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The Effect of Fuel Ingestion on Turbojet Engine Operation

Part 1—J35 and J47 Engines

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UNITED STATES DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES

THE EFFECT OF FUEL INGESTION ON TURBOJET ENGINE OPERATION*

PART I

J35 AND J47 ENGINES

FOREWORD

The investigation covered by this report was conducted at the Civil Aeronautics Administration's Technical Development Center, Indianapolis, Indiana, under WADC Contract No. AF33(616)54-15, Amendment No. A2(56-1935), and RDO No. R-523-369SR1Z.

SUMMARY

Tests were conducted to investigate the degree of hazard resulting from fuel entering aircraft turbojet engines with the engine primary-air supply. The J35-A-13D and J47-GE-25 series engines were used for the tests. During engine operation, measured quantities of JP-4 fuel were released and carried by engine primary air into the engine compressor. Each engine failed when the quantity of ingested fuel approached approximately 1 per cent by weight of the normal quantity of engine primary air with actual failures occurring between 0.8 and 1.1 per cent. However, each engine failed in a different manner; the J35 engine failed as a result of components becoming overheated and the J47 engine failed as the result of a compressor stall.

INTRODUCTION

Investigations of aircraft turbojet engine explosions have indicated that a possible cause might be the leakage of flammable fluids into the engine primary air. The probability of fuel, lubricants, and hydraulic fluid entering the engine with the primary-air supply has been increased by recent trends in design. In order to accomplish ground cooling of the engine compartments of some aircraft, the cooling or secondary air after passing through the compartment is drawn into the engine with the primary air. A recent trend is to eliminate the firewall between the compressor and the burner compartments of the engine and allow the secondary air to enter aft of the engine, pass over the entire length of the engine surfaces, including the fuel and lubrication systems, and then be drawn into the engine compressor with primary air. In addition to these recent design trends, leakage and spillage during in-flight refueling of turbojet aircraft also has added to the possibility of flammable fluids entering into the primary-air inlet of engines; for instance, when aircraft are refueled in midair, a small amount of excessive line fluid escapes after the refueling hose is decoupled.

In view of the explosion record and these recent trends in design, it was decided that the degree of hazard associated with turbine-engine fuel ingestion should be investigated. In line with these needs, tests were conducted by the Civil Aeronautics Administration's Technical Development Center, Indianapolis, Indiana, under contractual agreements with the Department of the Air Force.

TEST FACILITIES AND EQUIPMENT

A test cell constructed to provide explosion protection together with an adjacent control building and an attached auxiliary powerplant room were used for conducting the engine tests. These buildings are shown in Fig. 1. A J35-A-13D engine is shown mounted in the test cell in Fig. 2, and a view of the control room and the instrumentation is shown in Fig. 3.

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*Reprinted for general distribution from a limited distribution report dated August 1957.

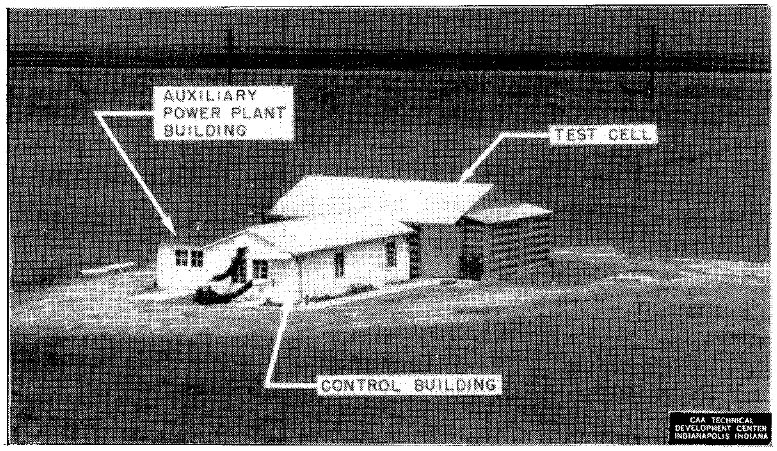


Fig. 1 Jet Engine Test Facility, Civil Aeronautics Administration, Technical Development Center, Indianapolis, Indiana

Engine speed was measured by a tachometer with a specially contructed Strobotac. Fuel rates were measured by Fisher and Porter rotameter-type flow meters. A vibration meter, a five-inch oscilloscope, and a seven-inch recording oscillograph were used to monitor engine vibration. Two vibration pickups were mounted on each engine installation. Chromel-Alumel thermocouples, used with Minneapolis-Honeywell Brown temperature recorders, continuously recorded engine and exhaust gas temperatures throughout the tests. Compressor-stage pressures were measured with pressure-transducer-type pickups and direct-pressure gages. An American Society of Mechanical Engineers' (ASME) bellmouth section, shown in Fig. 4, was utilized to measure the quantity of air consumed by the engine under the various conditions of test. This section was calibrated in accordance with ASME test codes. 11-1946 prior to its use.

A nozzle assembly shown in Figs. 5 and 5A was constructed and used to spray fuel into the engine inlet during the tests. Figure 6 shows the nozzle discharging fuel into the bellmouth inlet at the rate of 540 lb.fuel/hr.

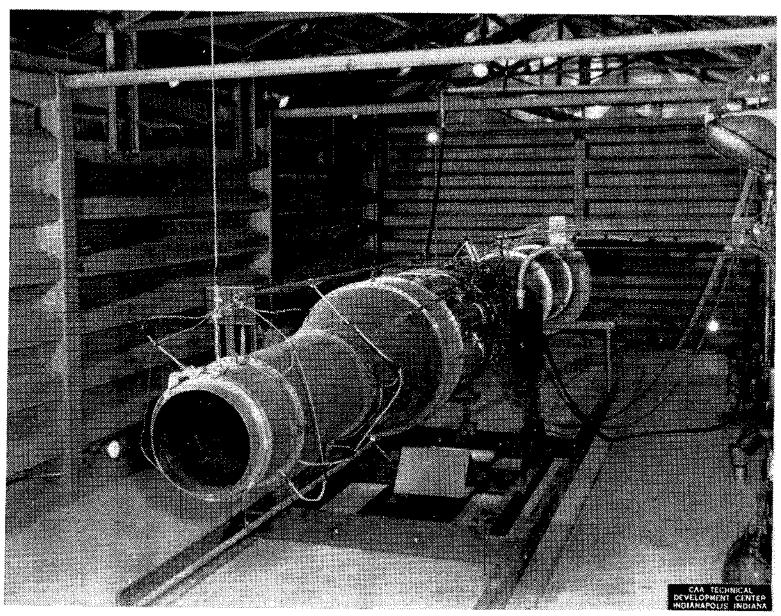


Fig. 2 Test Cell Installation of J35-A-13D

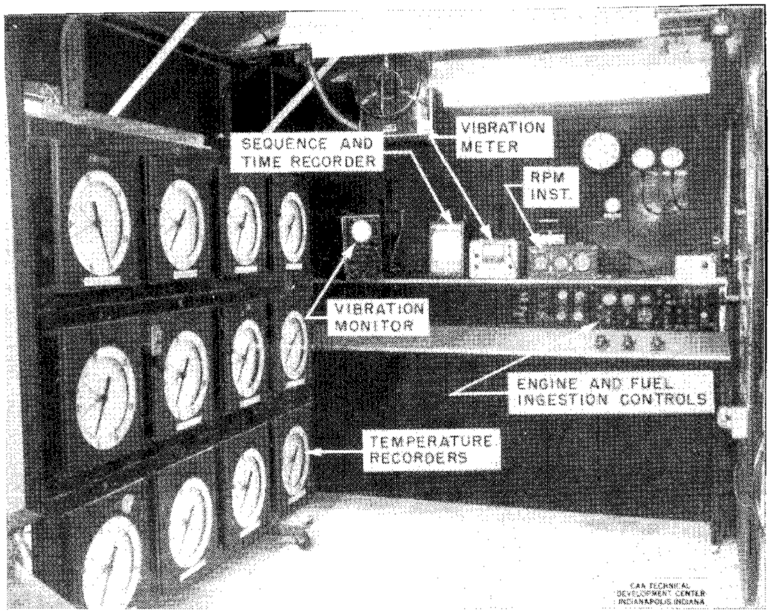


Fig. 3 Jet Engine Test Facility Control Room Showing Instrumentation

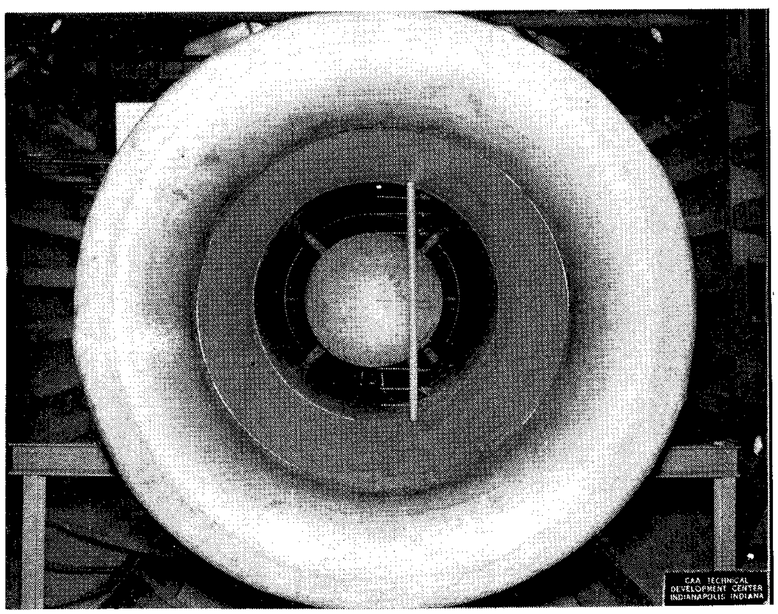


Fig. 4 American Society of Mechanical Engineers' Bellmouth Section and Airflow Traverse Section Used During Fuel Ingestion Tests

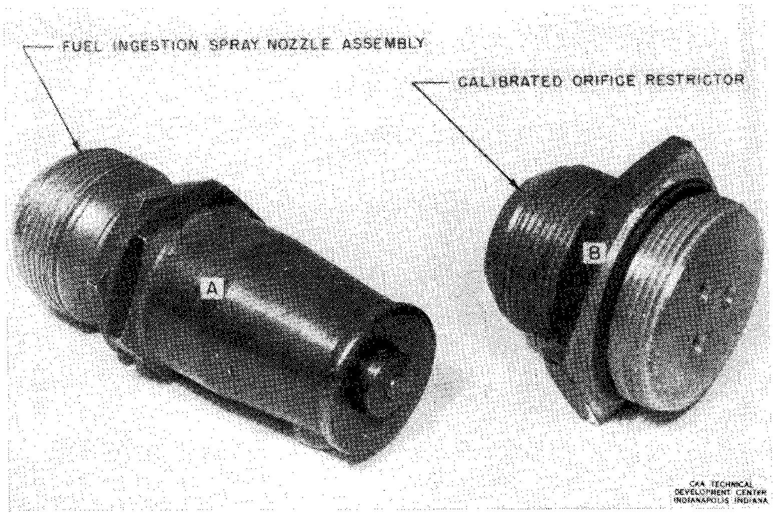


Fig. 5 Fuel Ingestion Nozzle and Orifice Restrictor

DESCRIPTION OF TEST ARTICLES

The first series of tests was conducted using a J35-A-13D turbojet engine, Serial No. A-501338, manufactured by Allison Division, General Motors Corporation. The engine was rated at 3,750 pounds of thrust at 7,700 revolutions per minute (rpm). It was rebuilt after a failure occurred during the 85 per cent rpm fuel ingestion tests and was used again for the 100 per cent rpm tests. This engine did not have an automatic fuel control to compensate for rpm variations. The locations of the thermocouple, vibration, and pressure pickups used in the J35 engine tests are shown in Fig. 7 and are described in Table I.

A second series of fuel ingestion tests was conducted using a J47-GE-25 turbojet engine manufactured by the General Electric Company. The engine, Serial No. 076333, was rated at 5,970 pounds of thrust at 7,950 rpm (without water augmentation). This engine was equipped with an automatic fuel control which compensated for rpm variations. The locations of the thermocouple, vibration, and pressure pickups used in the J47 engine tests are shown in Fig. 8 and are described in Table II.

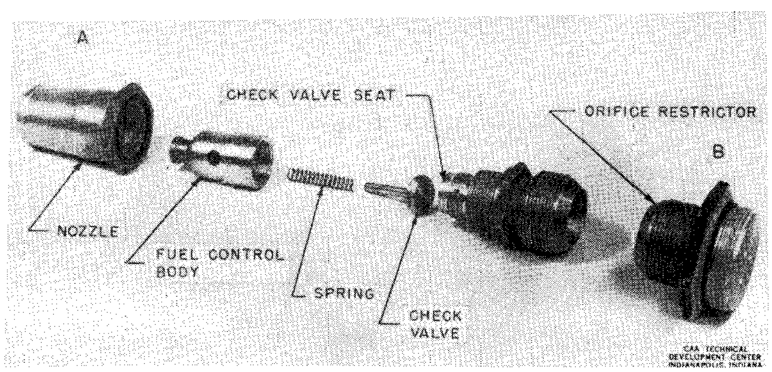


Fig. 5A Fuel Ingestion Nozzle Assembly and Orifice Restrictor, Exploded View

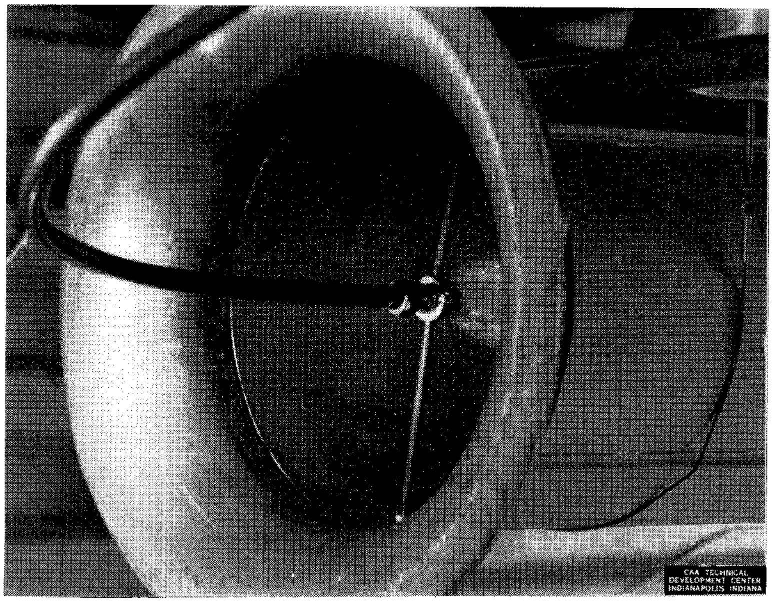
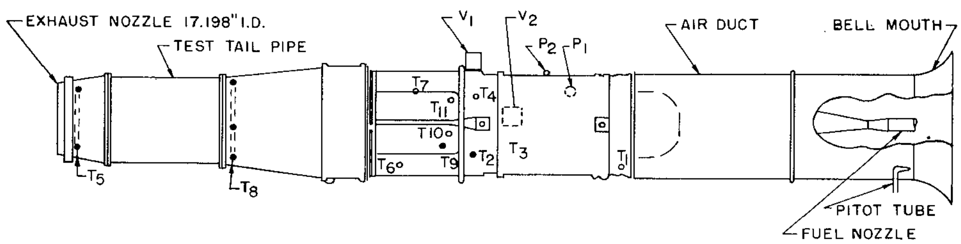


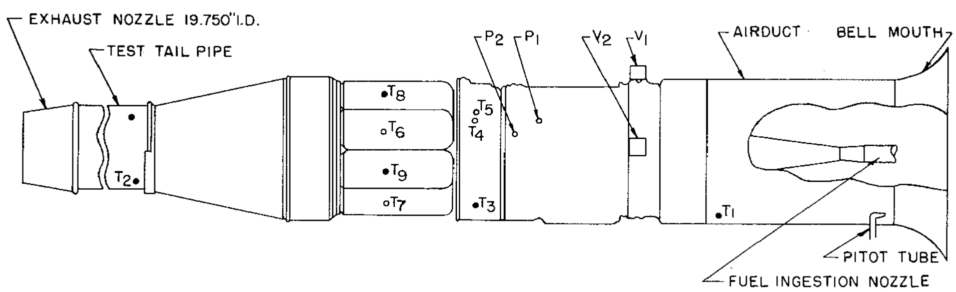
Fig. 6 Release of JP-4 at Rate of 540 Lb./Hr. into J35 Air Inlet



NOTE: SEE TABLE I FOR DETAILED DESCRIPTION OF PICK-UP LOCATIONS

"V" DESIGNATES A VIBRATION PICKUP
"P" DESIGNATES A PRESSURE PICKUP
"T" DESIGNATES A TEMPERATURE PICKUP

Fig. 7 Schematic Diagram of Temperature, Pressure, and Vibration Pickup Locations for Fuel Ingestion Tests on the J35-A-13D Engine



NOTE: SEE TABLE II FOR DETAILED DESCRIPTION OF PICK-UP LOCATIONS

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Fig. 8 Schematic Diagram of Temperature, Pressure, and Vibration Pickup Locations for Fuel Ingestion Tests on the J47-GE-25 Engine

TABLE I

LOCATIONS OF VIBRATION, TEMPERATURE, AND PRESSURE PICKUPS FOR FUEL INGESTION TESTS
(Engine J35-A-13D)

Pickup	Location*	Measurement
V_1	12 o'clock position on engine midframe	Vertical vibration
V_2	3 o'clock mounting position on compressor housing	Horizontal vibration
P_1	4 stage bleed air pressure	Static pressure
P_2	6 stage bleed air pressure	Static pressure
T_1	Compressor inlet, 6 o'clock position	Air temperature
T_2	Aft stage of compression, 4 o'clock position	Air temperature
T_3	Aft stage of compression, 8 o'clock position	Air temperature
T_4	Aft stage of compression, 10 o'clock position	Air temperature
T_5	4 pickups in parallel at 2, 4, 8, and 10 o'clock positions, 12 inches forward of aft end of exhaust test ring	Average gas temperature
T_6	Bottom center of No. 5 burner can outer skin	Skin temperature
T_7	Bottom center of No. 1 burner can outer skin	Skin temperature
T_8	4 pickups in parallel at 3, 6, 9, and 12 o'clock positions in tail cone.	Average gas exhaust temperature
T_9	Spark ignitor hole, 4 o'clock position in burner can No. 3 between inner and outer skin	Air temperature
T_{10}	Spark ignitor hole, 10 o'clock position in burner can No. 6 between inner and outer skin	Air temperature
T_{11}	Spark ignitor hole, 10 o'clock position in burner can No. 8 between inner and outer skin	Air temperature

*See Fig. 7 for physical locations of pickups on J35 engine.

TABLE II

LOCATIONS OF VIBRATION, TEMPERATURE, AND PRESSURE PICKUPS FOR FUEL INGESTION TESTS
(Engine J47-GE-25)

Pickup	Location*	Measurement
V_1	12 o'clock position on forward engine mounting pad	Vertical vibration
V_2	3 o'clock position on forward engine mounting pad	Horizontal vibration
P_1	Air extraction fitting on 8th stage of compressor	Total pressure
P_2	Air extraction fitting on 12th stage of compressor	Total pressure
T_1	6 o'clock position at bottom of air inlet duct 3 inches inward toward centerline of duct	Duct temperature
T_2	4 pickups in parallel 35 inches aft of turbine in tail pipe at 2, 4, 8, and 10 o'clock position	Exhaust gas temperature
T_3	Midframe 4 o'clock position in air extraction port cover	Compressor discharge temperature
T_4	Midframe 2 o'clock position in air extraction port cover	Compressor discharge temperature
T_5	Midframe 10 o'clock position in air extraction port cover	Compressor discharge temperature
T_6	10 o'clock position in bottom of No. 7 burner can between inner and outer liner	Air temperature
T_7	8 o'clock position in bottom of No. 6 burner can between inner and outer liner	Air temperature
T_8	1 o'clock position in bottom of No. 1 burner can between inner and outer liner	Air temperature
T_9	3 o'clock position in bottom of No. 2 burner can between inner and outer liner	Air temperature

*See Fig. 8 for physical locations of pickups on J47 engine.

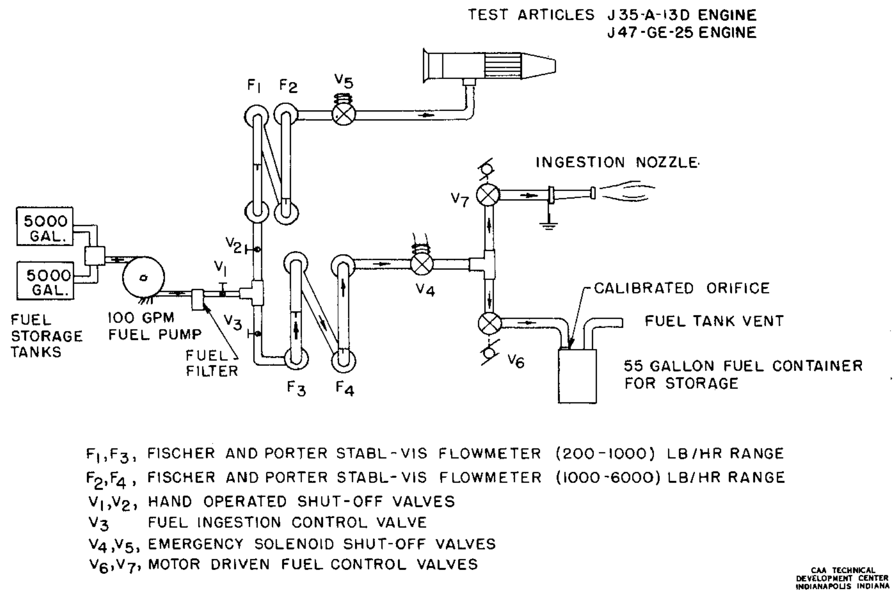

Fig. 9 Schematic Diagram of Fuel Control Equipment Used During Fuel Ingestion Tests on the J35 and J47 Engines

Both engines were supported for testing by a test-cell fixture which provided a three-point mounting. The engines were supported on each side near the midpoint by a horizontal trunnion mount and at the bottom by a mount located on the engines' forward frame. The side mounts transmitted all loads to the rigid test-cell mount. The bottom support permitted vertical alignment of the engines.

GENERAL TEST PROCEDURE

Tests were conducted to determine engine air consumption at idle, cruise, and takeoff rpm throttle settings. The ASME bellmouth section was utilized to obtain these measurements. Air consumption was measured at the beginning of each fuel ingestion test by a single velocity pickup. Measurements obtained with this pickup were correlated with the velocity-traverse measurements obtained during the normal operation tests. Fuel quantity in terms of weight was calculated in multiples of 0.0005 Q, where Q equals the weight of air consumed by the engine for the throttle setting (rpm) used. The fuel ingestion tests were conducted by: (1) setting the throttle for the rpm required for the test; that is, 2,822 rpm was considered idle for the J35-A-13D, (2) spraying the increasing quantities of fuel into the engine air inlet during each consecutive test, and (3) recording temperature, pressure, and vibration data throughout the ingestion period. The fuel ingestion period was the amount of time required for the speed to stabilize while fuel was being sprayed into the engine air inlet. This procedure was repeated until the quantity of fuel entering the engine air inlet caused the engine to fail. Samples of the fuel used during the ingestion tests were analyzed by the Fuels Laboratory, Wright-Patterson Air Force Base, Ohio, and found to be within specification limits for MIL-F-5624C Grade JP-4. A schematic diagram of the fuel control used is shown in Fig. 9. The flow rate of the fuel entering the air inlet was controlled by opening valve V6 and setting valve V3 to the required rate for the test. The fuel then flowed through the calibrated orifice to simulate the ingestion nozzle flow. When the required rate was stabilized, V6 was closed and V7 was opened simultaneously. This procedure was repeated for each test until engine failure occurred. When failure occurred, the fuel pumps were shut off and all valves were closed immediately.

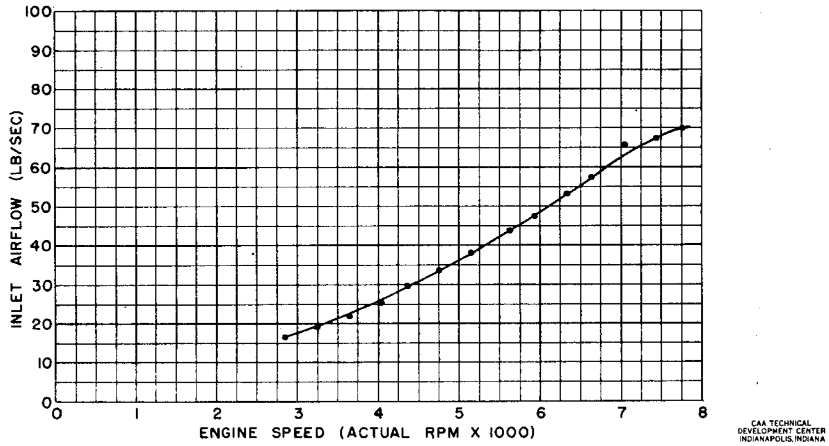

Fig. 10 Graph Showing Airflow Versus Speed (rpm) During Normal Operation of J35-A-13D Engine

RESULTS OF THE TESTS ON THE ALLISON J35-A-13D ENGINE

Normal Operation Tests.

Normal operational data on the J35 engine for idle, cruise, and takeoff rpm throttle settings were recorded prior to the fuel ingestion tests. Tests were conducted with the engine drawing ambient primary air to determine air consumption and performance at various rpm throttle settings. The data obtained from these tests are presented in Table III. The results of these tests are presented in Figs. 10 through 15. The results indicated that the engine operated normally in all speed ranges.

Fuel Ingestion Tests at Idle (2,819) RPM.

Fuel in quantities up to 564 lb.fuel/hr. (0.0068 lb. fuel/lb.air) entered the primary inlet of the J35 engine at which time the speed increased from 2,819 to 3,940 rpm, the exhaust gas temperature (EGT) increased from 925° F. to 1,191° F., and the engine fuel flow remained constant at 790 lb./hr.

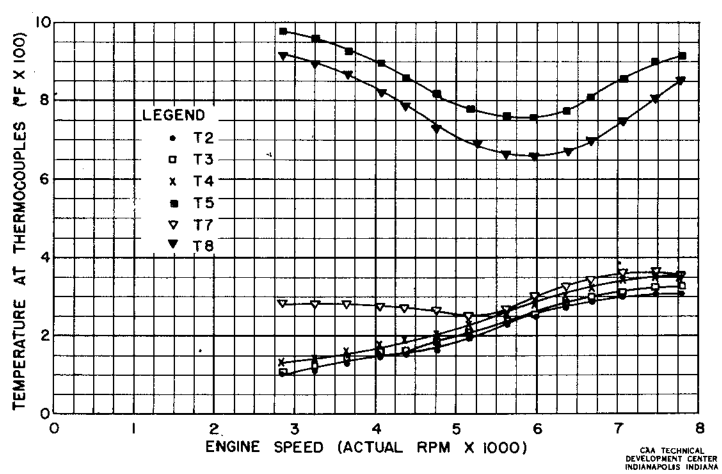

Fig. 11 Graph Showing Temperatures Versus Speed During Normal Operation of J35-A-13D Engine

TABLE III

NORMAL OPERATION DATA J35-A-13D TURBOJET ENGINE HAZARD STUDIES

Engine Speed Per Cent of Rated RPM (per cent)	Actual Speed (rpm)	Inlet Air Flow (lb/sec)	Engine Fuel Flow (lb/hr)	[1]Temperatures at Thermocouples (°F) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	[1]Total Pressure (in. hg.) P_1	P_2	[1]Vibration Amplitude (mils) V_1	V_2
35	2822	16.26	785	55	102	105	132	982	117	280	920	100	95	77	2.5	4.8	.20	.30
40	3241	19.18	885	55	117	122	145	960	132	280	887	112	105	90	3.4	6.6	.15	.25
45	3613	22.01	970	55	130	132	152	925	142	277	867	127	122	95	4.8	7.0	.24	.43
50	4012	25.02	1085	55	145	150	172	890	147	277	812	145	138	110	4.9	10.4	.30	.45
55	4386	29.64	1163	55	152	158	185	855	160	275	782	155	150	132	6.0	12.5	.30	.51
60	4759	33.93	1274	55	175	182	202	812	175	260	732	175	172	148	7.5	15.2	.40	.66
65	5147	38.71	1378	55	198	205	232	788	195	255	690	195	193	162	8.4	18.5	.42	.98
70	5614	43.33	1505	55	223	230	253	763	220	258	665	218	205	185	9.0	22.0	.84	.75
75	5937	47.97	1660	55	245	250	283	758	240	300	655	238	232	205	9.8	25.5	.63	1.05
80	6344	53.08	1852	55	270	272	295	767	255	322	667	260	255	232	10.2	28.8	.80	1.00
85	6652	58.54	2095	55	285	295	322	802	282	338	700	283	283	252	10.4	32.0	1.40	1.80
90	7014	62.58	2130	55	300	315	345	852	302	352	752	305	300	280	10.4	34.2	1.50	2.00
95	7465	66.35	2445	55	305	325	352	900	345	362	802	325	325	297	10.5	36.0	1.30	2.30
100	7782	68.57	2860	52	305	322	352	910	345	352	847	342	342	312	10.5	37.0	1.20	1.20

[1]Locations of thermocouple, pressure, and engine vibration probes are shown in Table I and Fig. 7.

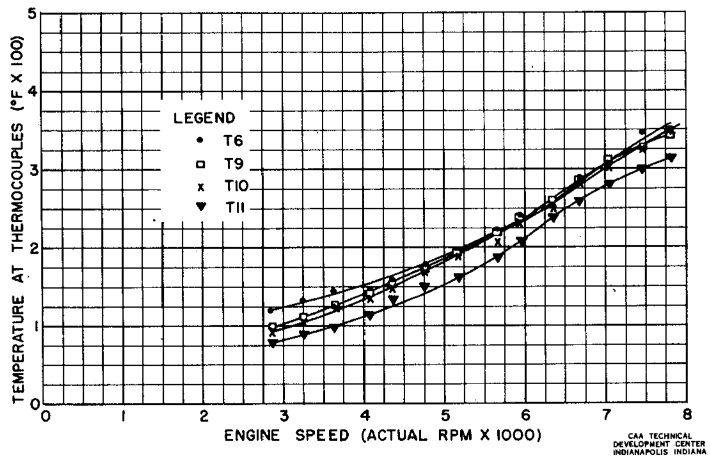

Fig. 12 Graph Showing Temperatures Versus Speed During Normal Operation of a J35-A-13D Engine

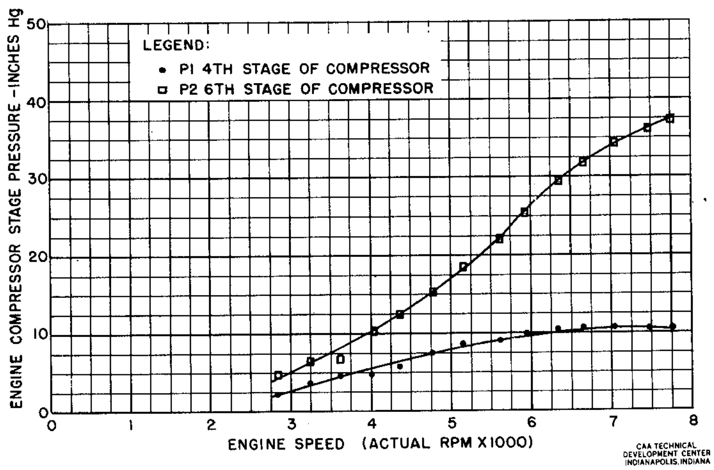

Fig. 13 Graph Showing Compressor Pressures Versus Speed During Normal Operation of J35-A-13D Engine

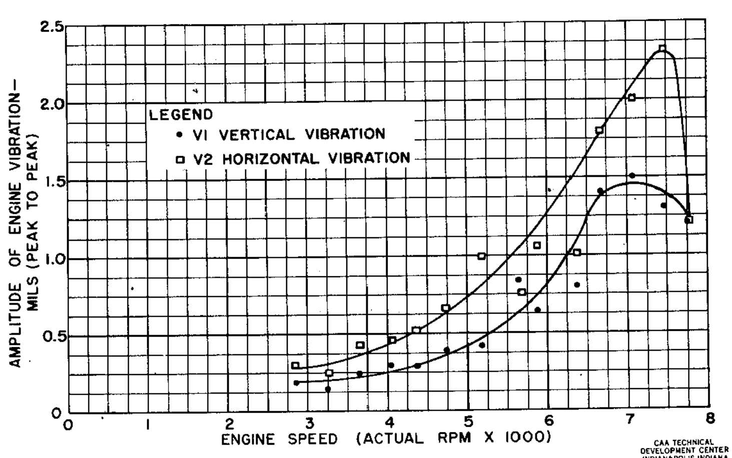

Fig. 14 Graph Showing Vibration Versus Speed During Normal Operation of a J35-A-13D Engine

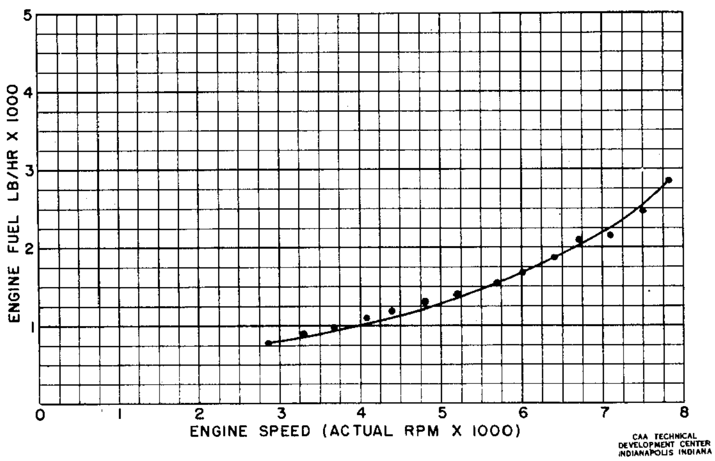

Fig. 15 Graph Showing Engine Fuel Versus Speed During Normal Operation of a J35-A-13D Engine

An inspection of the engine after the fuel ingestion tests at idle rpm revealed no apparent damage to the engine. The data obtained during the idle rpm fuel ingestion tests are presented in Tables IV and IV-A. Graphical presentations of the effect of fuel ingestion on engine rpm and exhaust gas temperature at idle and cruise throttle settings are shown in Figs. 16 and 17.

Fuel Ingestion Tests at Cruise (6,768) RPM.

Fuel ingestion data for cruise rpm conditions are presented in Tables V and V-A. A graphical presentation of the effects of fuel ingestion at cruise rpm on temperature is shown in Fig. 18. The results indicated that the speed and exhaust gas temperature exceeded the 100 per cent rpm conditions.

Engine failure occurred on Test No. 20 at a speed of 8,341 rpm or an overspeed of 1,573 rpm from the initial speed at cruise rpm throttle setting. The exhaust gas temperature prior to failure had reached 1,448° F., an overtemperature of 703° F. from the initial temperature prior to fuel ingestion. The engine primary fuel-air ingestion mixture was 0.0008 lb.fuel/lb.air when the failure occurred. This was at the rate of 1,938 lb.fuel/hr. into the air inlet.

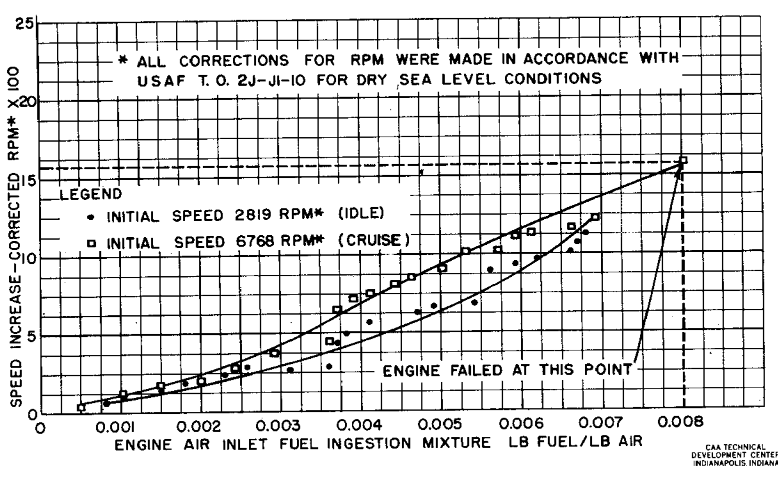

Fig. 16 Graph Showing Effect on RPM of Ingesting Sprayed Fuel into the Engine Air Inlet of the J35-A-13D Engine

TABLE IV

FUEL INGESTION DATA FOR IDLE (2819) RPM THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)
1	2880	2876	930	935	48	790	16.72	.0008
2	2920	2916	940	945	60	790	16.73	.0010
3	2960	2957	950	955	90	790	16.93	.0015
4	3020	3016	975	980	114	790	17.25	.0018
5	3058	3054	985	990	144	790	17.47	.0023
6	3110	3106	995	1000	162	790	17.76	.0025
7	3135	3088	1010	980	192	790	17.17	.0031
8	3160	3113	1025	994	228	790	17.16	.0036
9	3180	3278	900	986	270	790	19.56	.0037
10	3200	3298	905	991	252	790	19.66	.0038
11	3290	3391	910	996	300	790	20.21	.0041
12	3335	3437	955	1044	348	790	20.43	.0047
13	3380	3484	960	1049	366	790	20.71	.0049
14	3400	3504	975	1065	402	790	20.83	.0054
15	3620	3719	1005	1086	444	790	22.03	.0056
16	3655	3755	1025	1107	468	790	22.19	.0059
17	3695	3796	1040	1123	498	790	22.40	.0062
18	3725	3827	1045	1128	540	790	22.55	.0066
19	3780	3884	1100	1186	552	790	22.87	.0067
20	3835	3940	1105	1191	564	790	23.22	.0068
NORMAL OPERATION DATA								
	2822	2819	920	925	0	790	16.26	

[1] All corrections for rpm and exhaust gas temperature have been made according to U. S. Air Force T. O. 2J-J1-10 for dry sea-level conditions.

TABLE IV-A

FUEL INGESTION DATA FOR IDLE (2819) RPM THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Temperature at Thermocouples (°F.) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Total Pressure (in.hg.) P_1	P_2	Vibration Amplitude (mils) V_1	V_2	Ingestion Time (sec)
1	50	75	100	105	840	75	120	930	100	100	100	3.0	6.0	0.10	0.13	86
2	50	80	95	100	1025	75	110	940	100	100	100	3.0	6.0	0.10	0.13	89
3	50	80	95	105	1050	80	110	950	100	100	100	3.0	6.0	0.10	0.13	78
4	60	80	95	110	1060	80	120	975	100	100	105	3.0	6.0	0.10	0.13	90
5	60	80	95	110	1075	80	120	975	110	105	110	3.0	6.0	0.10	0.13	65
6	70	110	125	140	1095	90	130	995	110	105	110	3.0	6.0	0.10	0.14	86
7	70	100	120	125	1120	90	130	1010	120	120	125	3.0	6.0	0.16	0.22	79
8	25	65	75	95	1125	80	90	1025	120	120	125	3.0	6.0	0.16	0.22	91
9	25	60	65	90	980	80	90	900	75	75	80	4.0	7.0	0.12	0.17	88
10	25	50	65	80	995	70	95	905	75	75	80	4.0	7.0	0.12	0.17	85
11	25	50	65	80	1000	70	95	910	80	80	80	4.0	8.0	0.19	0.34	86
12	25	50	65	80	1005	75	95	955	80	80	80	4.0	8.0	0.18	0.34	70
13	25	50	65	80	1010	75	95	960	80	80	80	4.0	8.0	0.18	0.33	70
14	25	75	90	100	1005	75	105	975	80	80	90	4.0	8.0	0.17	0.32	108
15	25	70	80	100	1015	75	105	1005	100	95	90	4.5	10.0	0.13	0.34	75
16	25	70	80	100	1020	75	105	1025	100	95	95	4.5	10.0	0.11	0.31	80
17	25	70	85	100	1070	75	105	1040	100	100	95	4.8	10.0	0.11	0.22	86
18	25	70	95	100	1070	75	105	1045	100	100	100	5.0	10.0	0.12	0.29	66
19	25	75	90	105	1100	80	115	1100	110	110	110	4.8	10.0	0.19	0.15	80
20	25	75	95	105	1090	80	125	1105	110	115	110	4.5	10.0	0.19	0.15	70
NORMAL OPERATING DATA																
	50	90	100	120	982	75	120	920	100	95	77	3.0	6.0	0.10	0.13	

TABLE V

FUEL INGESTION DATA FOR CRUISE (6768) RPM THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)
1	6700	6817	700	745	108	2093	62.15	.0005
2	6750	6868	705	750	234	2093	62.53	.0010
3	6820	6940	725	771	342	2093	63.18	.0015
4	6830	6950	730	776	432	2093	63.19	.0019
5	6925	7047	740	787	558	2093	64.07	.0024
6	7020	7142	755	802	678	2093	64.95	.0029
7	7090	7214	790	849	846	2093	65.59	.0036
8	7120	7420	790	911	876	2093	69.06	.0037
9	7180	7483	810	922	984	2093	69.63	.0039
10	7220	7524	820	933	1049	2093	70.02	.0041
11	7275	7582	820	933	1128	2093	70.56	.0044
12	7210	7618	840	954	1164	2093	70.90	.0046
13	7370	7681	855	971	1272	2093	71.39	.0050
14	7460	7775	940	1063	1380	2093	72.26	.0053
15	7480	7796	955	1080	1476	2093	72.54	.0057
16	7580	7883	1000	1118	1560	2093	73.14	.0059
17	7600	7904	1040	1161	1620	2093	73.34	.0061
18	7620	7925	1155	1286	1740	2093	73.53	.0066
19	7675	7982	1160	1291	1830	2093	74.06	.0069
20[2]	8020	8341	1305	1448	2150	2093	74.30	.0080
NORMAL OPERATING DATA								
	6652	6768	700	745		2093	61.70	

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

[2]Engine failure occurred on this test.

TABLE V-A

FUEL INGESTION DATA FOR CRUISE (6768) RPM THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Temperature at Thermocouples (°F.) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Total Pressure (in.hg.) P_1	P_2	Vibration Amplitude (mils) V_1	V_2	Ingestion Time (sec)
1	35	250	260	275	829	250	300	700	270	275	280	11.0	34.0	.50	1.40	54
2	35	255	275	290	852	250	305	705	275	280	290	11.5	34.5	.50	1.30	50
3	35	260	275	300	862	240	310	725	280	290	295	11.5	34.5	.50	1.30	50
4	35	260	275	290	862	250	310	730	280	280	290	11.5	35.0	.50	1.40	47
5	35	275	275	295	867	260	310	740	280	280	290	11.5	35.5	.50	1.25	52
6	35	275	290	300	885	250	325	755	295	295	300	11.5	35.5	.50	1.30	54
7	35	275	280	300	890	230	325	790	295	295	330	11.5	36.0	.50	1.15	76
8	35	250	260	290	895	240	300	790	275	275	275	11.0	37.0	.50	1.20	53
9	25	250	275	290	900	240	305	810	280	280	280	11.0	37.0	.60	1.20	63
10	25	255	275	290	905	245	310	820	280	280	280	11.0	37.0	.60	1.20	69
11	25	260	275	295	930	245	310	820	290	290	280	11.0	37.0	.60	1.15	61
12	25	260	275	295	950	245	320	840	290	290	280	11.0	37.0	.60	1.30	50
13	25	260	280	295	975	250	320	855	290	290	280	11.0	37.0	.50	1.10	51
14	25	260	280	295	980	250	325	940	295	290	280	11.0	37.0	.50	1.10	62
15	25	270	280	300	1000	260	325	955	300	290	295	11.0	37.0	.60	1.20	44
16	35	275	290	300	1080	270	340	1000	300	305	300	11.0	37.0	.50	1.00	38
17	25	275	295	305	1025	270	345	1040	300	305	300	11.0	37.0	.60	1.10	38
18	25	275	295	305	1115	270	345	1155	305	305	300	11.0	37.0	.60	1.15	32
19	25	275	300	305	1115	270	345	1160	325	305	300	11.0	37.0	.60	1.00	35
20[1]	25	280	300	310	1280	270	355	1305	440	305	320	11.0	37.0	.65	1.10	19
NORMAL OPERATING DATA																
	35	240	250	250	802	250	300	700	283	283	252	10.0	32.0	.30	1.00	

[1] Engine failure occurred on this test.

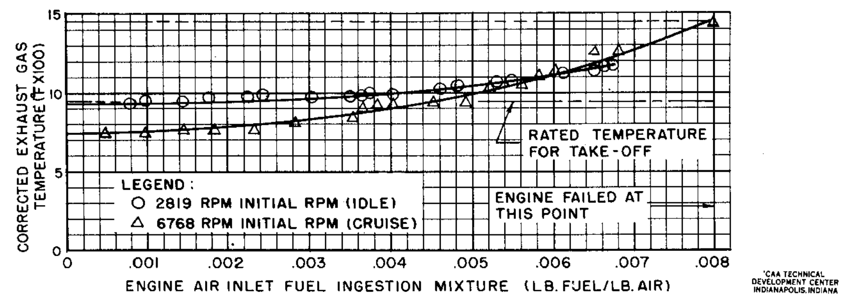

Fig. 17 Graph Showing Effect on Exhaust Gas Temperature of Ingesting Sprayed Fuel into the Engine Air Inlet of the J35-A-13D Engine

The interconnector between the No. 1 and No. 2 burner cans failed and caused a loud hissing noise which was immediately detected by the operator in the engine control room. The connector was cut in two, and Nos. 1, 2, and 8 burner cans showed signs of discoloration and warpage caused by an overheat condition. After failure occurred, the rpm and EGT started to decrease. The failure occurred without advance warning by a sudden change in temperature, pressure, or vibration. There were no indications of rapid temperature or pressure rise, or excessive vibration prior to failure.

Damage to engine components resulting from the fuel ingestion tests conducted at cruise rpm condition is shown in Figs. 19 to 24, inclusive. The following is noted in connection with the failure:

1. No apparent damage was suffered by the compressor.
2. The No. 1 transition liner was overheated and had several small segments missing from the trailing edge. A photograph of this damage is shown in Fig. 22.
3. The crossover tube between burner cans No. 1 and No. 2 had a large segment burned out from overheating. A photograph of this damage is shown in Fig. 21.
4. Damage to the No. 1 can and its crossover connector is shown in Figs. 23 and 24.
5. The turbine nozzle diaphragm showed general signs of being overheated and was burned through aft of the No. 1 transition liner.
6. The turbine wheel showed evidence of overheat and signs of foreign residue which had formed on the blades. A photograph of this damage is shown in Figs. 19 and 20, inclusive.

The engine was disassembled, inspected, and overhauled at the Powerplant Laboratory, Wright-Patterson Air Force Base, Ohio, in preparation for additional fuel ingestion tests at takeoff (7,759) rpm throttle setting.

Fuel Ingestion Tests at 100 Per Cent (7,759) RPM.

Data recorded during fuel ingestion tests at 100 per cent rpm throttle setting are presented in Tables VI and VI-A. A graphical presentation of the test data is shown in Figs. 25 to 28, inclusive. Fuel was sprayed into the engine air inlet in quantities up to a rate of 3,300 lb.fuel/hr. (0.0130 lb. fuel/lb.air) when failure was initially detected. Failure occurred gradually with the speed increasing to 7,836 rpm and then decreasing to 6,740 rpm, at which time the engine was shut down. The exhaust gas temperature had risen rapidly to 1,418° F. at the time of shutdown.

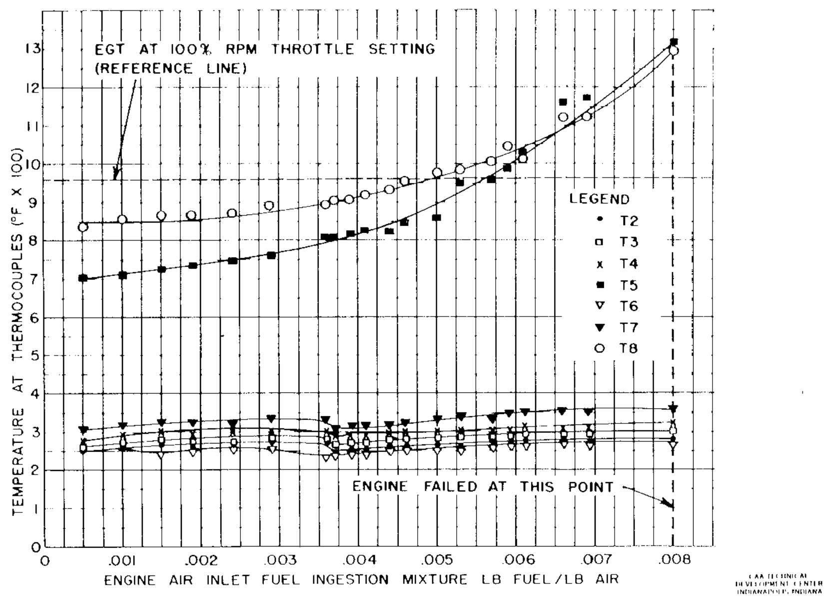

Fig. 18 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet on the Operating Temperature of a J35-A-13D Engine

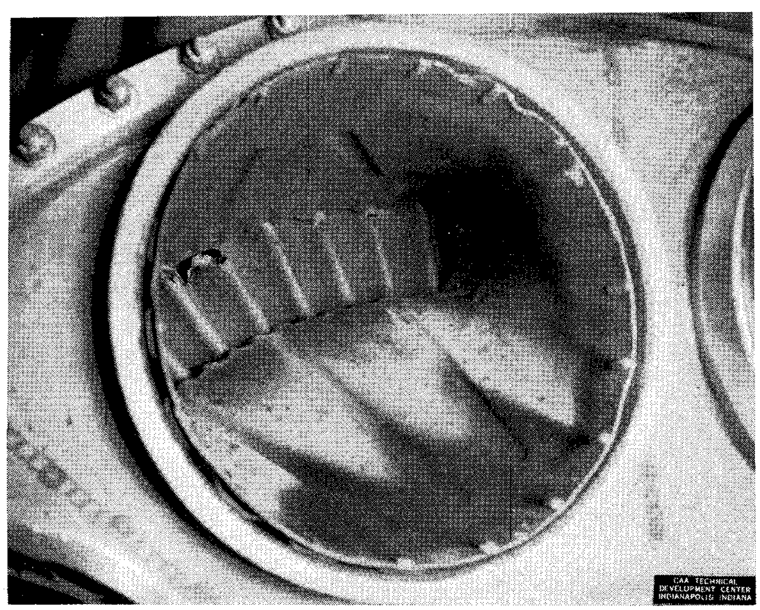

Fig. 19 Damage to Nozzle Diaphragm at No. 1 Transition Liner From Fuel Ingestion - Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

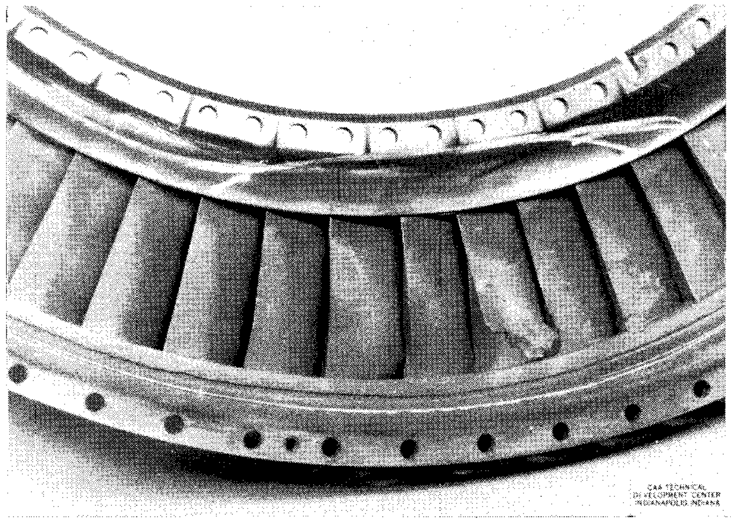

Fig. 20 Damage to Turbine Nozzle Diaphragm Aft of No. 1 Transition Liner From Fuel Ingestion - Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

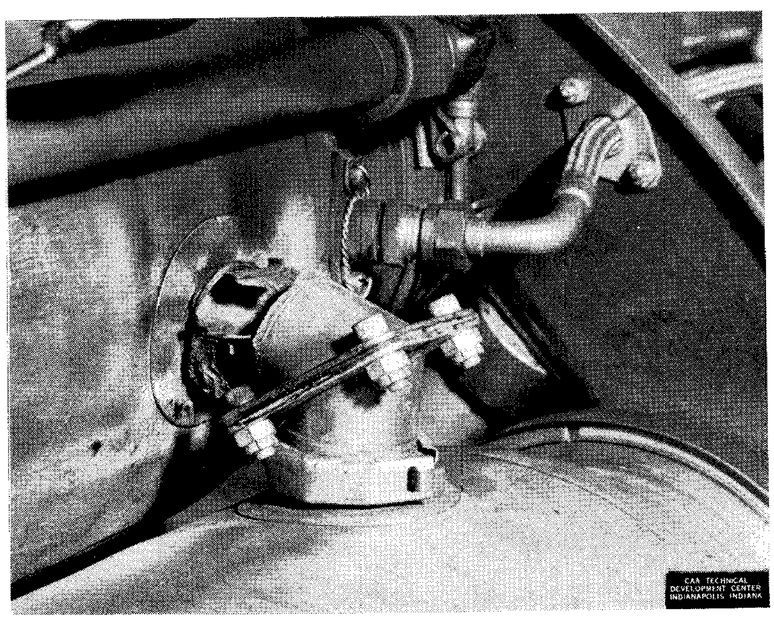

Fig. 21 Damage to Crossover Tube Between No. 1 and No. 2 Burner Cans From Fuel Ingestion - Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

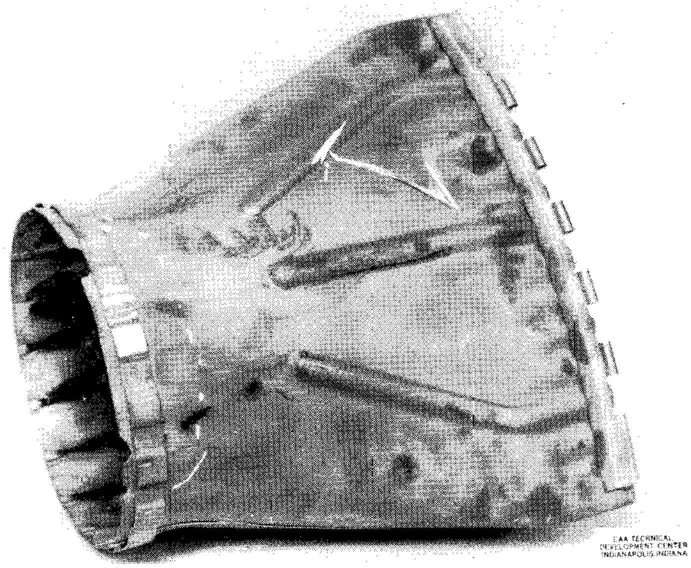

Fig. 22 Damage to No. 1 Transition Liner From Fuel Ingestion - Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

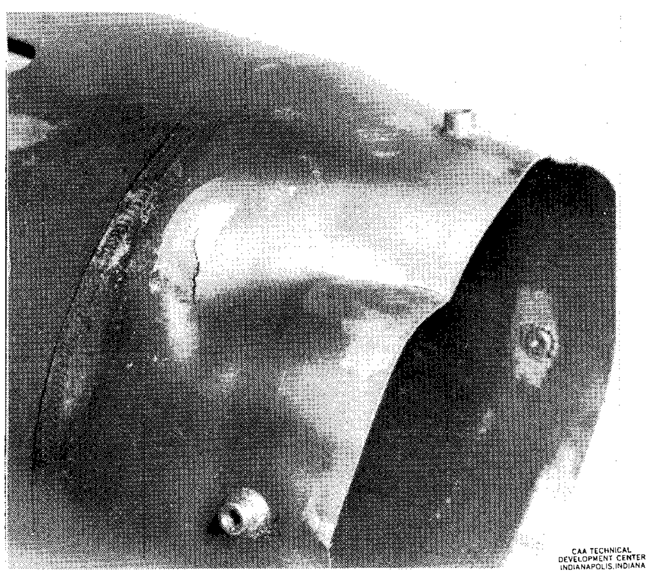

Fig. 23 Damage to No. 1 Burner Can Inner Liner From Fuel Ingestion Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

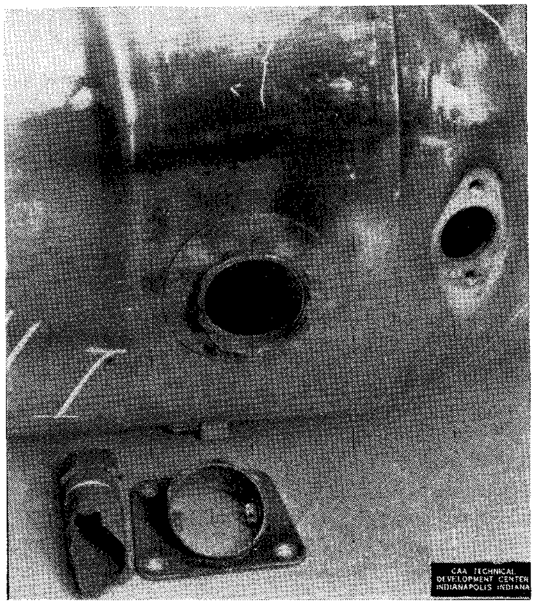

Fig. 24 Damage to Crossover Tube Between No. 1 and No. 2 Burner Cans From Fuel Ingestion - Engine: J35-A-13D, Throttle Setting of Cruise (6,768 rpm)

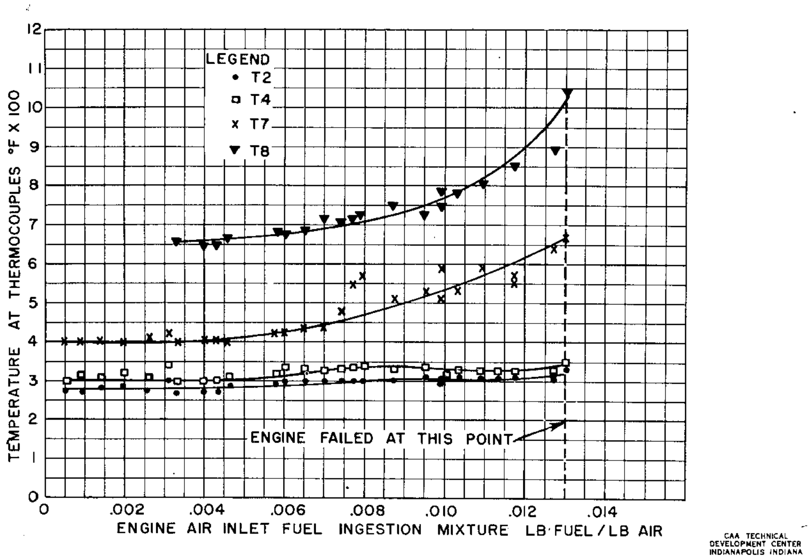

Fig. 25 Graph Showing Effect on Operating Temperatures of Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine, Throttle Setting of Takeoff (7,759 rpm)

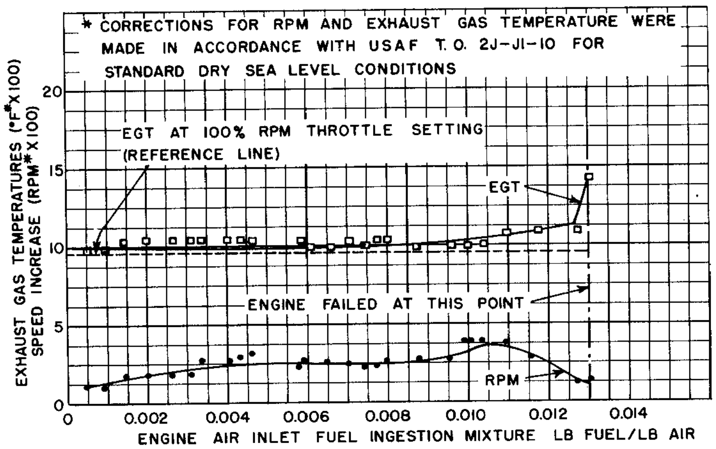

Fig. 26 Graph Showing Effect on Speed and Exhaust Gas Temperatures of Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting of Takeoff (7,759 rpm)

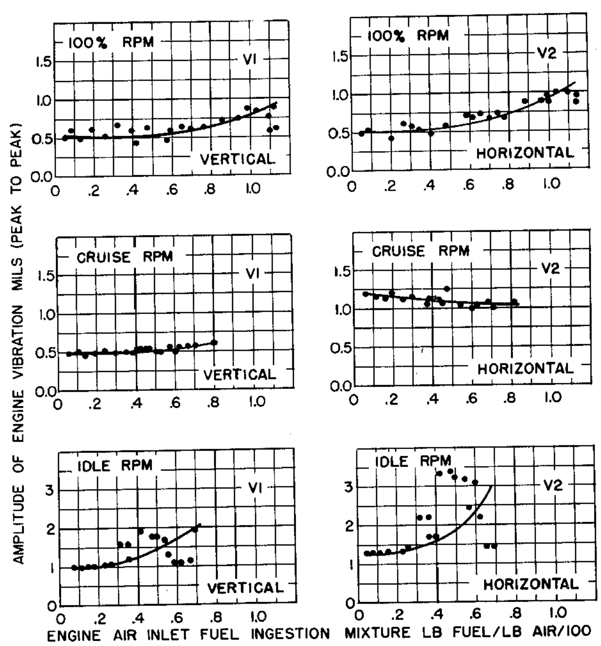

Fig. 27 Graph Showing Effect on Engine Vibration of Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine While Operating at Various Throttle Settings

TABLE VI

FUEL INGESTION DATA FOR TAKEOFF (7759) RPM[1] THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)
1	7782	7821	945	966	142	3260	73.59	.0005
2	7786	7825	950	971	246	3220	73.59	.0009
3	7802	7890	975	1013	354	3030	69.85	.0014
4	7802	7890	970	1008	486	2950	69.85	.0020
5	7802	7890	985	1024	648	2920	69.85	.0026
6	7822	7911	1000	1039	780	2860	70.17	.0031
7	7842	7973	975	1028	952	2880	72.14	.0033
8	7860	7991	970	1023	1020	2800	70.86	.0040
9	7880	8012	960	1012	1152	2780	74.53	.0043
10	7900	8032	975	1027	1206	2640	72.69	.0046
11	8020	7956	1020	1005	1440	2560	68.67	.0058
12	8035	7972	1010	995	1476	2500	67.90	.0060
13	8035	7972	1000	984	1632	2400	70.30	.0065
14	8035	7972	1040	1026	1758	2360	70.30	.0070
15	8025	7961	1000	984	1816	2320	68.35	.0074
16	8025	7961	1025	1011	1920	2240	69.30	.0077
17	8030	7975	1045	1031	2004	2140	70.21	.0079
18	8030	7975	1000	989	2196	2110	70.21	.0087
19	8040	7985	1000	989	2400	2160	70.21	.0095
20	8030	8102	1000	989	2508	2240	70.57	.0099
21	8035	8108	1000	989	2538	2080	71.22	.0099
22	8035	8108	1000	989	2652	2020	71.35	.0103
23	8035	8108	1025	1059	2820	2180	71.57	.0109
24	7935	8008	1045	1079	3024	1910	71.57	.0117
25	7935	8008	1040	1074	3036	1840	72.15	.0117
26	7935	7836	1100	1074	3216	1820	70.60	.0127
27[2]	7935	7836	1450	1418	3300	1810	70.60	.0130
NORMAL OPERATING DATA								
	7720	7759	940	961	0	3280	73.59	0

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

[2]Engine failure occurred on this test.

TABLE VI-A

FUEL INGESTION DATA FOR TAKEOFF (7759) RPM[1] THROTTLE SETTING
(Engine J35-A-13D) (Fuel JP-4)

Test No.	Temperature at Thermocouples (°F.) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Total Pressure (in.hg.) P_1	P_2	Vibration Amplitude (mils) V_1	V_2	Ingestion Time (sec)
1	52	275	300	300	945	295	400	*	340	325	340	8.0	38.0	0.50	0.55	29
2	52	275	325	310	950	300	400	*	340	325	340	8.0	38.0	0.65	0.55	26
3	46	280	325	310	975	300	400	*	350	340	350	8.0	38.0	0.50	0.50	38
4	46	285	325	320	970	300	400	*	340	340	350	8.0	38.0	0.65	0.45	38
5	46	275	315	310	985	280	405	*	340	340	350	8.0	38.0	0.55	0.65	27
6	46	300	340	340	1000	280	415	*	350	350	355	8.0	38.0	0.70	0.60	22
7	41	270	250	300	975	280	400	655	345	325	340	8.0	38.0	0.50	0.55	30
8	41	275	260	300	970	290	400	645	335	325	340	8.0	38.0	0.60	0.50	27
9	41	275	250	300	960	290	400	650	340	340	345	8.0	38.0	0.45	0.65	27
10	41	285	270	305	975	295	400	660	340	325	345	8.0	38.0	0.65	0.60	25
11	64	290	275	315	1020	325	420	680	350	345	350	8.0	38.0	0.50	0.70	26
12	64	300	295	335	1010	325	425	680	350	345	350	8.0	38.0	0.60	0.70	26
13	64	300	295	335	1000	325	435	680	350	345	350	8.0	38.0	0.65	0.75	26
14	64	300	290	325	1040	325	435	710	350	350	350	8.0	38.0	0.60	0.70	23
15	64	300	295	330	1000	310	475	705	350	350	350	8.0	38.0	0.60	0.75	22
16	64	300	300	330	1025	310	545	710	300	350	350	8.0	38.0	0.65	0.70	20
17	63	300	295	335	1045	365	575	725	300	355	360	8.0	38.0	0.65	0.85	30
18	63	300	295	335	1000	395	510	745	345	355	350	8.0	38.0	0.75	0.90	25
19	63	305	295	335	1000	455	525	725	350	350	350	8.0	38.0	0.80	0.90	32
20	48	295	275	310	1000	425	595	745	340	335	345	8.0	38.0	0.90	0.90	33
21	48	300	275	320	1000	440	510	780	390	340	340	8.0	38.0	0.70	0.95	32
22	48	300	275	320	1000	570	525	775	640	325	340	8.0	38.0	0.78	1.00	25
23	48	305	295	325	1025	645	595	805	650	345	350	8.0	38.0	0.70	1.00	24
24	48	305	290	325	1045	675	555	845	350	345	350	8.0	38.0	0.70	1.10	28
25	48	300	280	325	1040	720	545	845	345	340	350	8.0	38.0	0.65	1.10	25
26	68	300	295	325	1100	720	640	890	400	440	350	8.0	38.0	0.65	0.95	34
27	68	325	305	350	1450	790	675	1040	505	500	600	8.0	38.0	0.90	0.90	34
NORMAL OPERATING DATA																
	52	275	300	300	945	295	400	980	340	325	340	8.0	38.0	0.50	0.55	

*Instrument inoperative.

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

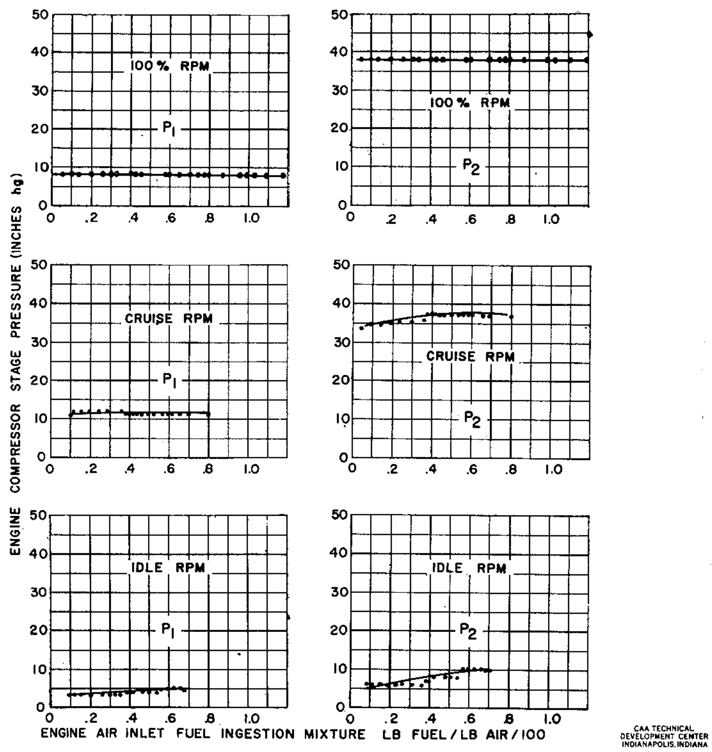

Fig. 28 Graph Showing Effect on Compressor-Stage Pressures of Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine While Operating at Various Throttle Settings

The J35 engine failure from fuel ingestion at 100 per cent rpm throttle setting is shown in Figs. 29 to 33, inclusive. It was noted that:

1. The transition liner aft of the No. 6 burner can had a leading edge burned as a result of the burner-can inner liner failure; however, all transition liners were intact with no cracked or blown-out segments.
2. The burner-can outer liners were discolored from being overheated, and all the burner-can inner liners were cracked and discolored from being overheated. All burner-can crossover connectors were cracked or burned out completely. Figure 32 shows the burned-out crossover tube between the No. 2 and No. 3 burner cans.
3. The turbine shrouding was discolored from overheating.
4. The turbine nozzle diaphragm was burned through aft of burner cans Nos. 3, 6, 7, and 8. A photograph of this damage is shown in Figs. 30 and 31.
5. Several of the turbine wheel blades had been peened by loose metal particles. The leading edges of these blades were covered with metal deposits which had separated from the burner cans, crossover connectors, and the turbine nozzle diaphragm. Figure 33 shows a section of the turbine wheel with foreign metal deposits on the blades.

GENERAL OBSERVATIONS

The effect of ingesting fuel into the inlet of the J35 engine on vibration is presented in Fig. 27. The vibration did not reach an abnormal (peak-to-peak) displacement on any of the series of tests conducted.

The effect of ingesting sprayed fuel into the inlet of the J35 engine on compressor-stage pressures is presented in Fig. 28. The fuel ingestion mixture had little effect on compressor-stage pressure during the fuel ingestion tests.

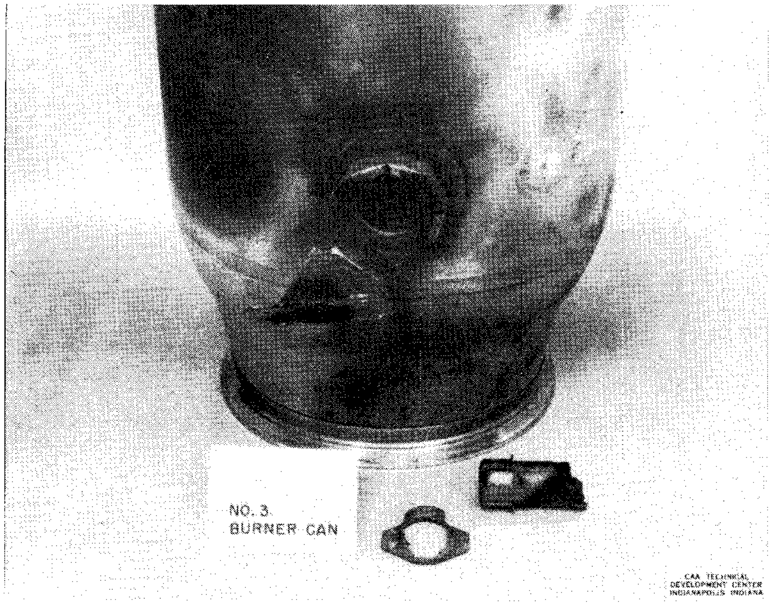

Fig. 29 Damage to Burner Can From Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting of 100 Per Cent (7,759 rpm)

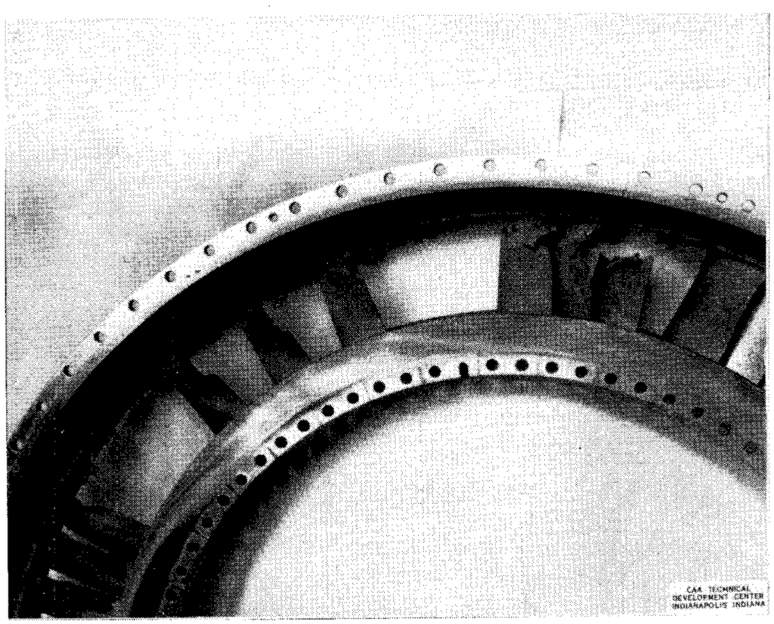

Fig. 30 Damage to Turbine Nozzle Diaphragm From Ingesting Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting of 100 Per Cent (7,759 rpm)

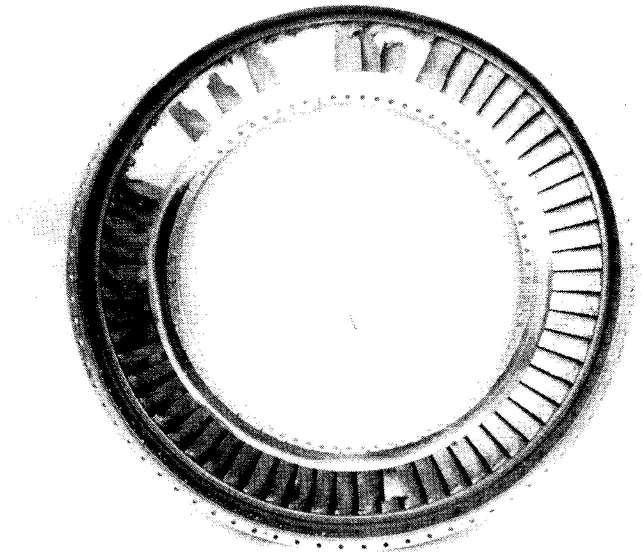

Fig. 31 Damage to Turbine Nozzle Diaphragm From Ingesting Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting of Takeoff (7,759 rpm)

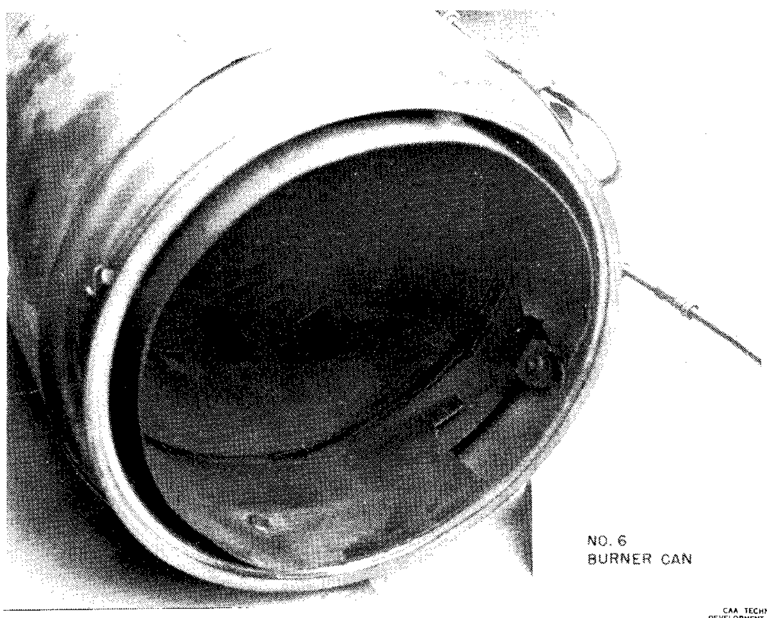

Fig. 32 Damage to No. 6 Burner Can Inner Edge From Ingesting Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting for 100 Per Cent (7,759 rpm)

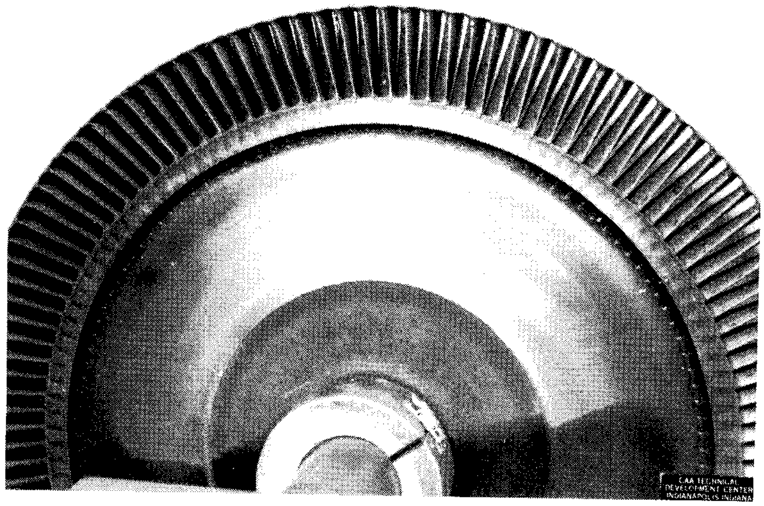

Fig. 33 Damage to Turbine Wheel Blades From Ingesting Fuel into the Air Inlet of a J35-A-13D Engine While Operating at a Throttle Setting for 100 Per Cent (7,759 rpm)

The effect of ingesting fuel into the J35 inlet on engine fuel flow is presented in Fig. 34. The engine fuel flow remained constant for idle and cruise rpm throttle settings and decreased proportionally at the 100 per cent rpm throttle setting.

The results of the J35 fuel ingestion tests shown in Figs. 16, 17, and 26 indicated that, as the engine air-inlet fuel-ingestion mixture (lb.fuel/lb.air) became richer, the speed and the exhaust gas temperature increased until failure was detected.

A warning of impending failure was observed by a gradual increase in rpm and a rise in exhaust gas temperature during the tests conducted at idle and cruise rpm throttle settings. The aforementioned condition did not exist after the engine speed approached 100 per cent rpm because at this speed the auto-fuel control cut in and regulated the amount of fuel to the engine.

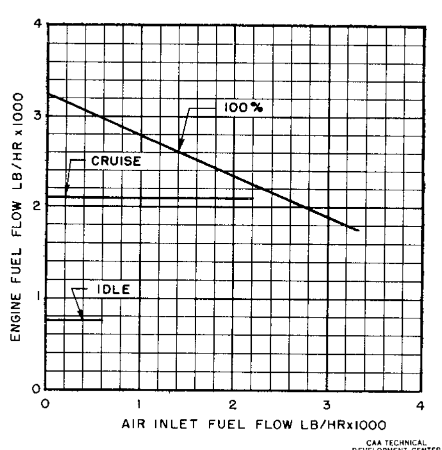

Fig. 34 Effect of Ingesting Sprayed Fuel into the Air Inlet of a J35-A-13D Engine on Fuel Consumption

The tests conducted at 100 per cent rpm throttle setting indicated that the speed started to decrease gradually as the fuel ingestion mixture approached 1 per cent. This condition might have been the result of impending failure which was not immediately detected by instrumentation.

The J35 engine failed as the result of a series of fuel ingestion tests with large quantities of JP-4 fuel being inhaled by the primary-air inlet at the time of failure. Failure occurred when the engine-inlet fuel-air ingestion mixture (lb.fuel/lb.air) approached a one per cent ratio.

CONCLUSIONS (J35-A-13D)

1. From the tests conducted at idle, cruise, and 100 per cent rpm throttle settings, the results indicated that failure will occur by overheating of engine components and the eventual loss of turbine blades rather than by an explosion or a compressor stall.
2. The change in engine vibration or pressure conditions from fuel ingestion was not sufficient to indicate abnormal operation or impending failure.
3. The J35-A-13D automatic fuel control had no effect on engine operation during fuel ingestion tests at idle and cruise rpm throttle settings. The rpm and exhaust gas temperatures continued to rise steadily as the quantity of ingested fuel increased. However, the fuel control stabilized the speed and exhaust gas temperature during the fuel ingestion tests conducted at 100 per cent rpm throttle setting.
4. Warning of impending failure from fuel ingestion on this engine depended upon whether the automatic fuel control was in effect. At cruise and idle rpm throttle settings engine failure from fuel ingestion could be detected by a rise in rpm and exhaust gas temperature. This was not true at 100 per cent rpm throttle setting, where these changes were less pronounced until just prior to engine failure.
5. It is not possible, from the tests conducted, to conclude whether the engine failed as the result of the large quantities of fuel which entered the engine air inlet on the final tests just prior to failure or as the result of the entire series of tests.

RESULTS OF TESTS ON THE GENERAL ELECTRIC J47-GE-25 ENGINE

Normal Operation Tests.

Tests were conducted to determine the effect of rpm on engine fuel consumption, inlet airflow, temperature, pressure, and vibration during normal operation. The data obtained from these tests are presented in Table VII. Graphical presentations of these data are also shown in Figs. 35 to 40, inclusive. Airflow readings were recorded at idle, normal cruise, and 100 per cent rpm throttle settings for estimating the required fuel flow for a given fuel ingestion mixture. Airflow readings also were recorded during the fuel ingestion tests at idle, cruise, and 100 per cent rpm throttle settings to determine the fuel-air mixture (lb.fuel/lb.air) into the engine inlet for each test. Tests conducted during normal operation indicated the performance of the J47 engine was satisfactory at all speeds for idle, cruise, and 100 per cent throttle settings.

Fuel Ingestion Tests at Idle (3,074) RPM.

Fuel in quantities up to 936 lb./hr. (0.0096 lb.fuel/lb.air) entered the inlet of the J47 engine at which time the speed increased gradually from 3,074 to 3,429 rpm. The exhaust gas temperature also increased from 675° F. to 875° F. as the engine fuel consumption decreased. The data obtained during the idle rpm fuel ingestion tests are presented in Tables VIII and VIII-A. Graphical presentations of the effects of ingesting sprayed fuel into the air inlet of the J47 engine on speed, exhaust gas temperature, operating temperatures, engine fuel consumption, compressor-stage pressures, and vibration are shown in Figs. 41 to 46, inclusive. These data indicated that the ingested fuel into the engine inlet was not sufficient to create abnormal operating conditions. A visual inspection of the engine after the tests revealed no apparent damage to the engine

TABLE VII

NORMAL OPERATION DATA
(Engine J47-GE-25)

Engine Speed Per Cent of Rated RPM (per cent)	Engine Speed Actual Speed (rpm)	Inlet Air Flow (lb/sec)	Engine Fuel Flow (lb/hr)	[1]Temperature at Thermocouples (°F.)									[1]Pressure at Probes (in. hg.)		[1]Vibration Amplitude (mils)	
				T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	P_1	P_2	V_1	V_2
38.0	3000	25.5	980	20	675	50	65	50	85	30	95	75	4.0	7.5	0.05	0.08
87.6	6960	91.6	3610	20	700	305	325	295	340	300	350	325	31.0	88.0	0.74	0.37
93.0	7360	96.4	4250	20	760	350	355	335	360	325	380	350	31.0	89.0	0.85	0.45
96.0	7630	99.3	4750	20	815	375	380	360	380	350	405	380	31.0	97.0	0.88	0.47
98.0	7800	101.2	5110	20	850	390	395	375	400	360	420	400	31.0	101.0	0.94	0.52
100.0	7950	103.5	5220	20	910	405	405	385	420	375	445	415	31.0	106.0	1.02	0.54

[1]See Fig. 8 for location of thermocouple, pressure, and vibration pickups.

TABLE VIII

FUEL INGESTION DATA FOR IDLE (3074)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)	Ingestion Time (sec)
1	3000	3074	725	786	72	990	22.5	.0008	62
2	3000	3074	725	786	108	990	22.5	.0013	55
3	3000	3074	725	786	150	955	22.5	.0019	80
4	3020	3095	725	786	198	955	23.8	.0023	68
5	3040	3115	740	802	228	940	23.8	.0027	50
6	3075	3151	745	807	252	940	23.8	.0029	52
7	3090	3166	845	913	306	940	25.2	.0034	47
8	3105	3182	800	865	384	915	25.2	.0042	46
9	3105	3169	820	877	432	895	25.2	.0048	64
10	3100	3169	810	867	456	875	25.2	.0050	39
11	3130	3233	805	821	588	875	25.8	.0063	42
12	3160	3264	815	831	598	870	25.8	.0063	39
13	3170	3274	815	831	612	845	25.8	.0066	45
14	3200	3305	840	857	672	840	25.8	.0073	37
15	3205	3310	855	872	762	825	25.8	.0082	37
16	3205	3310	855	872	810	790	25.8	.0087	36
17	3230	3336	850	867	852	785	27.0	.0088	41
18	3250	3357	855	872	870	780	27.0	.0090	34
19	3290	3398	875	892	924	750	27.0	.0095	31
20	3320	3429	875	892	936	700	27.0	.0096	36
NORMAL OPERATING DATA									
	3000	3074	675	731	0	980	25.5	0	

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U.S. Air Force T.O. 2J-J1-10 for standard dry sea-level conditions.

NOTE: See Fig. 8 for locations of thermocouple, pressure, and vibration pickups.

TABLE VIII-A

FUEL INGESTION DATA FOR IDLE (3074)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Temperatures at Thermocouples (°F.) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Total Pressure (in. hg.) P_1	P_2	Vibration Amplitude (mils) V_1	V_2
1	35	725	60	75	X	100	X	105	105	4.0	7.0	.04	.04
2	35	725	60	75	X	100	X	105	105	4.0	7.0	.04	.05
3	35	725	60	75	X	100	X	105	105	4.0	7.0	.05	.05
4	35	725	60	75	X	100	X	105	105	4.0	7.0	.05	.05
5	35	740	60	75	X	100	X	105	105	4.0	7.0	.05	.07
6	35	745	68	75	X	100	X	105	105	4.0	7.0	.05	.06
7	35	845	68	75	X	100	X	105	105	4.5	8.0	.05	.05
8	35	800	68	75	X	100	X	105	105	4.5	8.0	.05	.06
9	40	820	68	90	X	100	X	105	105	4.5	8.0	.04	.05
10	40	810	68	100	X	100	X	105	105	4.5	8.0	.05	.05
11	55	805	95	125	X	125	X	125	125	4.0	8.0	.06	.06
12	55	815	95	130	X	125	X	125	125	4.0	8.0	.10	.06
13	55	815	95	130	X	125	X	125	125	4.0	8.0	.07	.05
14	55	840	95	130	X	125	X	125	125	4.0	8.0	.12	.06
15	55	855	95	140	X	125	X	125	125	4.0	8.0	.10	.07
16	55	855	90	145	X	115	X	125	125	4.0	8.0	.11	.05
17	55	850	90	145	X	115	X	125	125	4.5	8.5	.14	.05
18	55	855	90	145	X	115	X	125	125	4.5	8.5	.14	.05
19	55	875	90	145	X	115	X	125	125	4.5	8.5	.14	.07
20	55	875	90	150	X	115	X	125	125	4.5	8.5	.14	.07
					NORMAL OPERATING DATA								
	35	675	50	65	X	85	30	95	75	4.0	7.5	.05	.08

X - Inoperative instrument.

[1] All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

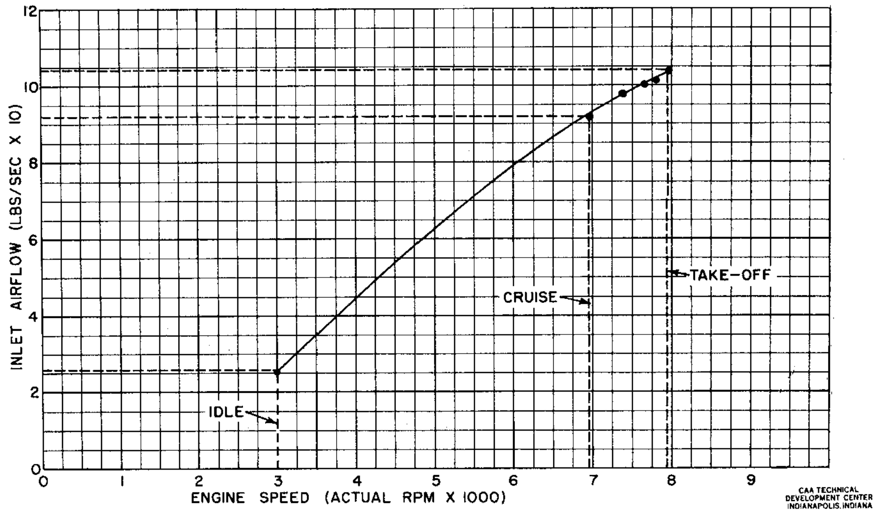

Fig. 35 Graph Showing Inlet Airflow Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

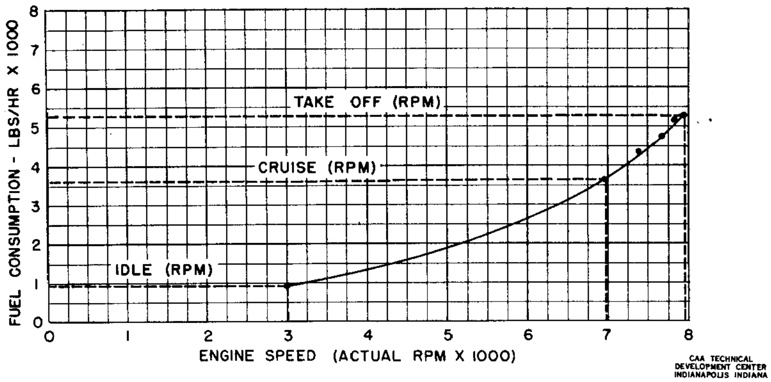

Fig. 36 Graph Showing Fuel Consumption Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

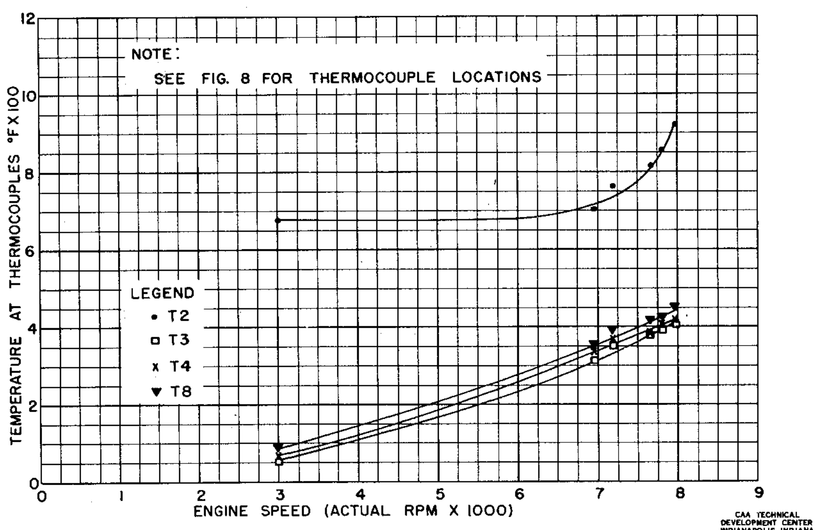

Fig. 37 Graph Showing Temperatures Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

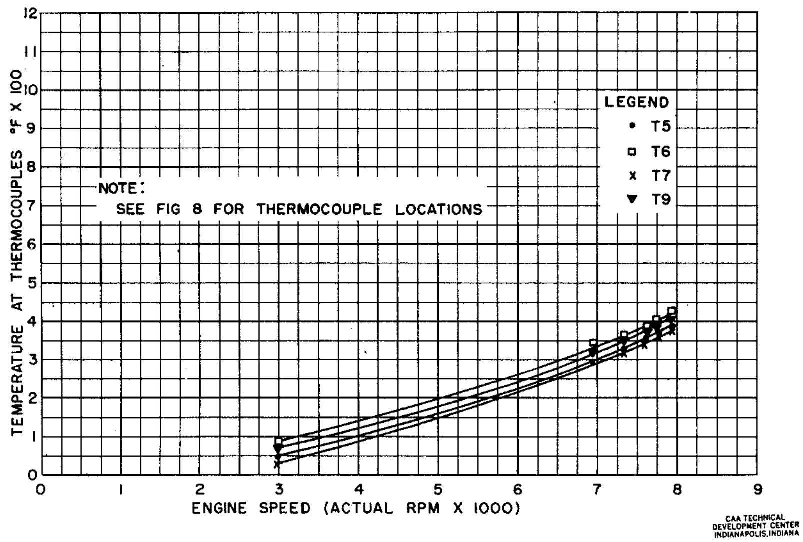

Fig. 38 Graph Showing Temperatures Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

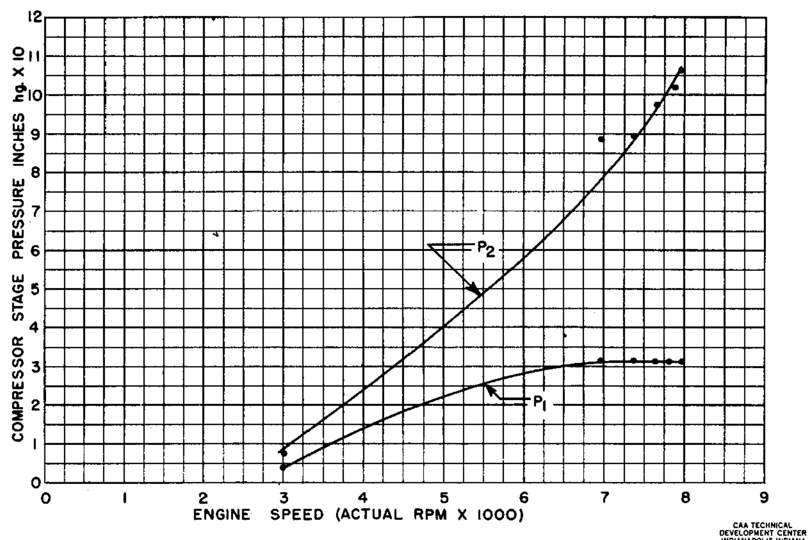

Fig. 39 Graph Showing Compressor Pressures Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

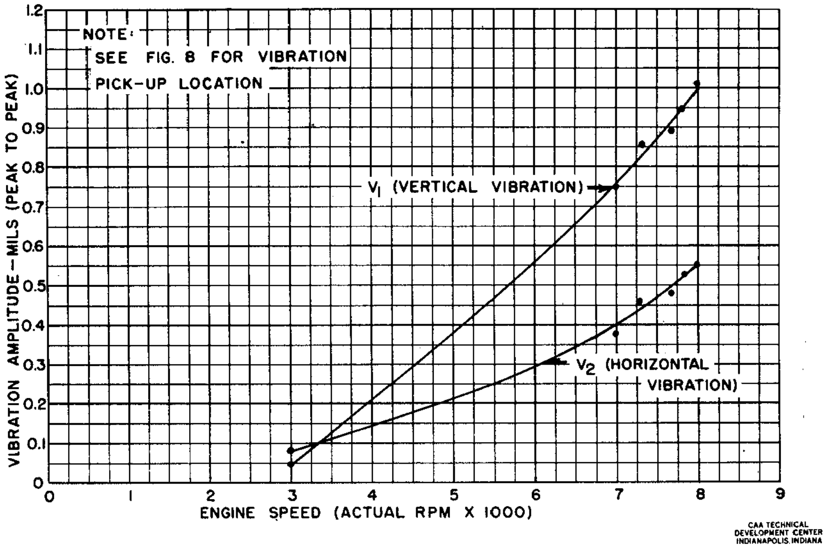

Fig. 40 Graph Showing Vibration Versus Engine Speed During Normal Operation of a J47-GE-25 Engine

Fuel Ingestion Tests at Cruise (7,038) RPM.

Fuel in quantities up to 3,100 lb./hr. (0.0087 lb.fuel/lb.air) was sprayed into the primary-air inlet of the J47 engine. The data obtained from the fuel ingestion tests with the throttle initially set at cruise rpm are presented in Tables IX and IX-A. Graphical presentations of the effects of ingesting sprayed fuel into the J47 engine air inlet on rpm, exhaust gas temperature, engine fuel consumption, compressor-stage pressures, vibration, and engine temperatures are shown in Figs. 41 to 49, inclusive. Engine failure occurred in Test No. 19 when the compressor stalled. The failure was accompanied by two loud explosions which were detected by operating personnel in the engine control room. When this occurred, all fuel to the engine and inlet was immediately shut off. Smoke followed the explosion and as a precautionary measure, the test cell was closed and flooded with CO_2. The results shown in Figs. 41 and 42 indicated that the speed and exhaust gas temperature did not exceed the 100 per cent condition. The speed increased from 7,038 rpm to over 7,322 rpm while the exhaust gas temperature increased from 758° F. to 973° F. when failure occurred. The failure occurred without advance warning by a sudden change in temperature, pressure, or vibration.

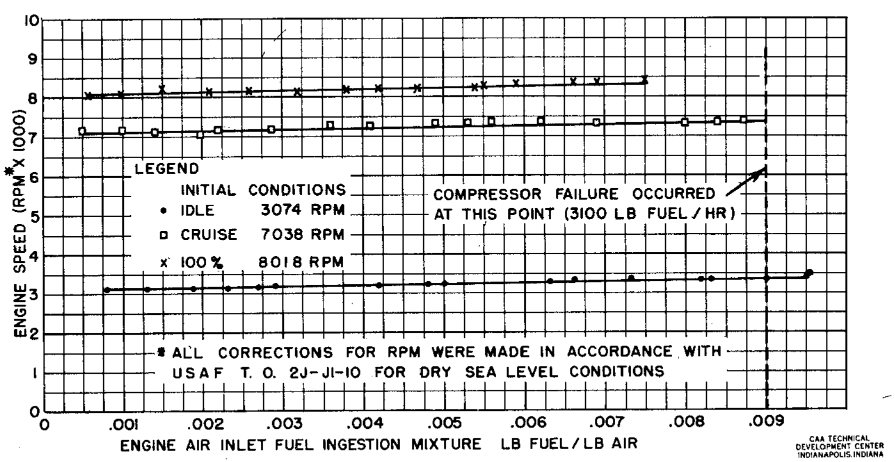

Fig. 41 Graph Showing Effect on Speed of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

TABLE IX

FUEL INGESTION DATA FOR CRUISE (7038)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)	Ingestion Time (sec)
1	7060	7141	775	807	168	3440	88.8	.0005	48
2	6990	7070	765	798	306	3320	89.1	.0010	52
3	7020	7100	765	798	456	3320	89.1	.0014	42
4	7000	7080	760	793	630	3200	89.1	.0020	37
5	7010	7090	765	798	702	3200	89.1	.0022	40
6	6990	7164	750	813	948	3130	90.2	.0029	51
7	7040	7215	760	823	1170	3100	90.4	.0036	35
8	7030	7205	760	823	1344	3020	90.4	.0041	61
9	7060	7236	760	823	1578	2960	89.9	.0049	30
10	7050	7225	760	823	1698	2860	89.4	.0053	40
11	7050	7256	760	834	1740	2900	91.6	.0053	42
12	7070	7276	775	850	1860	2840	91.8	.0056	42
13	7090	7297	790	866	2064	2710	92.5	.0062	34
14	7100	7307	810	888	2328	2600	93.9	.0069	28
15	7100	7307	815	893	2352	2530	93.9	.0070	36
16	7100	7281	855	926	2640	2475	91.5	.0080	32
17	7120	7301	890	963	2772	2420	91.5	.0084	31
18	7140	7322	925	999	2856	2320	91.7	.0087	30
19	*	*	900	973	3100	*	*	*	21
NORMAL OPERATING DATA									
	6960	7038	700	758	0	3620	91.6	0	

*Compressor failed on this test.

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

NOTE: See Fig. 8 for locations of thermocouple, pressure, and vibration pickups.

TABLE IX-A

FUEL INGESTION DATA FOR CRUISE (7038)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Temperature at Thermocouples (°F.) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Total Pressure (in. hg.) P_1	P_2	Vibration Amplitude (mils) V_1	V_2
1	45	775	345	360	X	350	310	365	350	30.0	78.0	0.48	0.34
2	45	765	345	360	X	350	310	365	350	30.0	76.0	0.52	0.37
3	45	765	345	360	X	350	310	365	350	30.0	76.0	0.52	0.33
4	45	760	345	360	X	350	310	365	350	30.0	76.0	0.53	0.33
5	45	765	345	360	X	350	310	365	350	30.0	76.0	0.55	0.34
6	40	750	330	350	X	350	300	350	340	30.0	78.0	0.57	0.37
7	40	760	330	350	X	350	300	350	350	30.0	78.0	0.57	0.35
8	40	760	330	350	X	350	300	350	350	30.0	78.0	0.59	0.41
9	40	760	330	350	X	350	300	360	350	30.0	78.0	0.57	0.42
10	40	760	330	350	X	350	300	360	350	30.0	78.0	0.54	0.40
11	30	760	315	275	330	340	290	350	335	30.0	78.0	0.56	0.40
12	30	775	315	275	330	340	290	350	335	30.0	78.0	0.60	0.50
13	30	790	315	275	330	340	290	350	335	30.0	78.0	0.60	0.45
14	30	810	315	275	330	340	310	350	335	30.0	78.0	0.60	0.45
15	30	815	315	275	330	340	310	350	335	30.0	78.0	0.60	0.45
16	30	855	315	275	330	340	350	350	350	30.0	78.0	0.50	0.40
17	30	890	325	275	340	350	325	350	360	30.0	78.0	0.60	0.40
18	30	925	325	275	345	355	310	360	410	30.0	78.0	0.64	0.40
19*	30	900	325	300	355	360	310	370	540	*	*	0.65	0.40
NORMAL OPERATING CONDITIONS													
	20	700	305	325	295	340	300	350	325	31.0	88.0	0.66	0.54

X - Instrument inoperative.

*Compressor failed on this test.

[1]All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

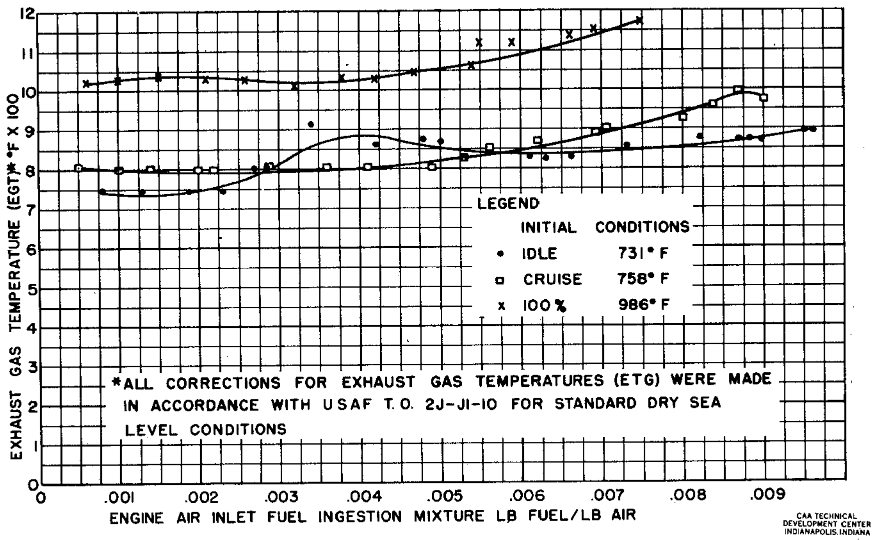

Fig. 42 Graph Showing Effect on Exhaust Gas Temperature of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

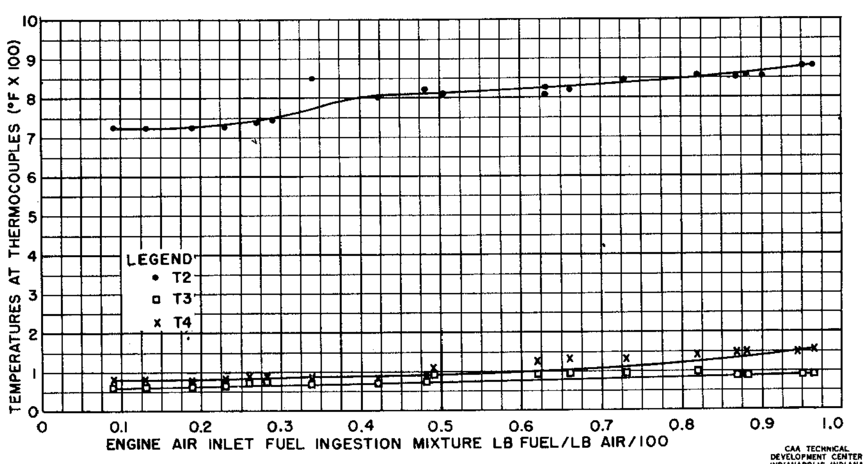

Fig. 43 Graph Showing Effect on Temperatures of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

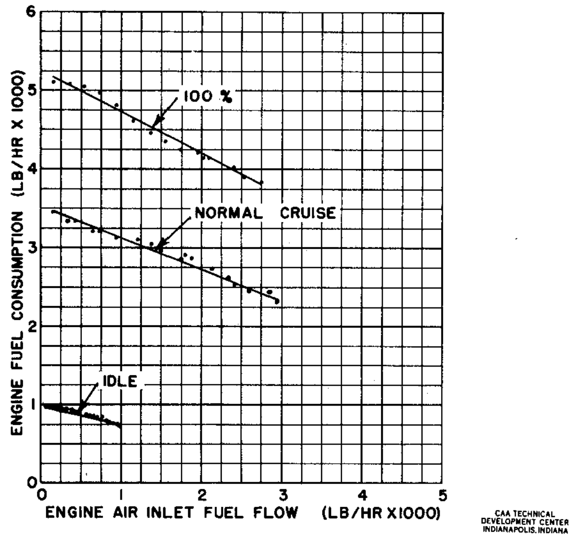

Fig. 44 Graph Showing Effect on Fuel Consumption of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

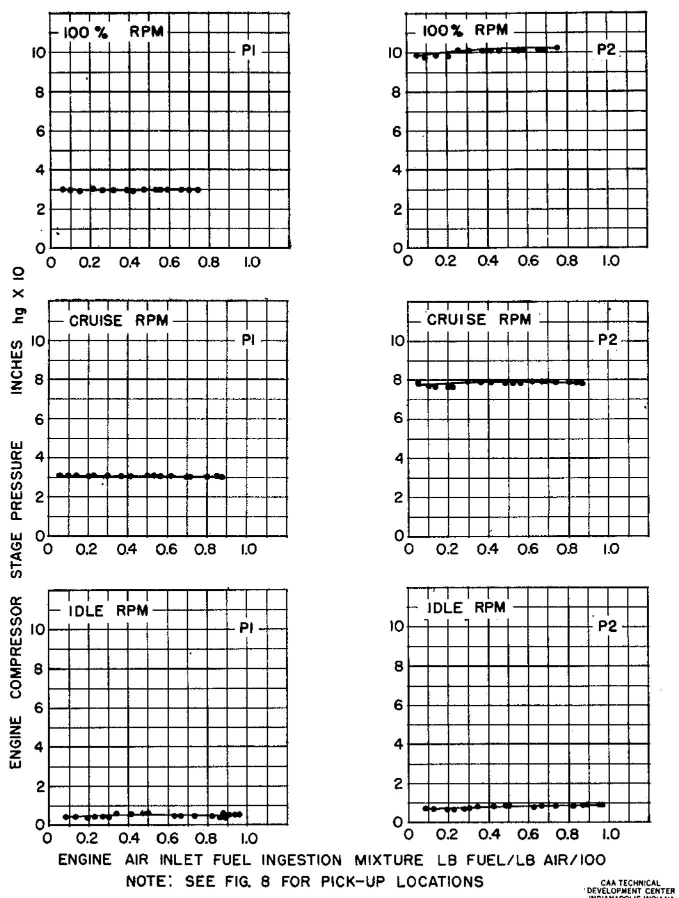

Fig. 45 Graph Showing Effect on Compressor Pressures of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

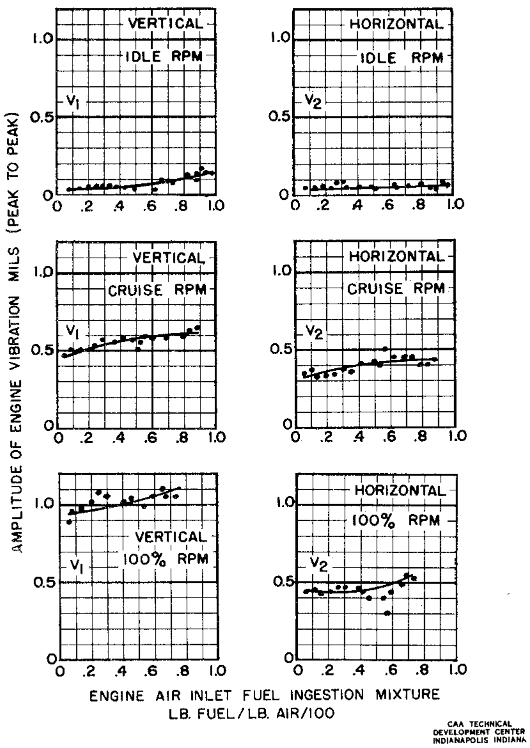

Fig. 46 Graph Showing Effect on Vibration of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine

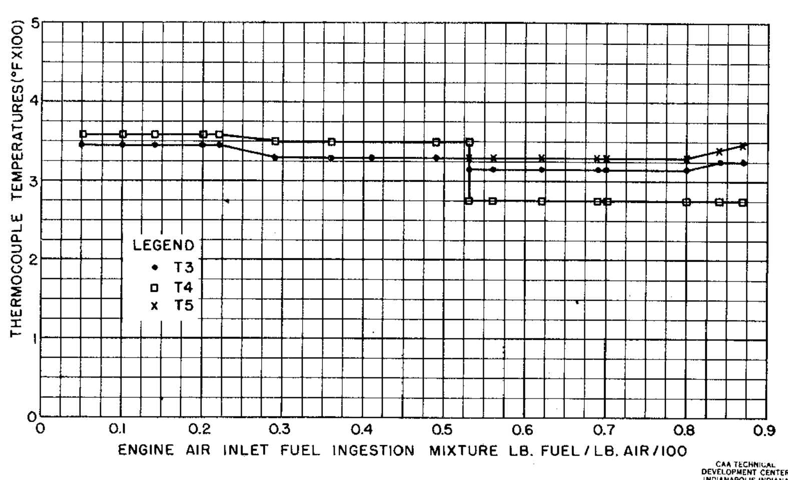

Fig. 47 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine on Engine Temperatures - Throttle Setting for Cruise (7,038 rpm)

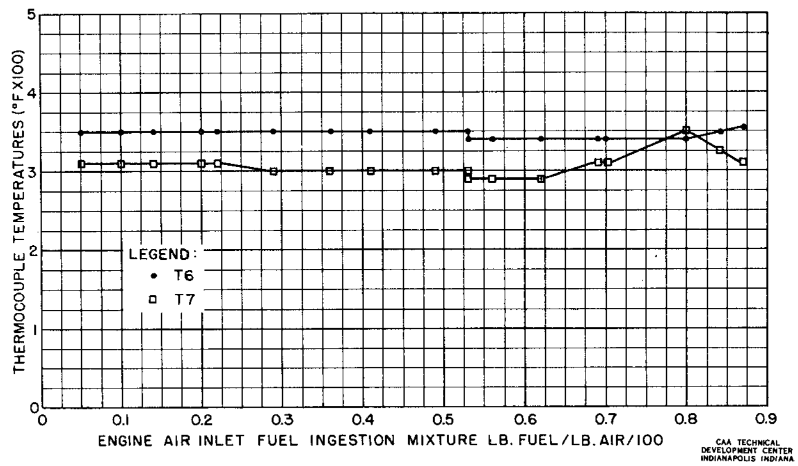

Fig. 48 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine on Engine Temperatures - Throttle Setting of Cruise (7,038 rpm)

Damage to the engine components resulting from fuel ingestion tests conducted at cruise rpm throttle setting is shown in Figs. 50 to 56, inclusive. The following is noted in connection with the failure:

1. Damage occurred in the compressor section in the first four stages of compression. A view of the damage prior to engine disassembly is shown in Fig. 50. The failure appeared to start in the first stage of compression where the stator and rotor blades interfered under load, the load being created by the fuel entering the inlet.
2. Deformation of the bullet nose accessory covering is shown in Fig. 51. This was probably caused by the compressor stall.
3. Damages to the compressor stator and rotor are shown in Figs. 52 and 53. The first-stage stator blades were deformed and the second- and third-stage stator blades were completely sheared away.
4. The first four stages of blades in the compressor-rotor assembly were deformed with several of the blades torn out at the roots. This type of damage is indicative of a compressor stall.
5. Foreign metal particles were found in the burner cans and transition liners. These particles are shown in Figs. 54, 55, and 56.
6. The burner and exhaust sections were not damaged from the fuel ingestion tests.

Fuel Ingestion Tests at 100 Per Cent (8,018) RPM.

The data recorded from ingesting sprayed fuel into the air inlet of the J47 engine with the throttle set at 100 per cent rpm are presented in Tables X and X-A. These data indicated that the rpm and exhaust gas temperatures increased slightly as the amount of fuel released into the engine inlet increased. Graphical presentations of the effects of ingesting sprayed fuel into the engine inlet on rpm, exhaust gas temperature, fuel consumption, compressor-stage pressure, vibration, and engine temperatures are shown in Figs. 41 to 46, inclusive, and 57 and 58.

An inspection of the engine after the fuel ingestion tests at 100 per cent rpm indicated no apparent damage to the engine. These tests were concluded with Test No. 15 in order to obtain a maximum amount of data on each test condition before a failure occurred. Testing was completed when failure occurred on the cruise rpm tests.

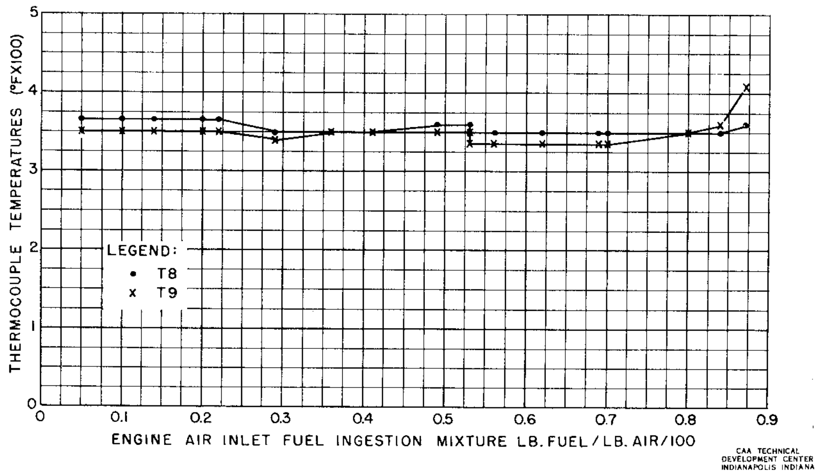

Fig. 49 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine on Engine Temperatures - Throttle Setting for Cruise (7,038 rpm)

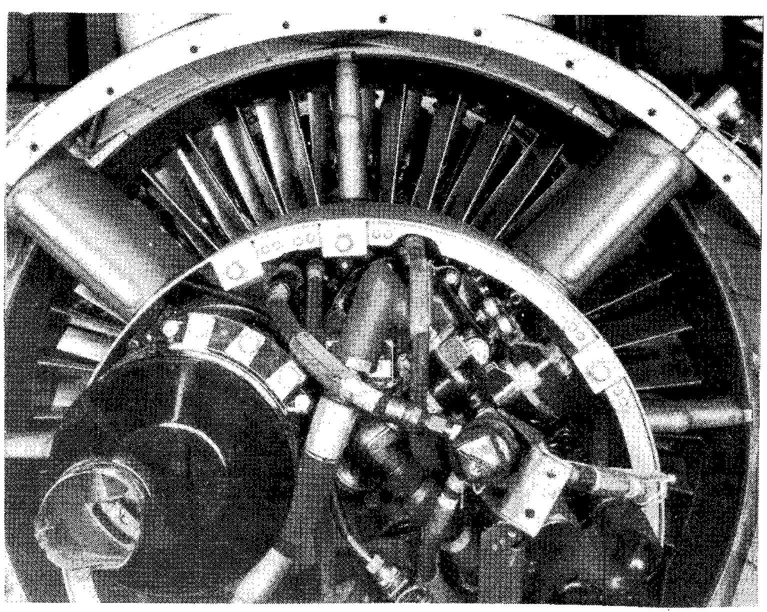

Fig. 50 Damage to Compressor Section From Fuel Ingestion
Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

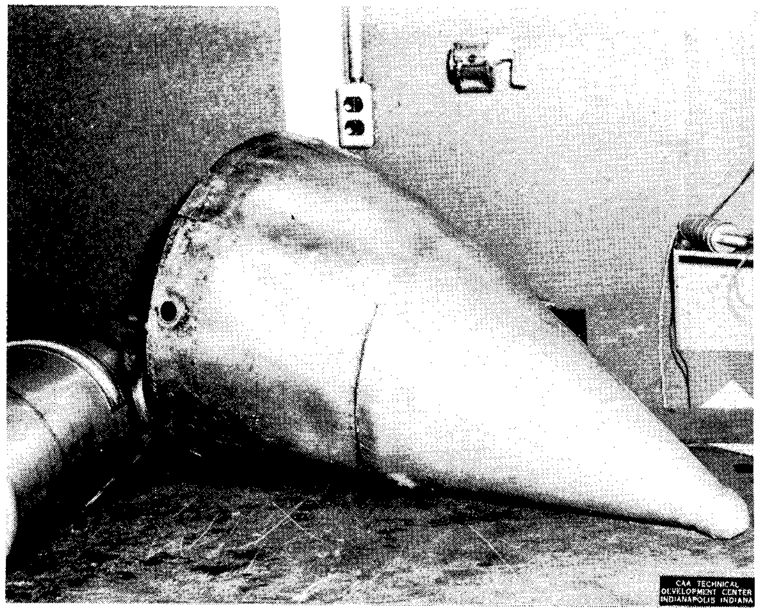

Fig. 51 Damage to Bullet Nose Accessory Cover From Fuel Ingestion
Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

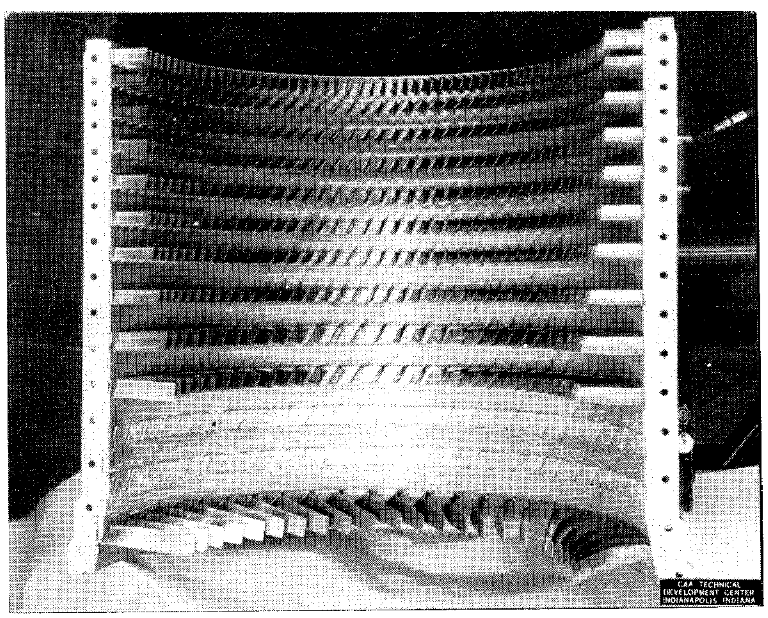

Fig. 52 Damage to Compressor Stator From Fuel Ingestion
Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

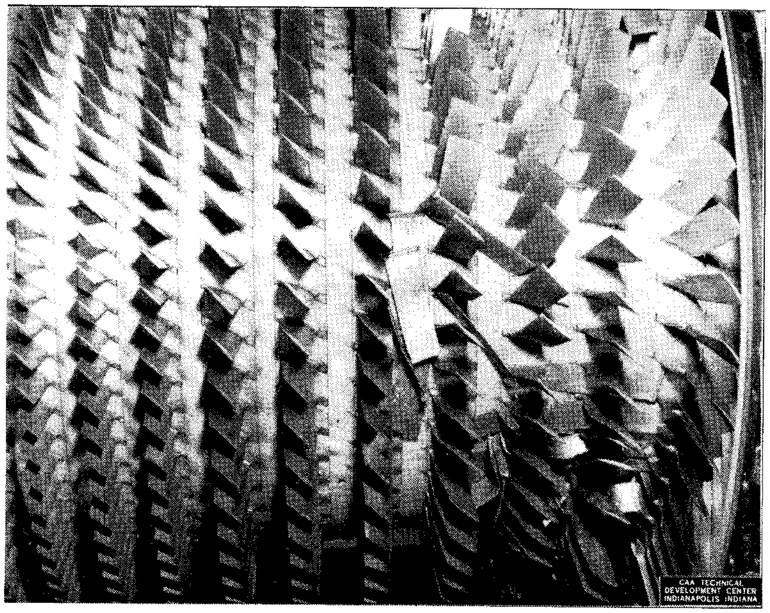

Fig. 53 Damage to Compressor Rotor Assembly From Fuel Ingestion
Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

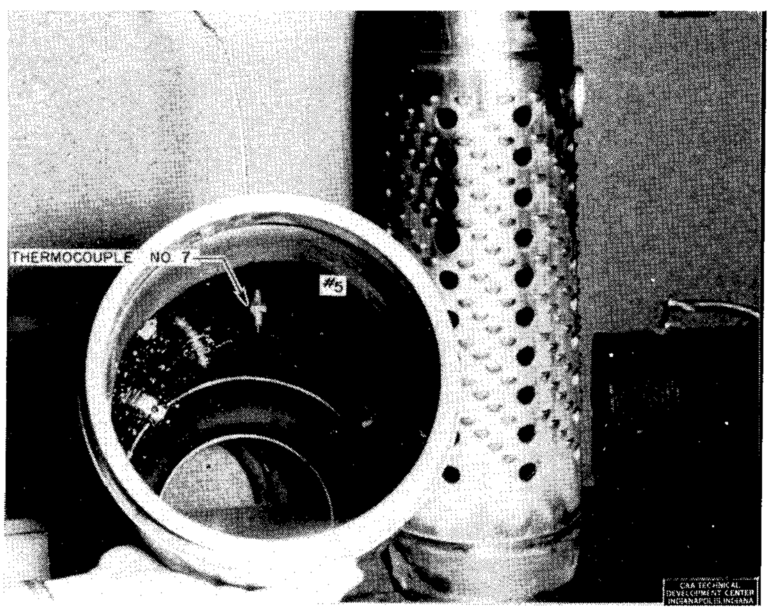

Fig. 54 Foreign Metal Particles in Burner Can No. 5 Caused by a Compressor Failure During Fuel Ingestion Tests
Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

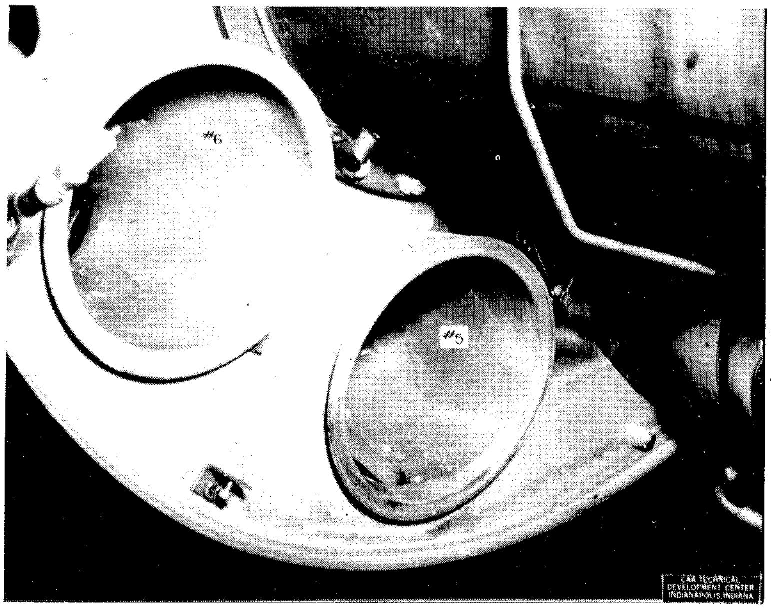

Fig. 55 Foreign Metal Particles in Transition Liners No. 5 and No. 6 Caused by a Compressor Failure During Fuel Ingestion Tests Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

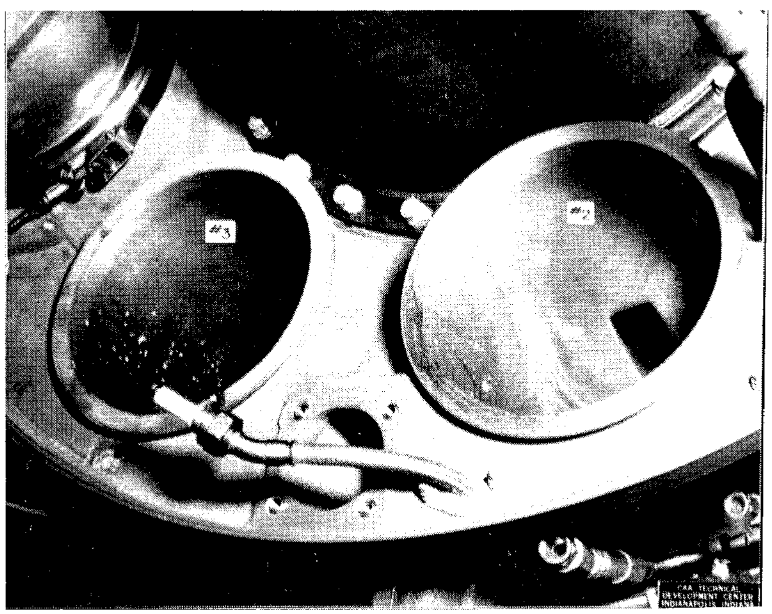

Fig. 56 Foreign Metal Particles in Transition Liners No. 2 and No. 3 Caused by a Compressor Failure During Fuel Ingestion Tests Engine: J47-GE-25 - Throttle Setting for Cruise (7,038 rpm)

TABLE X

FUEL INGESTION DATA FOR TAKEOFF (8018)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Engine Speed Actual (rpm)	Engine Speed Corrected[1] (rpm)	Exhaust Gas Temperature Actual (°F.)	Exhaust Gas Temperature Corrected[1] (°F.)	Fuel Flow Air Inlet (lb/hr)	Fuel Flow Engine (lb/hr)	Inlet Air Flow (lb/sec)	Inlet Mixture (lb.fuel/lb.air)	Ingestion Time (sec)
1	7970	8138	960	1021	198	5100	99.7	.0006	37
2	8000	8168	970	1030	354	5080	98.8	.0010	30
3	8040	8209	975	1035	552	5040	99.7	.0015	34
4	8010	8178	965	1025	756	4940	99.7	.0021	38
5	8030	8190	960	1021	930	4800	100.8	.0026	31
6	8010	8178	950	1009	1170	4600	100.8	.0032	27
7	8010	8178	970	1030	1380	4460	100.8	.0038	30
8	8010	8178	970	1030	1548	4320	101.2	.0042	32
9	8030	8199	980	1040	1716	4240	100.8	.0047	28
10	8030	8199	1000	1061	1950	4200	101.2	.0054	32
11	8020	8261	1020	1110	2004	4140	101.2	.0055	32
12	8030	8271	1020	1110	2160	4140	101.5	.0059	32
13	8050	8291	1045	1137	2400	4000	101.5	.0066	35
14	8050	8291	1055	1147	2520	3900	101.7	.0069	30
15	8085	8328	1075	1169	2760	3820	101.7	.0075	34
NORMAL OPERATING DATA									
	7950	8018	910	986	0	5200	103.5	0	

[1] All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

NOTE: See Fig. 8 for locations of thermocouple, pressure, and vibration pickups.

TABLE X-A

FUEL INGESTION DATA FOR TAKEOFF (8038)[1] RPM THROTTLE SETTING
(Engine J47-GE-25) (Fuel JP-4)

Test No.	Temperatures at Thermocouples (°F.)									Total Pressure (in. hg.)		Vibration Amplitude (mils)	
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	P_1	P_2	V_1	V_2
1	40	1021	400	430	X	425	375	450	425	30.0	98.0	0.88	0.44
2	40	1030	400	430	X	425	375	450	425	30.0	98.0	0.96	0.45
3	40	1035	400	440	X	425	375	450	425	30.0	98.0	0.99	0.44
4	40	1025	400	425	X	425	375	450	425	30.0	100.0	1.02	0.45
5	40	1021	400	425	X	425	375	450	425	30.0	100.0	1.08	0.47
6	40	1009	400	425	X	425	375	450	425	30.0	100.0	1.06	0.47
7	40	1030	400	425	X	425	375	450	425	30.0	100.0	0.99	0.47
8	40	1030	400	430	X	425	375	450	425	30.0	100.0	1.02	0.46
9	40	1040	400	430	X	425	375	450	425	30.0	100.0	1.04	0.46
10	40	1061	400	425	X	425	375	450	425	30.0	100.0	0.85	0.32
11	25	1110	375	325	400	420	365	440	420	30.0	100.0	0.99	0.45
12	25	1110	380	325	400	420	365	440	420	30.0	100.0	1.05	0.50
13	25	1137	385	325	400	420	375	445	420	30.0	100.0	1.10	0.50
14	25	1147	385	325	400	420	380	445	455	30.0	100.0	1.05	0.55
15	25	1169	400	325	420	440	400	450	475	30.0	100.0	1.05	0.55
NORMAL OPERATING CONDITIONS													
	20	910	400	405	385	420	375	445	415	31.0	106.0	0.95	0.45

X - Instrument inoperative.

[1] All corrections for rpm and exhaust gas temperature were made in accordance with U. S. Air Force T. O. 2J-J1-10 for standard dry sea-level conditions.

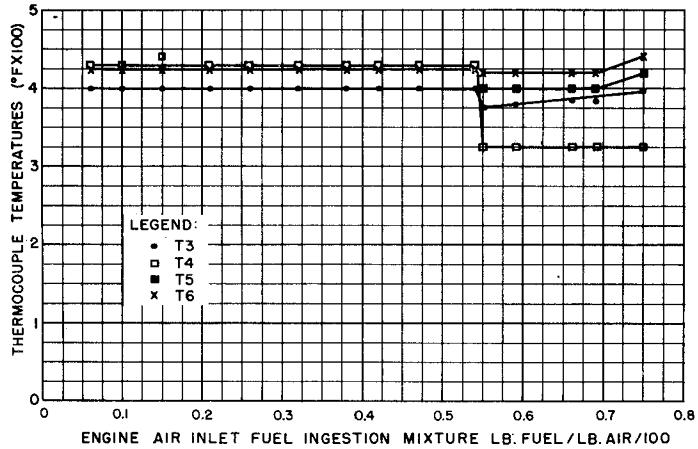

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Fig. 57 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine on Engine Temperatures - Throttle Setting for Takeoff (8,018 rpm)

CONCLUSIONS (J47-GE-25)

1. The results indicated that failure would result from a compressor stall or from an explosion rather than by overheating of engine components in the burner or exhaust sections.
2. Changes in engine vibration, pressure, and exhaust gas temperatures were not sufficient to indicate abnormal operation or impending failure.
3. It is not likely that the J47 engine will fail as a result of sprayed fuel ingestion into the inlet in mixtures of less than 0.075 lb.fuel/lb.air for a short time period of less than one minute.
4. The J47-GE-25 engine fuel control limited the rpm and exhaust gas temperatures and prevented damage to the burner and exhaust sections.
5. Warning of impending failure from fuel ingestion could not be detected by the instrumentation used during the tests on the J47 engine.

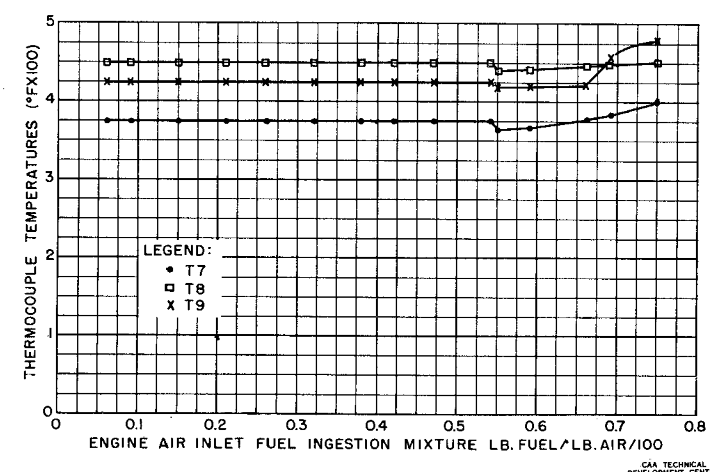

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Fig. 58 Graph Showing Effect of Ingesting Sprayed Fuel into the Air Inlet of a J47-GE-25 Engine on Engine Temperatures - Throttle Setting for Takeoff (8,018 rpm)

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