NACA

RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE EVALUATION OF J71-A-11 TURBOJET ENGINE

By James W. Useller and George E. Pappas

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation of the altitude performance of the J71-A-11 turbojet engine was conducted in the NACA Lewis altitude wind tunnel. Data were obtained with five exhaust-nozzle areas and with the variable-area exhaust nozzle interlinked with the control system at conditions simulating flight at a Mach number of 0.8 and altitudes of 35,000 and 45,000 feet. Data simulating operation at zero flight Mach number at an altitude of 15,000 feet are also included. Engine component performance data are presented in addition to the over-all engine performance.

INTRODUCTION

In cooperation with the U. S. Air Force, an altitude performance evaluation of the J71-A-11 turbojet engine was made in the NACA Lewis altitude wind tunnel. A calibration of the Douglas thrust rake was also made to provide a means of measuring thrust during the flight application of the J71 turbojet engine. Data were obtained with five exhaust-nozzle areas and with the engine control system modulating the fuel flow and engine speed.

The engine performance was obtained for a range of engine rotor speeds from 4500 to 6100 rpm at conditions simulating flight at a Mach number of 0.8 at altitudes of 35,000 and 45,000 feet. Performance data were also obtained at zero flight Mach number at an altitude of 15,000 feet. Component performance data are presented in addition to the over-all engine performance.

APPARATUS AND PROCEDURE

Engine

The J71-A-11 turbojet engine (fig. 1) has an annular inlet, a 16-stage axial-flow compressor, a cannular-type combustor with 10 cylindrical inner liners, a three-stage turbine, and a variable-area iris-type exhaust nozzle. The engine has a military thrust rating of 9700 pounds at 6100 rpm and a turbine-outlet gas temperature of 1150° F at sea-level static conditions.

To facilitate acceleration in the engine-speed range below 85 percent of rated speed, the engine is equipped with two-position compressor-inlet guide vanes and four air-bleed ports at the compressor eighth stage. The guide vanes are closed and the bleed ports open up to 85 percent of rated rotor speed. At higher speeds, the ports are closed and the guide vanes assume the normal open position.

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Instrumentation

Instrumentation for measuring temperatures and pressures was installed at various stations throughout the engine as shown in figure 1(a). The table accompanying the figure indicates the number and type of measurements obtained at each station. Air flow to the engine was measured by a venturi section in the ram pipe ahead of the engine.

Figure 1(b) shows a schematic of the arrangement of the total-pressure and temperature probes in the engine tail pipe. The pressure probes of the Douglas rake were manifolded to indicate an average pressure, while the probes of the more comprehensive survey (station 9) were read individually. The comprehensive pressure survey was made with instrumentation supplied by Arnold Engineering Development Center (AEDC) and was located $6\frac{1}{4}$ inches downstream of the Douglas rake.

Installation

The engine was mounted on a wing section that spanned the 20-foot-diameter test section of the altitude wind tunnel. Dry, refrigerated air was supplied from the tunnel make-up air system through a duct to the engine inlet. The inlet-air duct was connected to the engine by means of a frictionless slip-joint which permitted installation drag and thrust to be measured by the tunnel balance scales. The air leakage through the engine-inlet-screen actuator ports was calibrated and included in the values given for engine air flow.

Procedure

Steady-state performance data were obtained at conditions simulating flight at a Mach number of 0.8 at altitudes of 35,000 and 45,000 feet. Data were also obtained at a simulated altitude of 15,000 feet at zero flight Mach number. For the 35,000- and 45,000-foot flight conditions, the engine was operated with both the variable-area exhaust nozzle interlinked with the engine control system and with five fixed exhaust-nozzle areas. The five exhaust-nozzle areas were established by limiting the stroke of the variable-area exhaust-nozzle operating mechanism to establish exhaust areas of 100, 104, 109, 114, and 119 percent of rated area. The variable-area exhaust nozzle had an area range from rated to 126 percent of rated exhaust area. Engine speeds from 4500 to 6100 rpm were investigated with each nozzle area. All operation was with the inlet guide vanes and compressor-bleed ports fixed in the normal, high-speed positions.

All performance data were obtained at standard NACA inlet conditions of pressure and temperature corresponding to the indicated flight conditions. In addition, data were obtained at an altitude of 35,000 feet, with the interlinked control system, at inlet-air temperatures of 475°, 450°, and 430° R.

The fuel used throughout this investigation conformed to the specifications of MIL-F-5624a, grade JP-4, and had a lower heating value of 18,700 Btu per pound and a hydrogen-carbon ratio of 0.171.

A list of the symbols used herein is contained in the appendix, and a tabulation of the data obtained is presented in table I.

PRESENTATION OF DATA

The over-all engine performance of the J71-A-11 turbojet engine using five exhaust-nozzle areas is presented in figures 2 to 4 at zero flight Mach number at an altitude of 15,000 feet and a flight Mach number of 0.8 at altitudes of 35,000 and 45,000 feet. The specific-fuel-consumption data presented were based on the thrust measured by the balance system. All exhaust-gas temperature data, unless otherwise noted, are based on measurements from the AEDC rake. All engine performance data have been adjusted by the factors δ_a and θ_a to NACA standard altitude conditions to eliminate small deviations in setting test conditions. Similar engine performance data are shown in figure 5 for the two higher altitudes when the engine fuel flow and exhaust-nozzle area were modulated by the manufacturer's control system. To evaluate the effect of deviation of the engine-inlet-air temperature from NACA standard temperature (440° R) for the indicated flight condition, the engine was operated at inlet-air temperatures of 430°, 440°, 450°, and 475° R. The variation of the net thrust and fuel flow with inlet-air temperature is shown in figure 6.

The performance of the engine components (compressor, combustor, turbine and tail pipe) is presented in figure 7. Data are shown for operation with the five exhaust-nozzle areas and with the variable-area exhaust nozzle. The component performance has been adjusted to sea-level conditions to permit generalization of the data. The deviation of some of the performance variables with the variable-area exhaust nozzle from the efficiencies obtained with the fixed areas in the low-speed range is due to the fact that at low speeds the nozzle area, when operating on interlinked control, was larger than that of the largest fixed-nozzle setting.

It was anticipated that, when the engine was installed in the flight vehicle, the Douglas thrust rakes installed in the tail pipe would provide an average tail-pipe total pressure that can be used to indicate a function of jet thrust that will be readable during flight operation. To evaluate the average pressure reading indicated by the Douglas rake, a more comprehensive pressure survey was installed as near as practical 3917 to the plane of the Douglas rake. The indicated tail-pipe total pressure from the Douglas rake is compared with the average pressure determined from the detailed survey in figure 8. The failure of the data for operation at an altitude of 35,000 feet to coincide with that at 45,000 feet is probably due to a shift in the pressure profile in the tail pipe and/or a shift in the swirl pattern leaving the turbine as the turbine operating conditions are changed with altitude. The tail-pipe total pressure determined by the Douglas rake may be used to determine a jet-thrust parameter as is shown in figure 9. The thrust parameter shown here is based on the balance-system measurements and shows relatively good agreement with the values of the pressure parameter based on the Douglas rake average total pressure. A detailed discussion of the deviation and reliability of the thrust parameter is contained in reference 1.

A calibration of the air leakage through the engine-inlet-screen actuator ports is shown in figure 10. For flight Mach numbers less than 0.4 the leakage flow is into the engine inlet, and for higher Mach numbers the leakage is out of the engine inlet. The engine air-flow data presented include the air leakage and represent the actual air flow to the compressor.

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APPENDIX - SYMBOLS

A area, sq ft

$F_{j,a}$ jet thrust from AEDC rake

$F_{j,D}$ jet thrust from Douglas rake

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$F_{j,s}$ jet thrust from balance system

$F_{n,D}$ net thrust from Douglas rake

$F_{n,s}$ net thrust from balance system

M Mach number

N engine rotor speed, rpm

P total pressure, lb/sq ft

p static pressure, lb/sq ft

T total temperature, $^{\circ}R$

W_a air flow, lb/sec

W_f fuel flow, lb/hr

W_s weight flow, lb/sec

β correction factor for variation of specific heats,

$$\frac{\gamma^*}{\gamma}\frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}}{\left(\frac{\gamma^*+1}{2}\right)^{\frac{\gamma^*}{\gamma^*-1}}}$$

γ ratio of specific heats

δ_a ratio of total pressure to NACA standard total pressure at indicated flight condition

δ_{sl} ratio of total pressure to static sea-level pressure, P/2116

η efficiency, percent

θ_a ratio of total temperature to NACA standard total temperature at indicated flight condition

θ_{sl} ratio of total temperature to static sea-level temperature, T/519

Subscripts:

b combustor

c compressor

e compressor-inlet screens

t turbine

0 free stream

1 engine inlet

2 compressor outlet

3 combustor inlet

4 turbine inlet

5 turbine outlet

9 exhaust-nozzle inlet

Superscript:

* NACA standard sea-level condition

REFERENCE

1. Sivo, Joseph N., and Fenn, David B.: A Method of Measuring Jet Thrust of Turbojet Engines in Flight Installations. NACA RM E53J15, 1954.

TABLE I. - ALTITUDE PERFORMANCE

Run	Altitude, ft	Flight Mach number, M_0	Engine speed, N, rpm	Altitude static pressure, p_0, lb/sq ft	Engine-inlet total pressure, P_1, lb/sq ft	Engine-inlet temperature, T_1, °R	Compressor-outlet total pressure, P_2, lb/sq ft	Compressor-outlet temperature, T_2, °R	Turbine-inlet total pressure, P_4, lb/sq ft	Turbine-inlet temperature, T_4, °R	Turbine-outlet total pressure, P_5, lb/sq ft	Turbine-outlet temperature, T_5, °R
												Fixed-area
1	15,000	0	6103	1193	1196	456	10,510	944	9972	2173	2988	1584
2			5900	1195	1198	455	9,947	919	9432	2037	2786	1456
3			5704	1197	1202	458	9,373	902	8886	1930	2632	1376
4			5504	1196	1202	463	8,877	883	8299	1842	2443	1307
5			5301	1197	1205	460	8,037	856	7618	1737	2374	1232
6			5102	1197	1204	463	7,286	834	6895	1637	2068	1187
7			4903	1197	1206	467	6,543	814	6178	1658	1912	1114
8			6101	1197	1206	456	10,540	940	9799	2078	2810	1487
9			5904	1192	1198	463	9,655	924	9146	1988	2605	1393
10			5904	1202	1206	457	9,812	920	9292	1961	2640	1391
11			5706	1202	1211	458	9,290	898	8805	1861	2560	1311
12			5506	1202	1215	460	8,703	878	8226	1773	2345	1242
13			5502	1194	1203	459	8,646	875	8153	1785	2326	1260
14			5302	1191	1196	458	7,964	851	7541	1687	2163	1177
15			5254	1201	1210	459	7,819	848	7457	1654	2122	1160
16			5104	1191	1196	457	7,332	824	6934	1587	2017	1118
17			4901	1193	1199	452	6,704	786	6330	1493	1879	1061
18			6102	1197	1198	452	10,164	933	9622	2023	2627	1426
19			5903	1197	1204	459	9,624	918	9106	1897	2478	1323
20			5700	1197	1207	462	9,052	900	8574	1805	2337	1259
21			5505	1197	1208	465	8,418	882	7968	1720	2187	1198
22			5303	1197	1207	464	7,770	857	7344	1626	2041	1134
23			5106	1196	1209	468	7,059	837	6661	1540	1891	1063
24			4903	1195	1206	471	6,343	812	5974	1465	1744	1042
25			6099	1197	1203	453	10,075	926	9530	1943	2488	1348
26			5902	1198	1204	452	9,549	910	9034	1828	2365	1269
27			5705	1197	1208	453	8,893	888	8512	1732	2239	1194
28			5607	1195	1206	456	8,422	868	7965	1647	2100	1158
29			5300	1197	1204	460	7,784	848	7350	1559	1965	1083
30			5104	1198	1207	458	7,125	824	6718	1482	1836	1035
31			4900	1185	1202	460	6,435	801	6055	1415	1723	998
32			6101	1195	1203	454	9,909	925	9272	1916	2368	1324
33			6104	1191	1191	462	9,761	936	9223	1910	2333	1318
34			5904	1191	1194	467	9,191	917	8693	1804	2204	1240
35			5704	1193	1196	467	8,644	902	8176	1717	2087	1175
36			5503	1193	1197	472	8,050	884	7589	1628	1957	1122
37			5502	1193	1201	481	7,865	895	7432	1649	1929	1140
38			5302	1193	1198	477	7,381	866	6961	1551	1826	1074
39			5101	1192	1197	471	6,766	836	6391	1467	1714	1026
40			4905	1193	1200	475	6,156	815	5785	1409	1623	996
41	35,000	0.6	6105	509.1	778.2	450	6,817	943	6472	2257	1940	1625
42			5897	508.0	777.6	450	6,471	918	6118	2098	1823	1495
43			5695	510.0	779.0	451	6,089	897	5743	1976	1713	1397
44			5496	507.0	779.2	450	5,720	868	5417	1834	1593	1295
45			5300	508.2	779.3	447	5,239	845	4965	1744	1456	1230
46			5104	508.0	781.2	450	4,860	823	4588	1625	1324	1144
47			4902	507.4	780.4	450	4,299	795	4052	1485	1169	1060
48			4698	509.0	779.7	450	3,807	767	3576	1357	1043	960
49			4501	506.2	778.2	451	3,341	739	3132	1245	927.9	883
50			6102	510.5	780.5	452	6,659	944	6317	2144	1803	1526
51			6102	509.4	782.4	453	6,740	941	6385	2159	1815	1527
52			6100	509.5	779.0	454	6,686	942	6342	2168	1826	1548
53			5900	510.2	780.6	452	6,310	919	5981	2023	1700	1431
54			5700	510.7	782.2	452	5,963	897	5656	1914	1598	1347
55			5500	509.9	781.2	452	5,558	872	5272	1803	1490	1267
56			5497	501.0	772.2	450	5,574	869	5287	1805	1491	1265
57			5303	501.1	772.4	450	5,162	846	4887	1699	1389	1189
58			5234	510.2	780.1	450	4,982	838	4717	1653	1311	1155
59			5104	502.8	772.7	452	4,682	817	4428	1574	1236	1101
60			4901	500.5	772.7	450	4,231	791	3981	1448	1119	1015
61			4700	499.3	773.4	451	3,738	767	3515	1322	981.1	927
62			4561	499.6	768.3	450	3,461	750	3228	1256	903.6	881
63			6097	506.9	778.9	451	6,575	930	6237	2071	1709	1460
64			5904	506.9	778.0	454	6,240	913	5906	1945	1613	1365
65			5704	504.8	774.3	453	5,869	889	5560	1821	1503	1269
66			5504	504.8	778.0	454	5,487	865	5195	1710	1404	1187
67			5298	504.8	778.2	452	5,055	839	4782	1608	1283	1118
68			5103	513.2	787.6	452	4,635	817	4368	1490	1170	1032
69			4904	504.1	773.4	452	4,073	791	3831	1374	1051	956
70			4698	506.2	776.7	452	3,690	764	3462	1263	930.0	878
71			4555	505.5	770.0	453	3,376	745	3158	1193	860.7	833
72			6102	497.3	769.0	447	6,480	925	6134	2004	1597	1384
73			5900	496.3	767.8	450	6,146	908	5816	1871	1505	1291
74			5701	497.3	767.2	449	5,803	883	5496	1758	1420	1213
75			5504	499.1	770.7	451	5,441	861	5148	1659	1328	1143
76			5300	498.3	770.8	451	5,030	837	4752	1558	1223	1072
77			5104	495.9	769.1	447	4,609	812	4340	1452	1108	996
78			4906	498.0	770.1	448	4,158	787	3904	1343	1000	928
79			4703	498.3	771.3	447	3,701	759	3465	1237	893.6	853
80			4590	498.7	771.1	448	3,474	745	3247	1185	843.9	818

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OF J71-A-11 TURBOJET ENGINE

Tail-pipe total pressure (AEDC rake), P_9, lb/sq ft	Tail-pipe total pressure (Douglas rake), $P_{9,D}$, lb/sq ft	Tail-pipe temperature (AEDC rake), T_9, °R	Tail-pipe temperature (Douglas rake), $T_{9,D}$, °R	Engine-inlet air flow, $W_{a,1}$, lb/sec	Inlet screen leakage, $\frac{W_{a,e}\sqrt{\theta_{s1}}}{\delta_{s1}}$, lb/sec	Fuel flow, W_f, lb/hr	Jet thrust scale, $F_{j,s}$, lb	Jet thrust (AEDC rake), $F_{j,a}$, lb	Jet thrust (Douglas rake), $F_{j,D}$, lb	Exhaust-nozzle area, A_9, percent rated area	Run
exhaust nozzles											
2301	2902	1540	1547	100.61	2.20	5438	6232	6383	6596	100	1
2726	2724	1438	1448	98.55	2.08	4765	5681	5837	5849	100	2
2571	2567	1364	1372	95.06	1.87	4202	5144	5293	5172	100	3
2405	2383	1301	1306	89.86	1.63	3676	4604	4685	4665	100	4
2224	2218	1230	1231	85.87	1.39	3199	4025	4115	4104	100	5
2046	2041	1168	1171	79.70	1.19	2725	3405	3478	3473	100	6
1879	1877	1116	1117	71.78	.71	2299	2813	2821	2819	100	7
2724	2720	1469	1478	100.26	2.03	5039	5887	5998	6010	104	8
2542	2535	1390	1403	96.62	1.97	4383	5310	5408	5426	104	9
2587	2575	1380	1388	98.82	2.09	4435	5409	5542	5542	104	10
2440	2439	1306	1314	95.97	1.83	3940	4948	5045	5057	104	11
2282	2284	1243	1248	90.34	1.52	3452	4410	4422	4431	104	12
2264	2264	1250	1256	91.11	1.61	3452	4378	4468	4479	104	13
2105	2106	1184	1189	86.22	1.50	3041	3850	3896	3904	104	14
2083	2079	1165	1172	85.32	1.32	2906	3754	3762	3767	104	15
1968	1967	1127	1147	81.61	1.28	2648	3337	3388	3419	104	16
1840	1836	1067	1063	76.42	1.08	2273	2830	2876	2867	104	17
2554	2559	1407	1414	99.02	2.14	4726	5478	5586	5600	109	18
2402	2413	1321	1324	97.85	2.00	4096	5043	5133	5157	109	19
2301	2272	1257	1259	92.88	1.80	3628	4551	4614	4577	109	20
2108	2127	1201	1202	90.42	1.58	3175	4028	4102	4135	109	21
1978	1988	1142	1143	83.86	1.37	2769	3493	3505	3526	109	22
1837	1845	1092	1094	78.73	1.10	2388	2899	2988	3005	109	23
1716	1715	1047	1046	73.15	.95	2008	2355	2504	2500	109	24
2431	2426	1344	1338	100.46	2.13	4398	5234	5359	5344	114	25
2263	2298	1263	1261	98.11	1.83	3856	4804	4825	4874	114	26
2141	2176	1200	1199	93.98	1.66	3429	4334	4320	4370	114	27
2006	2043	1146	1145	88.18	1.55	3017	3845	3792	3849	114	28
1893	1913	1095	1095	85.73	1.38	2636	3351	3361	3398	114	29
1778	1790	1047	1049	80.52	1.18	2286	2824	2874	2812	114	30
1667	1674	1004	1004	73.93	1.00	1973	2405	2381	2394	114	31
2220	2303	1520	1308	101.46	2.10	4224	5101	5043	5156	119	32
2197	2274	1315	1307	99.28	2.20	4108	4973	4901	5012	119	33
2066	2141	1239	1250	96.17	2.00	3580	4505	4383	4490	119	34
1957	2025	1180	1169	92.49	1.86	3164	4075	3906	3891	119	35
1901	1902	1129	1120	88.29	1.61	2780	3638	3542	3531	119	36
1826	1874	1146	1138	85.57	1.50	2747	3521	3315	3397	119	37
1747	1781	1085	1087	82.00	1.37	2402	3153	2932	3006	119	38
1659	1674	1036	1037	76.84	1.17	2089	2737	2508	2539	119	39
1581	1587	1000	998	71.04	.95	1792	2361	2106	2118	119	40
1887	1896	1592	1601	64.14	-3.68	3652	4732	4833	4852	100	41
1780	1894	1470	1480	62.49	-3.73	3175	4372	4439	4533	100	42
1669	1669	1388	1402	60.66	-3.79	2815	4032	4095	4113	100	43
1549	1551	1282	1293	58.55	-3.88	2461	3692	3702	3720	100	44
1434	1424	1221	1239	55.92	-3.93	2110	3267	3347	3361	100	45
1286	1262	1142	1152	52.42	-4.02	1782	2860	2893	2882	100	46
1147	1150	1051	1055	48.48	-4.10	1418	2398	2421	2430	100	47
1017	1019	965	962	44.44	-4.12	1130	1975	1872	1974	100	48
904.9	905.1	888	891	40.57	-4.18	894	1604	1591	1594	100	49
1755	1750	1497	1508	64.34	-3.72	3314	4506	4591	4602	104	50
1770	1765	1508	1517	64.34	-3.69	3383	4549	4620	4632	104	51
1778	1774	1516	1525	63.79	-3.71	3408	4485	4605	4618	104	52
1686	1653	1411	1423	62.23	-3.76	2850	4195	4224	4259	104	53
1551	1552	1332	1346	60.79	-3.79	2625	3855	3915	3935	104	54
1442	1448	1257	1265	57.69	-3.88	2286	3514	3539	3528	104	55
1443	1448	1257	1269	58.02	-3.89	2299	3505	3554	3577	104	56
1323	1329	1184	1192	55.23	-3.97	1994	3133	3163	3182	104	57
1284	1292	1152	1157	54.45	-3.96	1858	3008	3010	3025	104	58
1197	1204	1098	1102	51.97	-4.01	1639	2708	2728	2741	104	59
1074	1081	1015	1015	48.37	-4.10	1340	2295	2304	2313	104	60
952.7	960.2	933	931	44.15	-4.20	1058	1880	1867	1875	104	61
882.7	886.5	890	887	41.58	-4.19	906	1622	1619	1623	104	62
1652	1658	1435	1438	62.96	-3.72	3175	4344	4323	4331	109	63
1560	1569	1346	1353	62.01	-3.74	2792	4061	4035	4053	109	64
1450	1461	1261	1265	60.40	-3.81	2426	3723	3822	3841	109	65
1341	1361	1189	1190	57.85	-3.67	2110	3384	3477	3499	109	66
1232	1247	1117	1116	54.89	-3.98	1800	2957	2850	2865	109	67
1129	1145	1038	1039	52.02	-4.02	1479	2598	2543	2563	109	68
1091	1015	962	961	48.57	-4.09	1206	2174	2260	2163	109	69
898.2	908.3	889	888	44.89	-4.13	954	1783	1754	1768	109	70
822.7	839.0	842	840	41.31	-4.20	815	1531	1455	1480	109	71
1531	1553	1380	1380	65.09	-3.72	2972	4119	4291	4313	114	72
1438	1463	1287	1287	63.30	-3.79	2580	3814	3933	3858	114	73
1347	1377	1212	1209	61.41	-3.82	2264	3514	3601	3626	114	74
1254	1286	1142	1137	59.43	-3.89	1959	3219	3265	3296	114	75
1151	1187	1073	1065	56.71	-3.94	1688	2836	2893	2927	114	76
1041	1077	1001	991	53.33	-4.04	1415	2470	2489	2527	114	77
941.4	978.8	930	920	49.46	-4.10	1156	2057	2074	2120	114	78
845.9	875.6	859	850	45.88	-4.16	918	1681	1693	1732	114	79
803.1	825.1	826	818	43.52	-4.20	812	1501	1503	1535	114	80

TABLE I. - Concluded. ALTITUDE PERFORMANCE

Run	Altitude, ft	Flight Mach number, M_0	Engine speed, N, rpm	Altitude static pressure, p_0, lb/sq ft	Engine-inlet total pressure, P_1, lb/sq ft	Engine-inlet temperature, T_1, °R	Compressor-outlet total pressure, P_2, lb/sq ft	Compressor-outlet temperature, T_2, °R	Turbine-inlet total pressure, P_4, lb/sq ft	Turbine-inlet temperature, T_4, °R	Turbine-outlet total pressure, P_5, lb/sq ft	Turbine-outlet temperature, T_5, °R
Fixed-area												
81	35,000	0.8	6103	498.7	770.1	454	6374	928	6025	1932	1516	1336
82			5903	495.7	771.1	452	6072	908	5743	1819	1440	1249
83			5703	498.2	772.2	454	5744	885	5436	1724	1367	1179
84			5498	497.7	773.0	450	5388	857	5096	1625	1276	1110
85			5301	497.3	770.7	450	4999	834	4717	1530	1175	1046
86			5102	497.3	769.7	450	4566	811	4294	1423	1070	975
87			4900	499.4	770.2	450	4117	784	3860	1313	962.4	902
88			4776	499.0	771.9	450	3835	768	3590	1248	898.1	856
89			4632	498.0	768.8	450	3506	751	3276	1182	833.1	813
90	45,000	0.8	5997	314.8	481.7	442	4215	927	4000	2273	1206	1678
91			5904	315.4	482.7	447	4098	918	3892	2192	1170	1567
92			5701	317.7	483.2	444	3862	896	3665	2049	1091	1455
93			5301	317.7	482.2	446	3303	847	3159	1807	930.7	1268
94			4900	316.3	483.1	446	2702	793	2553	1535	746.7	1078
95			4755	316.8	485.8	443	2601	772	2359	1439	687.7	1012
96			6100	319.4	485.9	460	4188	958	3973	2232	1141	1592
97			5902	318.6	482.9	480	3967	932	3761	2120	1076	1505
98			5697	318.3	484.4	460	3775	916	3540	1998	1005	1408
99			5504	318.2	482.5	449	3523	873	3341	1872	948	1310
100			5303	320.2	483.5	450	3229	849	3066	1757	864	1250
101			5224	318.9	483.0	460	3093	848	2928	1724	825.3	1206
102			4972	314.9	483.1	452	2701	808	2550	1544	712	1073
103			6105	316.0	480.8	450	4097	940	3882	2149	1066	1507
104			5903	316.9	482.3	461	3905	918	3700	2032	1006	1422
105			5697	317.1	483.2	451	3659	894	3468	1915	940.7	1334
106			5295	315.2	483.8	450	3151	845	2980	1696	802.9	1175
107			4911	315.9	480.1	453	2575	797	2422	1460	654.9	1017
108			6104	308.2	473.2	442	4066	928	3851	2062	1002	1450
109			6103	308.2	474.1	444	4066	927	3851	2063	1001	1432
110			6098	307.7	474.5	444	4072	925	3884	2068	999.5	1438
111			5905	308.5	475.7	442	3897	909	3690	1949	958.0	1346
112			5705	310.0	473.9	443	3710	885	3466	1832	901.0	1260
113			5302	308.9	474.1	443	3169	837	2995	1650	770.2	1107
114			4851	305.1	473.3	443	2687	791	2529	1414	645.8	972
115			5896	306.3	472.1	460	3791	912	3584	1901	899.7	1306
116			5706	308.6	471.9	450	3585	890	3395	1800	848.7	1252
117			5502	307.5	475.0	450	3355	865	3175	1697	794.7	1160
118			5295	305.7	479.4	451	3104	839	2931	1589	731.6	1085
119			5013	310.0	474.5	450	2723	805	2561	1428	637.9	977
Variable-area exhaust nozzle												
120	35,000	0.8	6088	505.1	777.0	439	6834	924	6484	2201	1920	1579
121			5903	507.0	775.4	439	6422	904	6086	1996	1709	1407
122			5903	506.4	775.9	437	6455	901	6126	1962	1718	1391
123			5701	506.7	776.0	440	5879	870	5563	1726	1428	1150
124			5248	503.9	773.2	440	4895	815	4659	1442	1110	974
125			4896	506.7	779.3	439	4022	761	3776	1281	906.4	889
126			4756	507.3	777.1	439	3731	744	3496	1218	850.7	829
127	45,000	0.8	6087	316.5	480.4	441	4319	939	4088	2278	1215	1630
128			6085	316.0	484.6	436	4345	931	4136	2274	1230	1624
129			5894	315.4	480.4	436	4203	907	3815	2048	1068	1436
130			5704	315.2	483.3	436	3716	878	3519	1815	905.6	1243
131			5505	316.6	479.1	436	3391	848	3204	1626	768.8	1100
132			5258	314.0	481.4	440	3103	822	2930	1510	699.2	1022
133	35,000	0.8	6071	507.0	773.7	431	6900	915	6563	2192	1944	1576
134			5896	506.5	776.5	429	6499	890	6162	1969	1727	1391
135			5695	507.0	774.1	429	6022	856	5703	1752	1485	1210
136			5267	507.4	770.8	425	5113	798	4872	1454	1154	985
137			5242	506.5	773.0	421	4841	781	4578	1450	1092	977
138			6065	506.7	777.6	447	6796	937	6452	2187	1919	1568
139			5903	507.7	776.6	448	6355	914	6021	1971	1690	1382
140			5702	508.4	777.9	450	5760	884	5495	1791	1406	1181
141			5506	508.5	776.4	450	5341	855	5043	1561	1201	1055
142			5240	507.6	776.8	448	4825	825	4540	1431	1095	972
143			5220	506.7	778.3	450	4609	811	4353	1431	1020	969
144			4900	506.7	772.9	450	3890	744	3649	1283	882.5	871
145			6064	505.4	774.5	475	6471	971	6158	2231	1837	1607
146			5903	508.4	775.8	477	6076	945	5757	2020	1630	1430
147			5698	506.5	772.1	474	5465	914	5170	1753	1327	1211
148			5503	507.1	776.2	471	5082	885	4776	1575	1143	1077
149			5241	508.2	779.5	473	4548	853	4273	1446	1017	989
150			5206	508.0	776.0	471	4255	834	4004	1437	959.8	940
151			4909	505.4	774.5	471	3700	798	3488	1300	840.1	888

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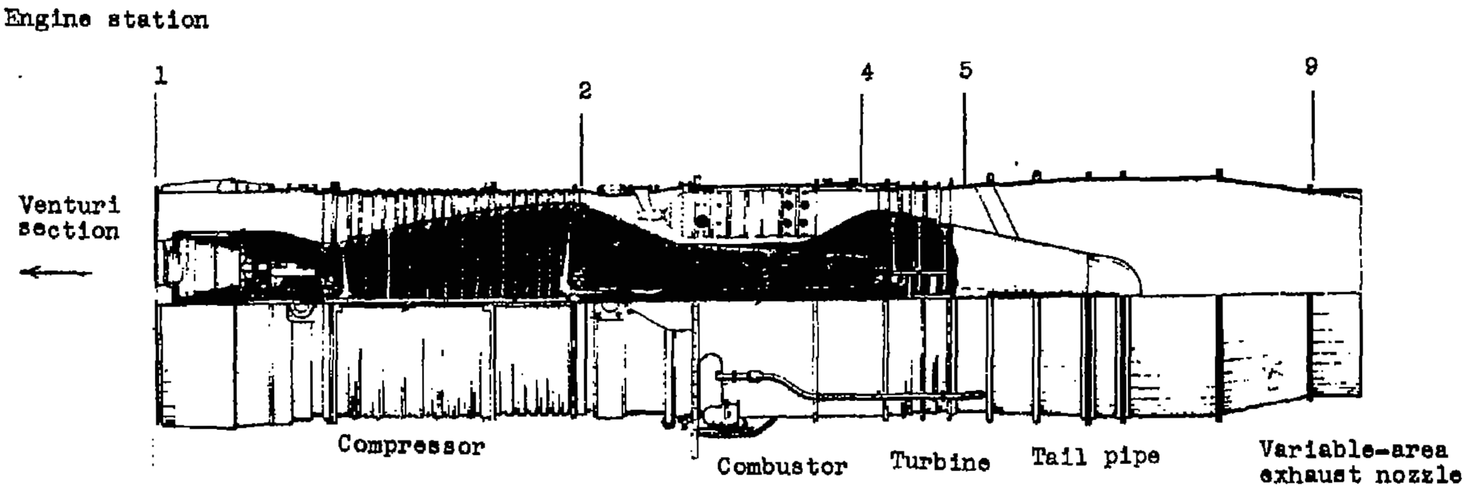
OF J71-A-11 TURBOJET ENGINE

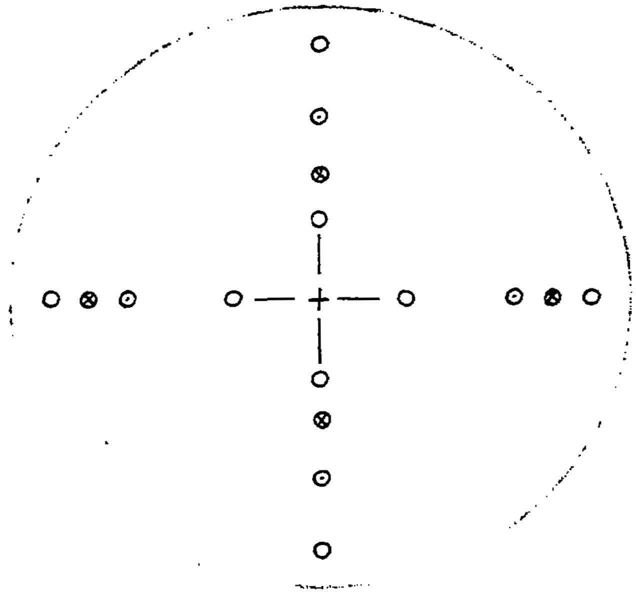
Tail-pipe total pressure (AEDC rake), P_g, lb/sq ft	Tail-pipe total pressure (Douglas rake), $P_{g,D}$, lb/sq ft	Tail-pipe temperature (AEDC rake), T_g, °R	Tail-pipe temperature (Douglas rake), $T_{g,D}$, °R	Engine-inlet air flow, $W_{a,1}$, lb/sec	Inlet screen leakage, $\frac{W_{a,s}\sqrt{\theta_{sl}}}{\delta_{sl}}$, lb/sec	Fuel flow, W_f, lb/hr	Jet thrust scale, $F_{j,s}$, lb	Jet thrust (AEDC rake), $F_{j,A}$, lb	Jet thrust (Douglas rake), $F_{j,D}$, lb	Exhaust-nozzle area, A_g, percent rated area	Run
exhaust nozzles											
1413	1471	1323	1309	61.74	-3.77	2747	3852	3861	3899	119	81
1337	1392	1243	1235	60.17	-3.86	2450	3663	3571	3618	119	82
1264	1318	1177	1168	58.58	-3.88	2185	3555	3292	3357	119	83
1177	1231	1110	1102	56.06	-3.96	1992	3066	2952	3007	119	84
1094	1134	1046	1039	53.53	-4.00	1632	2705	2628	2672	119	85
983.4	1035	978	971	49.68	-4.06	1368	2320	2208	2272	119	86
893.4	933.9	904	898	48.13	-4.11	1110	1927	1830	1887	119	87
830.1	873.4	860	851	44.85	-4.17	960	1898	1631	1695	119	88
774.7	810.8	819	808	42.22	-4.20	815	1468	1401	1457	119	89
1177	1175	1597	1606	39.45	-3.72	2338	2902	2986	2992	100	90
1143	1140	1539	1551	38.99	-3.73	2174	2796	2868	2876	100	91
1071	1062	1433	1447	37.90	-3.73	1900	2579	2626	2633	100	92
897.4	907.5	1256	1273	34.50	-3.89	1382	2064	2097	2119	100	93
698.1	665.2	1078	1080	30.03	-4.03	932	1551	1500	1461	100	94
667.6	663.6	1013	1017	28.55	-4.06	812	1330	1346	1356	100	95
1109	1109	1560	1571	39.16	-3.68	2206	2841	2866	2876	104	96
1045	1046	1478	1493	38.06	-3.69	1973	2626	2658	2672	104	97
975.1	978.5	1392	1406	36.95	-3.78	1709	2400	2442	2456	104	98
919	923	1299	1309	36.06	-3.78	1612	2204	2260	2262	104	99
836	841	1222	1221	34.01	-3.85	1292	2009	1971	1976	104	100
808.1	805.5	1203	1199	32.86	-3.90	1193	1830	1864	1858	104	101
690	896	1078	1067	30.00	-4.09	930	1536	1492	1492	104	102
1032	1038	1481	1487	39.38	-3.67	2057	2726	2750	2781	109	103
975.3	982.3	1400	1406	38.75	-3.71	1847	2512	2575	2587	109	104
906.7	914.5	1322	1326	37.68	-3.79	1596	2334	2362	2374	109	105
771.5	782.0	1168	1161	34.12	-3.97	1189	1758	1874	1881	109	106
627.9	637.7	1012	1007	29.56	-4.40	824	1340	1340	1351	109	107
959.6	976.4	1412	1409	39.43	-3.70	1911	2615	2643	2655	114	108
957.0	973.1	1413	1411	40.10	-3.71	1915	2606	2686	2700	114	109
955.6	972.5	1417	1416	39.70	-3.75	1963	2600	2665	2679	114	110
916.5	933.9	1334	1334	38.94	-3.77	1720	2432	2489	2507	114	111
856.6	874.8	1253	1247	37.72	-3.76	1497	2243	2270	2283	114	112
725.2	748.0	1106	1088	34.44	-3.93	1120	1796	1803	1815	114	113
605.4	629.8	973	958	30.87	-4.10	821	1394	1371	1335	114	114
838.8	870.6	1290	1276	37.63	-3.80	1592	2265	2291	2311	119	115
771.1	818.7	1221	1210	36.95	-3.77	1407	2071	2099	2147	119	116
733.2	786.5	1151	1138	35.64	-3.90	1239	1889	1920	1950	119	117
680.9	707.3	1079	1068	35.43	-4.02	1068	1704	1780	1805	119	118
576.8	618.1	977	960	32.09	-4.03	827	1326	1365	1419	119	119
interlinked with control											
1872	1869	1544	1550	65.06	-3.72	3592	4774	4824	4830	---	120
1660	1659	1387	1399	63.89	-3.71	2994	4240	4312	4329	---	121
1609	1668	1369	1383	64.59	-3.73	2972	4366	4339	4359	---	122
1343	1385	1180	1174	62.37	-3.78	2246	3604	3572	3608	---	123
998.6	1065	978	973	56.69	-3.93	1472	2569	2520	2618	---	124
818.6	873.0	872	868	52.10	-4.02	1058	1723	1774	1881	---	125
770.9	820.5	833	826	49.42	-4.09	924	1517	1547	1644	---	126
1176	1181	1597	1604	40.10	-3.83	2375	2977	3039	3048	---	127
1197	1196	1590	1597	40.85	-3.71	2414	3005	3095	3102	---	128
1035	1038	1413	1425	39.49	-3.70	1881	2620	2686	2706	---	129
852.7	877.3	1233	1223	38.52	-3.80	1501	2234	2278	2295	---	130
693.3	736.3	1095	1087	36.99	-3.78	1189	1790	1858	1918	---	131
627.3	671.2	1018	1009	34.85	-3.93	1001	1536	1591	1651	---	132
1884	1890	1539	1545	65.78	-3.65	3628	4858	4872	4886	---	133
1678	1677	1369	1386	65.35	-3.71	3017	4366	4395	4417	---	134
1423	1443	1200	1199	63.80	-3.72	2414	3766	3778	3795	---	135
1047	1115	982	981	56.77	-3.88	1621	2676	2599	2695	---	136
781.4	1044	974	974	57.56	-3.89	1545	2465	2431	2533	---	137
1880	1871	1543	1553	64.30	-3.71	3558	4701	4766	4776	---	138
1643	1644	1369	1385	63.05	-3.64	2895	4162	4207	4236	---	139
1321	1363	1180	1175	61.24	-3.79	2206	3472	3477	3519	---	140
1082	1152	1058	1053	58.89	-3.84	1739	2823	2897	2999	---	141
972.2	1038	975	970	54.96	-3.93	1415	2367	2378	2475	---	142
918.7	980.4	971	970	55.43	-3.96	1315	2143	2303	2414	---	143
799.0	851.7	875	870	50.05	-4.00	1010	1605	1742	1833	---	144
1780	1786	1571	1581	60.61	-3.75	3583	3865	4474	4489	---	145
1582	1585	1410	1427	59.47	-3.77	2792	3938	3979	4008	---	146
1241	1286	1205	1198	55.84	-4.23	2068	3168	3214	3221	---	147
1012	1094	1077	1076	55.21	-3.90	1624	2604	2656	2719	---	148
916.7	981.2	990	988	51.24	-4.00	1295	2143	2142	2249	---	149
864.5	923.1	981	978	51.79	-3.97	1236	1926	2056	2166	---	150
762.5	811.8	891	887	46.84	-4.08	933	1476	1569	1678	---	151

Station	Total pressures	Static pressures	Temperatures
1	8	4	16
2	16	-	16
4	10	-	10
5	15	-	15
9	32	-	20

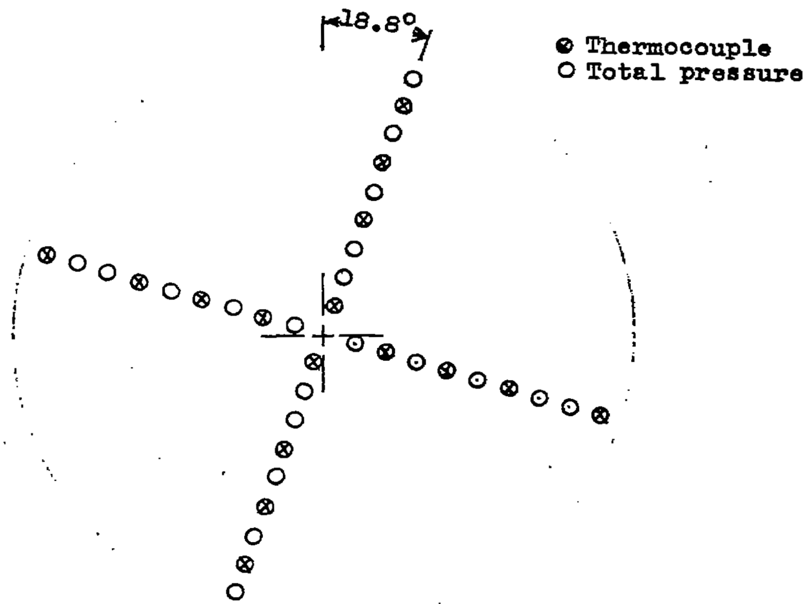


(a) Engine instrumentation stations.

Figure 1. – Schematic diagram of J71-A-11 turbojet engine with instrumentation stations and details.



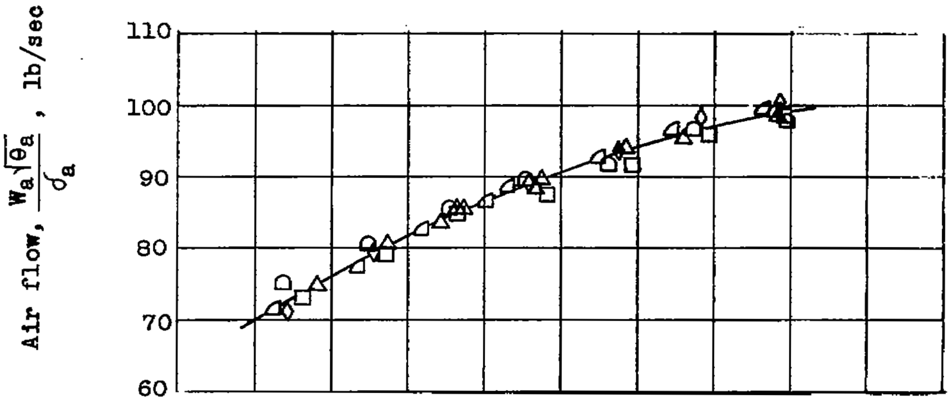
Douglas thrust rake



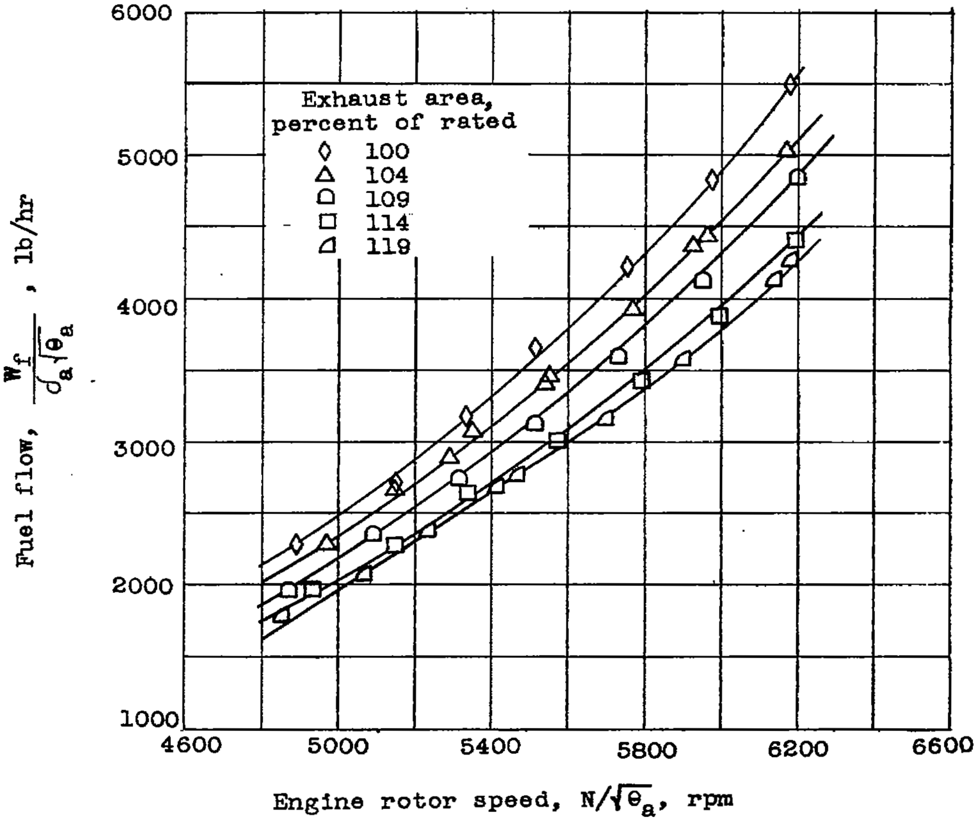
Comprehensive survey at station 9.

(b) Tail-pipe instrumentation details.

Figure 1. - Concluded. Schematic diagram of J71-A-11 turbojet engine.

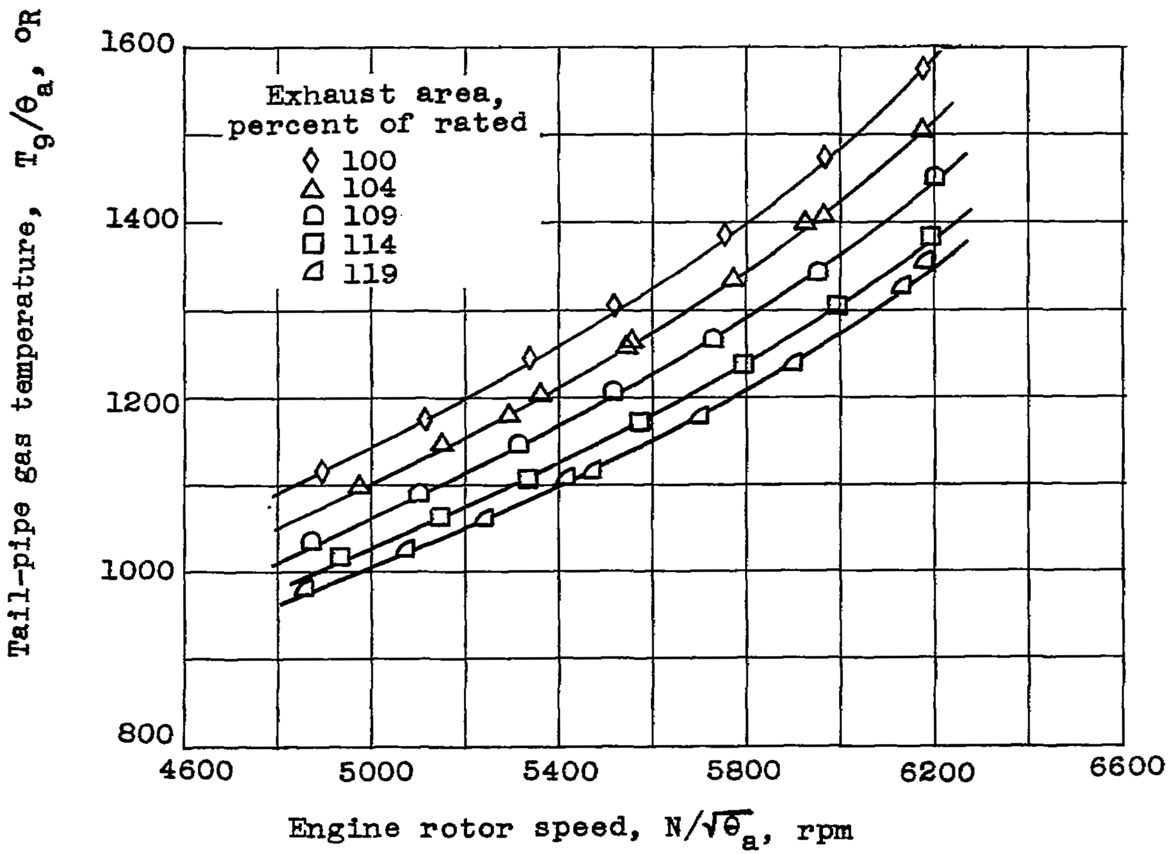


(a) Engine air flow.



(b) Engine fuel flow.

Figure 2. - Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 15,000 feet; flight Mach number, 0.



(c) Tail-pipe gas temperature.

Figure 2. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 15,000 feet; flight Mach number, 0.

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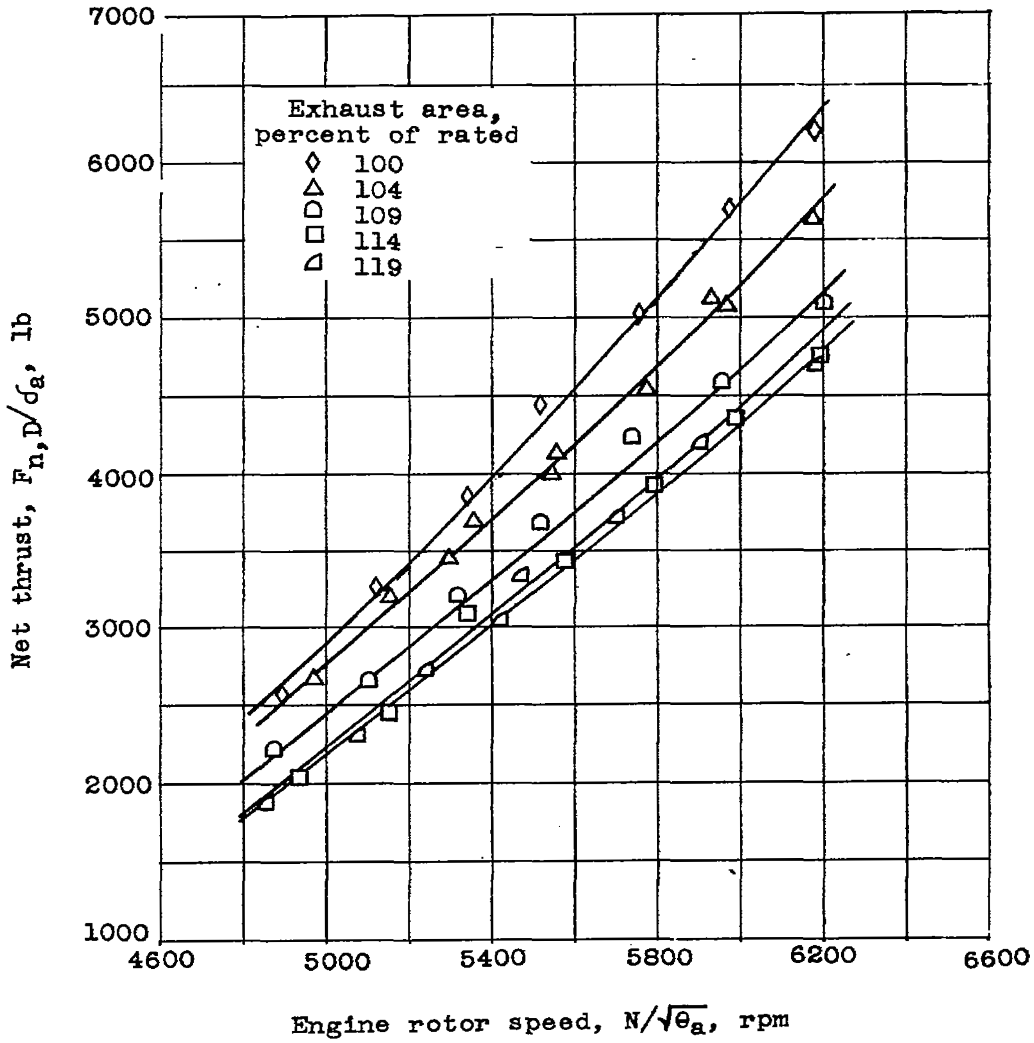

(d) Net thrust from Douglas rake.

Figure 2. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 15,000 feet; flight Mach number 0.

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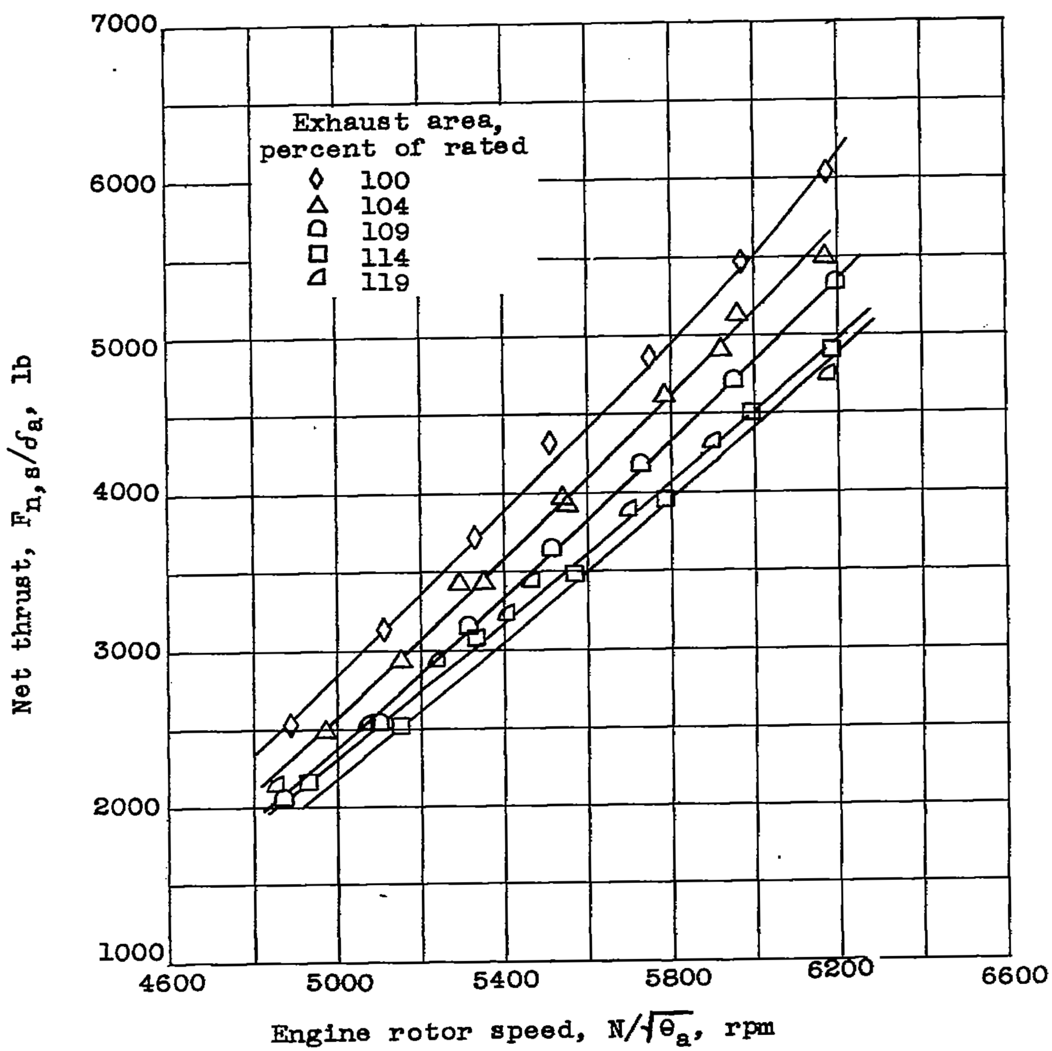
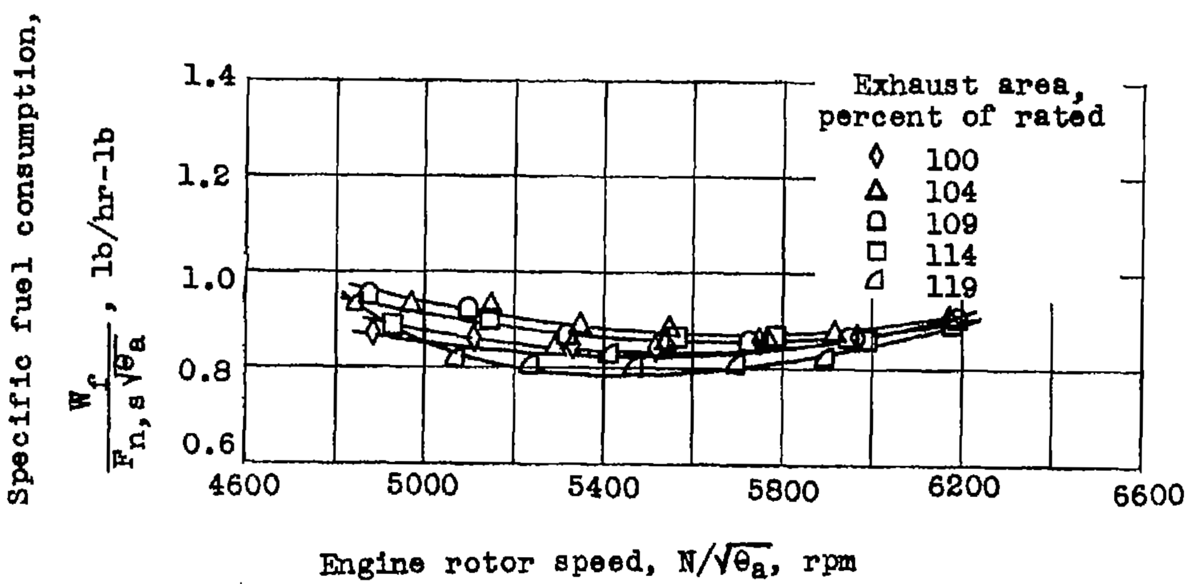


(e) Net thrust measured by balance system.

Figure 2. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 15,000 feet; flight Mach number, 0.



(f) Specific fuel consumption.

Figure 2. - Concluded. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 15,000 feet; flight Mach number, 0.

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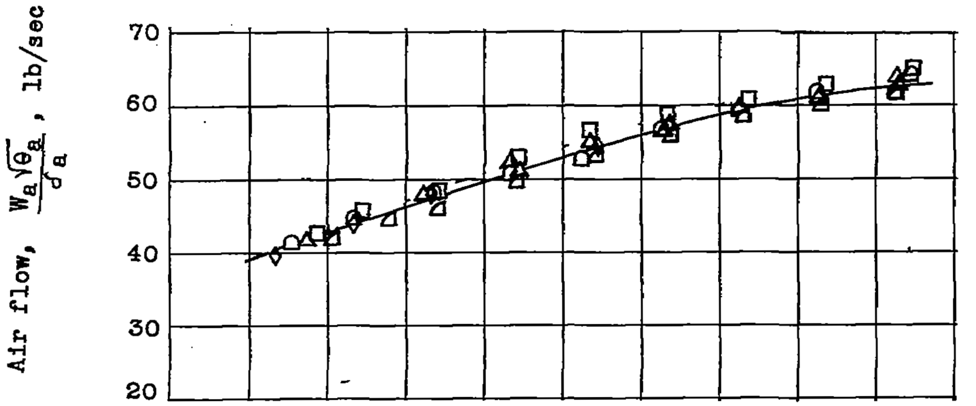
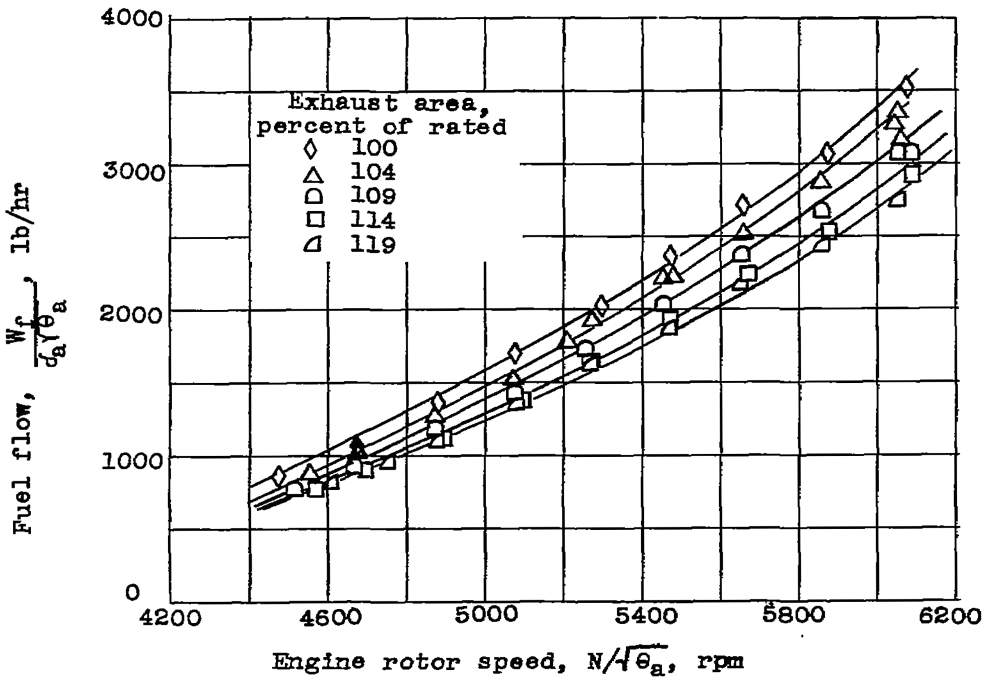


(a) Engine air flow.



(b) Engine fuel flow.

Figure 3. - Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 35,000 feet; flight Mach number, 0.8.

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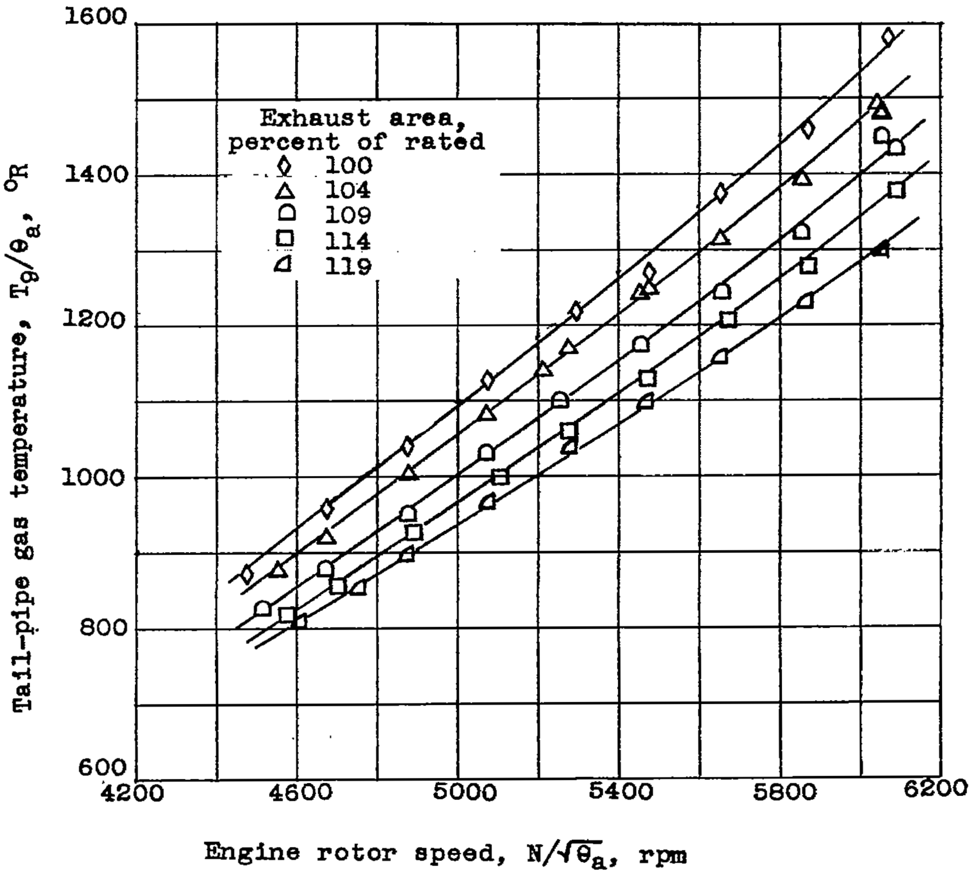
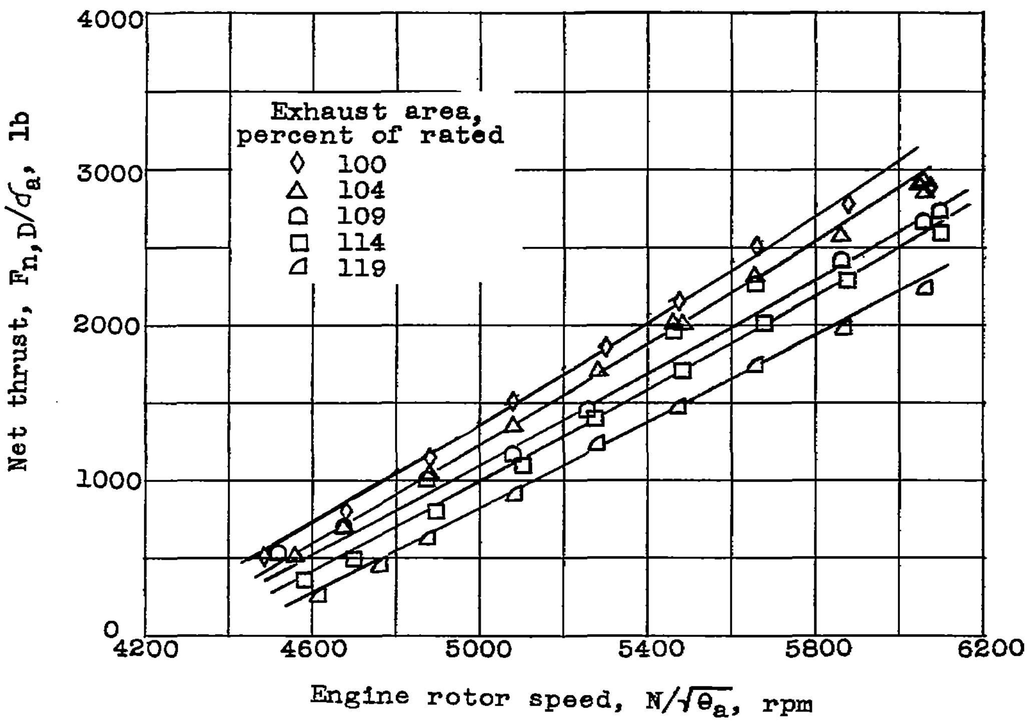


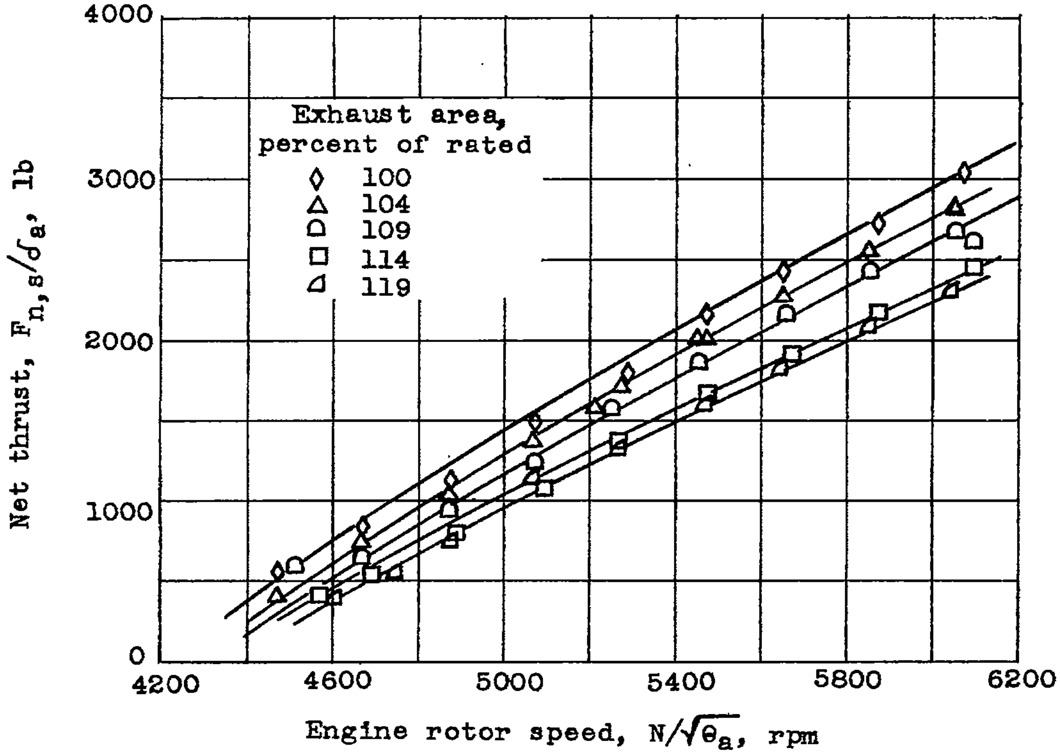
(c) Tail-pipe gas temperature.

Figure 3. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 35,000 feet; flight Mach number, 0.8.



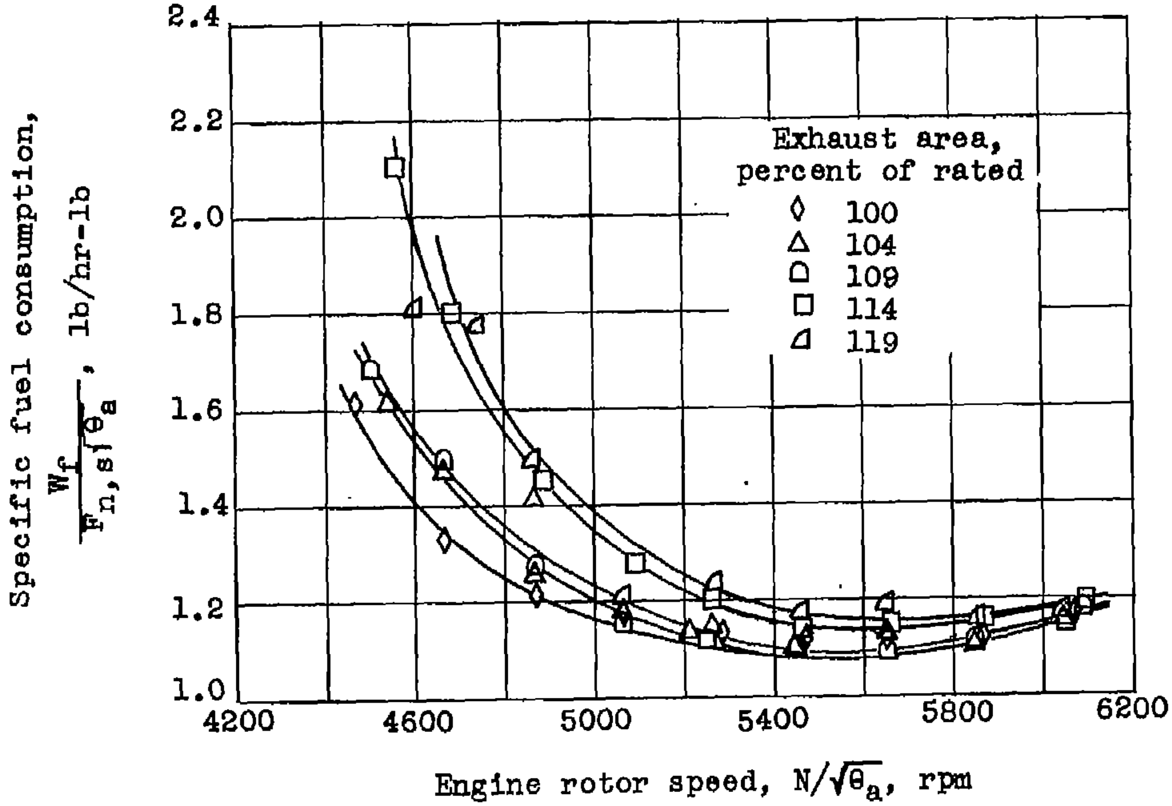
(d) Net thrust from Douglas rake.

Figure 3. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 35,000 feet; flight Mach number, 0.8.



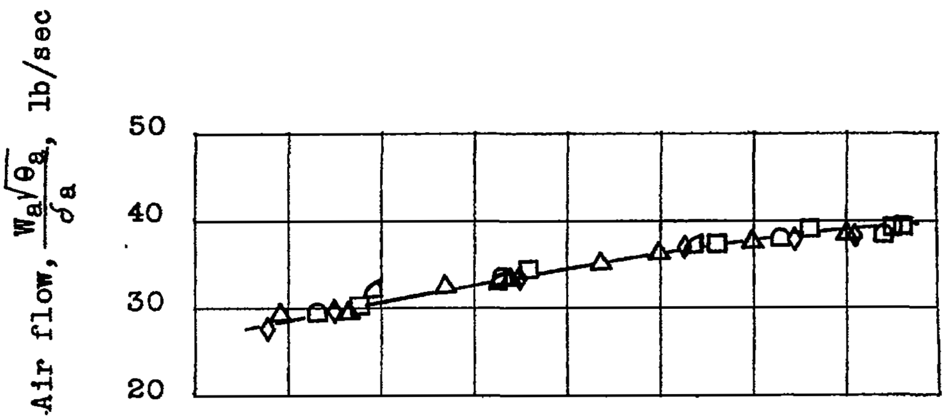
(e) Net thrust measured by balance system.

Figure 3. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 35,000 feet; flight Mach number, 0.8.

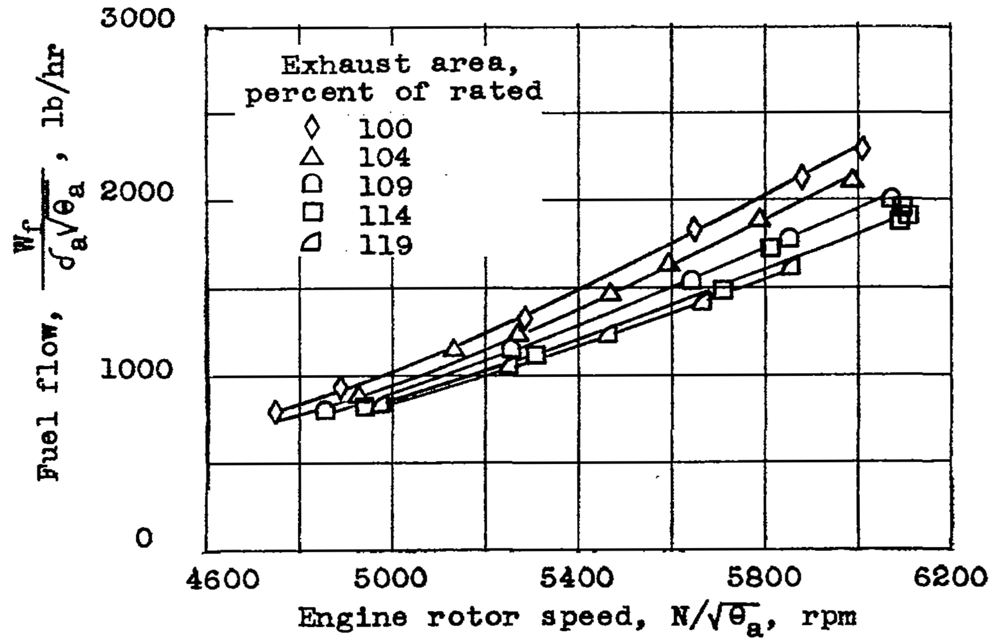


(f) Specific fuel consumption.

Figure 3. - Concluded. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 35,000 feet; flight Mach number, 0.8.



(a) Engine air flow



(b) Engine fuel flow.

Figure 4. - Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 45,000 feet; flight Mach number, 0.8.

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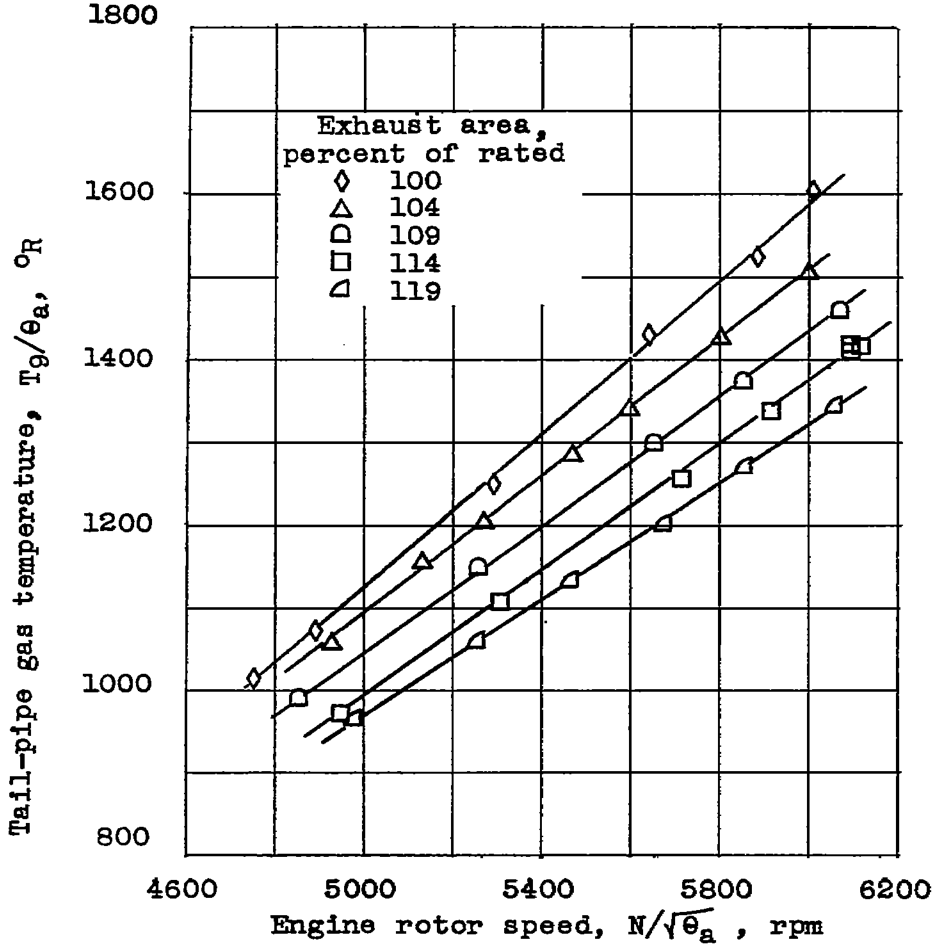
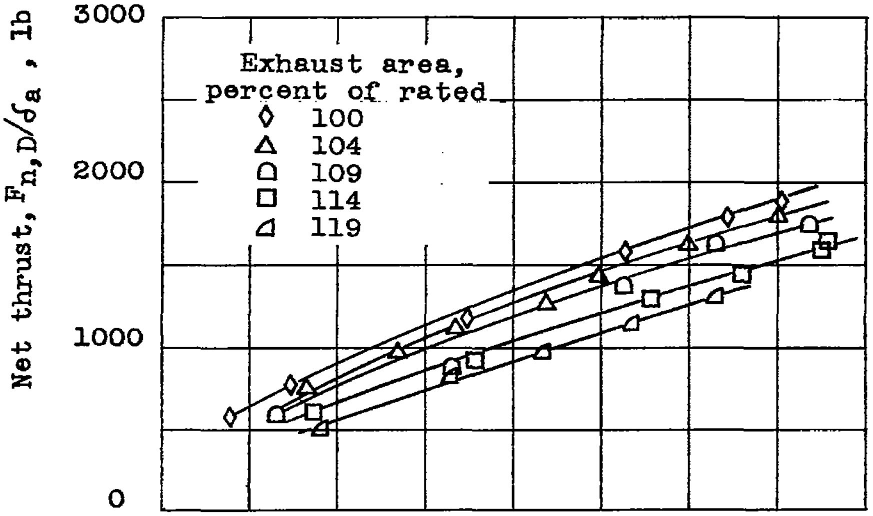


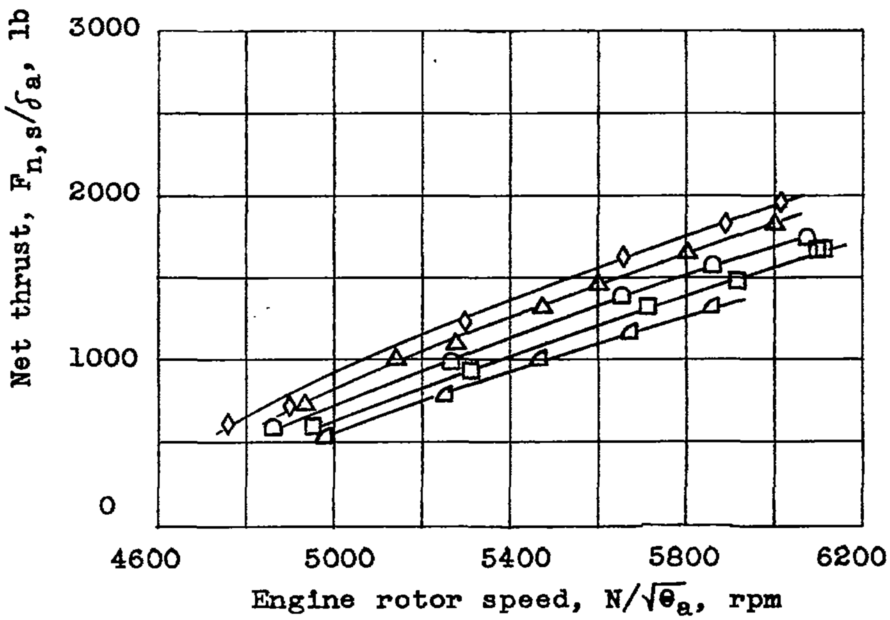
(c) Tail-pipe gas temperature.

Figure 4. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 45,000 feet; flight Mach number, 0.8.

3917



(d) Net thrust from Douglas rake.

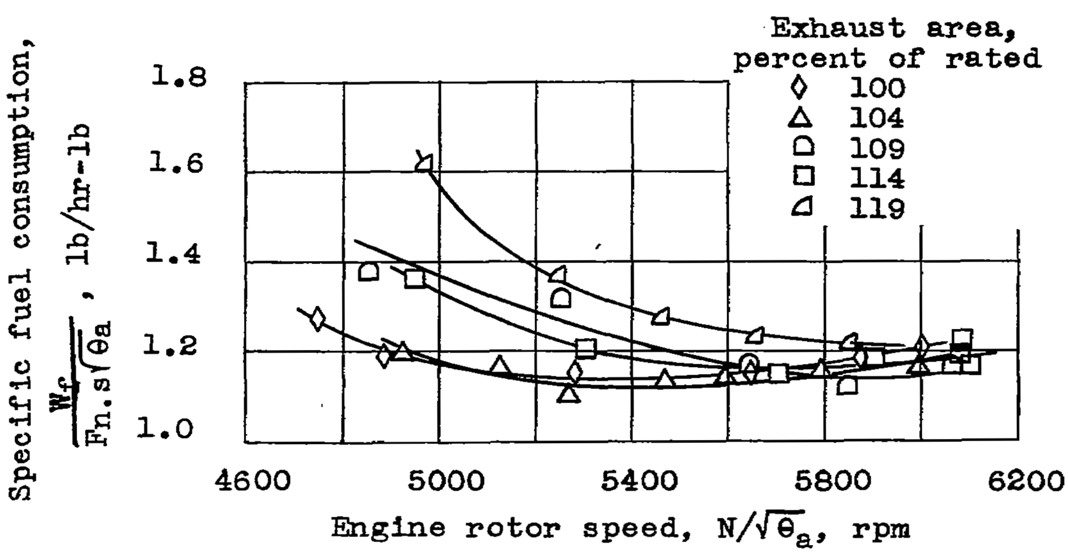


(e) Net thrust measured by balance system.

Figure 4. - Continued. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 45,000 feet; flight Mach number, 0.8.

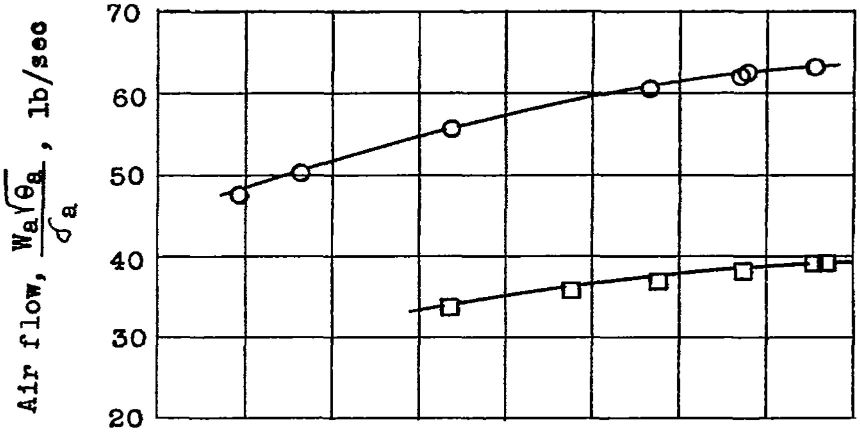
3917

CT-4 back

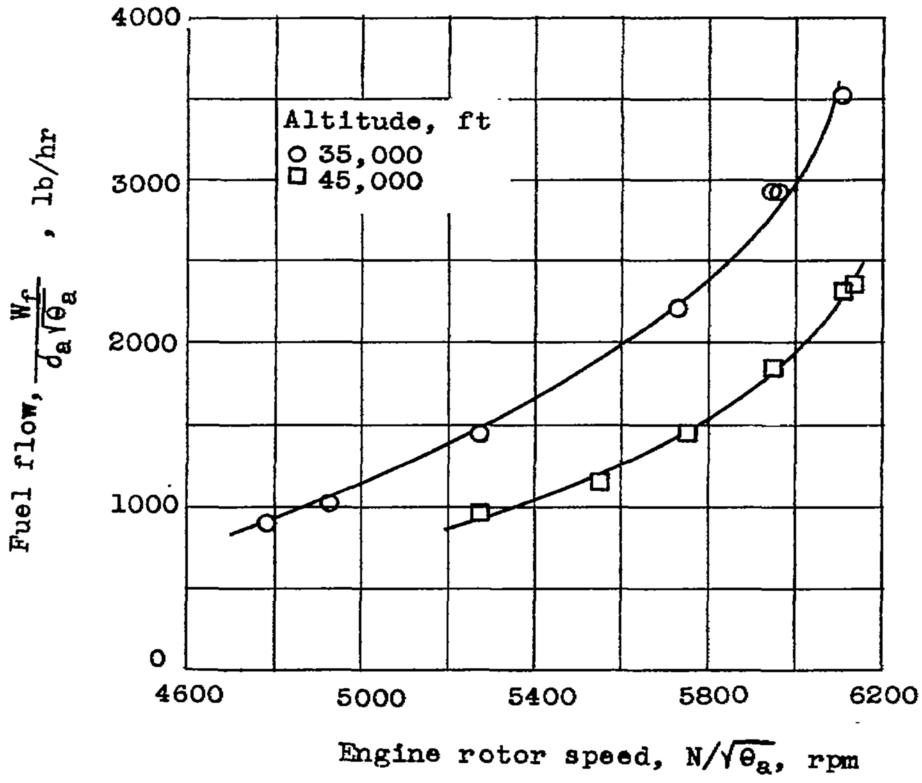


(f) Specific fuel consumption.

Figure 4.- Concluded. Performance of J71-A-11 turbojet engine with fixed-area exhaust nozzles. Altitude, 45,000 feet; flight Mach number, 0.8.



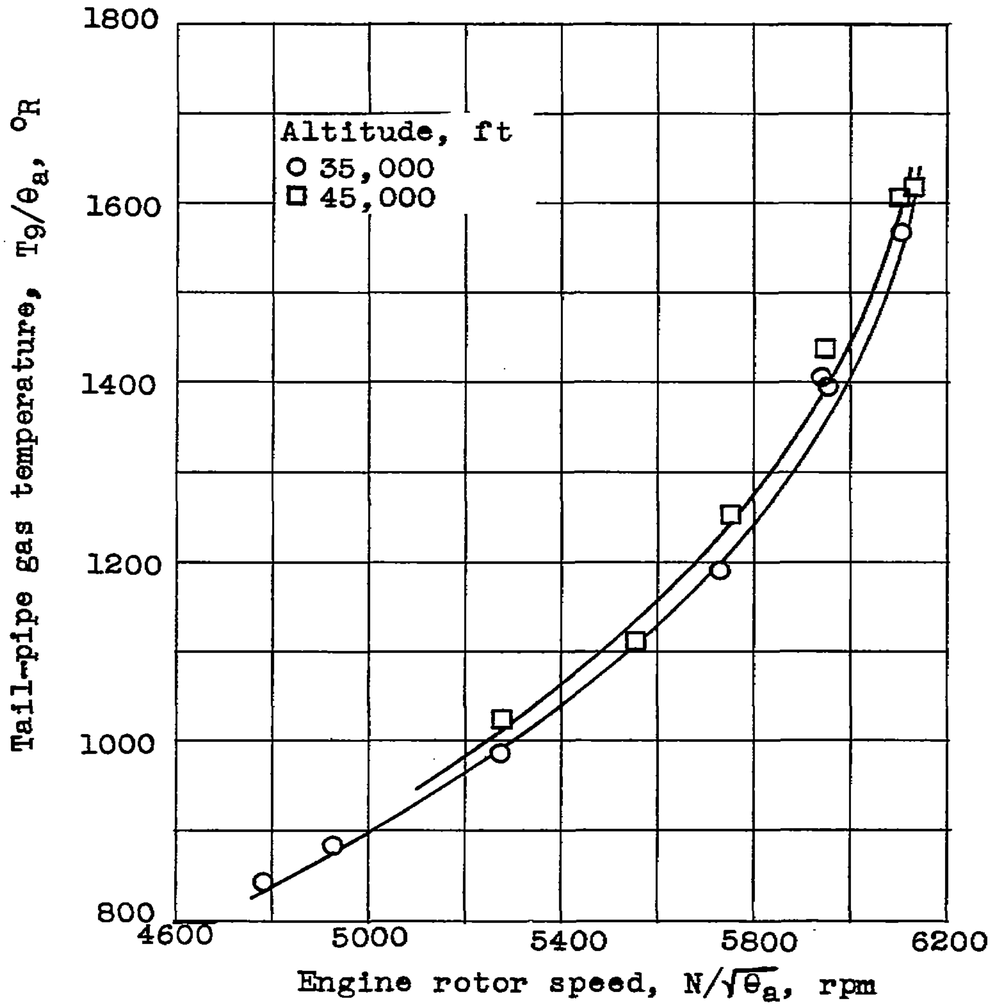
(a) Engine air flow.



(b) Engine fuel flow.

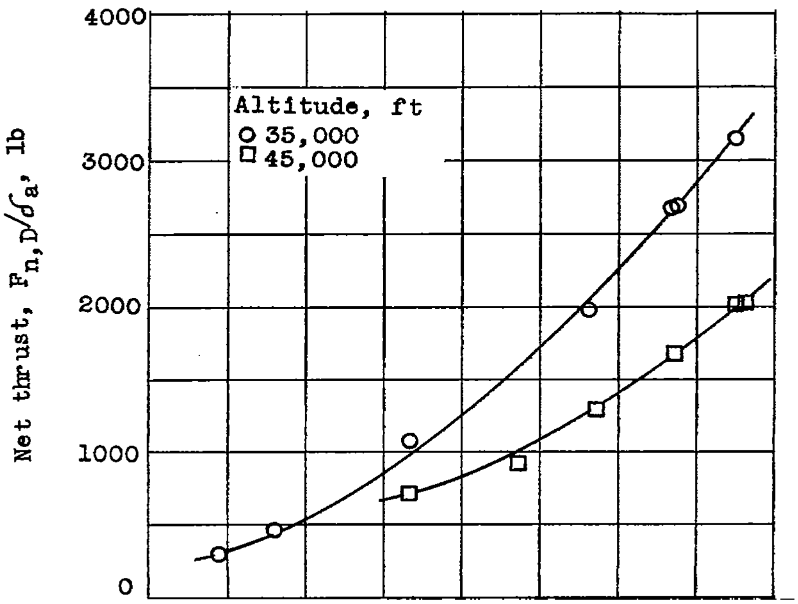
Figure 5. - Simulated flight performance of J71-A-11 turbojet engine using interlinked control system and variable-area exhaust nozzle. Flight Mach number, 0.8.

[redacted]

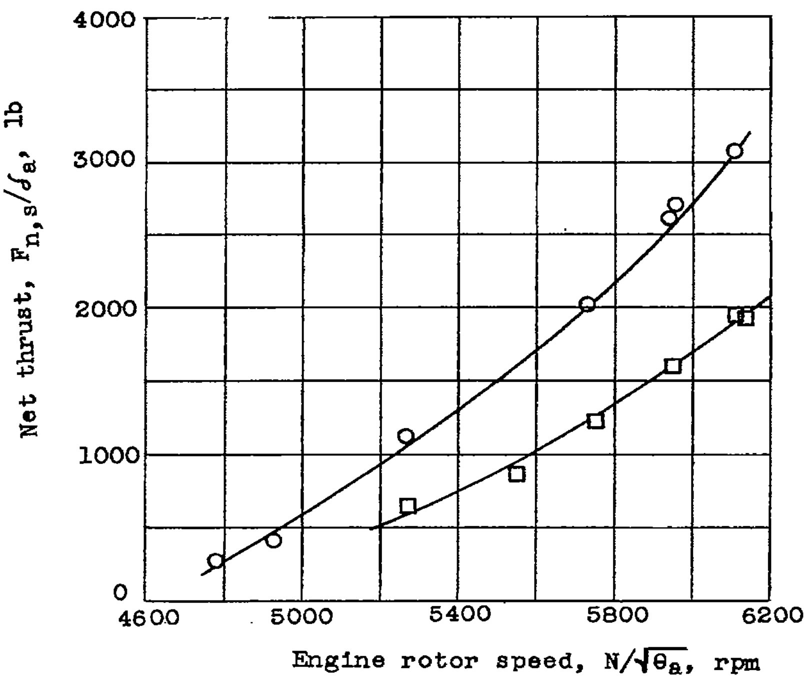


(c) Tail-pipe gas temperature.

Figure 5. - Continued. Simulated flight performance of J71-A-11 turbojet engine using interlinked control system and variable-area exhaust nozzle. Flight Mach number, 0.8.



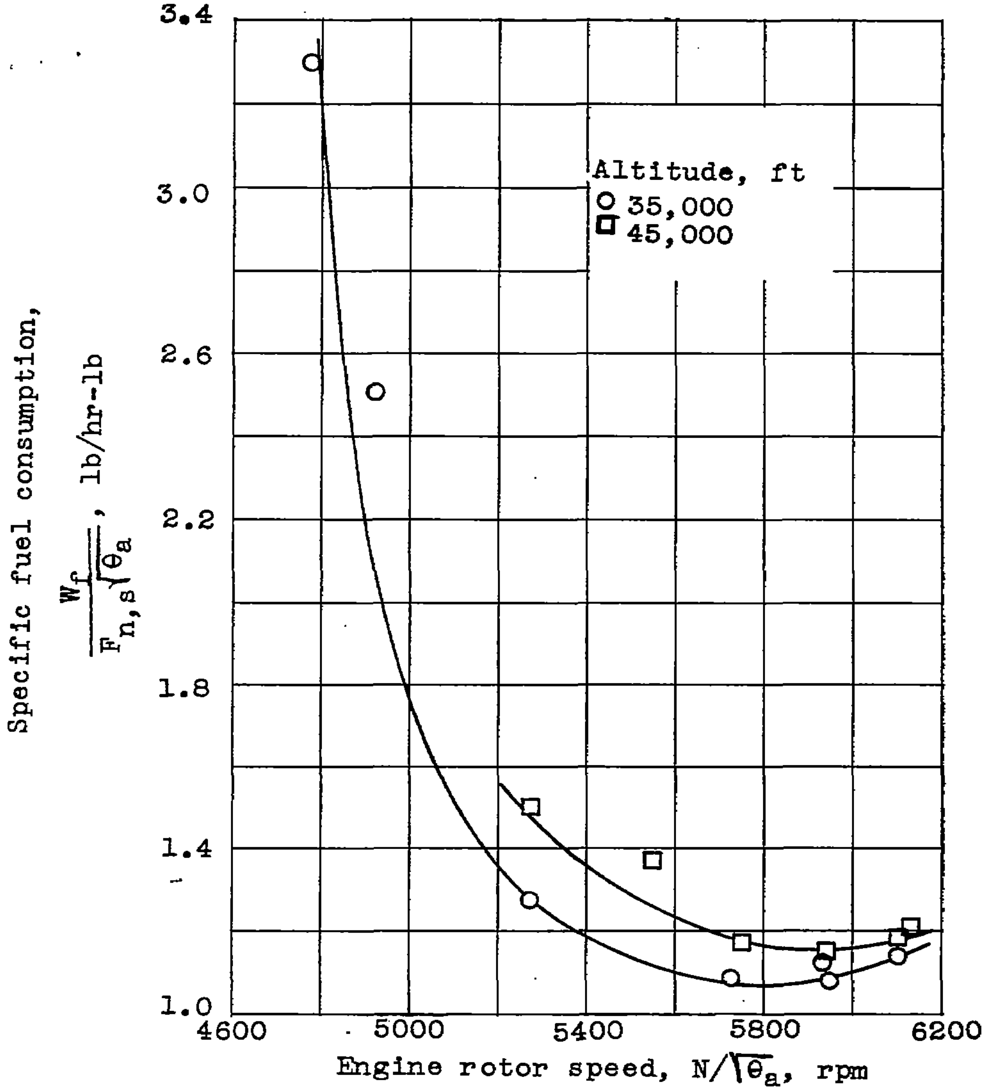
(d) Net thrust from Douglas rake.



(e) Net thrust measured by balance system.

Figure 5. - Continued. Simulated flight performance of J71-A-11 turbojet engine using interlinked control system and variable-area exhaust nozzle. Flight Mach number, 0.8.

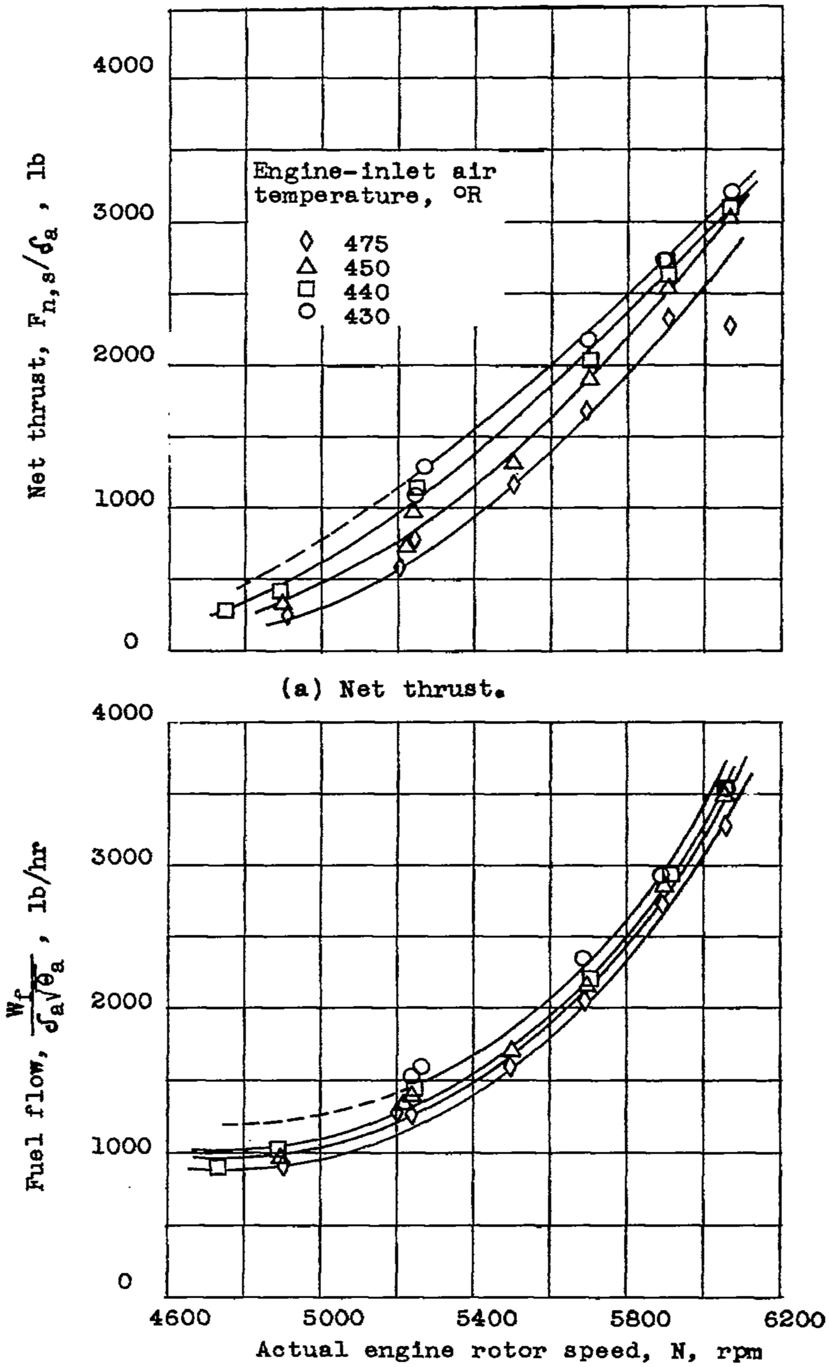
[redacted]



(f) Specific fuel consumption.

Figure 5. - Concluded. Simulated flight performance of J71-A-11 turbojet engine using interlinked control system and variable-area exhaust nozzle. Flight Mach number, 0.8.

[redacted]



(a) Net thrust.

(b) Engine fuel flow.

Figure 6. - Effect of engine-inlet temperature on altitude performance of J71-A-11 turbojet engine. Variable-area exhaust nozzle interlinked with engine control system. Altitude, 35,000 feet; flight Mach number, 0.8.

[redacted]

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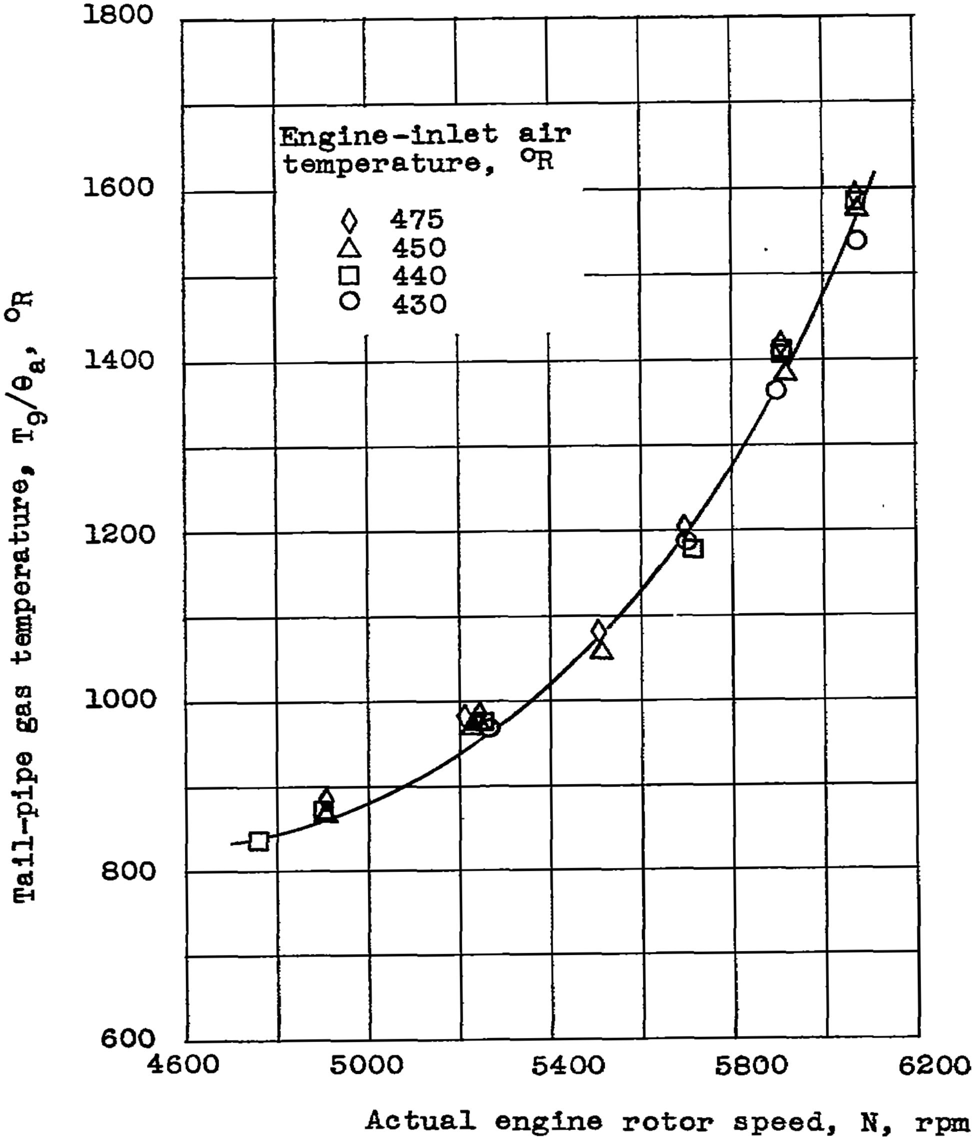

(c) Tail-pipe gas temperature.

Figure 6. - Concluded. Effect of engine-inlet temperature on altitude performance of J71-A-11 turbojet engine. Variable-area exhaust nozzle interlinked with engine control system. Altitude, 35,000 feet; flight Mach number, 0.8.

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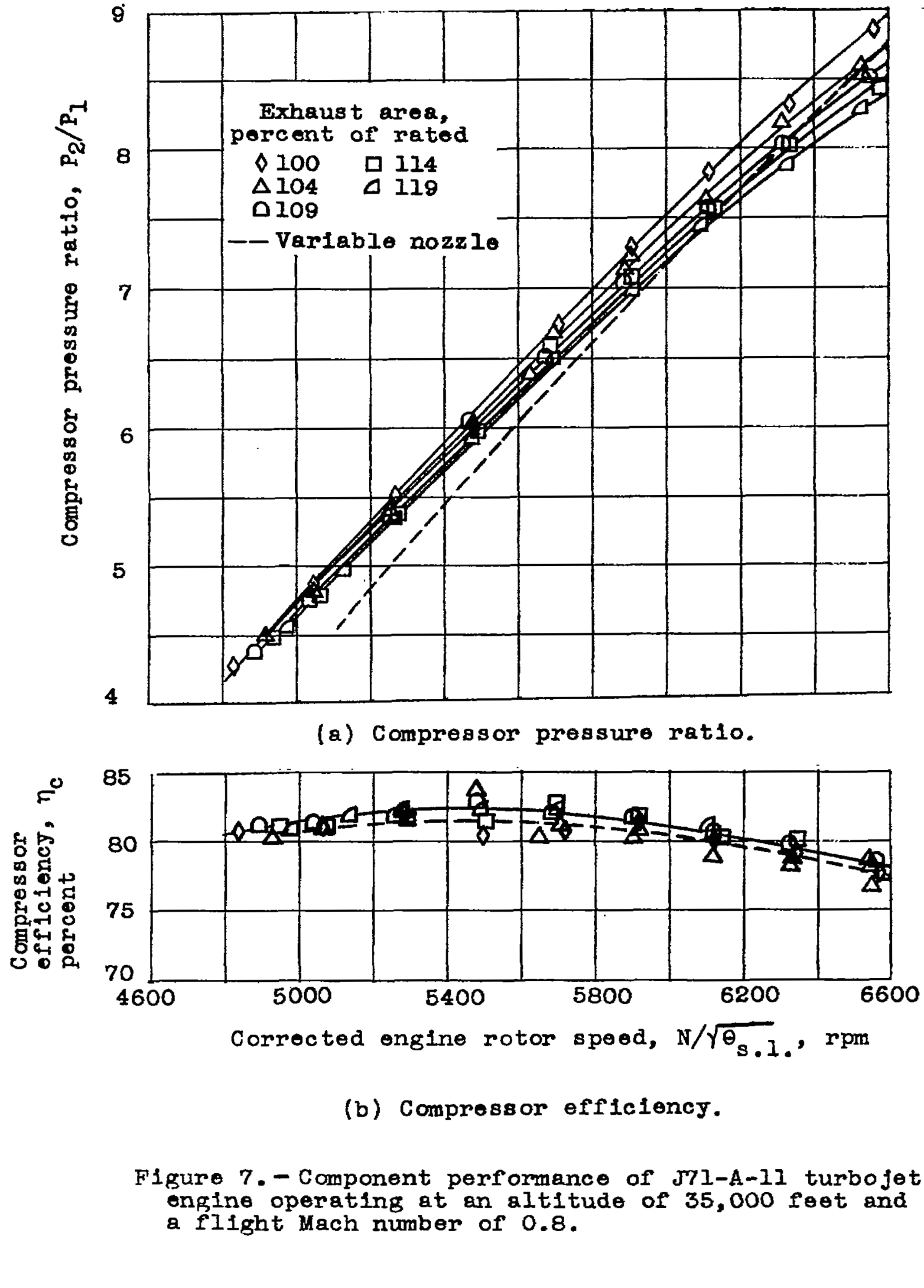

(b) Compressor efficiency.

Figure 7. - Component performance of J71-A-11 turbojet engine operating at an altitude of 35,000 feet and a flight Mach number of 0.8.

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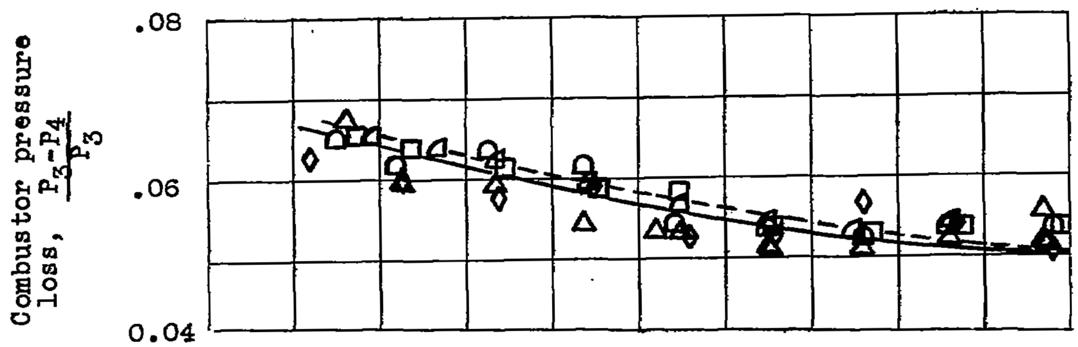
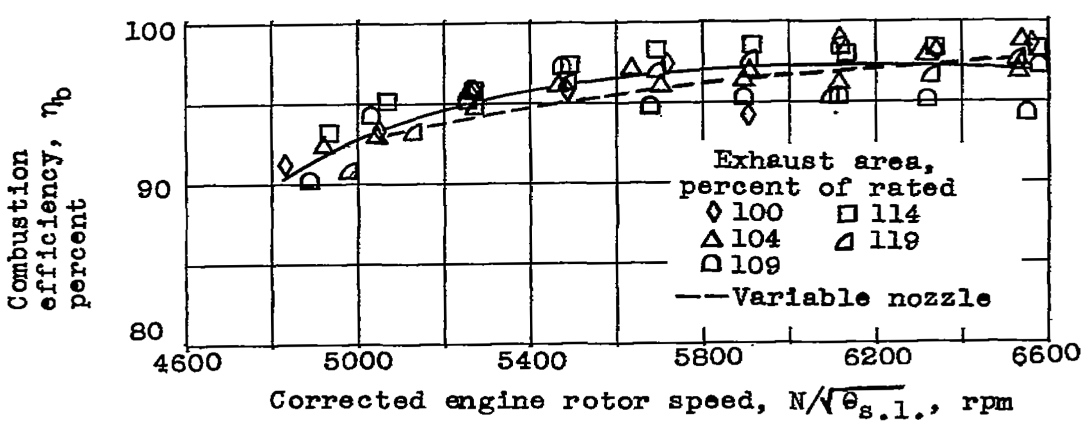
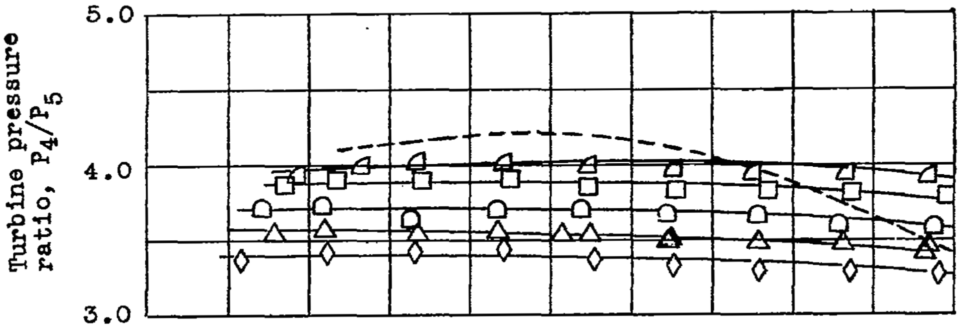


(c) Combustor pressure loss.

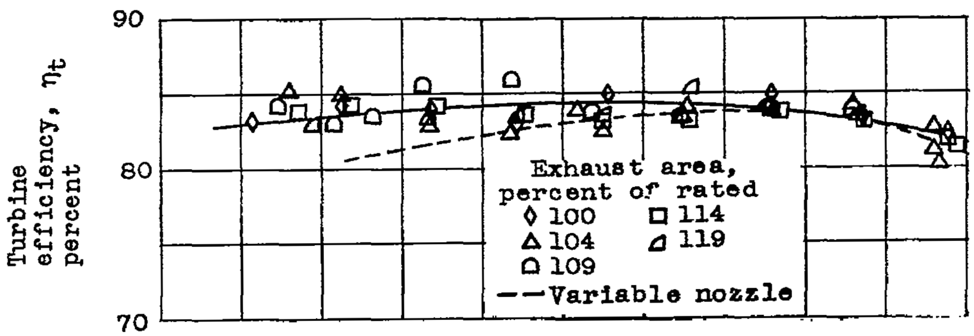


(d) Combustion efficiency.

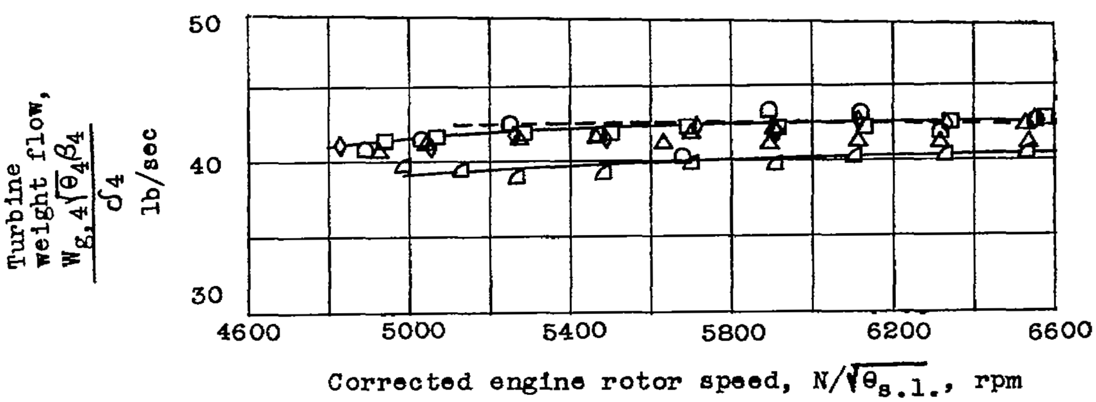
Figure 7. - Continued. Component performance of J71-A-11 turbojet engine operating at an altitude of 35,000 feet and a flight Mach number of 0.8.



(e) Turbine pressure ratio.

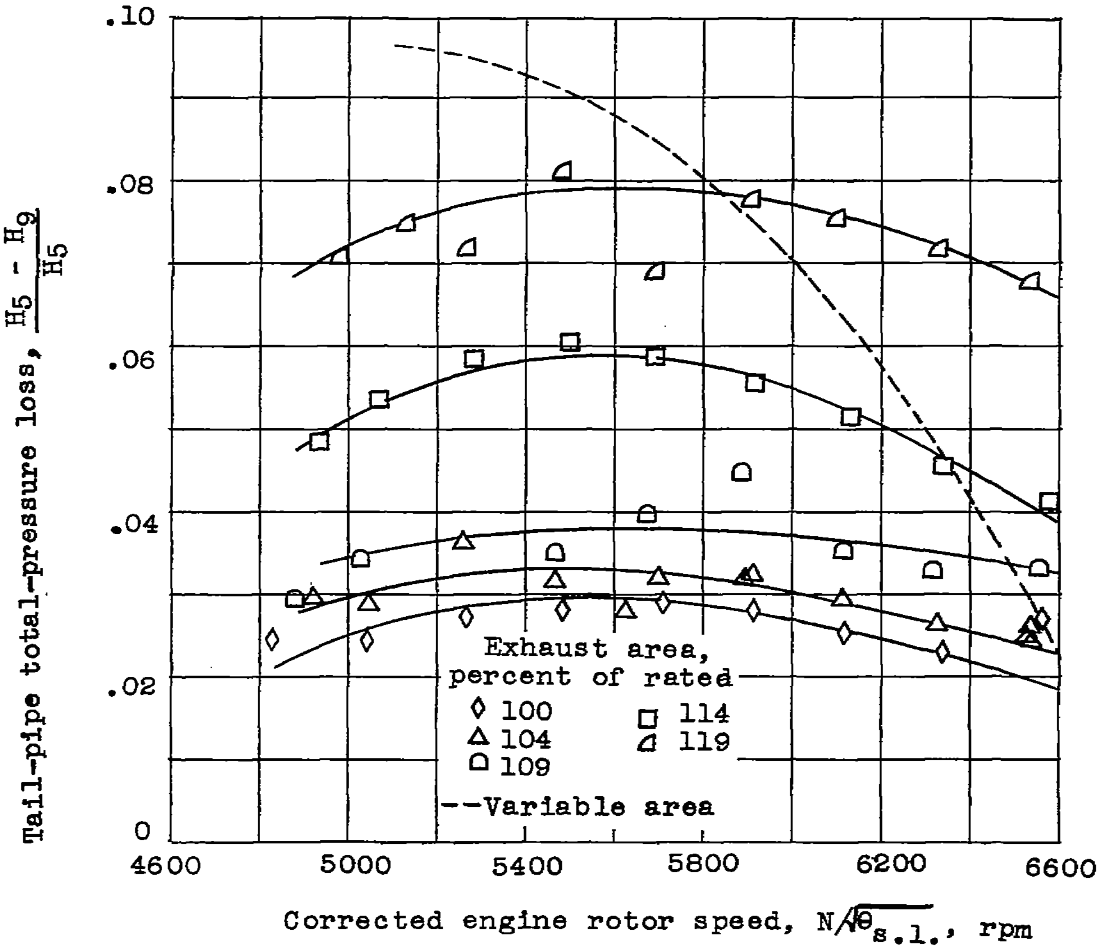


(f) Turbine efficiency.



(g) Turbine weight flow.

Figure 7. - Continued. Component performance of J71-A-11 turbojet engine operating at an altitude of 35,000 feet and a flight Mach number of 0.8.



(h) Tail-pipe total-pressure loss.

Figure 7. - Concluded. Component performance of J71-A-11 turbojet engine operating at an altitude of 35,000 feet and a flight Mach number of 0.8.

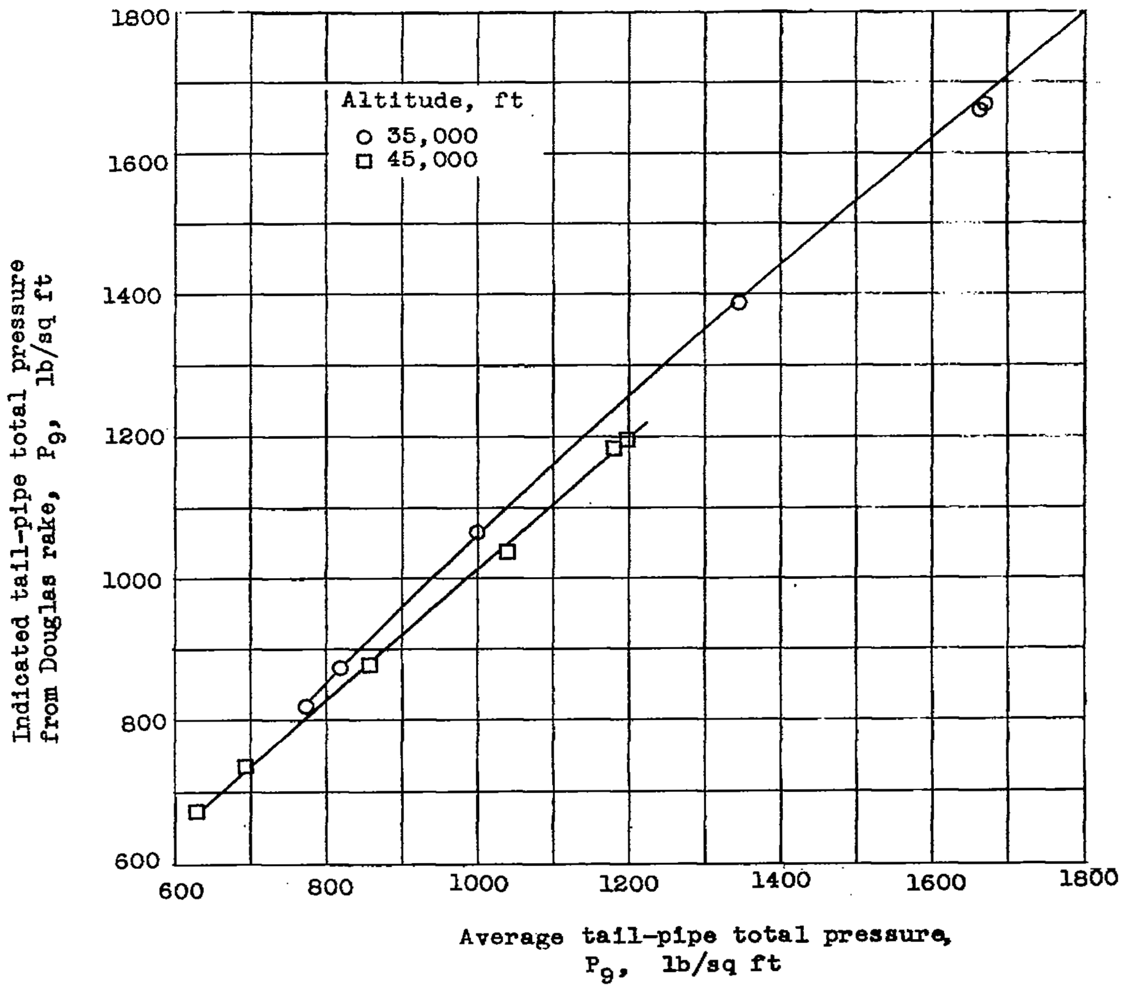


Figure 8. J71-A-11 turbojet engine tail-pipe total pressure indicated from Douglas rake compared with average of comprehensive pressure survey. Operation at a flight Mach number of 0.8.

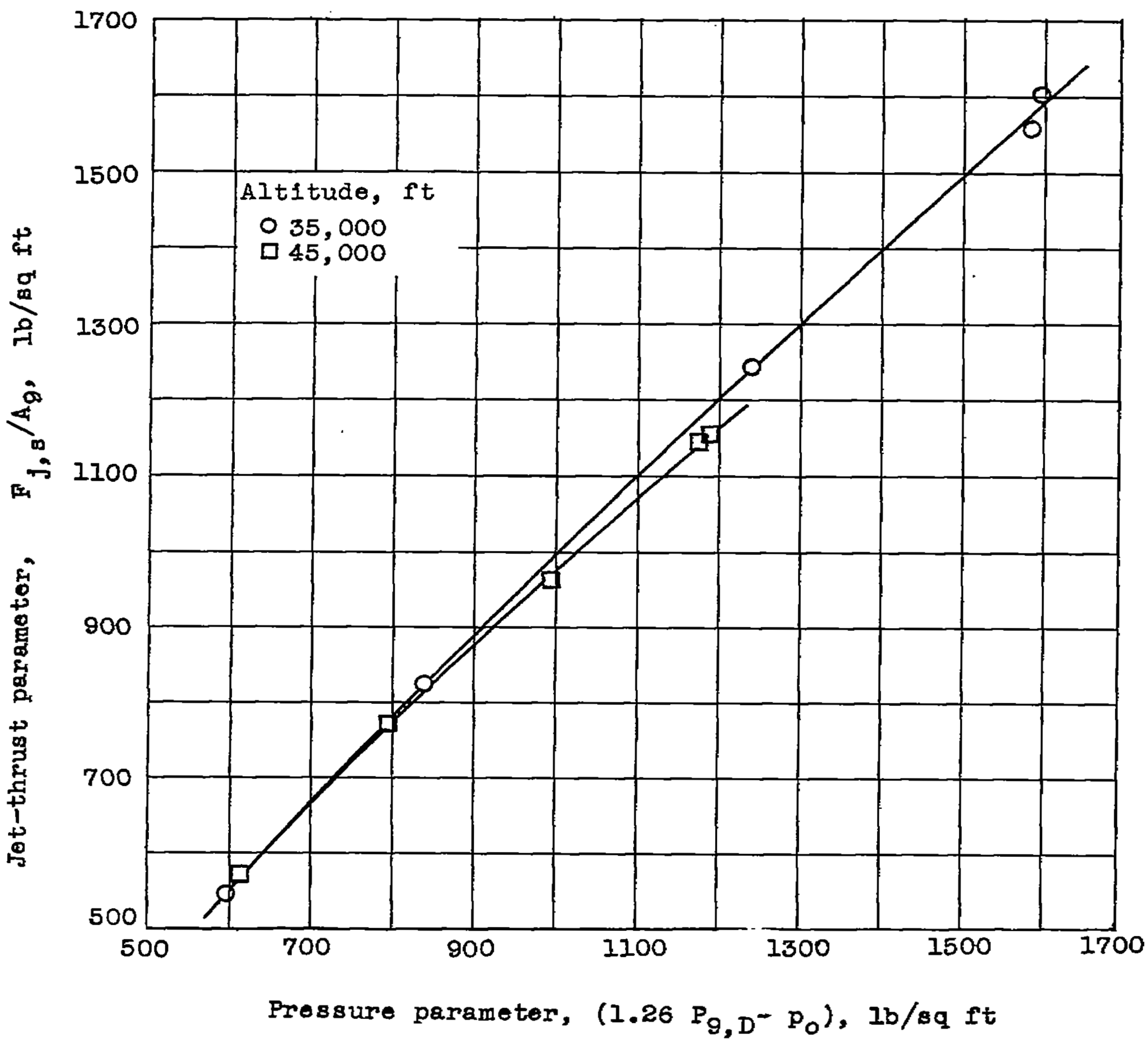


Figure 9. Jet thrust per unit exhaust-nozzle area as a function of Douglas rake indicated tail-pipe total pressure and altitude pressure. Flight Mach number, 0.8.

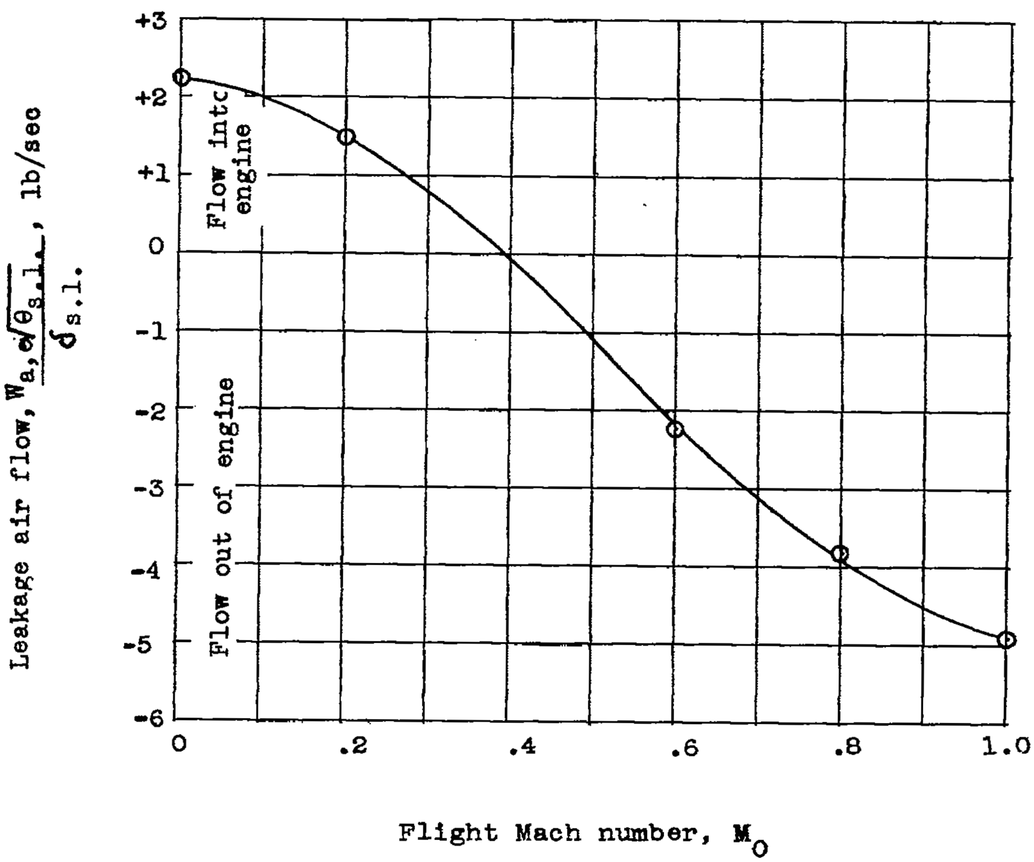


Figure 10. Calibration of air leakage at inlet-screen actuator holes. Corrected engine speed, 6100 rpm.

NACA - Langley Field, Va.