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RESEARCH MEMORANDUM

* PRELIMINARY PERFORMANCE EVALUATION OF BLENDS OF PENTABORANE AND JP-4 FUEL IN A FULL-SCALE TURBOJET ENGINE

By C. R. King, Roland Breitwieser, and J. N. Sivo

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

* Contains proprietary or obsolete info.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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3521

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PRELIMINARY PERFORMANCE EVALUATION OF BLENDS OF PENTABORANE AND JP-4 FUEL IN A FULL-SCALE TURBOJET ENGINE

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SUMMARY

A brief evaluation of pentaborane - JP-4 fuel mixtures was conducted in a turbojet engine at a simulated flight altitude of 50,000 feet and a Mach number of 0.8. A total of 265 pounds of pentaborane was used, which limited the evaluation to two individual test periods of 6- and 12-minutes duration.

Engine data including thrust and specific fuel consumption are presented herein in both tabular and graphical form for various pentaborane-JP-4 fuel blends as well as photographs showing the condition of the engine at the conclusion of the investigation.

CP-1

INTRODUCTION

In the course of improving the specific fuel consumption and, hence, the range of jet-engine powered aircraft, major developments are being made in improved engine design. Equal or even greater gains in specific fuel consumption can be made by the use of fuels possessing higher heating values than the present hydrocarbon fuels. High-energy fuels of current interest are those containing boron and hydrogen, the two currently available elements possessing higher heating values (on a weight basis) than current jet-engine fuels.

One representative boron hydride fuel that is available in limited quantities and is receiving major research attention is pentaborane. Pentaborane has a heating value of 29,140 Btu per pound in contrast with a heating value of 18,900 Btu per pound for a typical hydrocarbon fuel. The ratio of the heating values of the fuels roughly indicates the flight-range extension possible with the use of pentaborane when the fuel is burned at a lean fuel-air ratio such as in a turbojet engine.

Several problems are associated with the practical utilization of fuels containing boron in a turbojet engine. One such problem is the nature of the products of combustion. Boron oxide has a melting point of about 1000° F, does not vaporize rapidly, and therefore is a viscous liquid at normal turbojet-combustor outlet operating temperatures and can be solidified upon contact with cool engine parts. The presence of the viscous liquid or the formation of solid deposits may seriously hinder engine performance, thus negating the potential advantages of boron-containing fuel.

Experimental investigations of the performance of boron-containing fuels in ram-jet and turbojet engines and engine components have been conducted at the NACA Lewis laboratory through the cooperation of the Bureau of Aeronautics, Department of the Navy. Additional small-scale work on the reactivity and inflammability characteristics of boron hydrides has also been carried out.

The encouraging results of previous investigations indicated the desirability of investing a portion of the limited pentaborane supply available to evaluate the performance and operational characteristics of pentaborane - JP-4 fuel blends in a full-scale engine. The objectives of the investigation reported herein were (1) to demonstrate whether the use of these fuels to reduce specific fuel consumption was feasible in an essentially unmodified turbojet engine, and (2) to determine the nature of the problems that might arise with the use of these fuels in the standard turbojet engine. A current production-model turbojet engine was used in this investigation and the investigation was conducted at a Reynolds number index of 0.2, which corresponds to an altitude of 50,000 feet and a flight Mach number of about 0.8.

APPARATUS

Engine and Installation

A schematic sketch of the engine installed in the 10-foot-diameter altitude test chamber is shown in figure 1. The turbojet engine used in these tests contains a twelve-stage axial-flow compressor, eight tubular combustion chambers, and a single-stage turbine. A fixed-area nozzle was used which was sized for maximum allowable turbine-discharge temperature, 1250° F, at approximately 95 percent rated engine speed to allow a small margin of safety in engine operation during switching from one fuel to another.

Engine Modifications

The boron-containing fuels necessitated certain modifications to the engine and fuel system. The modifications to the engine combustor and tail pipe increased the metal temperature and reduced the cooling air recirculated into the primary gas stream, thus tending to reduce the amount of solid deposits. The various modifications are as follows:

Combustor. - A solid retaining ring was used in place of the standard serrated retaining ring at the end of the combustor. This reduced the quantity of cooling air bypassed around the combustor through the transition region and hollow turbine nozzles and back into the primary gas stream.

Fuel nozzles. - Standard fuel nozzles were installed in the combustors only during the basic JP-4 run. Air-atomizing fuel nozzles were used during the pentaborane - JP-4 blend runs. Two lengths of air-atomizing fuel nozzles were used; configuration 1 extending $2\frac{15}{16}$ inches into the combustor and configuration 2 extending $2\frac{7}{16}$ inches into the combustor (fig. 2).

Turbine shroud. - The standard turbine shroud was modified as shown in figure 3 by increasing the tip clearance from the leading edge to the trailing edge of the turbine blade.

Tail pipe. - The standard test tail pipe and fixed-area exhaust nozzle were wrapped with an aluminum insulation blanket from the turbine station to the exhaust nozzle.

Fuel Systems

A schematic diagram of the fuel system used with pentaborane fuels is shown in figure 4. The JP-4 fuel was pumped and metered through a conventional fuel system. The pentaborane fuel was pressurized with helium forcing it from a suspended tank through metering devices into the special fuel nozzles. Provision was made for purging the pentaborane fuel lines with JP-4 and/or helium.

Fuels

The properties of the two fuels evaluated in this program, pentaborane and MIL-F-2624, grade JP-4 fuel, are presented in table I. The pentaborane was supplied by the Bureau of Aeronautics. The purity of the pentaborane was approximately 99 percent.

Boron oxide B_2O_3, a product of combustion of pentaborane, exhibits the following melting points:

Crystalline, $^{\circ}$F	842
Vitreous, $^{\circ}$F	1070

Instrumentation

Location of instrumentation stations and the instrumentation at each station are shown in the diagram and table in figure 1. One of the products of combustion, B_2O_3, liquid at normal engine operating temperatures, required the use of a purge-type total-pressure probe at the stations downstream of the combustor. Engine air flow was measured at station 1, engine inlet. Engine fuel flow was measured by rotameters and Potter flowmeters. Engine thrust was measured with a null-type thrust cell.

PROCEDURE

The duration of engine running time for the two pentaborane fuel tests was 6 and 12 minutes because of the limited supply, and, hence, special operational and data taking procedures were necessary. In general, the procedure followed was to use a starting fuel to bring the engine to test conditions, then to transfer the engine over to the pentaborane - JP-4 fuel blends. During the time interval that the engine was operated on the blends, the engine speed was modulated so as to maintain constant exhaust-gas temperature. Data were taken at about a 1-minute frequency on the conventional steady-state instrumentation. Insofar as possible, the engine was held at constant operating conditions during the "steady-state" data-recording cycle. Adjustments, if necessary, were made in the 10- to 20-second period between data reading. Because of the toxic nature of the pentaborane fuel, the engine was operated on JP-4 fuel following each run on pentaborane - JP-4 fuel blend in order to flush out the fuel system and engine of any pentaborane vapors.

Data were obtained at a Reynolds number index of 0.2, which corresponds to a simulated altitude of 50,000 feet and a flight Mach number of 0.8. The engine was operated at an inlet-air temperature of about 500° R over a range of actual speeds from 7000 to 7600 rpm for a range of pentaborane - JP-4 fuel blends and JP-4 fuels. Adjusting the engine speed from the inlet temperature at which the data were taken to the inlet temperature for standard altitude of 50,000 feet Mach number 0.8 lowers the speed range to 6700 to 7200 rpm.

All symbols are defined in appendix A, and the methods of calculation are described in appendix B.

PRESENTATION OF DATA

Engine and component performance. - The effect of corrected engine speed on the engine total-temperature ratio and the total-pressure ratio for JP-4 fuel and pentaborane - JP-4 fuel blends are presented in figure 5. At corrected engine speeds below 7700 rpm, the engine total-temperature ratio and total-pressure ratio were higher with the engine operating on pentaborane - JP-4 fuel blends than when the engine was operating on JP-4 fuel alone. This change in performance level indicates a decrease in effective flow areas within the engine.

The variation in thrust and total engine fuel flow with actual engine speed is presented in figure 6. Lines of constant fuel blends (percent by weight of total fuel flow) are included in figure 6(a) to show the decrease in total engine fuel flow as the pentaborane concentration is increased. The data included in this figure have been adjusted for small variations in engine total pressure and total temperature, and altitude ambient pressure in order to correspond to a simulated altitude of 50,000 feet and a flight Mach number of 0.8. Figures 7 and 8 include data adjusted to this same flight condition.

The variation in thrust and specific fuel consumption based on net thrust with engine total-temperature ratio is presented in figure 7. Lines of constant fuel blends (percent by weight) are included in figure 7(b) to show the decrease in specific fuel consumption as the percent of pentaborane concentration is increased. For the highest blend investigated, 42 percent, the specific fuel consumption is about 18 percent lower than with the conventional fuel.

At an engine total-temperature ratio of 3.5, the variation in combustor efficiency, turbine efficiency, and specific fuel consumption based on net thrust with the percent of pentaborane in JP-4 concentration is presented in figure 8. The reduction of engine speed with time of operation of pentaborane fuel at approximately constant exhaust-gas temperature is shown in figure 9. Engine speed could have been held constant if a variable-area nozzle had been used and would have allowed operation at essentially constant thrust. Because a fixed-area exhaust nozzle was used and the percent of blend is changing with time, only the combined effect of time and fuel blend on engine speed can be determined from this limited investigation.

Fuel deposits. - The condition of the engine parts exposed to pentaborane combustion products is shown in figure 10 following the test run with the modified fuel nozzle 2. The test run comprised an interval of engine operation with JP-4 fuel, 12 minutes of operation with pentaborane - JP-4 fuel blends, and then followed by 32.9 minutes of operation with JP-4 fuel. The quantity of pentaborane fuel burned for this test run was 80 pounds and the resulting amount of boron oxide formed assuming 100 percent combustion efficiency was 220 pounds. No noticeable effect of these deposits on engine operation was observed during the investigation except the engine speed deterioration with time and blend. Subsequent engine operation with JP-4 fuel tended to remove the deposits and return the engine to its normal operating line.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 4, 1954

APPENDIX A

SYMBOLS

The following symbols are used in this report: 3521

A	area, sq ft
F_d	thrust system scale reading, lb
F_j	jet thrust, lb
F_n	net thrust, lb
f	fuel-air ratio
g	acceleration due to gravity, ft/sec^2
h	enthalpy, Btu/lb
h_f	lower heating value of fuel, Btu/lb
K	thermodynamic constant
M	Mach number
m	mass flow, slugs/sec
N	engine speed, rpm
P	total pressure, lb/sq ft
p	static pressure, lb/sq ft
T	total temperature, $^{\circ}$R
V	velocity, ft/sec
W_a	air flow, lb/sec
W_f	fuel flow, lb/hr
γ	ratio of specific heats
δ_a	ratio of engine-inlet total pressure P to P at M, 0.8; altitude, 50,000 ft

θ_a ratio of engine-inlet total temperature T to T at M, 0.8; altitude, 50,000 ft

θ_1 ratio of engine-inlet total temperature to NACA standard sea-level temperature, 519° R

η efficiency

Subscripts:

a air

b combustor

c compressor

cl compressor twelfth-stage leakage flow

g gas

m fuel manifold

t turbine

tl turbine cooling

0 ambient or free-stream conditions

1 engine inlet or compressor inlet

3 compressor outlet or combustor inlet

4 combustor outlet or turbine inlet

5 turbine outlet

9 exhaust-nozzle inlet

APPENDIX B

METHOD OF CALCULATION

The values used for c_p, γ, R and various enthalpies for air and hydrocarbon products of combustion were obtained from reference 1 and pentaborane and pentaborane blends from reference 2.

Engine air flow. - The compressor-inlet air flow was determined from total and static pressures and temperature measurements at station 1, the engine inlet. The compressor and turbine leakage was measured at two instrumented stations on the compressor and one on the turbine. Therefore,

$$W_{a,3} = W_{a,1} - W_{a,cl_1} - W_{a,cl} - W_{a,tl_1} \tag{B1}$$

Thrust. - The jet thrust determined from the thrust system measurements was calculated from the following equation:

$$F_j = F_d + A_s(p_1 - p_0) \tag{B2}$$

where A_s is the area of the seal around the engine inlet.

The net thrust was determined by subtracting the inlet momentum from the jet thrust:

$$F_n = F_j - \frac{W_{a,1}V_0}{g} \tag{B3}$$

When the test conditions deviated from the desired simulated flight condition (M_0, 0.8; altitude, 50,000 ft) the data were adjusted by the appropriate values of δ_a and $\sqrt{\theta_a}$.

Combustion efficiency. - Combustion efficiency was defined as

$$\eta_b = \frac{(1 + f)h_{a,9} - h_{a,1}}{f\ h_c} \tag{B4}$$

The JP-4 combustion efficiency was determined by

$$\eta_b = \frac{h_a\Big]_{T_1}^{T_9} + f\left(\frac{A_m + B}{m + 1}\right)\Big]_{T_m}^{T_9}}{f\ h_f} \tag{B5}$$

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where $\frac{A_m + B}{m + 1}$ accounts for the difference between the enthalpy of carbon dioxide and water vapor in the burned mixture and the enthalpy removed from the air by their formation (ref. 1). The temperature of the fuel prior to entry into the engine is T_m.

Pentaborane and pentaborane blends. - Pentaborane blends combustion efficiency was calculated as follows:

$$\eta_b = \frac{(h_9 - h_{a,1}) - f(K)}{f\ h_f} \tag{B6}$$

where h_g and K are from NACA unpublished data based on thermodynamic data from reference 2.

Turbine efficiency. - The turbine efficiency was calculated by

$$\eta_t = \frac{1 - \frac{T_9}{T_4}}{1 - \left(\frac{P_5}{P_4}\right)^{\frac{\gamma-1}{\gamma}}} \tag{B7}$$

A 5 percent total-pressure loss in the tail pipe was assumed as determined from previous tests. Therefore, P_5 was assumed to equal 1.0526 P_9.

Compressor efficiency. - The compressor efficiency was obtained from the equation

$$\eta_c = \frac{\left[\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{\left[\frac{T_3}{T_1} - 1\right]} \tag{B8}$$

REFERENCES

1. Turner, L. Richard, and Bogart, Donald: Constant-Pressure Combustion Charts Including Effects of Diluent Addition. NACA Rep. 937, 1947. (Supersedes NACA TN's 1086 and 1655.)

2. Huff, Vearl N., Gordon, Sanford, and Morrell, Virginia E.: General Method and Thermodynamic Tables for Computation of Equilibrium Composition and Temperature of Chemical Reactions. NACA Rep. 1037, 1951. (Supersedes NACA TN's 2113 and 2161.)

TABLE I. - FUEL PROPERTIES

Pentaborane[a], B_5H_9	
Formula weight	63.17
Melting point, $^{\circ}F$	-52
Boiling point, $^{\circ}F$ at 760 mm Hg	136
Heat of combustion, Btu/lb	29,127[b]
Specific gravity, 32° F	0.644
Stoichiometric fuel-air ratio	0.07635
Pounds of B_2O_3 per million Btu	94
MIL-F-5624A, grade JP-4	
Initial boiling point, $^{\circ}F$	
Percent evaporated at $^{\circ}F$	
5	180
10	243
20	292
30	316
40	331
50	341
60	355
70	371
80	390
90	421
95	447
Final boiling point	480
Residue, percent	1.0
Loss, percent	1.0
Reid vapor pressure, lb/sq in.	2.4
Specific gravity, $60^{\circ}/60^{\circ}$ F	0.778
Hydrogen-carbon ratio	0.168
Net heat of combustion, Btu/lb	18,675

[a]Pure.

[b]Heating value used at time report was prepared. A better value is 29,100 Btu/lb. Both values are based on water in the gaseous phase.

TABLE II. - ENGINE AND COMPONENT PERFORMANCE DATA

Run	Fuel		Time from start of fuel blending, min	Altitude ambient pressure, p_0, lb/sq ft abs	Engine-inlet total pressure, P_1, lb/sq ft abs	Engine-inlet total temperature, T_1, °R	Compressor-outlet total pressure, P_3, lb/sq ft abs	Compressor-outlet total temperature, T_3, °R	Combustor-outlet total pressure, P_4, lb/sq ft abs	Exhaust-nozzle-inlet total pressure, P_9, lb/sq ft abs	Exhaust-nozzle-inlet total temperature, T_9, °R	Engine speed, N, rpm	Engine-inlet air flow $W_{a,1}$, lb/sec
	JP-4, percent by weight	Blend, percent by weight											
							Standard fuel nozzle						
1	100	----	---	270	410	507	1835	836	1745	668	1492	6925	18.23
2	100	----	---	267	496	507	1911	860	1818	701	1580	7110	18.25
3	100	----	---	270	413	507	2075	866	1975	742	1636	7263	18.96
4	100	----	---	264	405	507	2068	885	1968	752	1688	7387	18.95
5	100	----	---	267	406	508	2135	898	2032	783	1760	7540	19.17
							Modified fuel nozzle 1						
6	100	----	---	272	408	506	2059	855	1957	751	1637	7271	18.95
7	100	----	---	270	408	505	2185	886	2079	800	1724	7552	19.24
8	100	----	---	270	404	504	2088	873	1986	766	1664	7383	18.89
9	100	----	---	266	404	504	1890	840	1805	693	1514	7003	18.07
10	100	----	---	275	414	504	1830	827	1740	674	1454	6869	18.00
11	100	----	---	268	404	499	1848	829	1756	674	1462	6913	18.16
12	100	----	0	261	400	500	2164	884	2061	792	1737	7552	19.39
13	89	11.0	1.0	274	405	500	2179	886	2075	800	1770	7554	19.26
14	77.9	22.1	2.5	271	410	500	2114	870	2013	779	1711	7319	19.12
15	71.0	29.0	4.2	265	411	500	2111	875	2010	777	1692	7308	19.41
16	65.2	33.8	6.0	268	414	500	2122	864	2020	788	1748	7236	19.49
17	100	----	13.0	265	404	500	2188	886	2083	801	1736	7574	19.75
							Modified fuel nozzle 2						
18	100	----	---	276	421	514	1957	864	1858	726	1561	7080	18.59
19	100	----	0	281	414	515	2230	908	2120	815	1722	7637	19.60
20	78	22	1.03	278	418	514	2235	901	2126	819	1779	7637	19.77
21	70.3	39.7	2.8	272	418	512	2226	904	2118	815	1752	7591	19.72
22	64.5	35.5	4.7	279	425	514	2238	905	2130	825	1781	7541	19.83
23	64.7	35.3	5.7	276	425	513	2243	896	2135	827	1783	7521	19.83
24	64.5	35.5	6.8	277	425	514	2240	901	2133	829	1791	7512	19.78
25	57.9	42.1	8.4	280	428	515	2229	903	2124	825	1780	7418	19.77
26	64.5	35.5	10.8	273	421	514	2213	900	2107	817	1801	7444	19.53
27	70.0	30.0	12.1	273	421	514	2214	895	2106	814	1776	7405	19.50
28	100	----	33.3	277	425	514	1923	850	1830	703	1498	6942	18.74
29	100	----	36.9	280	421	512	2075	870	1976	760	1613	7199	18.97
30	100	----	41.0	280	418	510	2224	893	2118	814	1720	7488	19.66
31	100	----	45.0	277	418	510	2022	875	2040	781	1640	7286	19.29

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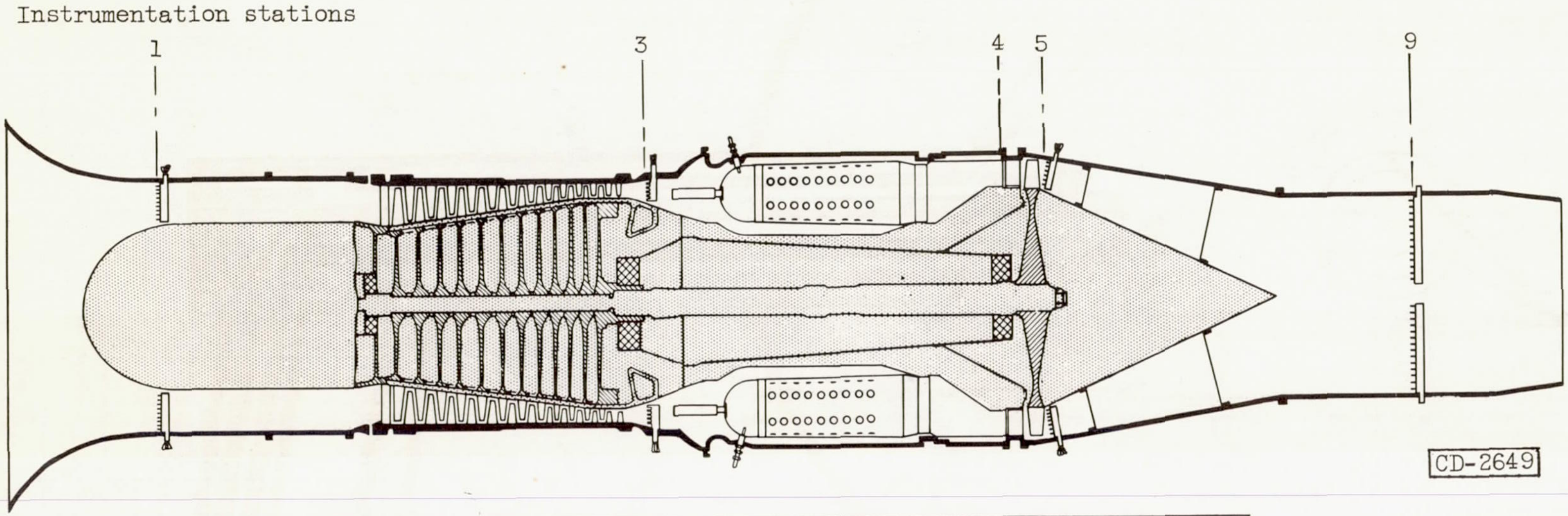
TABLE II. - Concluded. ENGINE AND COMPONENT PERFORMANCE DATA

Run	Compressor-outlet air flow, $W_{a,3}$, lb/sec	Total engine fuel flow W_f, lb/hr	Jet thrust, F_j, lb	Net thrust, F_n, lb	Specific fuel consumption, sfc, lb/hr/lb	Adjusted engine performance to altitude of 50,000 ft and M = 0.8: Engine speed, $\frac{N}{\sqrt{\theta_a}}$, rpm	Net thrust, $\frac{F_n}{\delta_a}$, lb	Specific fuel consumption, $\frac{sfc}{\sqrt{\theta_a}}$, lb/hr/lb	Corrected engine speed, $\frac{N}{\sqrt{\theta_1}}$, rpm	Engine total-temperature ratio, $\frac{T_9}{T_1}$	Engine total-pressure ratio, $\frac{P_9}{P_1}$	Compressor efficiency, η_c	Combustor efficiency, η_b	Turbine efficiency, η_t	Combustor pressure loss, $\frac{P_3-P_4}{P_3}$
Standard fuel nozzle															
1	17.81	895	1105	636	1.391	6475	573	1.305	7008	2.943	1.630	0.825	0.9828	0.797	0.0491
2	17.82	976	1179	709	1.377	6645	645	1.291	7195	3.116	1.728	.801	.979	.807	.0486
3	18.51	1096	1296	805	1.361	6795	721	1.276	7350	3.227	1.799	.829	.962	.794	.0483
4	18.48	1146	1328	834	1.374	6910	760	1.288	7476	3.329	1.855	.796	.964	.802	.0484
5	18.68	1250	1396	902	1.386	7040	826	1.294	7623	3.465	1.931	.792	.953	.807	.0483
Modified fuel nozzle 1															
6	18.47	1110	1274	794	1.398	6820	720	1.314	7366	3.235	1.841	0.854	0.961	0.773	0.0495
7	18.74	1250	1393	902	1.386	7090	819	1.300	7658	3.414	1.961	.816	.983	.796	.0485
8	18.41	1156	1309	832	1.389	6945	761	1.309	7494	3.302	1.896	.819	.941	.802	.0489
9	17.65	952	1135	671	1.419	6585	613	1.339	7108	3.004	1.715	.832	.938	.793	.0450
10	17.58	878	1070	613	1.433	6460	548	1.349	6972	2.885	1.628	.826	.946	.806	.0492
11	17.75	900	1090	630	1.428	6515	574	1.358	7051	2.930	1.668	.824	.951	.804	.0498
12	18.91	1253	1390	889	1.409	7120	822	1.331	7695	3.474	1.980	.808	.955	.798	0.0476
13	18.77	1229	1399	922	1.332	7120	840	1.262	7698	3.540	1.975	.801	.934	.810	.0478
14	18.64	1100	1348	861	1.278	6900	777	1.213	7458	3.422	1.900	.809	.932	.803	.0478
15	18.95	1050	1357	849	1.238	6890	766	1.166	7447	3.384	1.891	.796	.940	.813	.0479
16	19.01	1066	1371	863	1.235	6820	770	1.179	7373	3.496	1.903	.819	.959	.810	.0481
17	19.26	1266	1409	902	1.404	7140	824	1.329	7718	3.472	1.983	.805			.0480
Modified fuel nozzle 2															
18	18.13	1003	1210	726	1.381	6590	639	1.288	7151	3.049	1.726	0.811	0.954	0.820	0.0506
19	19.08	1285	1393	903	1.423	7100	807	1.325	7706	3.357	1.970	.798	.918	.825	.0494
20	19.27	1216	1458	952	1.277	7105	843	1.193	7713	3.475	1.960	.818	.924	.799	.0488
21	19.2	1140	1452	936	1.218	7075	827	1.141	7697	3.435	1.952	.802	.921	.815	.0485
22	19.3	1143	1462	946	1.207	7020	824	1.126	7616	3.479	1.942	.800	.928	.805	.0483
23	19.31	1135	1462	941	1.206	7005	819	1.125	7601	3.489	1.947	.816	.935	.801	.0481
24	19.26	1126	1458	940	1.198	6990	819	1.116	7587	3.498	1.952	.809	.937	.794	.0478
25	19.26	1083	1446	930	1.164	6895	804	1.086	7485	3.470	1.930	.8013	.9276	.800	.0472
26	19.03	1129	1438	924	1.222	6935	812	1.141	7518	3.518	1.942	.8091	.9386	.788	.0480
27	18.99	1131	1426	912	1.24	6895	804	1.154	7479	3.469	1.935	.8201	.9317	.784	.0488
28	18.29	922	1148	657	1.40	6465	572	1.308	7011	2.926	1.655	.826	.978	.811	.0484
29	18.49	1107	1290	806	1.373	6710	707	1.273	7300	3.163	1.807	.827	.949	.846	.0477
30	19.14	1271	1416	919	1.335	6995	811	1.298	7623	3.386	1.949	.8271	.9320	.821	.0477
31	18.80	1140	1332	838	1.360	6805	742	1.273	7417	3.228	1.870	.796	.946	.824	.0406



	Station	Instrumentation		
		Static pressure	Total pressure	Total temperature
Engine inlet	1	8	24	12
Compressor outlet	3	2	12	12
Combustor outlet	4	-	8	16
Exhaust-nozzle inlet	9	-	12	12

Figure 1. - Schematic diagram of turbojet-engine installation in altitude test chamber.

Fuel nozzle configuration	Dimension A	Dimension B
1	$1\frac{3}{8}$	$1\frac{9}{16}$
2	$1\frac{3}{8}$	$1\frac{1}{16}$

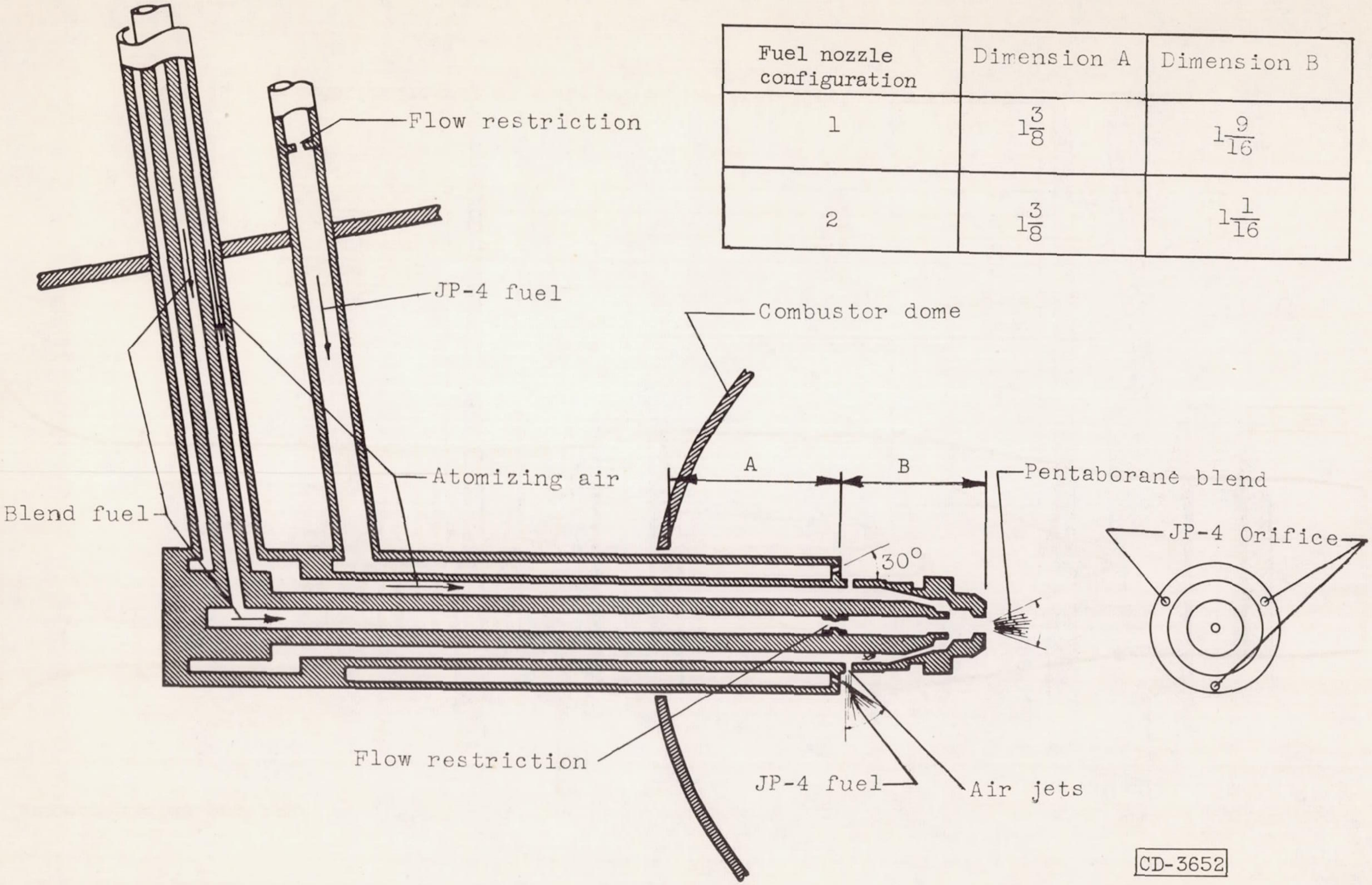
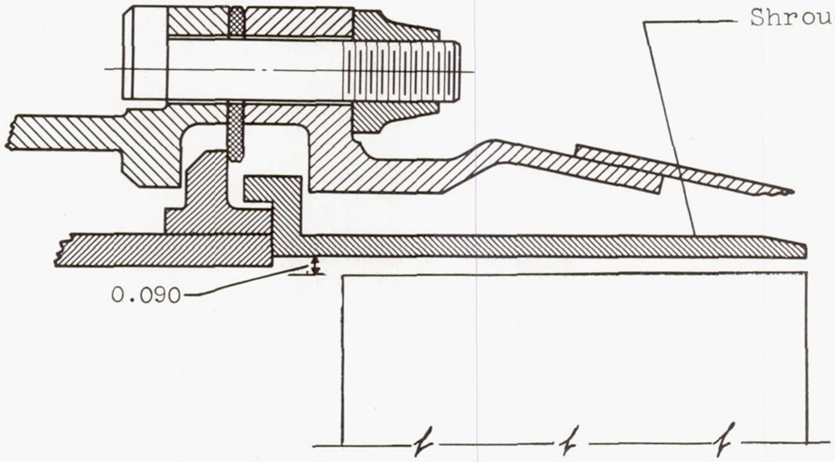
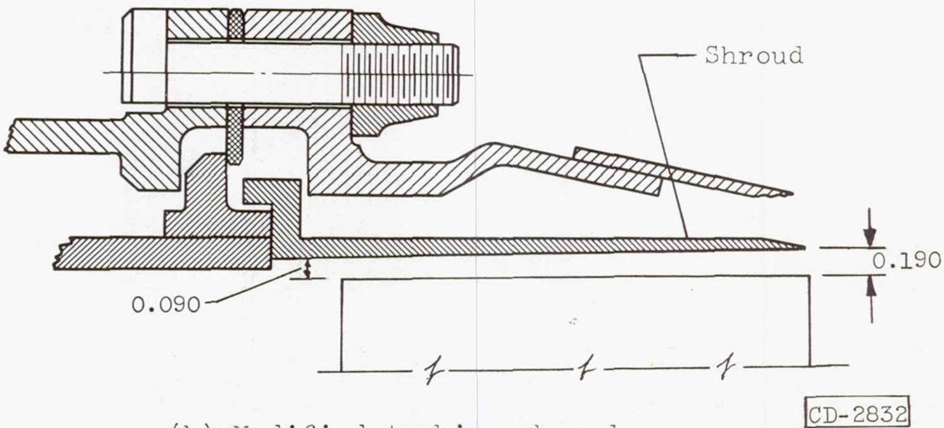


Figure 2. - Cross-section of modified fuel nozzle.



(a) Standard turbine shroud.



(b) Modified turbine shroud.

Figure 3. - Cross section of standard and modified turbine shroud.

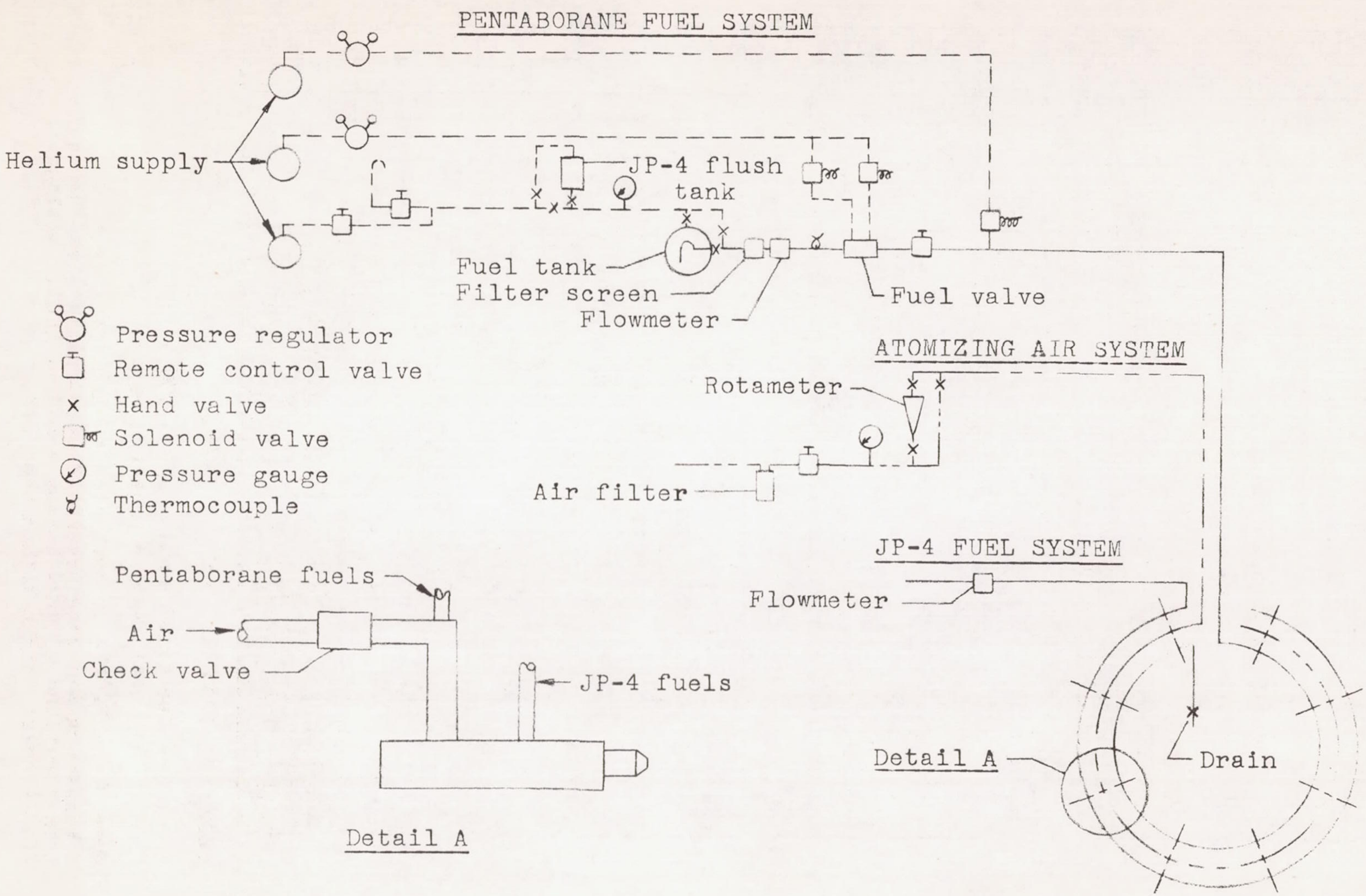
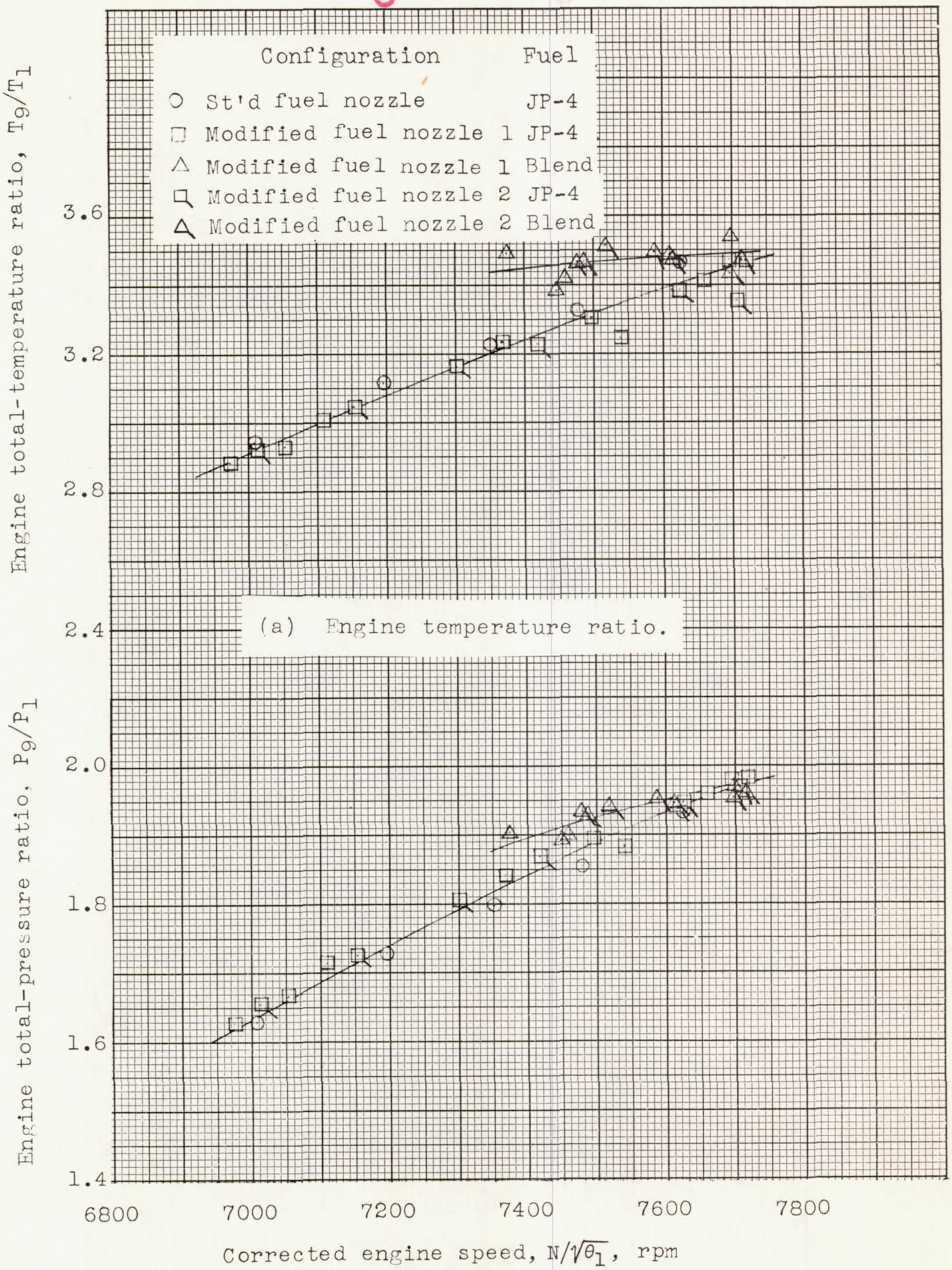
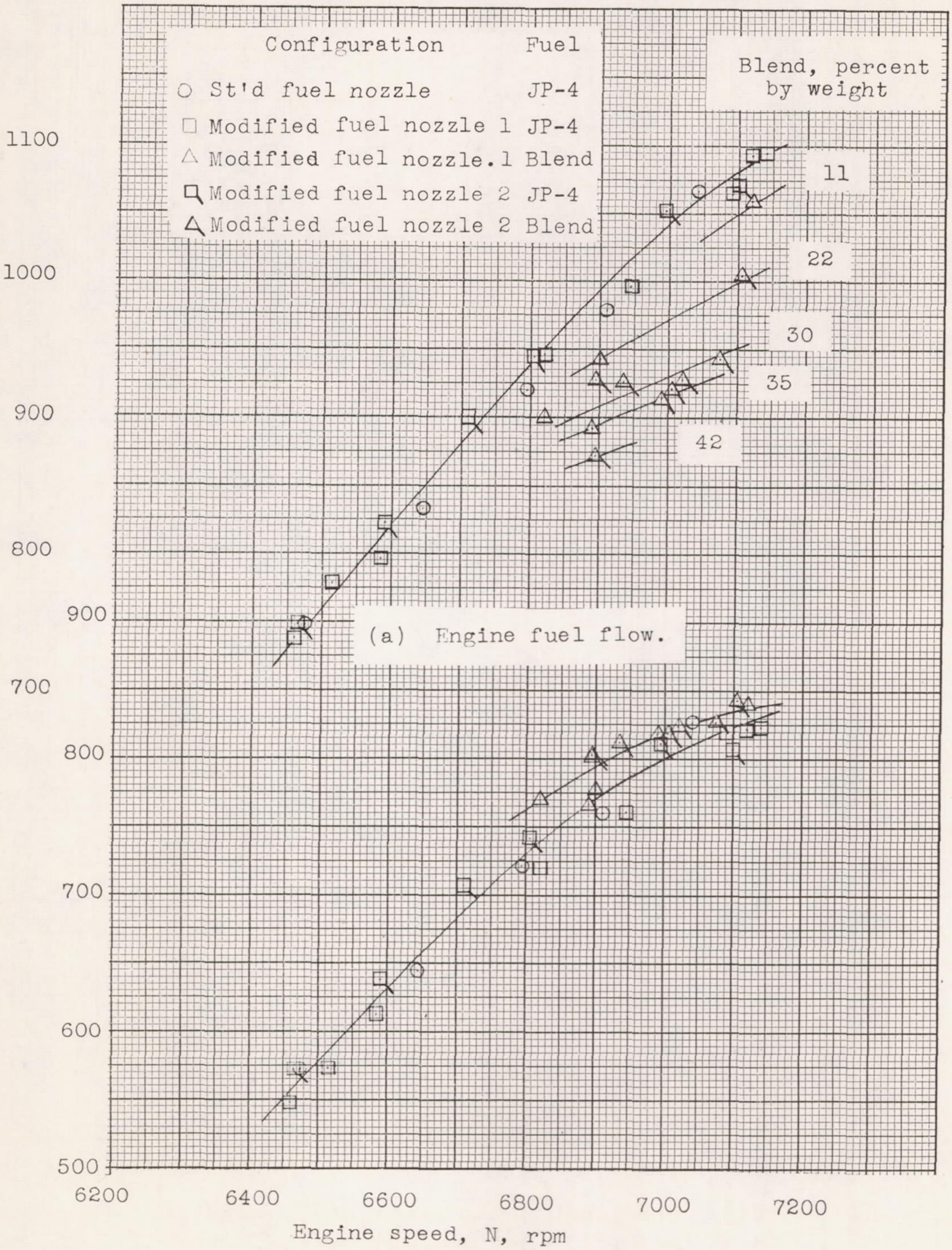


Figure 4 - Diagram of engine fuel system.



(b) Engine pressure ratio

Figure 5. - Effect of corrected engine speed on engine temperature and pressure ratio for JP-4 fuel and variable concentrations of pentaborane and JP-4 fuel. Altitude, 50,000 feet; flight Mach number 0.8.



(b) Net thrust

Figure 6. - Effect of engine speed on engine performance for JP-4 fuel and variable concentrations of pentaborane in JP-4 fuel. Altitude, 50,000 feet; flight Mach number 0.8.

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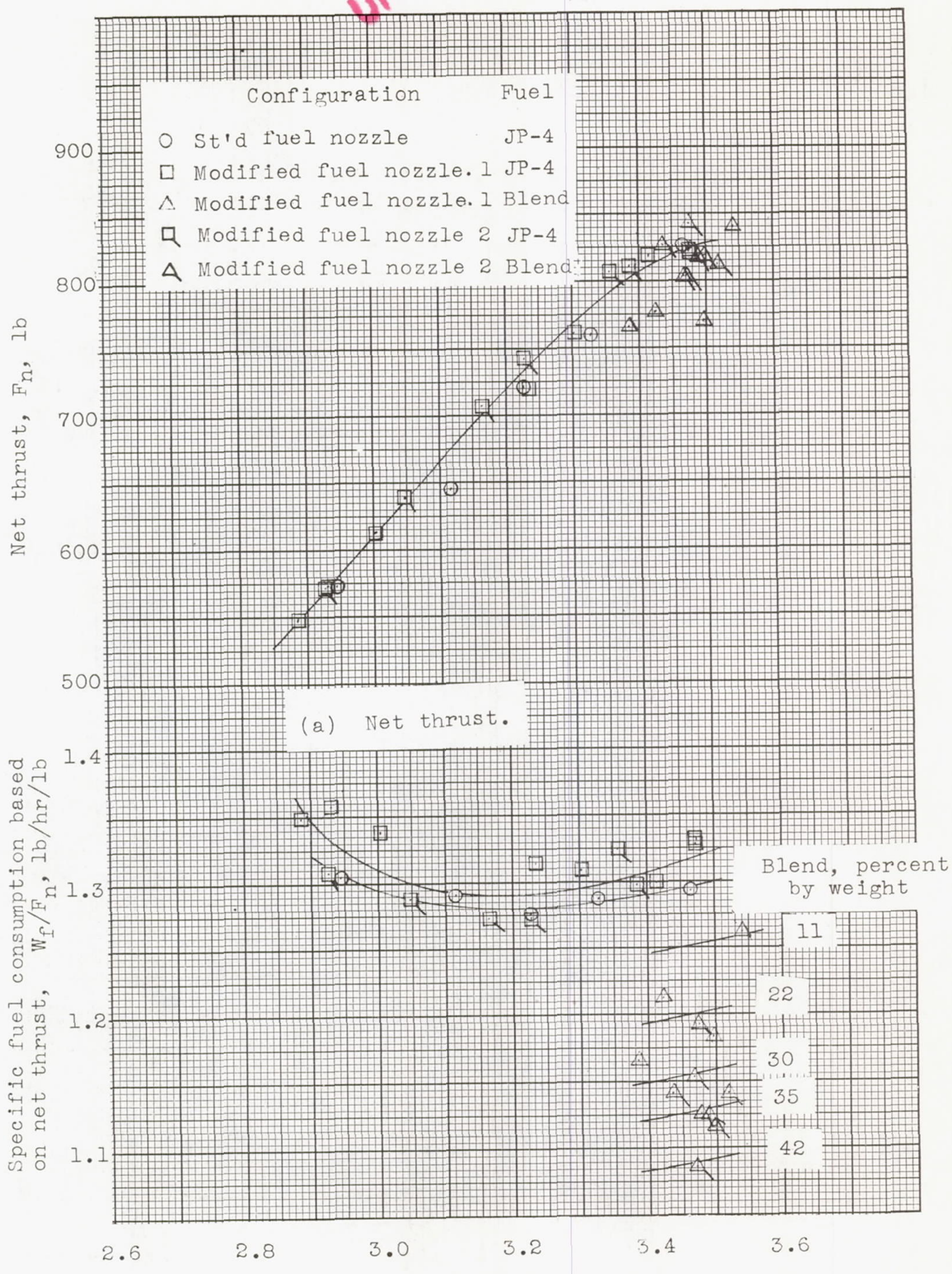

(b) Specific fuel consumption

Figure 7. - Effect of engine temperature ratio on engine performance for JP-4 fuel and variable concentrations of pentaborane in JP-4 fuel. Altitude, 50,000 feet; flight Mach number, 0.8.

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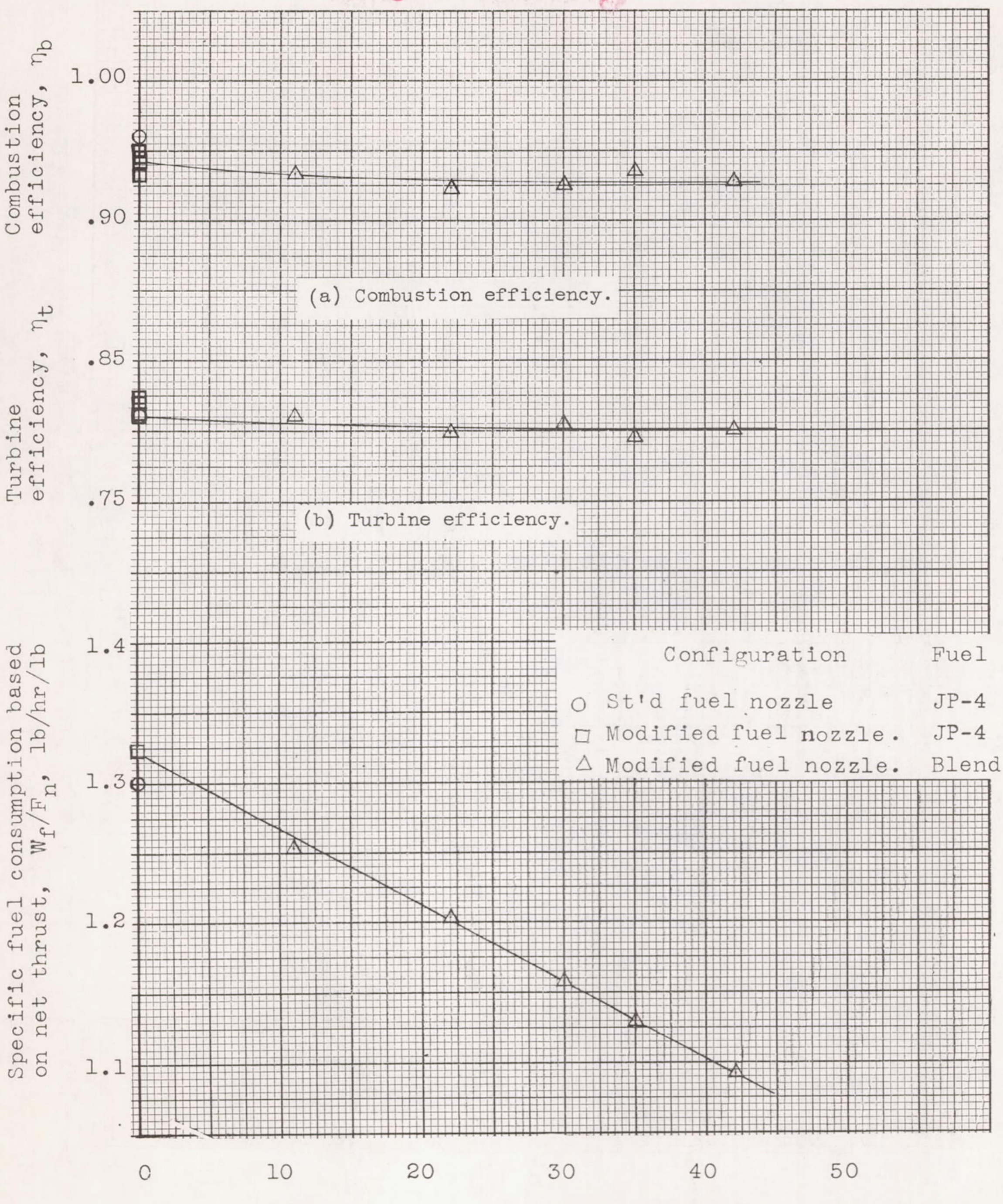

(c) Specific fuel consumption

Figure 8. - Engine performance for variable concentrations of Pentaborane in JP-4 fuel. Altitude, 50,000 feet; flight Mach number, 0.8. Engine temperature ratio, 3.5.

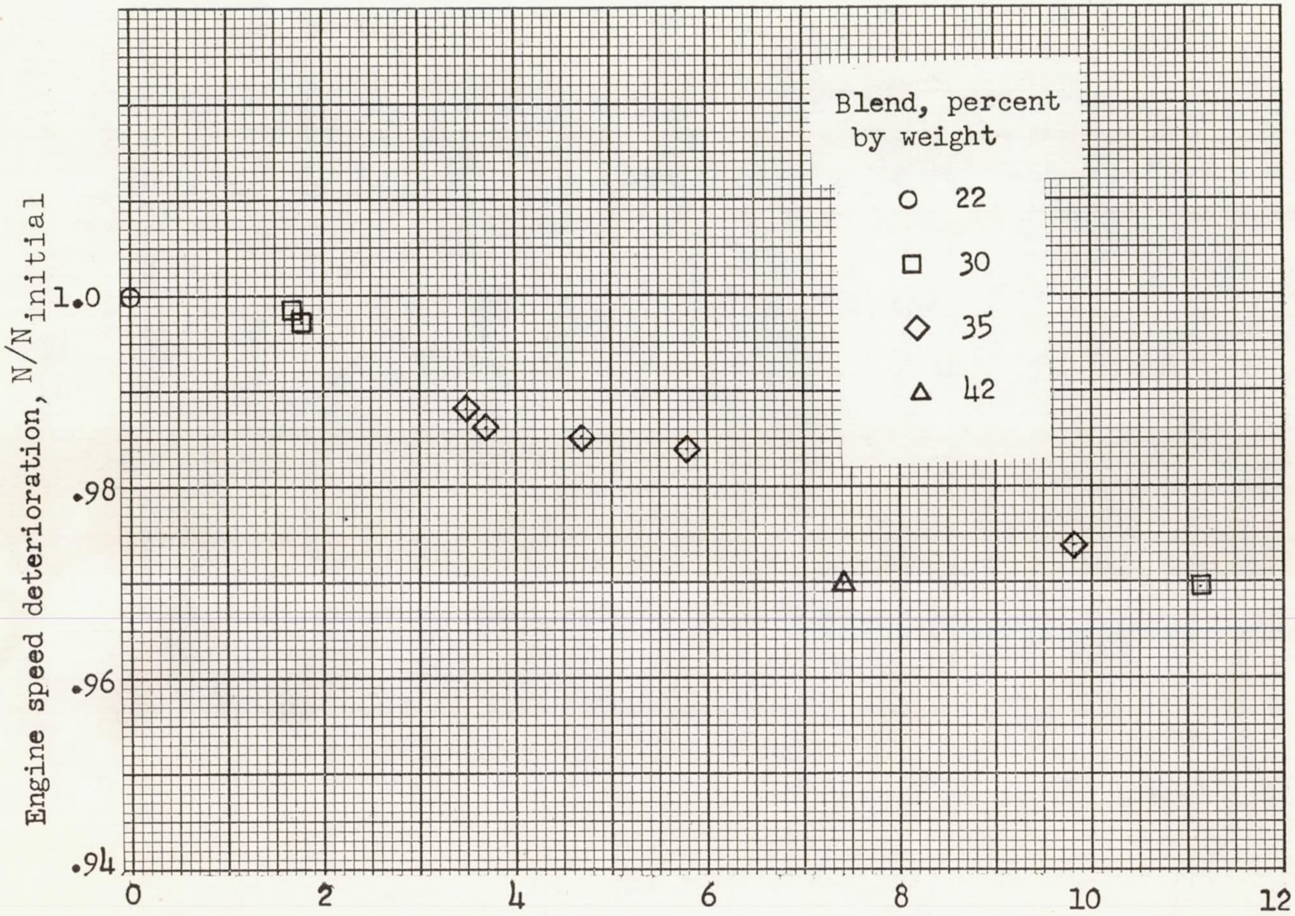

Figure 9. - Effect of operation with pentaborane - JP-4 fuel blends on engine speed. Exhaust-gas temperature, 1780 °R

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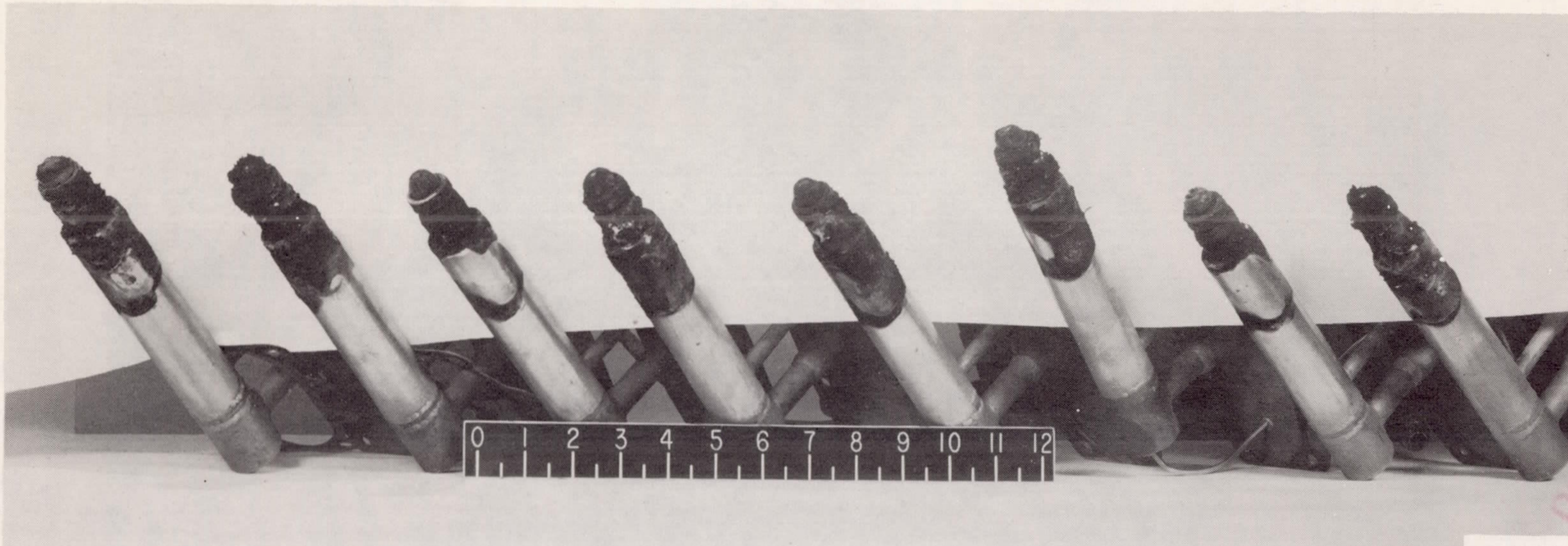

C-35419

(a) Fuel nozzles.

Figure 10. - Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)

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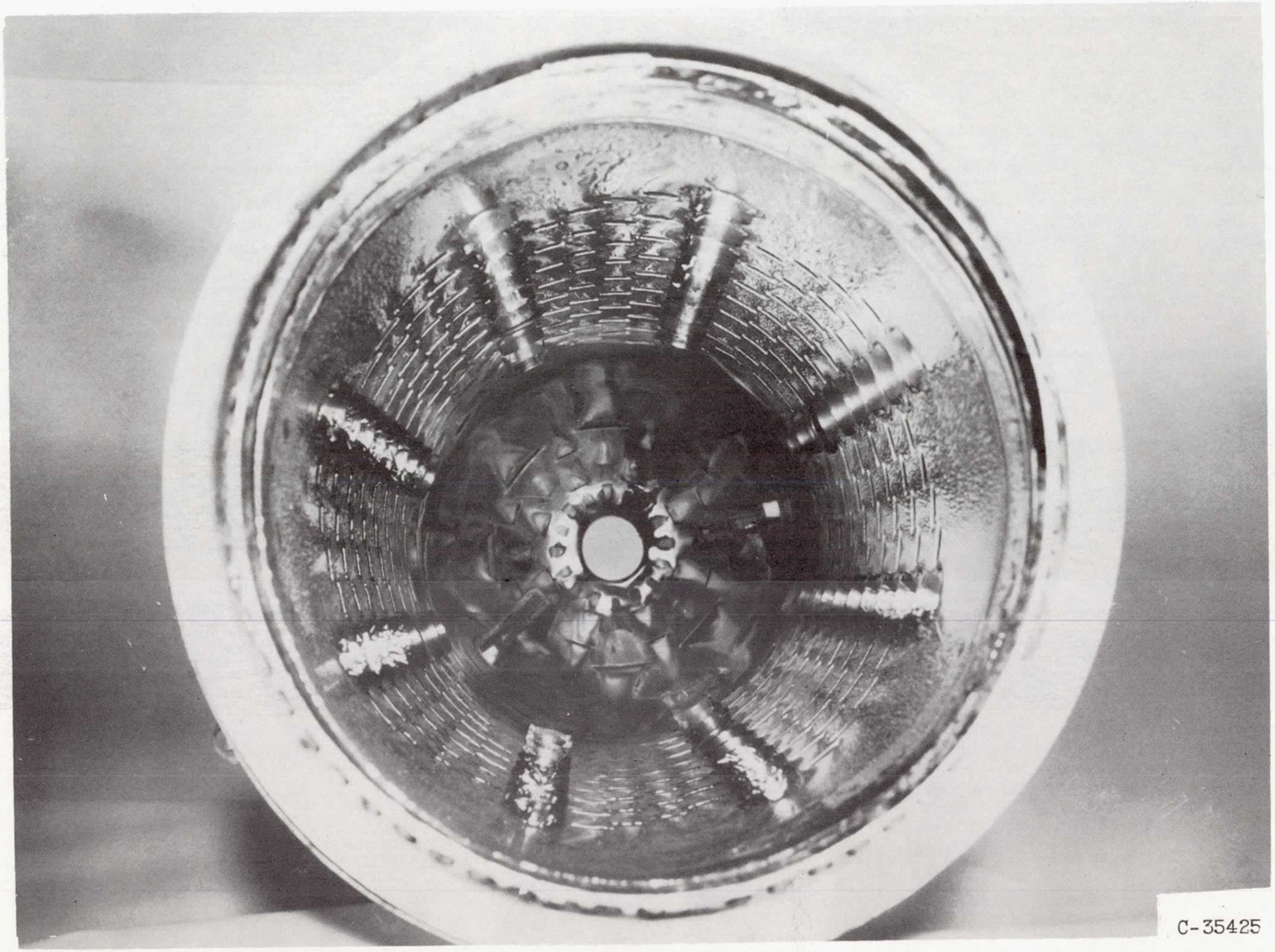

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(b) Combustor.

Figure 10. - Continued. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)

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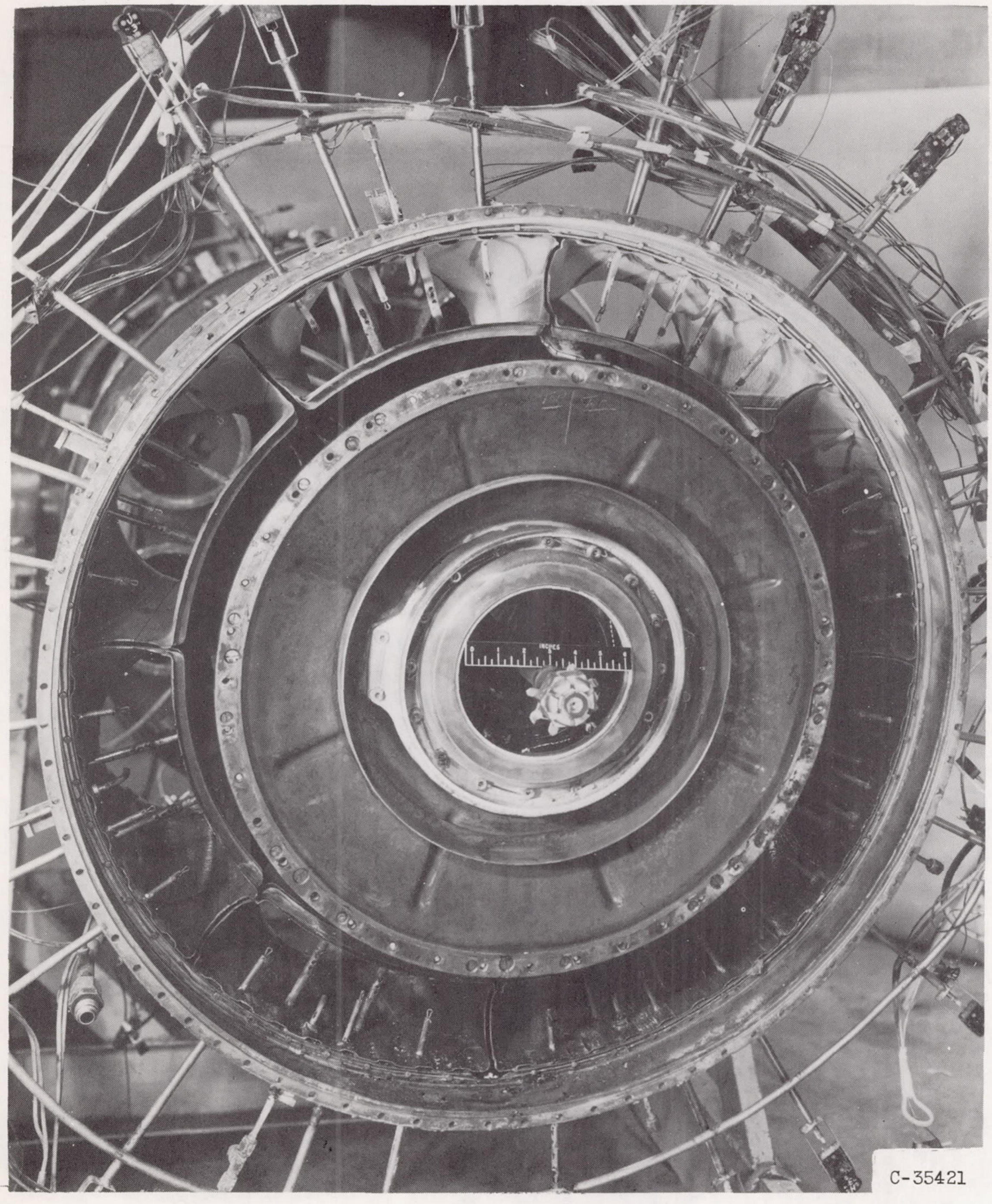

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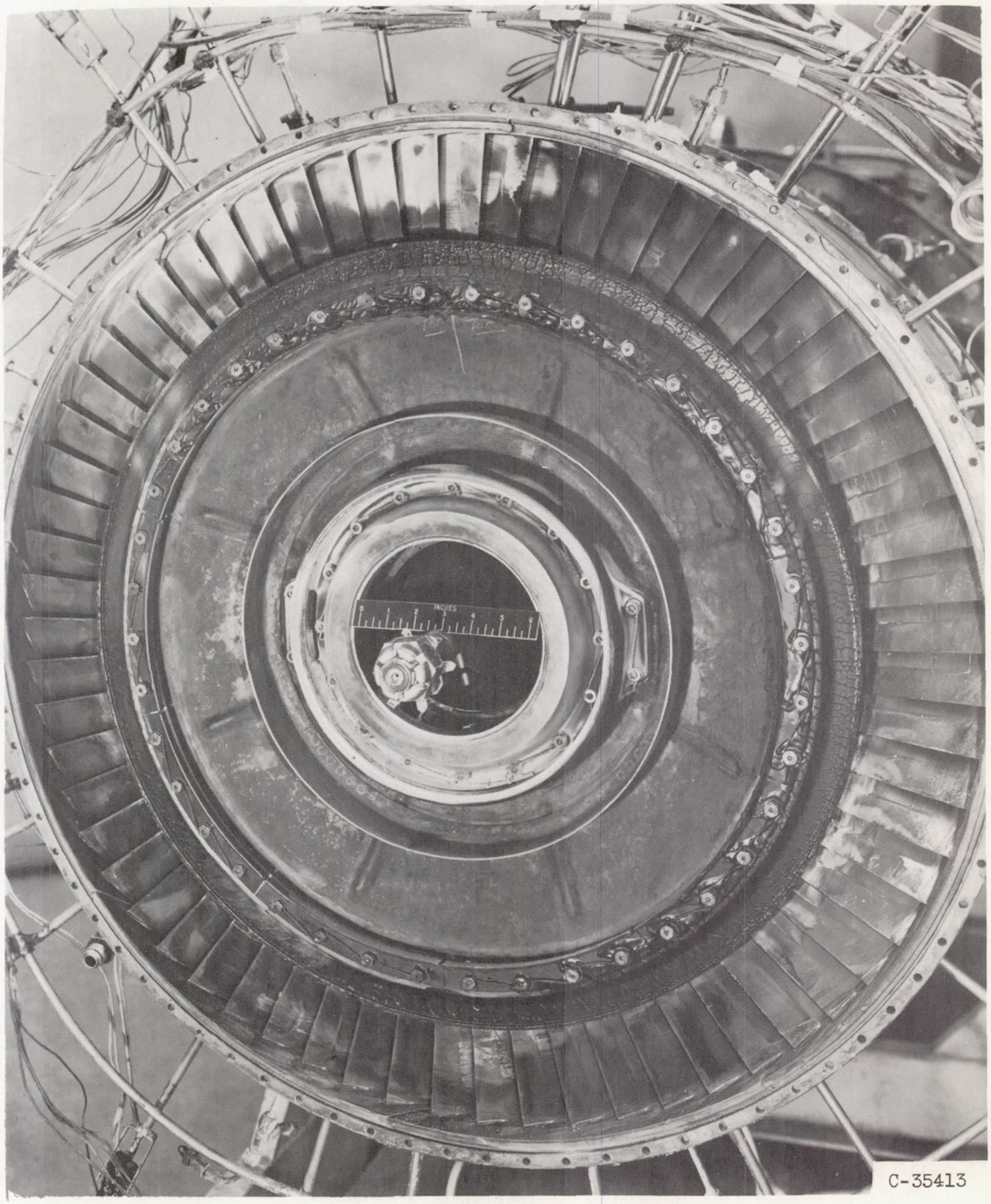
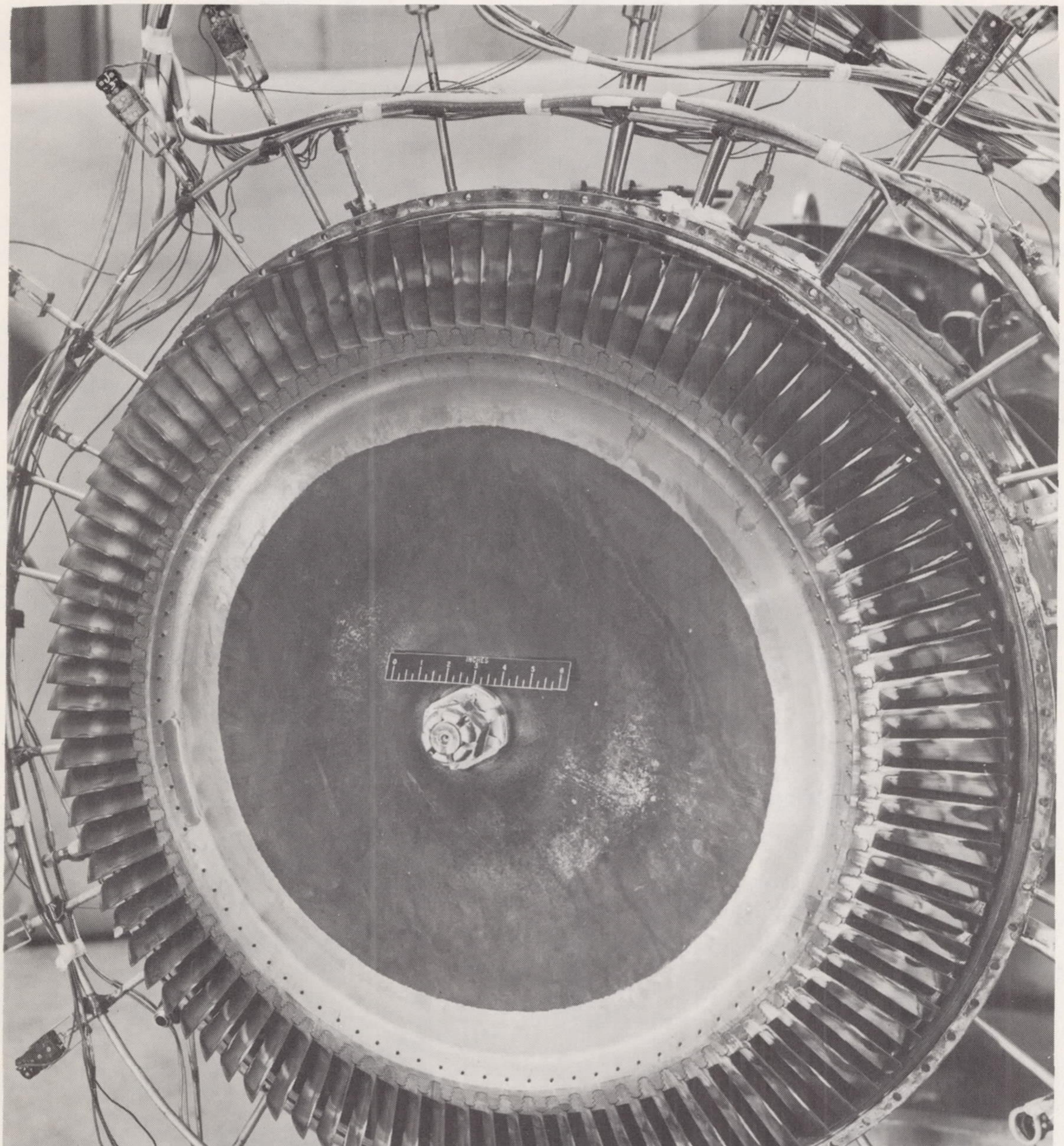
(c) Transition section.

Figure 10. - Continued. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)



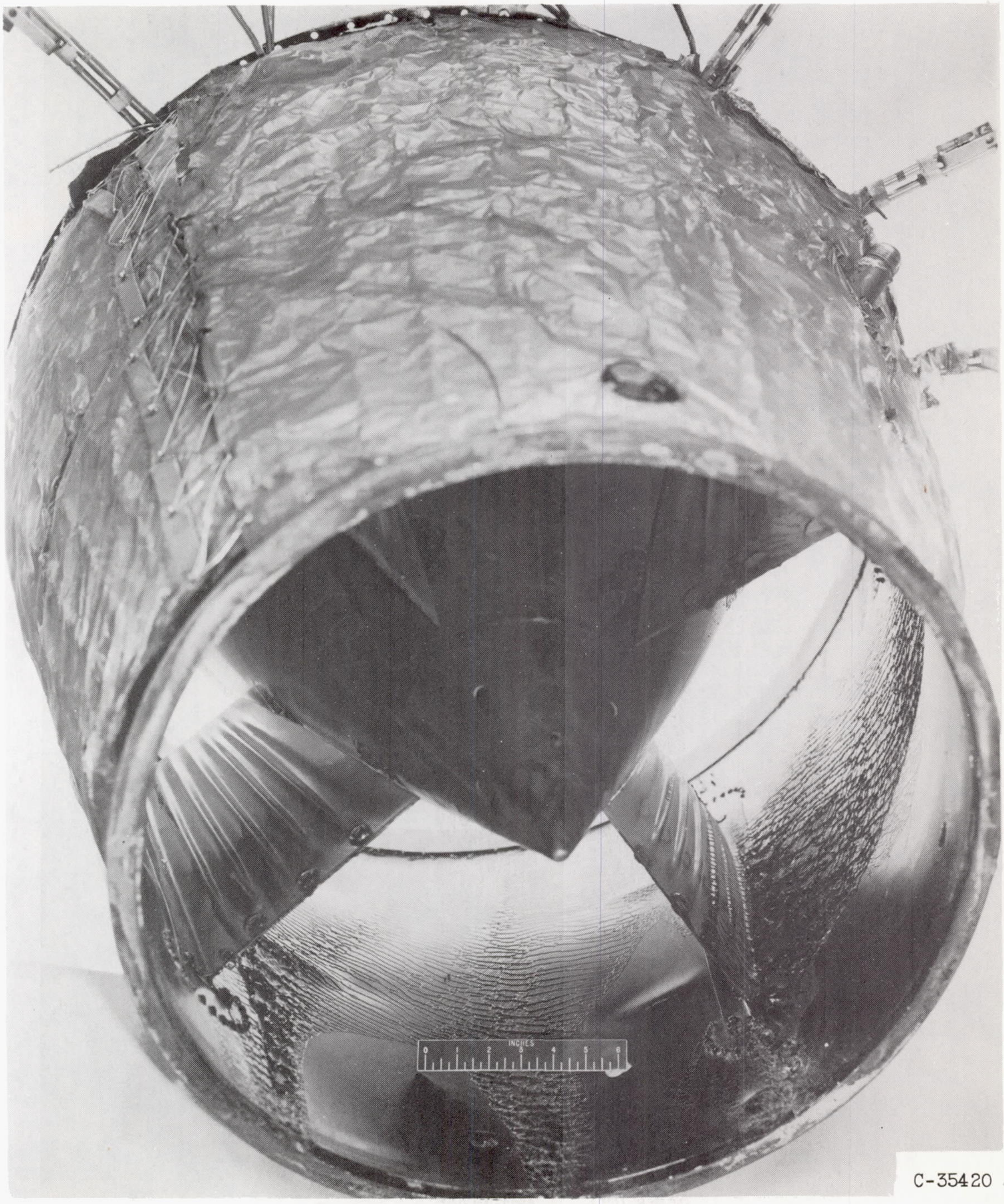
(d) Turbine nozzle diaphragm (downstream view).

Figure 10. - Continued. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)



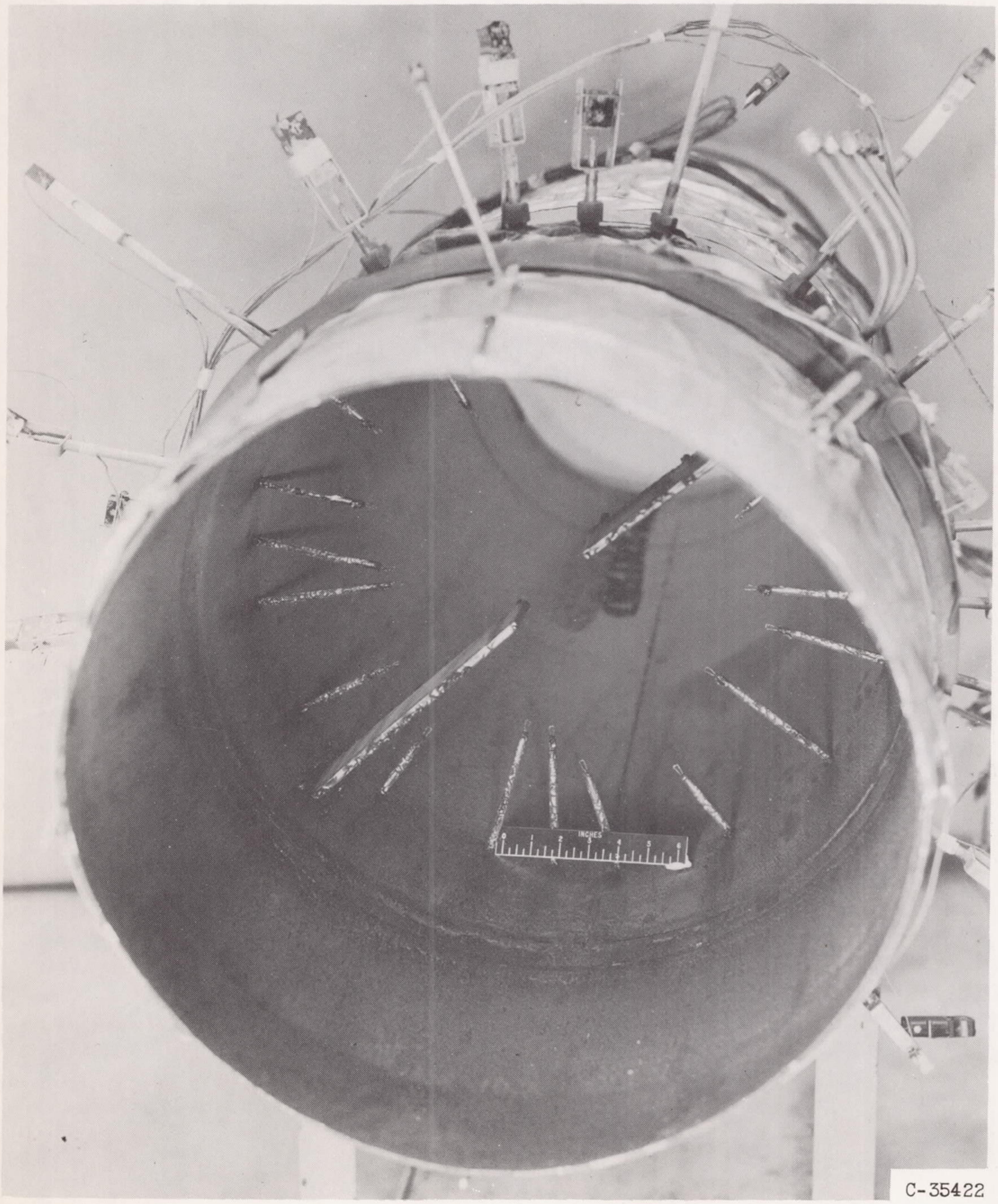
(e) Turbine.

Figure 10. - Continued. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)



(f) Tail cone.

Figure 10. - Continued. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)



(g) Tail pipe and exhaust nozzle.

Figure 10. - Concluded. Deposit characteristics of pentaborane - JP-4 fuel mixtures at end of modified fuel nozzle 2 test run. (Includes final fuel system clean-out run with JP-4 fuel.)

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