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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF AN-F-58 FUEL IN EXPERIMENTAL VERSION OF J47 TURBOJET ENGINE

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SUMMARY

An investigation was conducted in the NACA Lewis altitude wind tunnel to evaluate the performance of AN-F-58 fuel and, for comparative purposes, AN-F-32 fuel in an experimental turbojet engine. Data were obtained for a range of altitude, flight Mach number, and engine-speed conditions.

Combustion efficiencies obtained with AN-F-58 and AN-F-32 fuels were approximately equal; AN-F-58 combustion efficiencies were slightly higher than those for AN-F-32 fuel at the high altitudes and low flight Mach number. The effects of the fuels on other engine performance variables could not be determined because engine deterioration, accelerated by operation at severe engine conditions for a considerable length of time, made direct comparisons impossible. The minimum-speed altitude operational limit was essentially the same for the two fuels. The starting characteristics of the two fuels were approximately the same at the low windmilling speeds. Visual observation showed no apparent difference in the carbon-deposition rates of the two fuels.

INTRODUCTION

Fuel specification AN-F-58 was proposed because of the need for a fuel available in greater quantities than that currently used in gas-turbine engines. Because of the compromises involved in the specification, an investigation is being conducted at the NACA Lewis laboratory to evaluate the performance of AN-F-58 fuel in various turbojet engines and single combustors. As a part of this program, performance and operational characteristics of an experimental turbojet engine using such a fuel have been determined in the altitude wind tunnel. For comparative purposes, performance and operational characteristics of the engine using a fuel conforming to specification AN-F-32 are included; AN-F-32 is the standard fuel for the engine.

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Combustion-efficiency data are presented for the two fuels for a range of altitude, flight Mach number, and engine-speed conditions. The minimum-speed altitude operational limit of the engine is presented for both fuels. Windmilling starting characteristics of the engine with both fuels and results of inspection of the engine combustion chambers and spark plugs for carbon deposition after several hours of operation with AN-F-58 fuel are discussed.

FUELS

The AN-F-58 and the AN-F-32 fuel specifications and analyses for the fuels used in this investigation are presented in table I.

DESCRIPTION OF ENGINE

An experimental version of the J47 turbojet engine was used in the altitude-wind-tunnel investigation. This engine has a sea-level static thrust of approximately 5000 pounds at an engine speed of 7900 rpm. The engine has a 12-stage, axial-flow compressor, eight individual combustors, a single-stage turbine, and a fixed-area exhaust nozzle. The engine used for this investigation had no screen in the air passage ahead of the compressor.

The combustors are of the direct-flow type. Each chamber is a double-walled cylindrical assembly; air from the compressor passes into the annular space between the outer casing and the inner liner and enters the combustion zone through perforations in the inner liner. Fuel is injected into the combustion zone of each chamber by a duplex fuel nozzle. The combustors are interconnected by crossfiring tubes, which permit initial ignition by use of two spark plugs.

Gases from the combustors pass through transition sections and the single-stage turbine into the tail pipe and exhaust through a fixed-area exhaust nozzle. The exhaust nozzle used had an outlet area of 301.5 square inches.

INSTALLATION AND PROCEDURE

The engine was supported on an airfoil spanning the test section of the altitude wind tunnel. Instrumentation for obtaining pressure and temperature measurements was installed at the engine inlet and the exhaust-nozzle outlet, as shown in figure 1. Inlet pressures corresponding to the desired flight Mach numbers were obtained by introducing dry refrigerated air from the tunnel make-up air system through a duct to the engine inlet. This air was throttled from approximately sea-level pressure to the desired total pressure at the engine inlet. Gases from the engine exhausted into the wind-tunnel test section, which was maintained at the static pressure corresponding to the desired altitude.

With a fuel that conformed to specification AN-F-58, engine performance data were obtained at pressures corresponding to altitudes from 5000 to 50,000 feet and at flight Mach numbers from approximately 0.22 to 0.85; an engine-inlet temperature of $520^\circ \pm 10^\circ$ R was maintained for all conditions.

For comparative purposes, performance data obtained with the engine for a fuel that conformed to specification AN-F-32 are included. These data were obtained at pressures corresponding to altitudes from 5000 to 35,000 feet and at flight Mach numbers from approximately 0.21 to 0.81; the engine-inlet temperature for this phase of the program was held at approximately NACA standard values for each simulated flight condition except those of high altitude and low flight Mach number. No engine-inlet temperatures below 445° R were obtained.

With both AN-F-58 and AN-F-32 fuels, minimum-speed operational limits were determined at pressures corresponding to altitudes up to 50,000 feet at a flight Mach number of 0.21 and a limited number of windmilling starts were made at altitudes from 5000 to 25,000 feet. An engine-inlet temperature of $520^\circ \pm 10^\circ$ R was maintained. The fuel temperature at the fuel-pump outlet was estimated to be approximately 540° R.

The engine combustors and spark plugs were inspected for carbon deposits and deterioration after several hours of operation with AN-F-58 fuel.

The symbols and the methods of calculation used are presented in the appendix. Combustion efficiency was determined from the ratio of the actual increase in enthalpy of the gas to the theoretical increase in enthalpy that would result from complete combustion of the fuel. Enthalpy values were obtained from temperature-enthalpy charts using total temperatures. The combustion efficiencies for the two fuels are believed to be comparable because:

(1) Temperature after combustion was measured at the exhaust nozzle, which is far enough downstream of the turbine for good mixing of the hot gases; (2) temperature profiles across the diameter of the exhaust nozzle were similar for the two fuels; and (3) air-flow values calculated from temperature and pressure measurements at the exhaust nozzle agree within 3 percent with air-flow values calculated from measurements at the engine inlet.

RESULTS AND DISCUSSION

Performance

Comparisons of the combustion efficiencies obtained with AN-F-58 and AN-F-32 fuels are shown in figure 2 for a range of altitudes from 5000 to 50,000 feet and in figure 3 for a range of flight Mach numbers from 0.21 to 0.85. The data for AN-F-58 fuel were obtained at an engine-inlet temperature of approximately 520° R, whereas the data for AN-F-32 fuel were obtained at engine-inlet temperatures corresponding approximately to NACA standard values for each flight condition. A few check points were obtained for AN-F-32 fuel at an engine-inlet temperature of approximately 520° R; these data are included in figures 2 and 3 and indicate that inlet temperature within the range investigated had no appreciable effect on combustion efficiency.

At a flight Mach number of about 0.22 and a range of altitudes from 25,000 to 38,000 feet (figs. 2 and 3), the AN-F-58 combustion efficiencies are somewhat higher than those for AN-F-32. At an altitude of 5000 feet (fig. 2), the combustion efficiencies for the two fuels are approximately equal although the efficiencies for AN-F-58 fuel were slightly lower at high engine speeds. Data are unavailable for AN-F-32 fuel at an altitude of 50,000 feet (fig. 2). At the higher flight Mach numbers (fig. 3), differences in combustion efficiencies appear to be small, with AN-F-58 combustion efficiencies somewhat lower at high engine speeds.

Engine performance variables, such as net thrust, fuel consumption, and specific fuel consumption based on net thrust are not presented for the two fuels. The fuels were not consecutively investigated and engine deterioration, resulting from operation at severe engine conditions for a considerable length of time, made direct comparisons impossible.

Altitude Operational Limit

The effect of variation in altitude on the operable range of engine speeds at a flight Mach number of 0.21 is shown in figure 18

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for AN-F-58 and AN-F-32 fuels; only the minimum-speed operational limit is presented. The minimum-speed operational limit is defined as either the normal idling speed of the engine or the lowest engine speed from which acceleration could be affected without excessive turbine-outlet temperatures. The data were obtained by attempting accelerations from successively lower engine speeds while maintaining the desired altitude and flight Mach number until acceleration was impossible because of excessive turbine-outlet temperatures or combustion blow-out. No attempt was made to determine minimum speeds below 2000 rpm, the idling speed of the engine.

The available data, shown in figure 18, indicate that the minimum-speed operational limit is essentially the same with AN-F-58 or AN-F-32 fuel. The idling speed of 2000 rpm is obtainable at altitudes up to 40,000 feet. Acceleration from an engine speed of 2000 rpm was very difficult with both fuels at an altitude of 40,000 feet. The operational range decreased as the altitude was raised above 40,000 feet; at an altitude of 50,000 feet, the engine could not be operated at engine speeds below approximately 4750 rpm. The fuel pressures at engine speeds near the operational limit above an altitude of 40,000 feet are below the design limits of the engine fuel-control system and would not be encountered during stable operation of the engine under actual flight conditions.

Starting

A very limited number of windmilling starts were made at altitudes from 5000 to 25,000 feet with AN-F-58 and AN-F-32 fuels; the altitudes and the windmilling speeds at which successful starts were made are summarized in the following table:

Altitude (ft)	Engine windmilling speed (rpm)	
	AN-F-58 fuel	AN-F-32 fuel
5,000	700	700
7,800	2000	(a)
25,000	750	700
25,000	1500	1000[b]

[a] No attempt made at 2000 rpm.
[b] No attempt made between 1000 and 2000 rpm.

When either AN-F-58 or AN-F-32 fuel was used, the engine could not be started from a windmilling speed of 2000 rpm at altitudes of 25,000 feet or more. All starts were normal and no excessive turbine-outlet temperatures were encountered. The starting characteristics of the two fuels were approximately the same at the low windmilling speeds. Comparative starting characteristics of the two fuels could not be determined at higher windmilling speeds because of the limited range of windmilling speeds from which the engine could be started.

Carbon Deposition

The spark plugs were removed after $8\frac{1}{2}$ hours of engine operation with AN-F-58 fuel and were found to be clean and free from carbon deposits. The combustor liners were inspected after 16 hours of engine operation with AN-F-58 fuel and were free of carbon deposits and showed no evidence of warpage. Visual observation showed no apparent difference in the carbon-deposition rates of AN-F-58 and AN-F-32 fuels.

Scale

The AN-F-58 fuel was supplied to the engine fuel system from a large tank outside the wind-tunnel test section and passed through two filters in series before reaching the engine fuel system. The filters were of the full-flow type with 25-micron replaceable elements. After 16 hours of engine operation with AN-F-58 fuel, the two filters were found to contain excessive amounts of metallic scale; none of this scale was found in the engine fuel system. The origin of the metallic scale is unknown; it may have been picked up from tank cars, storage tanks, or fuel lines and held in suspension because of rapid handling. Similar trouble was not experienced with AN-F-32 fuel, possibly because storage time permitted foreign particles to settle.

SUMMARY OF RESULTS

An altitude-wind-tunnel investigation of the performance of AN-F-58 and AN-F-32 fuels in an experimental turbojet engine over a range of simulated altitudes and flight Mach numbers gave the following results:

1. Combustion efficiencies obtained with AN-F-58 and AN-F-32 fuels are approximately equal; AN-F-58 combustion efficiencies were slightly higher than those for AN-F-32 fuel at high altitudes and low flight Mach number. The effects of the fuels on other engine performance variables could not be determined because engine deterioration, accelerated by operation at severe engine conditions for a considerable length of time, made direct comparisons impossible.

2. The minimum-speed altitude operational limit was essentially the same with either AN-F-58 or AN-F-32 fuel.

3. All starts were normal and no excessive turbine-outlet temperatures were encountered. The starting characteristics of the two fuels were approximately the same at the low windmilling speeds.

4. The spark plugs and combustor liners were free of carbon deposits after $8\frac{1}{2}$ and 16 hours of engine operation, respectively, with AN-F-58 fuel. From visual observation, there was no apparent difference in the carbon-deposition rates of AN-F-58 and AN-F-32 fuels.

Lewis Flight Propulsion Laboratory,
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APPENDIX - CALCULATIONS

Symbols

The following symbols are used in this report:

A	cross-sectional area, sq ft
f/a	fuel-air ratio
g	acceleration due to gravity, 32.2 ft/sec^2
H_a	enthalpy of air, Btu/lb
H_f	enthalpy of fuel, Btu/lb
h_f	lower heating value of fuel, Btu/lb
M_0	flight Mach number
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
R	gas constant, 53.3 ft-lb/(lb)($^{\circ}$R)
T	total temperature, $^{\circ}$R
T_i	indicated temperature, $^{\circ}$R
t	static temperature, $^{\circ}$R
W_a	air flow, lb/sec
γ	ratio of specific heats
η_b	combustion efficiency
θ	ratio of absolute ambient static temperature to absolute static temperature of NACA standard atmosphere at sea level
$N/\sqrt{\theta}$	corrected engine speed, rpm

Subscripts:

0	free air stream
1	engine inlet
10	exhaust-nozzle outlet

Methods of Calculation

Air flow. - Engine air flow was calculated from pressure and temperature measurements obtained at the engine inlet (station 1) by use of the relation

$$W_a = p_1 A_1 \sqrt{\frac{2\gamma g}{Rt_1(\gamma - 1)} \left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

Combustion efficiency. - Combustion efficiency was calculated from the relation

$$\eta_b = \frac{H_{a,10} + (f/a)\, H_{f,10} - H_{a,1}}{(f/a)\, h_f}$$

The enthalpy values of this relation were obtained from temperature-enthalpy charts using total temperatures.

Flight Mach number. - The flight Mach number was determined, assuming complete ram-pressure recovery, from the relation

$$M_0 = \sqrt{\frac{2}{\gamma - 1} \left[\left(\frac{P_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

Temperatures. - Total temperature was obtained from the indicated temperature by use of a thermocouple recovery factor of 0.85 when the following relation was used:

$$T = \frac{T_i\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}}}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

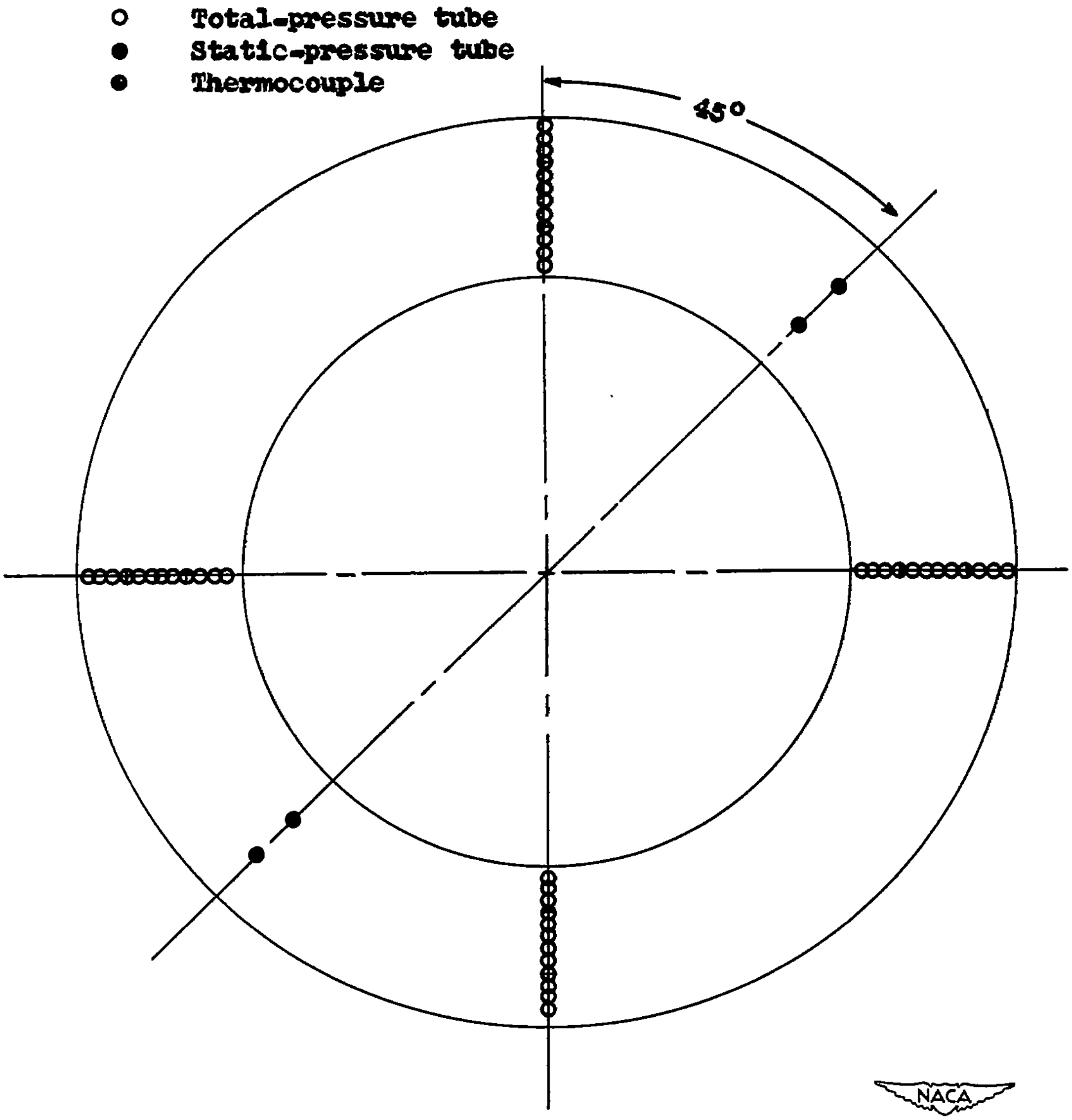
REFERENCE

1. 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 ANALYSES OF FUELS USED

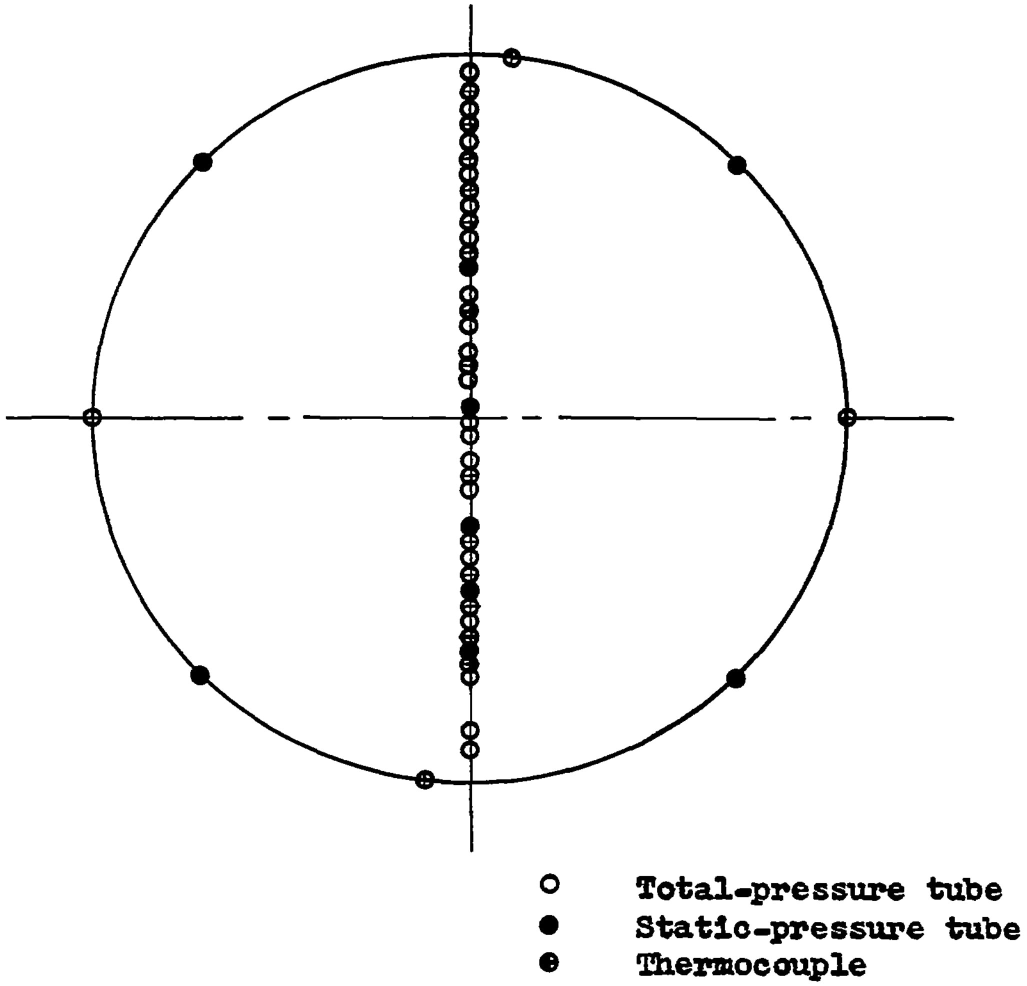
	Specifications		Analysis	
	AN-F-58	AN-F-32	AN-F-58[a]	AN-F-32[b]
A.S.T.M. distillation D 86-46, °F				
Initial boiling point	----------	----------	110	336
Percentage evaporated				
5	----------	----------	135	349
10	----------	410(max.)	157	355
20	----------	----------	192	360
30	----------	----------	230	365
40	----------	----------	270	370
50	----------	----------	314	375
60	----------	----------	351	381
70	----------	----------	388	387
80	----------	----------	427	394
90	425(min.)	490(max.)	470	405
Final boiling point	600(max.)	572(max.)	560	446
Residue, (percent)	1.5(max.)	1.5(max.)	1.0	1.0
Loss, (percent)	1.5(max.)	1.5(max.)	1.0	1.0
Freezing point, °F	-76(max.)	-76(max.)	< -76	--------
Accelerated gum, (mg/100 ml)	20(max.)	8.0(max.)	2.9	0
Air-jet gum, (mg/100 ml)	10(max.)	5.0(max.)	2.6	1.0
Sulfur, (percent by weight)	0.50(max.)	0.20(max.)	0.03	0.02
Aromatics, (percent by volume)				
A.S.T.M. D-875-46T	30(max.)	20(max.)	17	--------
Silica gel[c]	----------	----------	19	15
Flash point, °F	----------	110(min.)	--------	--------
Specific gravity	----------	0.850(max.)	0.769	0.831
Viscosity, (centistokes at -40° F)	10.0(max.)	10.0(max.)	2.67	--------
Bromine number	14.0(max.)	3.0(max.)	13.8	--------
Reid vapor pressure (lb/sq in.)	5 to 7	----------	5.4	--------
Hydrogen-carbon ratio	----------	----------	0.163	0.154
Heat of combustion, (Btu/lb)	18,200 (min.)	----------	18,640	18,530

[a] NACA fuel 48-249.
[b] NACA fuel 48-306.
[c] Reference 1.



(a) At engine inlet, station 1, $4\frac{3}{4}$ inches ahead of engine-inlet flange.

Figure 1. - Instrumentation.



(b) At exhaust-nozzle outlet, station 10, 1 inch ahead of rear edge of exhaust nozzle.

Figure 1. - Concluded. Instrumentation.

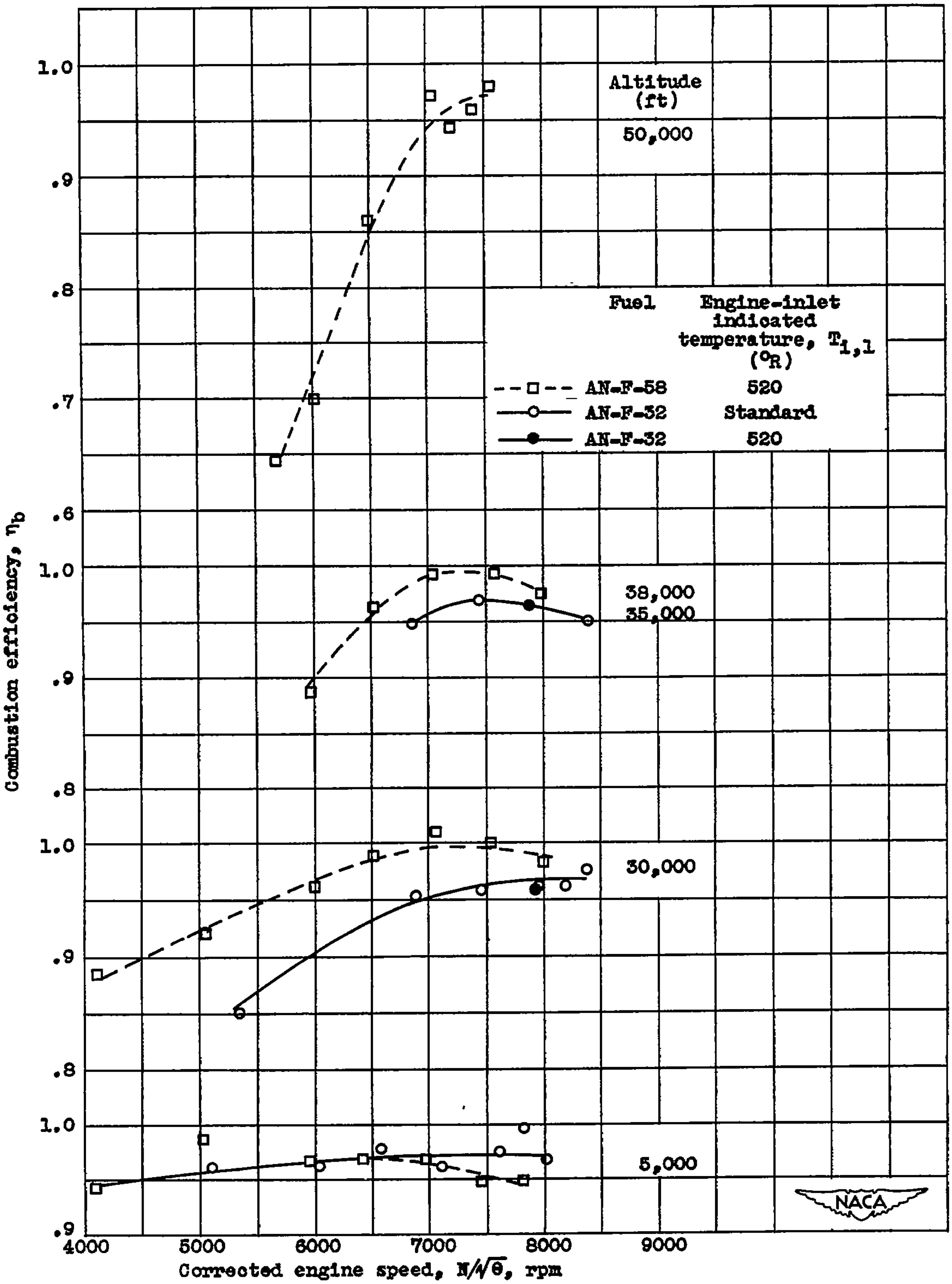


Figure 2. - Variation of combustion efficiency with corrected engine speed for range of altitudes. Flight Mach number, 0.22.

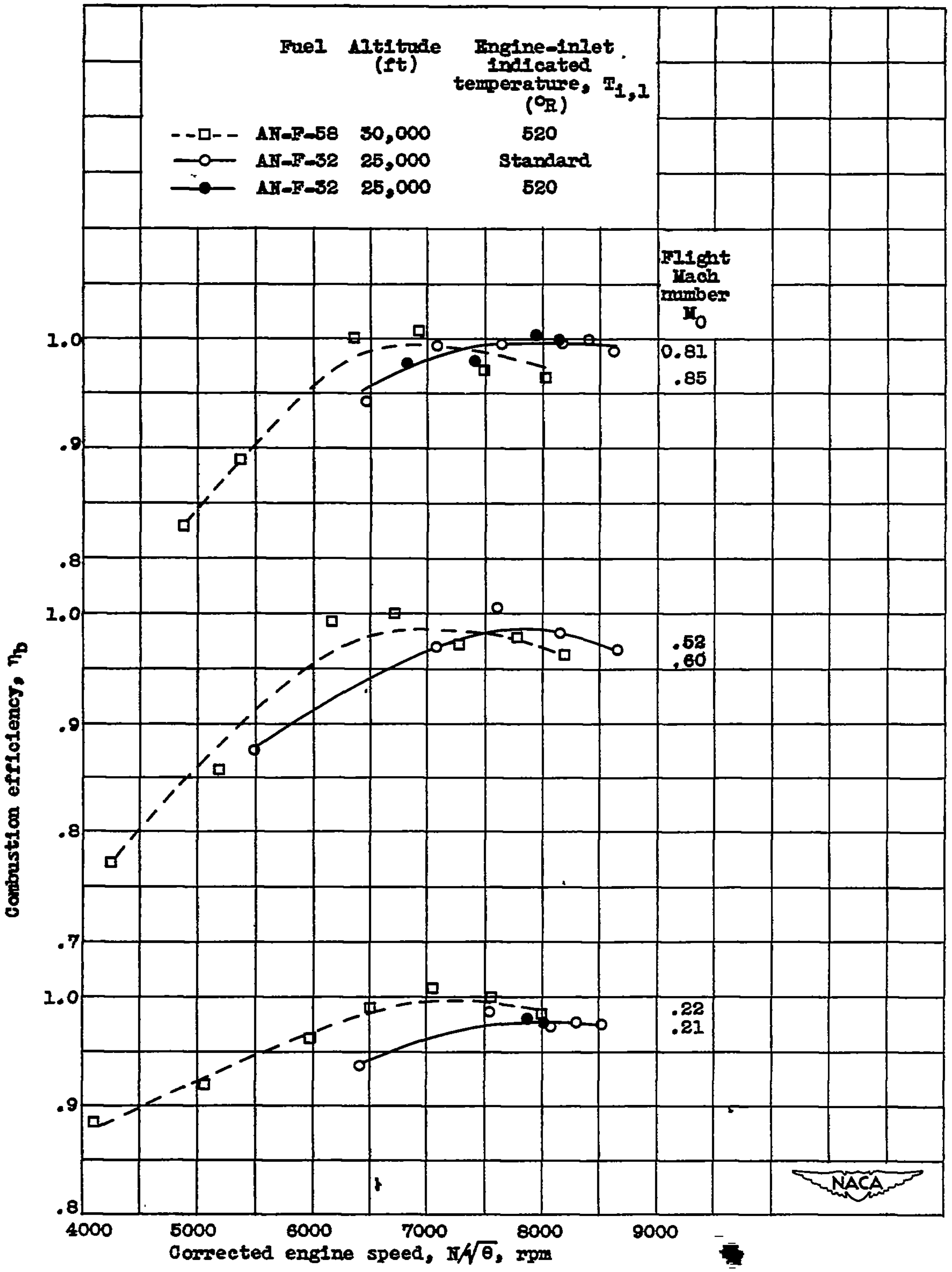


Figure 3. - Variation of combustion efficiency with corrected engine speed for range of flight Mach numbers.

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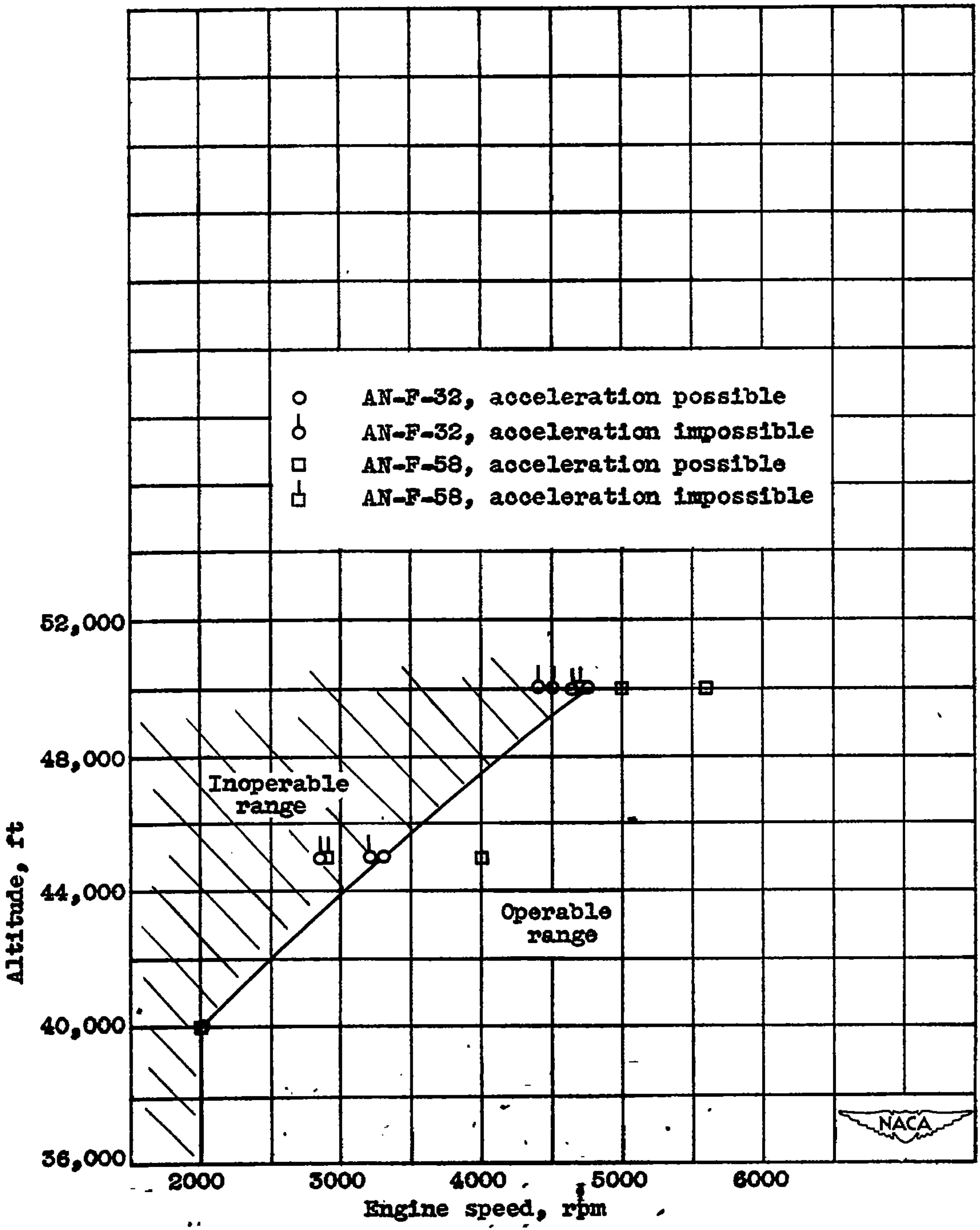

Figure 4. - Effect of altitude on minimum engine speed. Flight Mach number, 0.21.

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