMP 1 VOLUME FLOW
HF1/N2	FUEL PUMP 1 HEAD/(SPEED) ²
Q/QDF1	FUEL PUMP 1 (Q/N)/(Q/N) _D
ETAFM1	FUEL PUMP 1 EFFICIENCY
NSF-1	FUEL PUMP 1 SPECIFIC SPEED
SFM1	FUEL PUMP 1 SUCTION SPECIFIC SPEED
D*FM1	FUEL PUMP 1 DENSITY, SUCTION
PFSTM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-TOTAL
PFDTM2	FUEL PRESSURE MAIN PUMP 2 DISCHARGE-TOTAL
HFMNC2	HEAD RISE FUEL PUMP 2, NO. CAVITATING - TOTAL
QFSM2	FUEL PUMP 2 VOLUME FLOW
HF2/N2	FUEL PUMP 2 HEAD/(SPEED) ²
Q/QDF2	FUEL PUMP 2 (Q/N)/(Q/N) _D
ETAFM2	FUEL PUMP 2 EFFICIENCY
NSF-2	FUEL PUMP 2 SPECIFIC SPEED
NT	TURBINE SPEED

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TABLE A-II (cont.)

UNITS: LB, RPM, LB/SEC, °F, FT/LB/IN²

F	THRUST
NTOB	OXIDIZER BOOST PUMP SPEED
WOSB	OXIDIZER BOOST PUMP FLOW RATE
TOSB	OXIDIZER BOOST PUMP SUCTION TEMPERATURE
POSTB	OXIDIZER BOOST PUMP SUCTION PRESSURE-TOTAL
PODTB	OXIDIZER BOOST PUMP DISCHARGE PRESSURE-TOTAL
HOBNB	OXIDIZER BOOST PUMP HEAD RISE-NONCAVITATING, FT.- TOTAL
QOSB	OXIDIZER BOOST PUMP VOLUME FLOW, GPM
HOB/N2	OXIDIZER BOOST PUMP HEAD/(SPEED) ²
Q/QDOB	OXIDIZER BOOST PUMP (Q/N)/(Q/N)D
ETAOB	OXIDIZER BOOST PUMP EFFICIENCY
SHPOB	OXIDIZER BOOST PUMP SHAFT HORSEPOWER
SOB	OXIDIZER BOOST PUMP SUCTION SPECIFIC SPEED
PTITOB	OXIDIZER BOOST PUMP TURBINE INLET PRESSURE - TOTAL
DPTOB	OXIDIZER BOOST PUMP TURBINE ΔP - TOTAL TO STATIC
TTITOB	OXIDIZER BOOST PUMP TURBINE INLET TEMPERATURE
WTOB	OXIDIZER BOOST PUMP TURBINE FLOW RATE
ETATOB	OXIDIZER BOOST PUMP TURBINE EFFICIENCY
NTFB	FUEL BOOST PUMP SPEED
WFSB	FUEL BOOST PUMP FLOW RATE
TFSB	FUEL BOOST PUMP SUCTION TEMPERATURE
PFSTB	FUEL BOOST PUMP SUCTION PRESSURE-TOTAL
PFDTB	FUEL BOOST PUMP DISCHARGE PRESSURE-TOTAL
HFBNC	FUEL BOOST PUMP HEAD RISE-NONCAVITATING, FT.- TOTAL
QFSB	FUEL BOOST PUMP VOLUME FLOW, GPM
HFB/N2	FUEL BOOST PUMP HEAD/(SPEED) ²
Q/QDFB	FUEL BOOST PUMP (Q/N)/(Q/N)D
ETAFB	FUEL BOOST PUMP EFFICIENCY
SHPFB	FUEL BOOST PUMP SHAFT HORSEPOWER
SFB	FUEL BOOST PUMP SUCTION SPECIFIC SPEED
PTITFB	FUEL BOOST PUMP TURBINE INLET PRESSURE - TOTAL
DPTFB	FUEL BOOST PUMP TURBINE ΔP - TOTAL TO STATIC
TTITFB	FUEL BOOST PUMP TURBINE INLET TEMPERATURE
WTFB	FUEL BOOST PUMP TURBINE FLOW RATE
ETATFB	FUEL BOOST PUMP TURBINE EFFICIENCY
WOTS	OXIDIZER FLOW FROM BEARINGS TO TURBINE
WOBY	OXIDIZER BYPASSED TO SUCTION FOR BALANCE
WFBY	FUEL BYPASSED TO SUCTION FOR BALANCE
WFRTS	FUEL RETURN TO SUCTION

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TABLE A-II (cont.)

UNITS: LBS, PSI, LB/FT³, LBS/SEC, °F

F	THRUST
POT	OXID TANK PRESSURE AT OUTLET - TOTAL
DPOEI	ΔP TANK TO ENGINE INLET - TOTAL TO STATIC
POEIT	OXID PRESSURE AT ENGINE INLET - TOTAL
POEI	OXID PRESSURE AT ENGINE INLET - STATIC
DPOSB	ΔP ENGINE INLET TO BOOST PUMP SUCTION - S TO S
POSTB	BOOST PUMP SUCTION PRESSURE - TOTAL
POSB	BOOST PUMP SUCTION PRESSURE - STATIC
PODTB	BOOST PUMP DISCHARGE PRESSURE - TOTAL
PODB	BOOST PUMP DISCHARGE PRESSURE - STATIC
DPOSM	ΔP BOOST PUMP DISC. TO MAIN PUMP SUCTION - S TO S
POSTM	OXID PUMP SUCTION PRESSURE - TOTAL
POSM	OXID PUMP SUCTION PRESSURE - STATIC
PODTM	OXID PUMP DISCHARGE PRESSURE - TOTAL
PODM	OXID PUMP DISCHARGE PRESSURE - STATIC
DPOH	ΔP OXID HOUSING - STATIC TO STATIC
POHT	OXID HOUSING PRESSURE - TOTAL
POH	OXID HOUSING PRESSURE - STATIC
DPOORF	ΔP OXIDIZER HOUSING ORIFICE - STATIC TO STATIC
POJPC	PRIMARY INJECTOR OXID INLET PRESSURE - TOTAL
POJPC	PRIMARY INJECTOR OXID INLET PRESSURE - STATIC
DPOJPC	ΔP PRIMARY INJECTOR OXID CIRCUIT - S TO S
PCPC	PRIMARY INJECTOR PRESSURE
TOT	OXIDIZER TEMPERATURE IN TANK
D*OT	OXID DENSITY IN TANK
WOT	OXID TOTAL WEIGHT FLOW
WOSM	OXID FLOW RATE AT MAIN PUMP SUCTION
TODM	OXID TEMPERATURE AT MAIN PUMP DISCHARGE
D*ODM	OXID DENSITY AT MAIN PUMP DISCHARGE
WOPC	OXID FLOW RATE IN PRIMARY COMBUSTOR
WOPC	OXID FLOW RATE TRANSPIRATION COOLANT
WTOB	OXID FLOW RATE BOOST PUMP TURBINE
WOTS	OXID FLOW RATE TURBINE SEAL
TOJPC	OXID TEMPERATURE AT PRIMARY INJECTOR INLET
D*OJPC	OXID DENSITY AT PRIMARY INJECTOR INLET
REOJPC	OXID REYNOLDS NUMBER IN PRIMARY INJECTOR
REFJSC	FUEL REYNOLDS NUMBER IN SECONDARY INJECTOR

S TO S STATIC TO STATIC

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TABLE A-II (cont.)

UNITS: LBS, PSI, °F, LB/FT³, LB/SEC

F	THRUST
PFT	FUEL TANK PRESSURE AT OUTLET - TOTAL
DPFEI	Δ P FUEL TANK TO ENGINE INLET - STATIC TO STATIC
PFEIT	FUEL PRESSURE AT ENGINE INLET - TOTAL
PFEI	FUEL PRESSURE AT ENGINE INLET - STATIC
DPFSB	Δ P ENGINE INLET TO BOOST PUMP SUCTION - S TO S
PFSTB	FUEL BOOST PUMP SUCTION PRESSURE - TOTAL
PFSB	FUEL BOOST PUMP SUCTION PRESSURE - STATIC
PFDTB	FUEL BOOST PUMP DISCHARGE PRESSURE - TOTAL
PFDB	FUEL BOOST PUMP DISCHARGE PRESSURE - STATIC
DPFSM	Δ P BOOST PUMP TO MAIN PUMP SUCTION - S TO S
PFSTM	FUEL PUMP 1 SUCTION PRESSURE - TOTAL
PFSM	FUEL PUMP 1 SUCTION PRESSURE - STATIC
PFDTML	FUEL PUMP 1 DISCHARGE PRESSURE - TOTAL
PFDM1	FUEL PUMP 1 DISCHARGE PRESSURE - STATIC
DPSC1	Δ P SECONDARY COMBUSTOR FUEL LINE - S TO S
PSCORT	PRESSURE UPSTREAM OF SECONDARY FUEL ORIFICE-TOTAL
PSCOR	PRESSURE UPSTREAM OF SECONDARY FUEL ORIFICE-STATIC
DPSCOR	Δ P ORIFICE - STATIC TO STATIC
PSCVT	PRESSURE UPSTREAM OF SCFCV - TOTAL
PSCV	PRESSURE UPSTREAM OF SCFCV - STATIC
DPSCV	Δ P VALVE - STATIC TO STATIC
PFSCMT	PRESSURE UPSTREAM OF SEC. COMB. MANIFOLD - TOTAL
PFSCM	PRESSURE UPSTREAM OF SEC. COMB. MANIFOLD - STATIC
DPFSCM	Δ P MANIFOLD - STATIC TO STATIC
PFJSCT	INJECTOR INLET PRESSURE - TOTAL
PFJSC	INJECTOR INLET PRESSURE - STATIC
DPFJSC	Δ P FUEL INJECTOR - STATIC TO STATIC
PCFACE	CHAMBER PRESSURE AT INJECTOR FACE - STATIC
TFT	TEMPERATURE FUEL TANK
D*FT	FUEL DENSITY IN TANK
WFT	FUEL FLOW RATE FROM TANK
WFSM1	FUEL PUMP 1 FLOW RATE
TFDM1	TEMPERATURE AT FUEL PUMP 1 DISCHARGE
D*FDM1	DENSITY AT FUEL PUMP 1 DISCHARGE
WFSM2	FUEL PUMP 2 FLOW RATE
WFJSC	SECONDARY COMBUSTOR FUEL FLOW RATE
TFJSC	SECONDARY COMBUSTOR FUEL TEMPERATURE
D*FJSC	SECONDARY COMBUSTOR FUEL DENSITY

S TO S STATIC TO STATIC

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TABLE A-II (cont.)

UNITS: LB, PSI, °F, LB/FT³, LB/SEC

F	THRUST
PFDTM1	FUEL PUMP 1 DISCHARGE PRESSURE-TOTAL
PFDML	FUEL PUMP 1 DISCHARGE PRESSURE-STATIC
DPFSM2	Δ P FUEL PUMP 1 DISCHARGE TO FUEL PUMP 2 SUCTION - S TO S
PFSTM2	FUEL PUMP 2 SUCTION PRESSURE-TOTAL
PFSTM2	FUEL PUMP 2 SUCTION PRESSURE-STATIC
PFDTM2	FUEL PUMP 2 DISCHARGE PRESSURE-TOTAL
PFDML	FUEL PUMP 2 DISCHARGE PRESSURE-STATIC
DPFPCL	Δ P PRIMARY COMBUSTOR FUEL LINE - STATIC TO STATIC
PFPORT	ORIFICE INLET PRESSURE-TOTAL
PFPOR	ORIFICE INLET PRESSURE-STATIC
DPFPOR	Δ P ORIFICE - STATIC TO STATIC
PFPCVT	PCFCV INLET PRESSURE-TOTAL
PFPCV	PCFCV INLET PRESSURE-STATIC
DPFPVC	Δ P PCFCV - STATIC TO STATIC
PFPCMT	PRIMARY INJECTOR MANIFOLD INLET PRESSURE-TOTAL
PFPCM	PRIMARY INJECTOR MANIFOLD INLET PRESSURE-STATIC
DPFPCM	Δ P MANIFOLD - STATIC TO STATIC
PFJPCT	PRIMARY INJECTOR FUEL INLET PRESSURE-TOTAL
PFJPC	PRIMARY INJECTOR FUEL INLET PRESSURE-STATIC
DPFJPC	Δ P PRIMARY INJECTOR - STATIC TO STATIC
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE -STATIC
TFSM2	TEMPERATURE FUEL PUMP 2 SUCTION
D*FSM2	DENSITY FUEL PUMP 2 SUCTION
WFSM2	FLOW RATE FUEL PUMP 2
TFDM2	TEMPERATURE FUEL PUMP 2 DISCHARGE
D*FDM2	DENSITY FUEL PUMP 2 DISCHARGED
WFPCJ	PRIMARY INJECTOR FUEL FLOW RATE
WFRTS	FUEL FLOW RETURN TO SUCTION
TFJPC	PRIMARY INJECTOR FUEL TEMPERATURE
D*FJPC	PRIMARY INJECTOR FUEL DENSITY
REFJPC	PRIMARY INJECTOR FUEL REYNOLDS NUMBER

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TABLE A-II (cont.)

UNITS: LB, PSI, °F, LB/SEC, LB/FT³

F	THRUST
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE - STATIC
DPPC	ΔP PRIMARY COMBUSTOR - STATIC TO TOTAL
PTIT	TURBINE INLET PRESSURE-TOTAL
PTET	TURBINE EXIT PRESSURE-TOTAL
PTE	TURBINE EXIT PRESSURE-STATIC
DPTX	ΔP TURBINE EXHAUST PASSAGE - STATIC TO STATIC
PPIT	DISTRIBUTION PLATE INLET PRESSURE-TOTAL
PPI	DISTRIBUTION PLATE INLET PRESSURE-STATIC
DPPI	ΔP DISTRIBUTION PLATE - STATIC TO STATIC
PPET	DISTRIBUTION PLATE EXIT PRESSURE-TOTAL
PPE	DISTRIBUTION PLATE EXIT PRESSURE-STATIC
DPJHG	ΔP SECONDARY INJECTOR GAS PASSAGE - S TO S
PCFACE	SECONDARY COMBUSTOR CHAMBER PRESSURE FACE - STATIC
PCSC	THRUST CHAMBER PRESSURE - TOTAL AT THRUST
PESC	SECONDARY COMBUSTOR EXIT PRESSURE-STATIC
TGPC	PRIMARY COMBUSTOR GAS TEMPERATURE BASED ON MRPC (SEE PAGE 10)
WPC	PRIMARY COMBUSTOR GAS FLOW RATE
TTIT	TURBINE INLET TEMPERATURE - TOTAL BASED ON MRTI (SEE PAGE 10)
TTET	TURBINE EXIT TEMPERATURE - TOTAL BASED ON MRPC
TJHGT	TEMPERATURE IN TURBINE EXHAUST PASSAGE
WJHG	FLOW RATE IN TURBINE EXHAUST PASSAGE
PODTM	OXIDIZER PUMP DISCHARGE PRESSURE-TOTAL
POFCI	TRANSPIRATION COOLANT INLET PRESSURE - STATIC
DPOFCL	ΔP TRANSPIRATION COOLANT PASSAGE - S TO S
POJFCT	TRANSPIRATION COOL CHAMBER MANIFOLD PRESSURE-TOTAL
PLJFC	TRANSPIRATION COOL CHAMBER MANIFOLD PRESSURE-STATIC
DPOJFC	ΔP TRANSPIRATION COOL CHAMBER PASSAGES - S TO S
POFCD	PRESSURE AT EXIT OF TRANSPIRATION COOL PASSAGES-STATIC
WOFC	TRANSPIRATION COOL FLOW RATE
TOFC	TRANSPIRATION COOL TEMPERATURE IN CHAMBER MANIFOLD
D*OJFC	TRANSPIRATION COOL DENSITY IN CHAMBER MANIFOLD
S TO S	STATIC TO STATIC

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TABLE A-II (cont.)

UNITS: LB, LB/SEC, PSIA, LB/FT³, °F, FT/°R, FT/SEC

F	THRUST
WFC/WT	TRANSPIRATION COOLANT (TC) FRACTION
WOFC	TC FLOW RATE
POFCI	PRESSURE AT TC INLET
POFCDO	PRESSURE AT DISCHARGE OF TC ORIFICE
D*OFC	TC DENSITY

WOFCX	TC FLOW RATE THROUGH CIRCUIT X; X = 1-10
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PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE
PTIT	TURBINE INLET PRESSURE, TOTAL
PTE	TURBINE EXIT PRESSURE, STATIC
RPT	TURBINE PRESSURE RATIO
MRPC	PRIMARY COMBUSTOR (PC) MIXTURE RATIO
TGPC	PC GAS TEMPERATURE, OMR (1)
RGPC	PC GAS CONSTANT, OMR
KGPC	SPECIFIC HEAT RATIO, PC, OMR
C*PCTH	THEORETICAL CHARACTERISTIC VELOCITY, PC, OMR

WL/WT	LIQUID FRACTION IN PC PRODUCTS
MRTI	MIXTURE RATIO OF GASSIFIED PRODUCTS IN PC
TTIT	TURBINE INLET TEMPERATURE, TOTAL GMR (2)
RGTI	GAS CONSTANT, PC, GMR
KGTI	SPECIFIC HEAT RATIO, PC, GMR
ATGAS	TURBINE AREA AVAILABLE FOR GAS FLOW
CTI	TURBINE SPOUTING VELOCITY, GMR

U/C-GT	TIP VELOCITY/SPOUTING VELOCITY, TURBINE, GMR
TTET	TURBINE EXIT TEMPERATURE, OMR

(1) OMR - THESE GAS PROPERTIES ARE BASED ON OVER-ALL MRPC

(2) GMR - THESE GAS PROPERTIES ARE BASED ON GASSIFIED PRODUCTS ONLY (MRTI)

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Appendix

III, A, Steady State (cont.)

(U) The two fuel control valves perform three functions: (1) propellant phasing during start and shutdown is controlled by sequencing both the primary and secondary fuel control valves, (2) engine thrust is controlled by the primary combustor fuel control valve, and (3) engine mixture ratio is established by the preset open position of the secondary combustor fuel control valve.

B. THROTTLING AND OFF-DESIGN OPERATION

(U) The engine is throttled by varying the position of the primary combustor fuel control valve. The mechanism by which the primary combustor fuel valve controls the thrust is as follows: increasing the resistance in this valve reduces the fuel flow to the primary combustor, which in turn reduces turbine temperature and, to a lesser extent, the turbine mass flow. The reduction in turbine drive energy results in decreased turbopump speed, pump discharge pressures, propellant flow rate, and thrust. A plot showing several engine parameter variations during throttling is shown in Figure A-5. The engine system maintains nearly constant mixture ratio during throttling because the designed relationship between fuel and oxidizer pump heads almost exactly compensate for the other factors that influence engine mixture ratio.

(C) The throttling depth of an engine is normally limited by the injectors. As the engine is throttled to lower thrust, injector stiffness ($\Delta P/P_c$) decreases and at some throttling depth a feed-system-coupled instability may develop. The thrust level at which the instability develops must be determined experimentally on any given system. The purpose of the Throttling Primary Injector Program was to determine the throttling depth achievable with a platelet injector, with a program goal of demonstrating 10:1 throttling. The effect on the engine of the program test results can be briefly summarized as follows:

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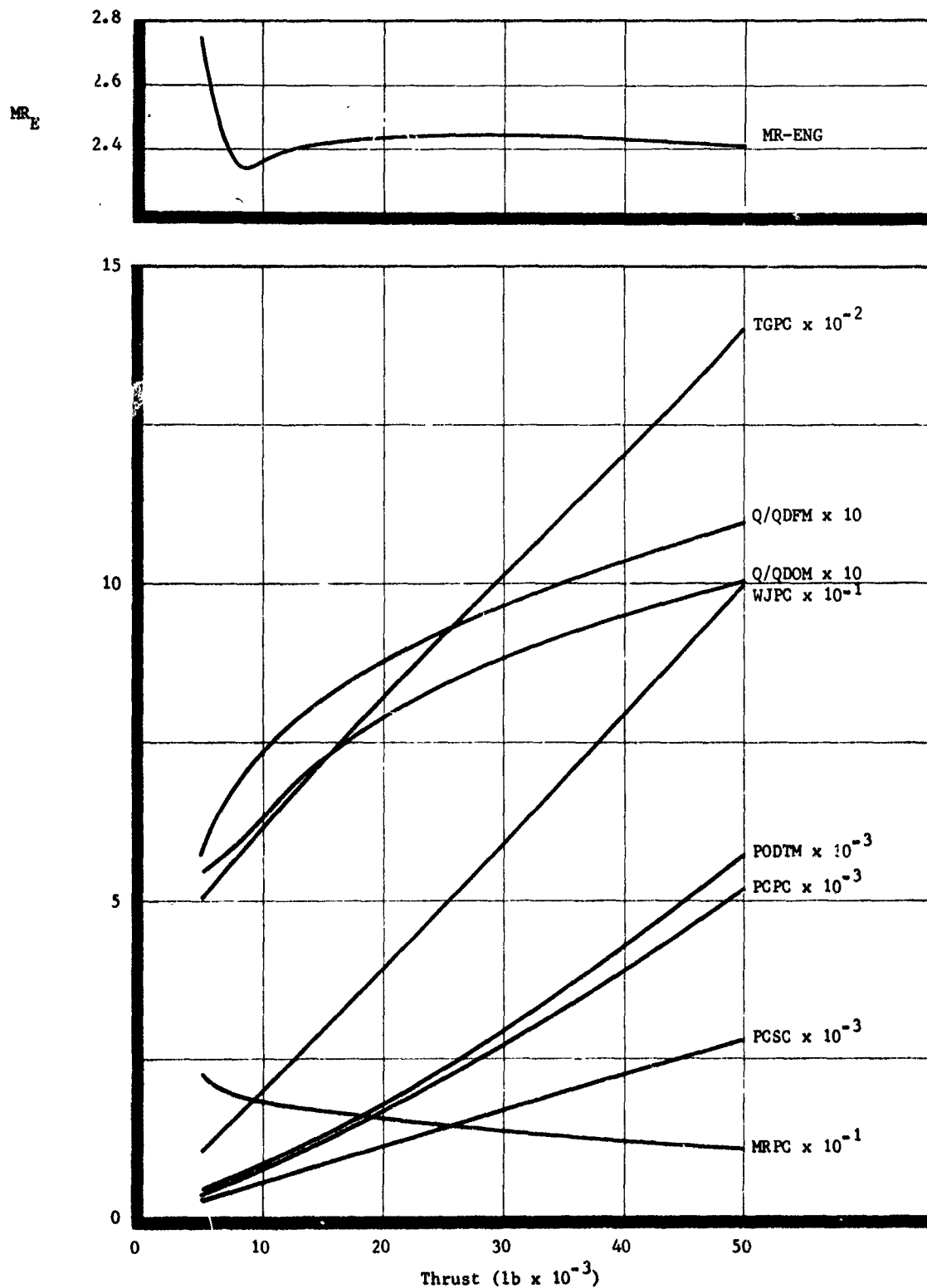


Figure A-5. MIST Throttling Parameters (U)

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III, B, Throttling and Off-Design Operation (cont.)

(C) The initial design, which is compatible with the pressure drops in Table A-I, showed smooth operation above an equivalent thrust level of approximately 18K. The subsequent higher pressure drop design exhibited stable operation when throttled to approximately 8K lb. Use of this higher pressure drop injector requires that thrust chamber pressure be dropped from 2800 psia to 2400 psia. The detailed engine parameters for the 2400 psi engine are shown in Table A-III. The dual manifold design exhibited capability to achieve stable operation down to 5K. Use of this design requires throttling of the oxidizer as well as the fuel circuit.

(U) The dual manifold injector requires engine modification as follows: an additional primary combustor fuel circuit must be added, and fuel throttling accomplished by use of two valves or a dual sleeve valve. Similarly, two oxidizer circuits are needed with a valve incorporated in one of these circuits. It is quite apparent from inspecting the design that the additional fuel circuit and valve would not greatly alter the engine overall design. However, considerable additional design effort is needed to determine how best to incorporate the additional oxidizer circuit and valve. This effort has not been accomplished to date.

C. START AND SHUTDOWN

(U) The engine starts from tank pressure. No auxiliary start system is needed. Therefore, the engine is inherently restartable. Engine start is initiated by opening the suction valves. These valves are sequenced in such a manner as to assure an oxidizer lead to approximately 5% of design admittance. Primary combustor ignition occurs and the turbopump accelerates. When the first stage fuel pump pressure reaches 150 psia, the secondary combustor fuel control valve opens to its operating point position. After ignition in the secondary combustor, the primary combustor fuel control valve is opened to the desired thrust position at a rate to assure a smooth rapid start.

(U) The shutdown operation is the reverse of the startup operation and ends with all engine valves closed.

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TABLE A-III

ENGINE PARAMETERS, FINAL (U)

PAGE	1	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70850	28005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19012	
PCSC	24000.05502	18000.04128	12033.46533	964.80247	726.63203	490.09726	371.87492	283.39643	
MR-ENG	2.42307	2.40618	2.40608	2.40742	2.41894	2.41283	2.42864	2.50932	
IS	326.73265	335.26353	332.89565	331.32841	328.82071	324.38286	320.02264	310.82336	
W-FNG	148.47294	111.76566	75.11524	60.36834	45.69682	30.82068	23.43611	16.08087	
WV	105.08490	70.96531	53.06190	42.64653	32.25844	21.79927	16.60083	11.80343	
WFT	43.38794	32.81782	22.03346	17.71472	13.33885	9.02210	6.83484	4.88466	
NT	36937.50144	29466.46926	21962.23853	18740.36499	15427.26485	11906.02209	9862.10266	7764.01968	
RPT	1.72064	1.86972	1.39500	1.32924	1.25902	1.19442	1.16117	1.12863	
POFIT	51.01642	51.49754	51.83981	51.93958	52.01745	52.07404	52.09402	52.10836	
TOEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	
PFEIT	39.84320	39.93424	40.44843	40.60089	40.72249	40.81060	40.84304	40.86771	
TPEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	
ATSC	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900	
ATT	1.60920	1.60920	1.60920	1.60920	1.60920	1.60920	1.60920	1.60920	
ATT*	1.76805	1.76707	1.77395	1.77432	1.79830	1.73130	1.70915	1.68461	
ATOBP	.02765	.02765	.02765	.02765	.02765	.02765	.02765	.02765	
ATFPP	.01280	.01280	.01280	.01280	.01280	.01280	.01280	.01280	
KWFSV	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065	
KWFCV	.70072	.24286	.14264	.12109	.10113	.08084	.07020	.05816	
CSFOR	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	
CPFOR	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660	
CPOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
CBSTOR	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	
CFSTOR	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	
COFCT	216081.62565	217646.76933	218514.97852	219366.80273	220917.89378	222170.43648	223422.49809	225336.61133	
DNFCOR	.24856	.24856	.24856	.24856	.24856	.24856	.24856	.24856	
KWOBV	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	
KWFBV	.15029	.15029	.15029	.15029	.15029	.15029	.15029	.15029	
CTIME	4.70730	7.71460	7.74018	9.02530	5.74436	6.80680	8.81110	11.03300	
CASE 1	NON ENG 6-25-65								
CASE 2	P=3750C								
CASE 3	P=2500C								
CASE 4	P=2000C								
CASE 5	P=1500C								
CASE 6	P=1000C								
CASE 7	P=750C								
CASE 8	P=500C								

CASE 1
CASE 2
CASE 3
CASE 4
CASE 5
CASE 6
CASE 7
CASE 8
NON ENG 6-25-65
P=3750C
F=2500C
P=2000C
F=1500C
P=1000C
F=7500
P=5000

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TABLE A-III (cont.)

PAGE	2	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	45996-04191	37477-70652	28026-53652	19999-57910	14993-17786	9996-76636	7500-08569	5000-19012	
POY	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000	
POSTB	44-11210	48-05684	51-08232	51-08232	52-11833	52-11833	52-11833	52-11833	
POSB	40-88277	48-07842	49-64354	50-74097	51-59970	52-22008	52-22008	52-22008	
PODB	144-08692	121-06126	98-07510	87-01052	77-72720	68-03723	68-03723	68-03723	
POSTM	133-68102	118-02638	93-00089	89-18446	76-65303	68-82210	68-82210	68-82210	
POSM	102-68182	97-31687	85-44059	79-70290	73-44964	67-00061	67-00061	67-00061	
PODM	8446-81482	3761-03367	2138-06618	1599-16142	1110-17493	704-39821	515-16963	336-83451	
POH	2630-50772	3732-97384	2134-87021	1597-07123	1118-24928	704-39821	515-16963	336-83451	
POJPC	8162-79620	3446-23380	1982-70766	1500-32852	1058-10818	468-11486	486-11394	317-35264	
PT	40-50000	40-50000	40-50000	40-50000	40-50000	40-50000	40-50000	40-50000	
PTSTB	31-47412	35-98455	38-65189	39-55977	40-26392	40-26392	40-26392	40-26392	
PTSB	23-44203	36-01270	36-44591	38-11618	39-44831	40-41361	40-41361	40-41361	
PTDB	97-32241	78-48850	73-48324	67-19023	60-85946	54-03364	50-69786	47-34732	
PTSTMI	82-88261	78-38081	68-92272	64-05491	58-71413	53-01825	50-04469	46-99622	
PTSMI	70-34534	71-22377	65-35031	61-70795	57-29123	52-29197	48-59261	45-76167	
PTDM	4061-24123	2491-28781	1721-34656	1318-10808	937-07378	694-47189	435-56913	285-11745	
PTCOR	3637-97776	2-7622141	1895-49236	1232-23339	889-42811	872-68953	423-24484	279-87412	
PTCV	3637-97776	2476-22141	1595-49236	1232-23339	889-42811	872-68953	423-24484	279-87412	
PTSCM	3454-77604	2466-92026	1541-49723	1196-54121	868-73012	563-02940	417-71046	277-45408	
PTJSC	2644-76012	1162-92720	1294-13070	1030-91237	770-88957	516-00562	385-88734	264-41442	
PTSTN2	4022-97210	2220-94320	1713-48813	1310-57657	934-92804	593-90198	435-44601	285-24040	
PTSM2	4022-97210	2220-94320	1713-48813	1310-57657	934-92804	593-90198	435-44601	285-24040	
PTDM2	6634-69330	4593-30872	2720-05475	2052-59204	1441-01291	897-29736	648-40523	285-23586	
PTPCV	6594-43170	4722-30640	2713-14847	2049-89926	1439-89926	648-31436	648-31436	415-04319	
PTPCM	6523-60634	4581-48712	2717-75235	2054-90747	1444-06577	900-39974	650-76191	410-53775	
P-JPC	6340-48842	3430-36488	2137-04089	1613-71713	1148-86432	726-88448	533-68031	349-65113	
PCPC	6334-89206	3427-97244	2136-21487	1613-76538	1148-86579	726-88448	533-68031	349-65113	
PCPC	4658-22394	3181-76389	1852-08427	1407-09201	1003-00150	639-03877	470-61963	309-90113	
PTTY	4528-72290	3466-11786	1801-75574	1368-85570	975-74593	621-66964	457-83102	301-47988	
PTET	2846-82282	1561-72429	1257-68591	1036-10532	777-68727	521-97781	395-23140	268-47501	
PTE	2632-00000	1533-29045	1293-43774	1032-90894	775-20136	520-47563	394-28372	267-83108	
PPI	2632-11002	1583-21828	1293-07307	1032-74992	774-82166	510-62323	394-27142	267-88878	
PDE	2527-14001	1586-32458	1298-44423	1007-69907	757-96448	510-60981	347-19447	263-88790	
PTFACE	2477-19498	1587-89990	1242-02496	995-81412	749-88816	505-88045	383-22809	261-54135	
PTSC	2400-85303	1556-84128	1203-34583	964-80247	726-63203	450-05726	371-87492	253-39643	
PESC	34481	27247	18201	14667	11103	07488	05705	03932	
CASE 1	MOR ENG 6-25-69								
CASE 2	F-3780C								
CASE 3	F-2580C								
CASE 4	F-2060C								
CASE 5	F-1900C								
CASE 6	F-1000C								
CASE 7	F-7500								
CASE 8	F-8080								

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TABLE A-III (cont.)

PAGE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	40990.04191	37477.79450	25008.33652	19099.37910	14993.17786	9596.76636	7500.08959	5000.19012
DP/PSF	.09271	.07748	.08474	.06746	.05730	.02465	.02083	.01437
DP/PRC	.11522	.05927	.07995	.06989	.05770	.04277	.03445	.02514
DP/PRF	.38074	.24634	.15342	.14093	.14222	.13735	.13391	.12822
PCSC	2400.05502	1800.04128	1203.34883	964.00247	726.03203	490.09726	371.87492	283.30043
MRSC	2.14441	2.18670	2.19326	2.19807	2.21282	2.22866	2.24596	2.26496
AE/AT	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000
ETAC	.99010	.98264	.98770	.98742	.98732	.98477	.98398	.98048
ETAN	.92012	.92093	.91554	.91263	.90630	.89416	.88268	.86106
CASC	5642.43942	5420.76813	5591.87122	5579.32257	5562.86091	5550.53803	5538.67810	5498.24127
CF	1.00010	1.01911	1.01638	1.01070	1.00191	1.00013	1.00000	1.00000
WGJSC	104.33341	77.50174	91.00949	41.33681	31.16743	20.96800	15.93128	11.01041
WFJSC	34.48177	27.07638	18.01307	15.21499	11.08677	8.01857	6.11850	4.13466
WDFC	9.65884	7.20512	4.63321	3.70764	2.74411	1.83717	1.38782	.93573
WFC/WT	.04507	.06442	.06249	.06143	.06018	.05961	.05922	.05817
DPFJSC	167.96012	108.02721	82.10582	35.09825	20.89781	10.18840	6.05925	2.87307
DPOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
WJRC	90.41832	67.06923	45.03869	38.08477	27.74002	18.63183	14.11523	9.71082
WFJPC	0.90617	0.74142	3.24039	2.39973	1.65177	1.00653	.71834	.44994
MRPC	10.15532	11.02093	14.00432	15.28703	16.79410	18.61058	19.64983	21.59973
TYIT	1421.99742	1210.22780	1151.57594	1129.09961	1112.65105	1110.08991	1125.58754	1129.88348
KGTI	1.25495	1.25222	1.20425	1.28600	1.28375	1.28749	1.28608	1.28566
RGTI	48.25864	48.28856	46.12050	46.09872	46.10140	46.40351	46.66662	46.84371
CAPC	2593.75912	2384.73236	2103.00975	1995.51941	1878.05109	1763.34405	1697.24390	1578.38330
MOB	162.58924	119.28327	74.50030	57.70248	41.06647	26.88547	19.62499	12.34599
MF8	191.77974	140.32612	95.40348	74.90520	54.00519	35.40701	25.52035	16.21195
MOH	8936.02747	5866.32831	3303.37167	2444.44728	1682.38280	1025.46225	726.69473	445.84826
MF1	10824.20394	7273.89593	4359.94310	3270.22805	2290.86406	1409.36778	1001.94043	617.94898
MF2	7274.90412	4624.82640	2653.59576	1973.67995	1338.36071	798.14622	556.77076	339.18661
NPSMOE	45.83370	50.48785	53.79963	56.76361	58.81086	59.06417	59.29741	59.39609
NPSMFE	73.61775	84.38267	92.24313	94.37380	96.43282	97.77956	98.27849	98.68259
LPSHOW	184.43923	199.8794	121.23968	107.77127	94.23135	81.31879	74.76017	68.08669
NPSMFW	203.98404	193.8654	169.40694	156.92949	143.23176	128.60131	120.96506	113.11106
NPSPOE	28.48810	31.34208	33.44093	34.04092	34.80934	34.84970	34.96987	35.08011
NPSPOF	28.75887	32.07525	35.02842	36.44607	37.87104	38.09594	38.29520	38.43016
NPSPOV	114.20534	106.54018	78.30492	66.92301	58.82631	50.81288	46.44487	42.20167
NPSPOV	76.01778	75.07359	65.76791	60.94353	56.63859	49.94436	46.99902	43.94512

NOM ENG 6-25-69

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CASE 7
CASE 8

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TABLE A-III (cont.)

PAGE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996-84195	37477-70850	29005-53662	19999-57910	14993-17782	9996-76436	7500-08569	8008-19012
ETA-Y	-72684	-72290	-70590	-69322	-67382	-64311	-61311	-587309
WT1	99-32452	73-81068	48-87904	39-08451	29-33186	19-83804	14-83387	10-16845
U/C-GT	-46502	-44000	-38692	-35027	-32884	-28681	-25967	-22623
SPRT	6124-7215C	3140-23792	1250-09042	775-08546	423-83787	189-86432	109-37802	50-97098
SPDM	3090-82932	1963-66039	619-53061	380-61957	208-88565	93-39685	53-91601	28-11889
SPDM1	2465-34182	1301-86244	528-32220	326-11873	177-79975	79-07643	48-31964	20-91488
SPDM2	544-67074	275-27982	110-21132	68-38313	37-93312	17-47274	10-28867	4-92788
RPT	1-72064	1-86972	1-39100	1-32524	1-25902	1-19442	1-6117	1-12543
WOSTM	133-62102	115-42622	93-80089	85-18446	78-63303	68-52210	64-38967	68-18709
PODM	5669-94238	3755-15628	2144-67584	1603-23342	1121-58772	708-53289	515-84985	337-17487
POMNC	8931-18884	5866-36902	3303-35080	2444-64725	1682-49962	1035-45938	726-78646	448-84886
QOSM	982-66131	440-55910	293-19135	243-24086	189-24222	137-60084	98-62244	69-71632
POM/N2	-5 6549732	-5 6672634	-5 6448949	-5 69459815	-5 70689330	-5 72341096	-5 73232657	-5 73942934
Q/ODOM	1-00812	-94706	-86802	-82274	-79305	-63288	-63079	-57214
ETA-OM	-60886	-59824	-57779	-56363	-54264	-50771	-48175	-44882
N-50	970-8125C	528-13363	871-83677	839-83224	799-30078	742-17128	706-77428	668-12888
SOM	17815-75486	14116-45951	10384-67957	8729-71240	6942-64232	4966-76938	3891-32276	2738-85903
DOSM	89-27422	86-34392	85-40138	85-42005	89-43726	89-48190	89-46021	89-47110
PFSTM1	62-45261	76-35981	68-92272	64-05491	58-71453	53-01525	50-04469	46-99622
PFDM1	4159-38698	2500-67220	1749-96884	1334-45877	948-81109	600-43745	439-29848	297-05251
PFMNC1	10524-437-2	7273-85707	4329-88322	3270-52808	2280-54405	1499-34760	1001-96044	617-94558
QFSM1	476-77625	372-76984	261-47316	215-71807	168-80881	121-20132	96-32700	69-91978
PF1/N2	-5 77137181	-5 82763882	-5 89767879	-5 92925886	-5 96241988	-5 99423940	-4 10055881	-4 10251259
Q/ODF1	1-24488	1-25396	1-18070	1-14613	1-03067	1-01468	96380	89764
ETA-FM1	-45848	-47154	-45532	-43012	-42923	-40961	-48271	-46822
NSF-1	778-64374	724-57716	665-32616	637-13000	605-38233	569-83897	549-01870	523-80998
SFM1	14991-69417	11028-65282	7563-17181	6216-67334	4841-37918	3432-40812	2480-66333	1871-84838
D+FM1	55-78692	55-65582	55-90431	55-92236	55-83701	55-94710	55-94887	55-94987
PFSTM2	4022-8721C	2220-96320	1713-46819	1310-57657	934-88804	593-90198	435-44601	285-24040
PFDM2	6842-01984	4693-54736	2759-92645	2077-53381	1455-13048	904-08624	652-58360	417-02662
PFMNC2	7274-96612	4824-82660	2693-59376	1973-67998	1338-38071	798-14662	598-77676	339-18661
QFSM2	55-47504	69-18749	43-63360	34-52075	25-98174	18-02630	14-13987	10-17926
PF2/N2	-5 5320711	-5 54917526	-5 5584345	-5 56078212	-5 56234364	-5 5638303	-5 56303617	-5 56268514
Q/ODF2	1-00381	-8698	-74054	-68887	-62778	-54358	-52909	-48869
ETA-FM2	-20036	-27444	-24167	-22587	-20784	-18669	-17409	-15882
NSF-2	467-68287	425-78821	388-00551	372-24076	355-37625	336-83403	325-94551	313-41209
NT	36937-50146	29646-46426	21962-23653	18760-36499	15437-24489	11906-03209	9462-10266	7764-01968

CASE 1
CASE 2
CASE 3
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CASE 5
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CASE 8

NOM ENG 8-25-69
P-3750C
P-2500C
P-2000C
P-1500C
P-1000C
P-7500
P-5000

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TABLE A-III (cont.)

PAGE	5	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996-64195	37477-70850	25005-33662	19999-37910	14993-17764	9996-76636	7800-08569	5008-19012	
NT08	15026-28674	9711-25110	7235-23096	6181-13727	5050-10504	3935-76831	3493-46411	2560-69843	
WDSB	105-6849C	76-64531	53-06190	42-64453	32-25844	31-79927	16-00083	11-50343	
YDSB	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	
POSTB	46-1121C	46-98884	51-03248	51-65107	52-11833	52-48784	52-57771	52-64374	
POD1B	147-17602	123-14249	97-36131	97-51878	78-01824	49-10998	64-77670	68-38080	
MOBNC	162-69852	119-28327	74-50030	97-70248	41-65647	26-88847	19-62499	12-36899	
QDSB	526-92506	355-84256	266-05248	213-82819	161-74165	109-39966	83-23498	87-67702	
MOB/M2	-5 11241762	-5 1264212	-5 14271004	-5 15102808	-5 16081748	-5 17384178	-5 18092712	-5 18888707	
Q/QO0B	1-17525	1-69961	9-9353	9-2400	-84873	-74176	-67504	-60161	
ETAB08	5-59717	6-61637	6-6162	5-58239	4-87338	3-8483	3-9146	3-4758	
SHPOB	52-62001	27-78515	11-75153	7-47709	4-26232	2-03381	1-50828	1-87789	
S0B	15672-24215	10202-69857	5935-92963	4491-97595	3182-60088	2008-34944	1482-79437	948-00769	
PT1Y0B	3886-67696	2282-65321	1483-83624	1114-01776	794-76363	500-16201	370-28233	247-84302	
DP10B	3742-68552	2461-25221	1387-26314	1027-00684	707-63966	431-12477	305-88289	187-82947	
Y1Y1Y0B	100-66312	93-68339	87-23339	93-13574	83-15615	81-40992	80-50438	79-51232	
NT0B	10-62672	6-73813	6-53730	5-61815	4-85886	3-63324	3-08778	2-39476	
ETAT0B	-44221	-44887	-44429	-44526	-4396	-44220	-44124	-43996	
NTFB	13987-27821	11556-33923	8819-91016	7631-11719	6322-64962	4933-39734	4130-14429	3223-66898	
YF SB	43-28794	32-81782	22-08346	17-71472	13-33858	9-03210	6-83484	4-86460	
PF STB	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	77-6000C	
PF DTB	31-47411	35-24525	38-65180	39-59977	40-28392	40-80867	41-00187	41-14978	
WFBNC	106-18032	92-56798	75-85658	68-73340	61-85361	54-46089	50-94838	47-46814	
QF SB	151-60932	146-32930	95-43371	74-90826	54-60320	38-09071	36-82935	16-21198	
WFB/M2	347-06282	262-53284	176-47655	141-70693	106-70128	72-17178	54-67403	36-87414	
Q/QDFB	-6 9803723C	-5 1095576	-5 12273704	-5 12894594	-5 13616856	-5 14488833	-5 14966124	-5 15888416	
ETAFB	1-10112	1-60887	8-8758	8-2510	7-7659	6-8048	5-88742	4-80479	
SHPFB	6-231C	6-2892	6-0241	5-7923	4-8346	3-8346	2-8346	1-8346	
SFB	24-20002	17-69155	6-35619	4-15315	2-43461	1-16963	99960	23800	
PT1YFB	10347-67634	6726-64168	3935-92966	2991-92490	2128-73772	1348-16229	978-44687	423-71788	
DP1YFB	3717-24891	2893-42862	1567-48898	1196-5083	832-13874	540-96344	397-00041	268-96140	
TT1YFB	3619-5134C	2106-47894	1406-00574	1129-33060	791-67919	486-93761	346-30278	213-81409	
WTFB	109-6408C	100-14447	91-88336	89-08603	66-67602	54-67279	43-92327	33-30336	
ETATFB	3-84652	3-26292	2-47386	2-15106	1-80066	1-41248	1-19112	93843	
	-37655	-36947	-36752	-36644	-36510	-36381	-36283	-36138	
NOTE	2-70311	2-65467	1-47714	1-23141	9-6233	7-8948	6-0662	4-7878	
NOBY	1-2012C	9-4881	6-8726	5-5371	4-5893	3-2772	2-8938	2-8072	
WFBY	1-10014	8-9044	5-9604	4-7999	3-7431	2-7367	1-84466	1-6748	
WRTS	3-46315	2-87064	2-19663	1-99439	1-88804	1-26128	1-04466	91908	

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NOTE ENG 6-25-69
P-3750C
P-2500C
P-2000C
P-1500C
P-1000C
P-750C
P-500C

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F	49966-04195	37477-70850	28006-53652	19999-57910	14993-17766	9996-74636	7500-08569	5000-19012
POT	91-50000	91-50000	51-50000	51-50000	51-50000	51-50000	51-50000	51-50000
DOE1	16-59011	9-89729	3-76653	2-21313	1-50033	1-50033	1-50033	1-50033
DOE2	31-91642	51-49754	51-49754	51-49754	52-07434	52-07434	52-07434	52-07434
DOE3	34-90567	42-46271	47-73317	49-28687	50-49967	51-38092	51-38092	51-38092
DOE4	-5-67956	-3-89751	-1-91037	-1-45409	-1-09792	-1-09792	-1-09792	-1-09792
DOE5	46-11216	48-65894	51-05248	51-65107	52-11833	52-11833	52-11833	52-11833
DOE6	40-38577	43-87842	49-64354	50-74057	51-89764	52-22068	52-22068	52-22068
DOE7	147-17602	123-14249	97-36131	87-51878	76-01824	69-16995	54-77670	50-35680
DOE8	144-68651	121-46135	96-57510	87-01092	77-72767	69-03723	54-77670	50-35680
DOE9	42-56971	24-91243	11-13441	7-30802	4-28071	2-03662	1-21505	60-31384
DOE10	132-88102	115-42638	93-80089	85-18446	76-88303	68-52210	64-38567	60-15709
DOE11	102-01126	97-31087	85-44059	79-70290	73-44656	67-00061	63-48069	59-70282
DOE12	969-54236	3755-15628	2144-67584	1603-24342	1121-56772	705-53289	515-84985	337-17467
DOE13	5646-81482	3741-6307	2138-46616	1599-16142	1119-17493	704-39531	515-14963	336-63451
DOE14	19-53190	11-65027	4-85308	3-08949	1-68245	-70300	37645	16908
DOE15	5444-56671	3746-97147	2138-51178	1599-42988	1119-59145	704-68593	515-68269	337-34163
DOE16	5830-50772	3725-97354	2134-87021	1597-07123	1118-24088	704-28834	515-33200	337-17519
DOE17	467-71151	284-73575	142-16255	96-74571	60-13213	39-16879	29-21446	19-82266
DOE18	5191-73657	3464-63827	2000-16425	1505-15166	1060-87212	666-36523	486-83062	317-69271
DOE19	5162-79620	3442-23350	1992-70766	1500-32952	1058-10812	665-11258	486-11354	317-35264
DOE20	507-57221	256-46991	140-62338	93-23351	59-10664	26-08179	15-49390	7-45150
DOE21	4655-22394	3121-76399	1852-08427	1407-09201	1003-80150	639-03477	470-61563	308-90113
TOT	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000	77-00000
DROT	89-51036	89-51036	89-51036	89-51036	89-51036	89-51036	89-51036	89-51036
WOT	105-08490	78-06531	53-06190	42-64653	32-25844	21-79927	16-60033	11-50343
WOSM	115-90567	87-70344	59-59928	48-25459	36-01524	25-43251	19-65861	13-69819
TODM	100-96215	93-58339	87-26339	85-13576	63-15818	51-40982	40-50438	30-51232
DODM	91-56794	50-84930	90-17273	89-96028	89-77806	81-62351	69-56157	59-51408
WOPC	90-41831	87-88923	45-63865	36-68477	27-74008	18-63183	14-11823	9-71852
WDFC	5-55882	7-20512	4-89321	3-70764	2-74411	1-83717	1-38782	9-3573
WTOB	10-82072	8-73813	6-53730	5-61815	4-65680	3-63324	3-08778	2-39476
WOTS	2-30734	1-79445	1-26331	1-03369	81322	60129	49109	37420
TQJPC	106-63642	96-97423	88-91580	86-24601	83-82917	81-78902	80-76320	79-66950
DQJPC	90-41820	50-11911	89-83935	89-73660	89-44274	89-54747	89-50376	89-48274
REDJPC	18223-89307	12818-91943	9170-79488	6453-22510	4802-67900	3183-16033	2395-49170	1637-63268
REFJSC	36064-98730	25864-56281	18550-26318	13091-82971	9743-81848	6547-08160	4956-14056	3328-64952

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MON ENG 8-25-68
P-378BC
P-288BC
P-2000C
P-1500C
P-1000C
P-7500
P-8080

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1	40906.04196 40.90000 5.40884 30.92324 31.91116 17765088C 1	37477.70880 40.50000 5.40884 30.92324 31.91116 17765088C 1	25008.53662 40.50000 2.25746 40.44843 38.24254 177662256 1	19990.57910 40.50000 1.34270 40.40089 39.15730 10411186 1	14993.17784 40.80000 8.1312 40.78249 39.89687 43865049 40.28392 39.44831 61.85861 60.65986 58.40324 58.24834 58.24834 64.09691 57.28123 948.61109 937.87376 32.31893 32.31893 1244.47903 1233.23529 0.00000 1244.47903 1233.23529 1855.48236 1613.62587 1855.48236 55.99459 1859.43704 1541.43753 247.33674 183.62885 1315.49750 1043.97091 1030.91237 35.08825 995.61412	7800.08649 40.50000 -1.1016 40.44304 40.41018 -15833207 41.00187 40.76902 50.46838 47.06814 80.69786 1.10824 50.04459 50.04459 49.99452 49.99452 439.99458 439.99458 14.11760 429.58488 429.58488 423.44484 0.00000 429.58488 423.44484 5.32638 9.03013 868.35468 563.03940 417.18464 27.83112 391.92394 389.08734 4.08825 383.82609	8008.19012 40.80000 -1.88880 40.64771 40.78880 -28377800 41.14878 41.03987 50.46838 47.06814 47.34732 -28864 50.04459 50.04459 48.99452 48.78167 287.06881 288.11748 4.28936 280.78888 279.87412 -20000 289.78888 279.87412 2.82064 278.33698 278.33698 377.48408 12.03966 248.28936 264.41428 2.87337 261.84138	
2	40906.04196 40.90000 5.40884 30.92324 31.91116 17765088C 1	37477.70880 40.50000 5.40884 30.92324 31.91116 17765088C 1	25008.53662 40.50000 2.25746 40.44843 38.24254 177662256 1	19990.57910 40.50000 1.34270 40.40089 39.15730 10411186 1	14993.17784 40.80000 8.1312 40.78249 39.89687 43865049 40.28392 39.44831 61.85861 60.65986 58.40324 58.24834 58.24834 64.09691 57.28123 948.61109 937.87376 32.31893 32.31893 1244.47903 1233.23529 0.00000 1244.47903 1233.23529 1855.48236 1613.62587 1855.48236 55.99459 1859.43704 1541.43753 247.33674 183.62885 1315.49750 1043.97091 1030.91237 35.08825 995.61412	7800.08649 40.50000 -1.1016 40.44304 40.41018 -15833207 41.00187 40.76902 50.46838 47.06814 80.69786 1.10824 50.04459 50.04459 48.99452 48.78167 287.06881 288.11748 4.28936 280.78888 279.87412 -20000 289.78888 279.87412 2.82064 278.33698 278.33698 377.48408 12.03966 248.28936 264.41428 2.87337 261.84138	8008.19012 40.80000 -1.88880 40.64771 40.78880 -28377800 41.14878 41.03987 50.46838 47.06814 47.34732 -28864 50.04459 50.04459 48.99452 48.78167 287.06881 288.11748 4.28936 280.78888 279.87412 -20000 289.78888 279.87412 2.82064 278.33698 278.33698 377.48408 12.03966 248.28936 264.41428 2.87337 261.84138	
3	40906.04196 40.90000 5.40884 30.92324 31.91116 17765088C 1	37477.70880 40.50000 5.40884 30.92324 31.91116 17765088C 1	25008.53662 40.50000 2.25746 40.44843 38.24254 177662256 1	19990.57910 40.50000 1.34270 40.40089 39.15730 10411186 1	14993.17784 40.80000 8.1312 40.78249 39.89687 43865049 40.28392 39.44831 61.85861 60.65986 58.40324 58.24834 58.24834 64.09691 57.28123 948.61109 937.87376 32.31893 32.31893 1244.47903 1233.23529 0.00000 1244.47903 1233.23529 1855.48236 1613.62587 1855.48236 55.99459 1859.43704 1541.43753 247.33674 183.62885 1315.49750 1043.97091 1030.91237 35.08825 995.61412	7800.08649 40.50000 -1.1016 40.44304 40.41018 -15833207 41.00187 40.76902 50.46838 47.06814 80.69786 1.10824 50.04459 50.04459 48.99452 48.78167 287.06881 288.11748 4.28936 280.78888 279.87412 -20000 289.78888 279.87412 2.82064 278.33698 278.33698 377.48408 12.03966 248.28936 264.41428 2.87337 261.84138	8008.19012 40.80000 -1.88880 40.64771 40.78880 -28377800 41.14878 41.03987 50.46838 47.06814 47.34732 -28864 50.04459 50.04459 48.99452 48.78167 287.06881 288.11748 4.28936 280.78888 279.8741	

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F	49996-04195	37477-70850	25005-53662	19999-57910	14933-17786	9996-76636	7500-06569	5000-19012
PFDTM1	4189-36658	2500-07220	1743-96884	1336-48877	948-81105	600-43745	439-29848	287-05281
PFDM1	4061-24152	2641-29781	1721-34650	1315-10808	937-07375	594-56913	435-56913	286-11745
DFFSM2	38-80197	20-53365	7-96169	4-58371	2-11527	96385	13188	-11841
PFSTM2	4022-87210	2826-56320	1713-46919	1310-87657	934-98804	593-44601	435-44601	285-24040
PFSTM2	4022-87210	2826-56320	1713-46919	1310-87657	934-98804	593-44601	435-44601	285-24040
PFDTM2	6842-01084	4893-54736	2759-92645	2077-53381	1455-13048	904-08624	852-58360	417-02662
PFDM2	6634-69330	4553-30872	2720-09475	2052-59204	1441-01291	857-59736	648-40923	414-86488
DFPCL	50-15790	20-55943	6-34247	3-34299	1-82895	34708	33384	-10367
DFPCRT	6791-82220	4678-58774	2753-02173	2074-22849	1454-10997	903-78775	652-48877	417-20493
DFPCR	6884-43170	4572-35640	2713-14947	2049-28619	1439-99224	866-99884	648-31438	415-04319
DFPFC	60-82322	10-81327	-4-60388	-5-62128	-4-97351	-3-38690	-2-44753	-1-48457
DFPCVT	6631-24750	4605-62322	2731-98877	2082-08144	1448-03558	901-72703	651-45494	416-79952
DFPCV	6923-60638	4561-48712	2717-75235	2054-90747	1444-96577	900-39574	650-76191	416-52775
DFPCV	162-71790	636-90309	580-71146	441-19034	259-10146	173-31125	117-08160	66-87862
DFPCMT	4448-65057	3575-33221	2151-24561	1621-49197	1149-84077	728-24718	534-37383	349-92301
DFPCM	6340-88892	3530-56468	2137-04080	1613-71713	1145-86432	726-68445	533-66031	349-65113
DFPCM	6-32430	2-61163	-85002	-45178	-21352	07412	04026	01878
DFJPC	6334-62201	3528-60146	2136-29409	1613-27040	1145-45316	726-60621	533-64050	349-63553
DFJPC	6334-62201	3528-60146	2136-29409	1613-27040	1145-45316	726-60621	533-64050	349-63553
DFJPC	1679-32812	776-20856	286-13060	206-17334	142-64926	87-77056	63-02041	39-73421
PCPC	4655-22394	3151-76389	1852-08427	1407-09201	1003-00160	639-03477	470-61953	309-90113
TFMS2	109-94080	100-14447	91-86336	69-08603	86-67905	64-92279	83-92327	83-30336
DFSM2	55-80130	55-88460	55-94303	55-95732	55-96352	55-96282	55-95761	55-94919
WFSM2	12-36832	8-61308	5-43901	4-30412	3-23982	2-24778	1-76300	1-26899
TFDM2	141-10321	123-87886	107-38806	101-48995	96-06053	91-88969	88-78578	86-59445
DFDM2	55-32852	55-45357	3-64639	55-70613	55-76252	55-81739	55-84385	55-86916
WFJPC	8-90617	5-74145	3-24039	2-39973	1-85177	1-06653	071834	44994
WFJPC	8-90617	5-74145	3-24039	2-39973	1-85177	1-06653	071834	44994
TFJPC	151-67484	1-08173	5-84420	5-10921	4-31235	3-33305	2-93782	2-37688
DFJPC	54-59310	4-66969	111-72340	104-79330	98-21467	92-34983	89-65014	87-10371
REFJPC	6037-72601	3-77332	1712-23637	1205-16957	55-47872	55-72760	55-78195	55-83287
REFJPC	6037-72601	3-77332	1712-23637	1205-16957	55-47872	55-72760	55-78195	55-83287

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F	49996-04194	37477-70550	28006-23642	19999-57910	14993-17784	9996-76636	7800-08569	8000-19012	
POPC	4053-22364	3181-76385	1882-00427	1407-09201	1003-00180	639-03477	470-41563	309-90113	
DPPC	126-00104	85-64603	50-32854	38-23631	27-82582	17-26513	12-78862	8-42126	
PTIT	4528-7229C	3046-11766	1801-78574	1368-85570	978-74593	621-66964	487-83102	301-47988	
PTEY	2646-8228C	1401-72429	1297-88591	1036-10532	777-08727	521-97781	395-23149	268-47501	
PTE	2632-0008C	1493-29045	1293-63774	1032-08894	778-00138	820-47943	394-88372	267-83108	
DPTX	-1-11602	-07217	-36467	-15901	-17970	-14240	-01230	-05770	
DPTV	2646-8228C	1491-72429	1297-88591	1036-10532	777-08727	521-97781	395-23149	268-47501	
PPI	2633-11062	1533-21628	1293-67507	1032-08892	774-8216C	530-62223	394-87142	267-88678	
DPP1	105-8899C	64-69170	34-62885	25-03085	16-03717	10-01272	7-07696	4-30088	
PPET	2541-32752	1497-32442	1263-18422	1011-13806	760-30043	511-99141	388-17208	264-18370	
PPE	2627-24081	1888-52658	1288-44423	1007-69907	787-98448	510-60981	387-19447	263-88790	
DPJMG	86-04507	36-82859	16-41927	11-88496	7-99632	4-75906	3-36637	2-04689	
PCFACE	2477-19492	1357-85989	1242-02496	995-81412	749-98816	505-88042	383-82609	241-64138	
PCSC	2400-08802	1860-64126	1293-34683	964-80247	746-83203	450-08726	371-17492	253-39643	
PESC	-38424	-27247	-18261	-14667	-11102	-07468	-05708	-03932	
TGPC	1421-99768	1179-98201	930-40718	629-23514	723-40942	624-10326	569-41061	517-92641	
WPC	99-32452	73-61067	48-87904	39-08450	29-3918E	19-83806	14-83387	10-16848	
TTIT	1421-99768	1218-22780	1131-47594	1129-89261	1112-85109	1116-06991	1128-88784	1129-88349	
TTET	1278-2898C	1673-88692	865-89966	778-03331	684-78020	596-64697	547-44937	501-46020	
TJMG	1203-3486C	1056-67923	878-29308	791-35146	696-72278	604-01482	584-10868	505-51033	
WJMG	104-33351	77-58179	91-80949	41-33881	31-16743	20-46880	15-33128	11-01841	
PODTM	5609-94232	3795-15628	2144-67584	1603-24342	1121-86772	708-83289	516-84985	337-17467	
POFC1	5626-86293	3730-71240	2133-61316	1596-10193	1117-59228	703-69221	514-79318	336-67543	
POFOL	1528-7776C	891-83194	370-63261	232-77362	128-32388	88-09370	33-37012	15-28144	
POJFCT	4098-08327	2688-88048	1762-98055	1363-32831	989-16843	645-59852	481-42306	321-39399	
POJFC	4098-08327	2688-88048	1762-98055	1363-32831	989-16843	645-59852	481-42306	321-39399	
POJFJC	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	
POFCD	4098-08327	2688-88048	1762-98055	1363-32831	989-16843	645-59852	481-42306	321-39399	
WDFC	9-88986	7-20812	4-69321	3-70764	2-74411	1-83717	1-28782	93873	
TOFC	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	
D+OJFC	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	-8890C	

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Security Classification

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		2b GROUP 4
3 REPORT TITLE (Title Unclassified) Throtttable Primary Injector for Staged Combustion Engine		
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11 SUPPLEMENTARY NOTES		12 SPONSORING MILITARY ACTIVITY AFRPL, Air Force Systems Command United States Air Force Edwards, California
13 ABSTRACT (U) This report summarizes the work performed under Contract FO4611-69-C-0021, entitled "Throtttable Primary Injector for Staged Combustion Rocket Engine". The objective of this program was to demonstrate a throtttable primary injector for a storable space engine employing the staged combustion cycle. The program goal was to demonstrate throttling over a 10:1 range. (C) Specific accomplishments of the program were as follows: (1) completed the detailed design of a flightweight modular primary injector for the storable space engine using the HIPERTHIN injector concept, (2) demonstrated the injector over 90% of the desired throttling range (9K to 45K thrust), (3) established critical design and fabrication parameters for the HIPERTHIN injector concept, (4) demonstrated the performance of the HIPERTHIN injector through a chamber pressure range from 258 to 4390 psia and mixture ratio range from 10.7 to 27.0, (5) demonstrated durability by conducting 87 tests with one injector in excess of 200 sec, with durations ranging from 10 sec at high thrust to 72 sec at low thrust, and (6) conducted supporting studies to provide additional design data in the areas of fluid flow and low frequency instability.		

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Throtttable Injector Staged Combustion Primary Combustion Storable Propellant						

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