NACA

RESEARCH MEMORANDUM

COMPARISON OF FLIGHT PERFORMANCE OF AN-F-58 AND AN-F-32 FUELS IN J35 TURBOJET ENGINE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARISON OF FLIGHT PERFORMANCE OF AN-F-58 AND AN-F-32 FUELS IN J35 TURBOJET ENGINE

By Loren W. Acker and Kenneth S. Kleinknecht

SUMMARY

A flight investigation was conducted to determine the comparative performance of AN-F-58 and AN-F-32 fuels in a 4000-pound-thrust turbojet engine.

The results indicate that the performance of AN-F-58 fuel was equivalent to that of AN-F-32 fuel over the range of conditions investigated. The investigation of AN-F-58 fuel, compared with that of AN-F-32 fuel, indicated a 3-percent-higher net thrust and fuel consumption (same specific fuel consumption) at the high engine speeds; a slightly inferior blow-out limit (250 rpm higher); equally successful starts at altitudes between 5000 and 30,000 feet but somewhat longer acceleration time; and similarly small carbon deposits after $7\frac{1}{2}$ hours of operation. These small differences, however, are attributable to the normal reproducibility of test conditions and the scatter of data for this type of investigation.

INTRODUCTION

The need of the armed forces for a turbojet-engine fuel available in great quantities led to the development of the new specification fuel designated AN-F-58, which has much wider limits than the AN-F-32 specification fuel that is currently used.

As part of an extensive program undertaken at the NACA Lewis laboratory to investigate the performance of AN-F-58 fuel in several turbojet engines and single combustors from these engines, a flight investigation has been conducted to determine comparative performance of AN-F-58 and AN-F-32 fuels in a 4000-pound-thrust turbojet engine. Data presented compare the jet-engine performance parameters and operating characteristics of both fuels under similar operating conditions. The performance data were reduced to standard sea-level conditions using standard reduction parameters (reference 1).

APPARATUS

Two turbojet engines were used for the investigation, one a J35-C3 with a J35 fuel-control system and the other a J35-C-3A with a J33 fuel-control system. The engine change was made in compliance with an U.S. Air Force technical order, which was issued during the investigation. Both engines, however, have the same manufacturer's rating of 4000 pounds of static thrust at an engine speed of 7700 rpm. The principal components of the engines are the same and include an 11-stage axial-flow compressor, a single-stage turbine, and eight individual combustion chambers.

For the investigation, the engine was mounted on a carriage, which was lowered in flight from the forward bomb bay of a medium-bomber-type airplane (fig. 1). Pressure and temperature instrumentation was provided at the compressor inlet and the tail-pipe outlet for calculations of net thrust. A positive-displacement-type volumetric flowmeter was provided for measuring fuel flow to the engine.

The specifications and analysis of the properties for the two fuels used in this investigation are given in table I. Both fuels are within the specification limits.

PROCEDURE

Normal performance data using each fuel were obtained on the J35-C3 engine at pressure altitudes of 5,000, 10,000, 20,000, and 30,000 feet. At each altitude, the engine was operated over a speed range from 4000 to approximately 7000 rpm at a Mach number of 0.37 (ram pressure ratio, 1.1). This program was individually conducted on each fuel because the airplane could not simultaneously carry an ample supply of both fuels.

Engine starting and blow-out data, also using each fuel separately, were obtained on the J35-C3A engine at pressure altitudes of 5,000, 10,000, 20,000, and 30,000 feet at a Mach number of approximately 0.37. With the engine windmilling, engine starts were effected by opening the throttle until the small-slot fuel pressure reached a value of 30 to 40 pounds per square inch and then turning on the ignition. After the starts were made, the engine was accelerated as rapidly as possible to a speed of approximately 7000 rpm without exceeding the tail-pipe-temperature limit. The engine blow-out speed was obtained at a given altitude by slowly reducing the engine speed with the throttle until a sudden drop in tail-pipe temperature occurred.

RESULTS AND DISCUSSION

A comparative performance of AN-F-58 and AN-F-32 fuels is presented by means of a direct comparison of the jet-engine performance parameters obtained when operating with each fuel.

The comparison of corrected net thrust at a Mach number of 0.37 with both fuels is shown in figure 2. Above a corrected engine speed of 4000 rpm, the thrust obtained with AN-F-58 fuel was approximately 150 to 200 pounds greater than that obtained with AN-F-32 fuel. The difference is approximately 3 percent at a corrected engine speed of 8000 rpm. This small difference in the fuels is believed to be a result of the error in reproducibility of test conditions in flight.

A comparison of corrected jet-fuel consumption with the two fuels is presented in figure 3. Below a corrected engine speed of 5500 rpm, no difference occurred. At higher engine speeds, however, AN-F-58 fuel consumption increased gradually to a value of approximately 160 pounds per hour higher than the AN-F-32 fuel at the maximum engine speed. The value of 160 pounds per hour is approximately a 3-percent difference at a corrected engine speed of 8000 rpm. The net thrust, however, was also 3 percent higher for the AN-F-58 fuel than for the AN-F-32 fuel (fig. 2). Consequently, the corrected specific fuel consumption was the same at the higher speed as shown in figure 4. At engine speeds below 6750 rpm, the AN-F-58 fuel results show a somewhat lower specific fuel consumption than the AN-F-32 fuel. The close agreement of the specific-fuel-consumption data indicates that the combustion efficiency with the two fuels was equal at the high engine speeds.

The variation of corrected tail-pipe temperature with corrected engine speed for the two fuels is shown in figure 5. These data show no difference in tail-pipe temperature at the maximum engine speed but show an approximately 50° R higher temperature at the low engine speeds with AN-F-58 fuel. This temperature difference is consistent with the differences in net thrust and jet-fuel consumption (figs. 2 and 3) and is additional evidence that the performance discrepancy is due to the reproducibility limits of engine operation or test conditions rather than to a difference in fuel performance.

Combustor blow-out speeds at pressure altitudes from 5,000 to 30,000 feet at a Mach number of 0.37 are presented in figure 6. These blow-out speeds are the engine speeds at which a sudden drop in tail-pipe temperature to approximately 100° F occurred as the engine throttle was slowly closed. The actual engine speed at which the combustors blew out varied from 2900 to 3450 rpm for the AN-F-58 fuel and from 2600 to 3250 rpm for the AN-F-32 fuel over the range of altitudes. Although the data show the blow-out limit for the AN-F-58 fuel to be somewhat inferior by a value of 200 to 250 rpm, it is believed that this difference in the two fuels is within the normal scatter of data obtained for this type of investigation.

Data obtained from windmilling starts and engine accelerations at altitudes from 5,000 to 30,000 feet with the fuels are presented in table II. Successful starts were made at all the altitudes with both fuels. A longer period of time was required, however, to accelerate the engine with AN-F-58 fuel. Different engine operators conducted the experiments with the two fuels and the difference in acceleration time could be attributed to differences in the starting technique. Because reproduction of an acceleration maintaining the same tail-pipe temperature is almost impossible, such a difference in acceleration time would normally be experienced in practice.

Visual observations of the jet exhaust showed that no objectionable smoke trail was produced by either fuel. After $2\frac{1}{2}$ and $7\frac{1}{2}$ hours of engine operation with the AN-F-58 fuel, several burners and fuel injectors were removed and examined for carbon deposits. Traces of carbon were found both times on the burner liner, the burner dome, and the fuel injector. These deposits, however, were no more severe than the deposits found in the engine when operated with AN-F-32 fuel for approximately the same periods.

SUMMARY OF RESULTS

From a flight investigation conducted to compare the performances of AN-F-58 and AN-F-32 fuels in a 4000-pound-thrust turbojet engine, the following results were obtained:

1. The performance of AN-F-58 fuel was equivalent to that of AN-F-32 fuel for the range of conditions investigated.

2. The investigation of AN-F-58 fuel, compared with that of AN-F-32 fuel, indicated a 3-percent-higher thrust and fuel consumption (same specific fuel consumption) at the high engine speed; a slightly inferior blow-out limit (250 rpm higher); equally successful starts at altitudes between 5,000 and 30,000 feet, but somewhat longer acceleration time; and similarly small carbon deposits

1061

after $7\frac{1}{2}$ hours of operation. These small differences, however, are attributed to the normal reproducibility of test conditions and scatter of data for this type of investigation.

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REFERENCES

1. Sanders, Newell D.: Performance Parameters for Jet-Propulsion Engines. NACA TN No. 1106, 1946.

2. Gooding, Richard M., and Hopkins, Ralph L.: The Determination of Aromatics in Petroleum Distillates. Paper presented before Div. Petroleum Chem., Am. Chem. Soc. (Chicago, Ill.) Sept. 9-13, 1946, pp. 131-141.

TABLE I - SPECIFICATIONS AND ANALYSIS OF FUELS USED

1061

NACA fuel	Specification		Analysis	
	AN-F-58	AN-F-32	AN-F-58	AN-F-32
			48-210	48-306
A.S.T.M. distillation D 86-46, °F				
Initial boiling point	----------	----------	102	336
5 (evaporated)	----------	----------	149	349
10	----------	410(max.)	174	355
20	----------	----------	234	360
30	----------	----------	286	365
40	----------	----------	322	370
50	----------	----------	360	375
60	----------	----------	390	381
70	----------	----------	412	387
80	----------	----------	444	394
90	425(min.)	490(max.)	480	405
Final boiling point	600(max.)	572(max.)	545	446
Residue, (percent)	1.5(max.)	1.5(max.)	0.8	1.0
Loss, (percent)	1.5(max.)	1.5(max.)	0.2	1.0
Freezing point, °F	-76(max.)	-76(max.)	<-76	-------
Aromatics, (percent by volume)				
A.S.T.M. D-875-46T	30(max.)	20(max.)	23	-------
Silica gel[a]	----------	----------	29	15
Accelerated gum (mg/100 ml)	20(max.)	8.0(max.)	-------	0
Air jet residue (mg/100 ml)	10(max.)	5.0(max.)	20	1
Sulfur, (percent by weight)	0.5(max.)	0.20(max.)	0.09	0.02
Viscosity, (centistokes at -40° F)	10.0(max.)	10.0(max.)	4.26	-------
Bromine number	14.0(max.)	3.0(max.)	12.0	-------
Reid vapor pressure (lb/sq in.)	5-7(max.)	----------	5.7	-------
Hydrogen-carbon ratio	----------	----------	0.153	0.154
Heat of combustion (Btu/lb)	18,200 (min.)	----------	18,475	18,530
Specific gravity	----------	0.850(max.)	0.794	0.831
Flash point, °F	----------	110(min.)	-------	-------

[a]Reference 2.

TABLE II - WINDMILLING STARTING AND ACCELERATION DATA

[Flight Mach number, 0.37]

Altitude (ft)	Windmilling speed (rpm)	Free-air temperature (°F)	Successful start and acceleration	Maximum tail-pipe temperature (°F)	Acceleration	
					Time (sec)	Engine speed (rpm)
AN-F-32 Fuel						
5,000	1320	50	Yes	1150	36	6930
10,000	1280	47	---do.---	1140	61	6970
20,000	1300	15	---do.---	1300	68	7000
28,000	1130	-22	---do.---	1310	106	6930
AN-F-58 Fuel						
6,000	1300	44	---do.---	950	91	6780
10,000	1270	33	---do.---	810	74	[a]4940
20,000	1160	2	---do.---	1400	80	6990
30,000	1040	-38	---do.---	1380	153	6680

[a]No data obtained above 4940 rpm.

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Figure 1. - Turbojet engine extended from medium-bomber-type airplane in flight.

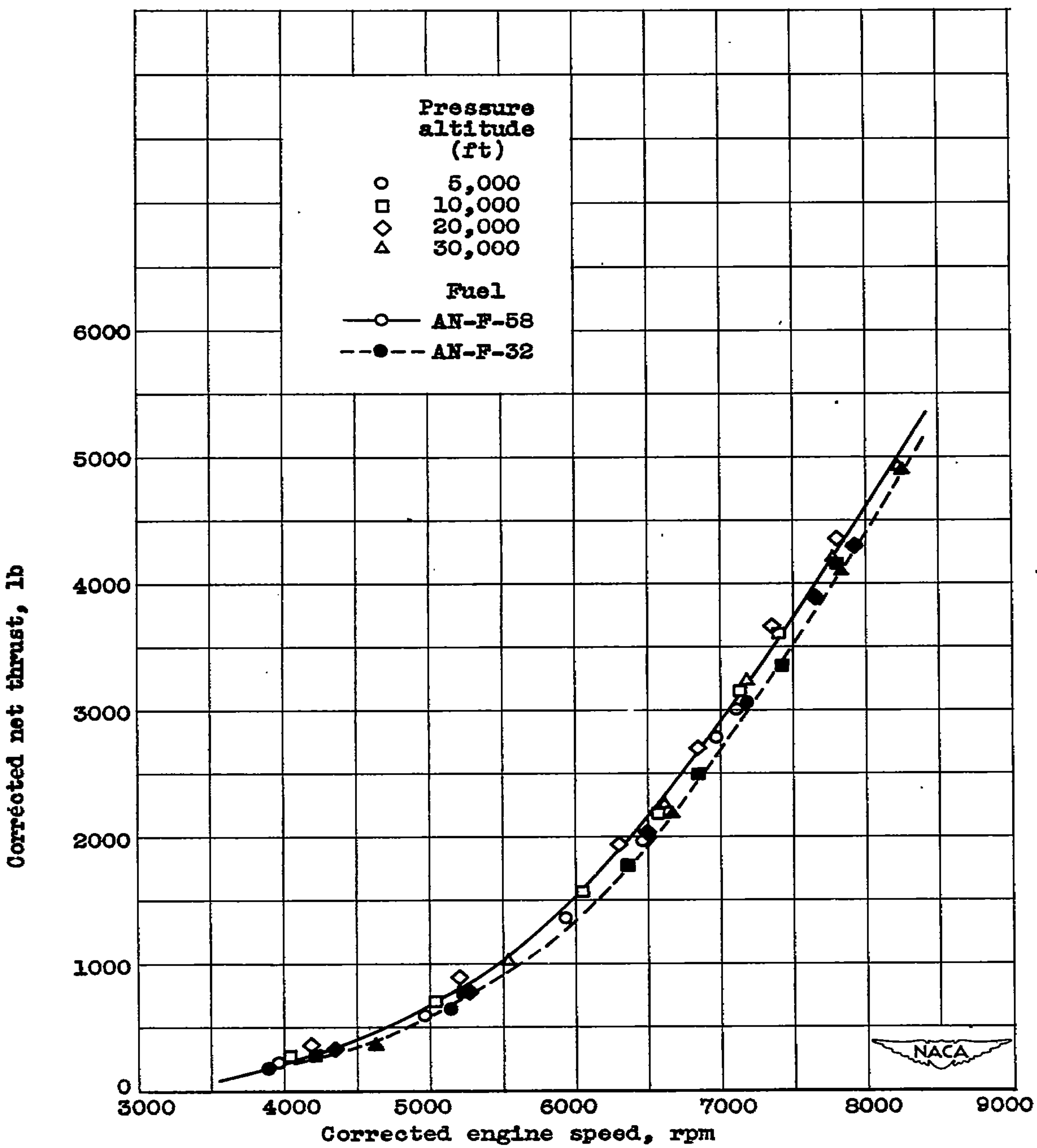

Figure 2. - Comparison of corrected net thrust with AN-F-58 and AN-F-32 fuels. Mach number, 0.37.

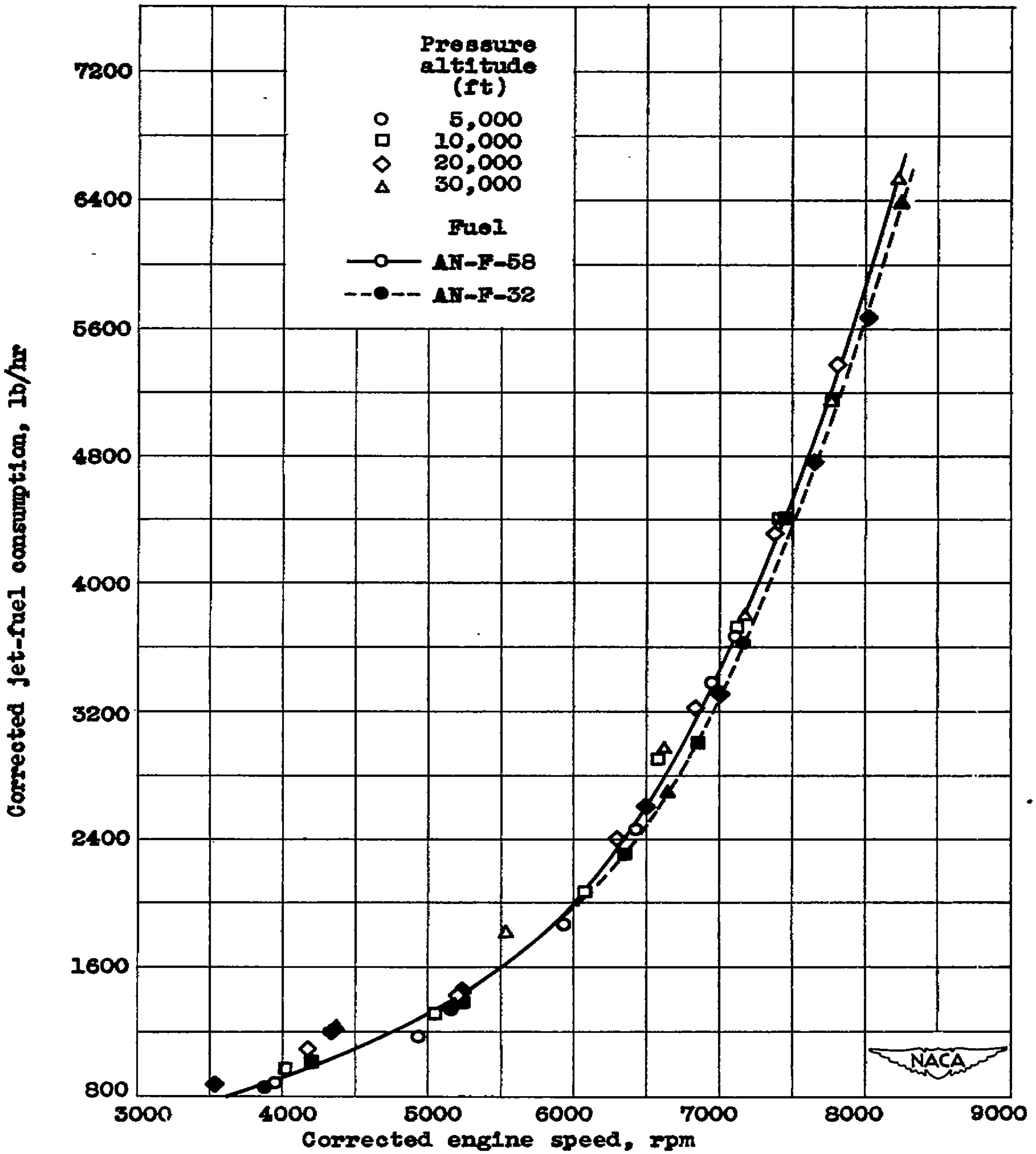

Figure 3. - Comparison of corrected jet-fuel consumption with AN-F-58 and AN-F-32 fuels. Mach number, 0.37.

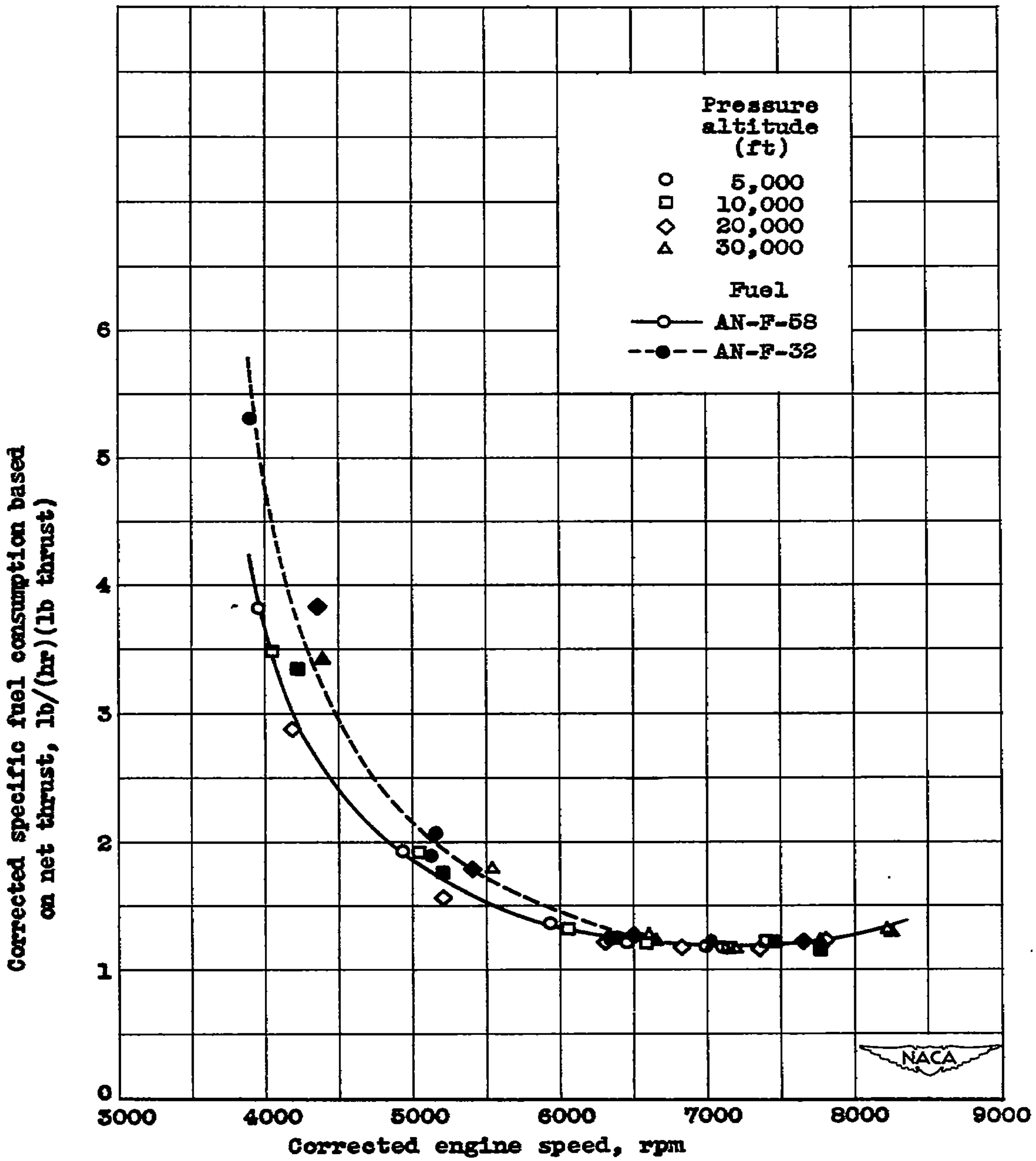

Figure 4. - Comparison of corrected specific fuel consumption based on jet thrust with AN-F-58 and AN-F-32 fuels. Mach number, 0.37.

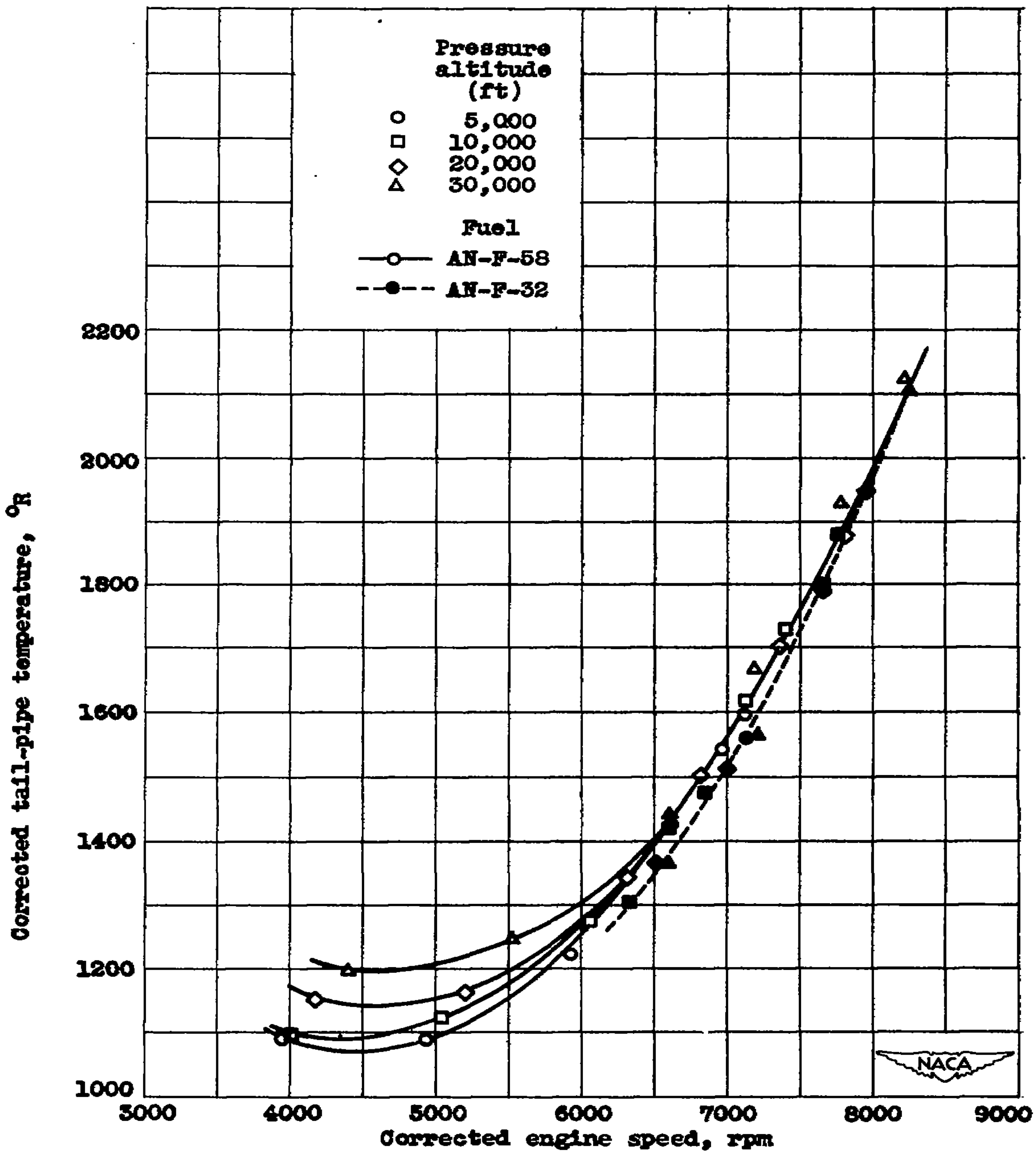

Figure 5. - Comparison of corrected tail-pipe temperature with AN-F-58 and AN-F-32 fuels. Mach number, 0.37.

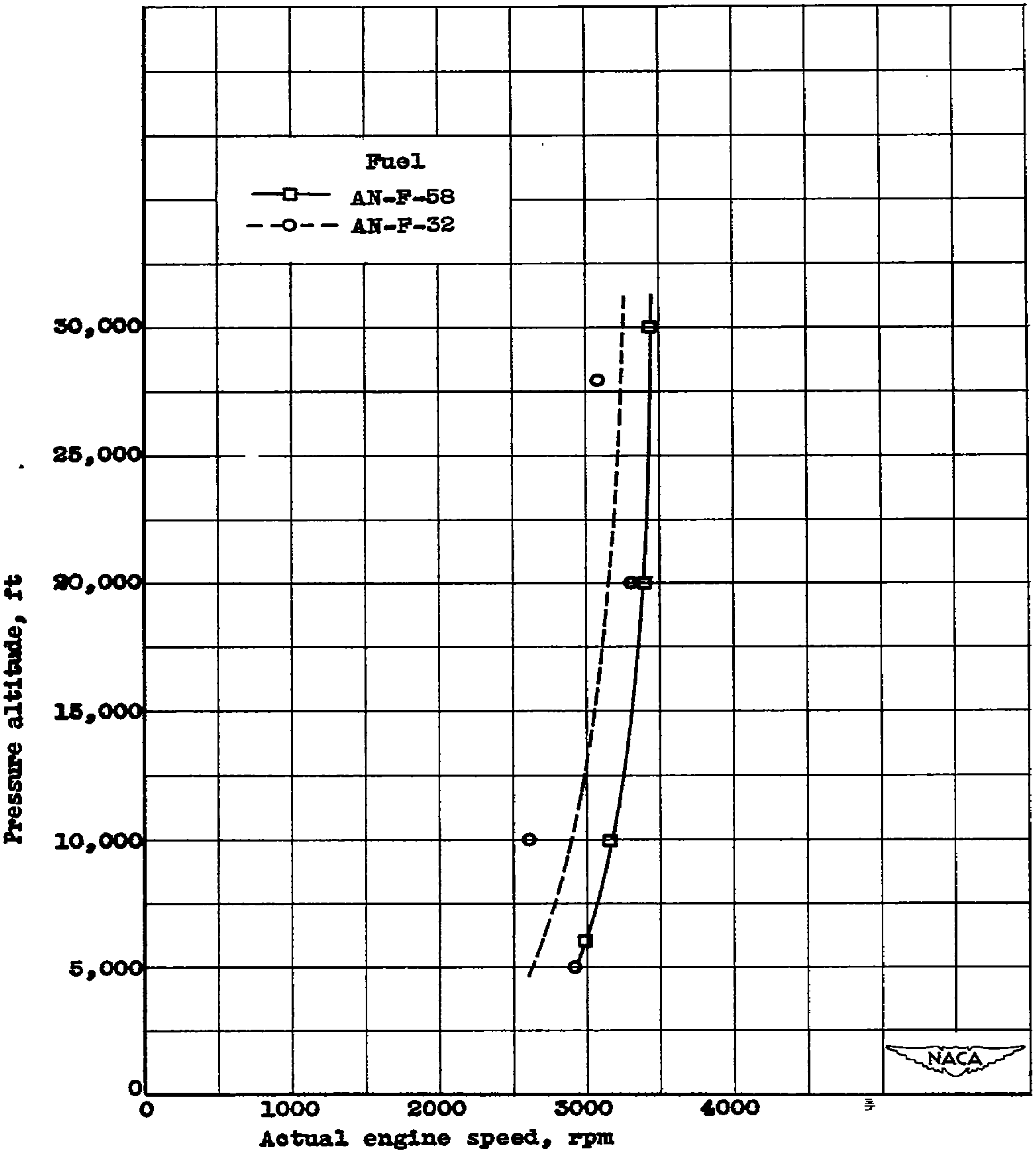

Figure 6. - Comparison of effect of altitude on combustor blow-out limits with AN-F-58 and AN-F-32 fuels. Mach number, 0.37.