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NACA

RESEARCH MEMORANDUM

COMPARISON OF PERFORMANCE OF AN-F-58 AND AN-F-32 FUELS IN J33-A-23 TURBOJET ENGINE

By H. D. Wilsted and J. C. Armstrong

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

June 2, 1949

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665

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Reply to Attn of 139A

TO: Distribution

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SUBJECT: Authority to Declassify NACA/NASA Documents Dated Prior to January 1, 1960

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Document No.	First Author
E-51A30	Nagey
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SUMMARY

As part of an extensive evaluation program to determine the comparative performance of fuels conforming to specifications AN-F-58 and AN-F-32, an investigation was conducted in an altitude chamber using a 4600-pound-thrust turbojet engine.

In comparison with the performance of AN-F-32 fuel, AN-F-58 had the following characteristics:

(1) Equal performance with AN-F-32 fuel in terms of engine thrust and fuel consumption

(2) Improved altitude starting characteristics

(3) Less tendency for blow-out at low engine speeds

(4) Higher carbon-deposition rate that, however, did not appear detrimental to engine performance

(5) Contamination with iron oxide particles. These particles probably were held in suspension because of rapid handling of the fuel.

Within the limits of this investigation, AN-F-58 fuel was essentially equal in performance and in some respects had improved performance as compared with AN-F-32 fuel. The AN-F-58 fuel is therefore considered satisfactory for service flight tests in the engine used.

INTRODUCTION

The need of the armed forces for a fuel available in greater quantities than that currently used for turbine-engine propelled aircraft led to the proposal of a new specification (designated AN-F-58), which has much wider limits than the AN-F-32 fuel specification. Because of the compromises between fuel quality and available quantity involved in extending the limits of the specification, investigation of the performance of the fuel in current turbojet engines was considered necessary.

As part of an extensive program to determine whether the new fuel could be used without detrimental effects and without decreased performance, an investigation was conducted at the NACA Lewis laboratory using a 4600-pound-thrust turbojet engine.

The investigation included comparisons of normal altitude performance, altitude starting limits, low-speed operational limits, and a qualitative comparison of carbon-deposition rates with AN-F-58 and AN-F-32 fuels.

FUEL SPECIFICATIONS

A comparison of specifications of AN-F-58 and AN-F-32 fuels and an analysis of the properties of the AN-F-58 and the AN-F-32 fuels used in this investigation are shown in table I.

The fuels used in the investigation are within the limits of the respective specifications.

APPARATUS

Power Plant

A J33-A-23 turbojet engine, which has 14 through-flow combustion chambers, was used in this investigation. The engine incorporates a single-stage, double-entry, centrifugal compressor 30.0 inches in diameter driven by a single-stage turbine 26.43 inches in diameter. The turbine-nozzle area is 123.1 square inches and the jet-nozzle area is 285 square inches.

The military rating of the engine (reference 1) at static sea-level conditions is 4600 pounds of thrust and a specific fuel consumption of 1.13 pounds of fuel per hour per pound of thrust at a rotor speed of 11,750 rpm.

The automatic fuel control used on the J33-A-23 engine performs the same function as did the barometric control, the governor, and the control valve on earlier model engines. The regulator so limits the engine acceleration rate as to prevent excessive exhaust-gas temperatures and, in addition, the regulator so limits the deceleration rate that the combustion flames will not be extinguished. An emergency fuel-control unit is provided (reference 1), however, which allows bypassing of the main automatic fuel-control regulator.

An automatic-starting fuel control, which is also incorporated in this engine, is designed to supply fuel only to the two combustion chambers equipped with spark plugs during the first 2 seconds of the starting cycle after which fuel is supplied to all 14 combustors. This procedure helps to prevent accumulations of raw fuel in the engine and resultant "hot" starts.

Altitude Test Chamber

The engine was installed in an altitude test chamber 10 feet in diameter and 60 feet long, on a thrust frame connected through linkage to a balanced-pressure diaphragm-type thrust indicator located outside the test chamber. (See fig. 1.)

The ram-air pressure was controlled by remote-controlled butterfly valves in the air-supply line near the entrance to the altitude chamber. Air was supplied (either refrigerated or unrefrigerated) at temperatures near those required to simulate the various altitude flight conditions. Accurate control and adjustment of air temperatures was made by use of electric heaters in a bypass line immediately preceding the entrance to the altitude chamber. The air entered the altitude chamber, passed through straightening vanes, and entered the engine cowling. The engine cowling was installed to prevent circulation of hot air from the tail-pipe region directly into the rear inlet of the compressor. The cowling therefore mixes any recirculating air well upstream of the compressor inlets and results in nearly equal temperatures at the two inlets.

The test section of the altitude chamber was separated from the exhaust portion by a bulkhead seal. The tail pipe passed through the bulkhead and a seal composed of three floating asbestos rings so installed as to allow axial movement required by engine expansion and thrust mechanism and to allow a reasonable amount of lateral motion to prevent binding.

The engine jet was discharged into the exhaust portion of the test chamber in which the high-velocity gases entered a diffuser located directly downstream of the jet nozzle. The exhaust gases passed from the diffuser directly into the laboratory exhaust system.

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Instrumentation

Total-pressure tubes and iron-constantan thermocouples were equally spaced around the periphery of the compressor-inlet screens, five each on the front screen and five each on the rear screen. Control of ram pressure and ram temperatures was based on the readings of these pressure probes and thermocouples.

A bayonet-type, chromel-alumel thermocouple was installed in each combustor outlet and connected to dial-type indicators in order that flame blow-out in any of the combustors could be easily detected.

Engine tail-pipe temperatures were measured by 14 chromel-alumel thermocouples equally spaced about the periphery of the tail pipe into which they protruded about 4 inches. These thermocouples were located immediately downstream of the tail cone. A total- and static-pressure tube rake was also located in the tail pipe about 1 diameter downstream of the thermocouples. The altitude pressure was measured by two static tubes located in the exhaust portion of the altitude chamber near the bulkhead.

Temperature of fuel entering the engine was measured by a thermocouple in the fuel line. Fuel consumption was measured by a calibrated variable-area orifice flowmeter, which allowed readings high on the flow scale for any flow rate by changing the orifice setting.

PROCEDURE AND RESULTS

Altitude Performance

Altitude performance was determined by simulating various altitudes and flight Mach numbers in the altitude chamber with the assumption of 100-percent ram recovery at the compressor inlet. Simulated flight conditions included flight Mach numbers of 0.25, 0.60, and 0.85 and altitudes from 5000 to 40,000 feet. The performance investigation was first made using AN-F-58 fuel and then repeated for the same conditions using AN-F-32 fuel.

A comparison of the jet-thrust performance of the two fuels investigated at various altitudes and flight Mach numbers is shown in figures 2 and 3, respectively. The data shown in these figures are typical results for varying altitude and flight Mach number. The results obtained with the two fuels show no appreciable difference in thrust as would be expected provided that no engine deterioration occurred during the runs and no burning occurred downstream of the turbine.

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Fuel consumption in pounds per hour is shown in figures 4 and 5 for the same altitudes and flight Mach numbers presented in figures 2 and 3, respectively. The data show no appreciable difference in fuel consumption obtained with the two fuels and, inasmuch as thrust was likewise unaffected, indicate no difference in specific fuel consumption or burner efficiency.

Indicated tail-pipe temperatures are shown in figures 6 and 7 for various altitudes and flight Mach numbers, respectively. Although a small scatter of data exists, there is no indication of a change in engine operating temperatures when a change is made from one fuel to the other.

Altitude Low-Speed Blow-Out Limits

The low-engine-speed blow-out limits were obtained at altitudes as high as 60,000 feet. Conditions simulating desired altitudes and flight Mach numbers were maintained in the altitude chamber; then with the automatic speed regulator bypassed (inoperative), engine speed was reduced very slowly until one burner had blown out. In general, such blow-out was easily detected by observing the temperatures indicated by 14 thermocouples, one located in each burner outlet. Blow-out was indicated when one of the gage readings dropped to a relatively low value. Engine fuel flow was then increased and the low gage reading would suddenly rise to approximate the other gage readings indicating a reignition thereby verifying the blow-out. At altitudes above 40,000 feet, however, burner temperature did not markedly decrease. At these conditions blow-out was detected by the rapid engine deceleration that accompanied blow-out and by failure of the engine to accelerate with increase in fuel flow.

The low-speed blow-out limits are shown in figure 8 for various flight Mach numbers and altitudes. As can be seen, AN-F-58 fuel was superior to AN-F-32 fuel as blow-out occurred at 5 to 10 percent lower engine speed at all altitudes and flight conditions, indicating a wider range of engine operation without danger of blow-out.

Idling Limits of Fuel-Metering Control

Engine idling limits as regulated by the fuel-metering control were obtained using each fuel over a range of simulated altitudes and at flight Mach numbers of 0.25, 0.60, and 0.85. The throttle was placed in the idling position and engine speed allowed to stabilize at the regulated idling limit. Results are shown in figure 9 in which it is seen that with AN-F-58 fuel the engine idling speed was about 2 to 6 percent higher than the idling speed with AN-F-32 fuel. The change in idling speed is probably caused by the change in mass flow through the fuel-metering control that results from use of fuels of different density and viscosity. The use of AN-F-58 fuel will therefore require a change in the automatic-fuel-metering control if the same engine-speed range is to be retained at altitude.

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Altitude Windmilling Starts

In order to obtain the starting limits of the J33-A-23 engine, ram pressure, temperature, and altitude exhaust conditions were established in the altitude chamber and engine windmilling speed was allowed to stabilize before an attempt was made to start the engine. Both fuels reached the engine at a temperature of approximately 60° F. Attempts to start were made at conditions representing altitudes at intervals of 5000 feet at flight Mach numbers of 0.25, 0.40, 0.60, and 0.85. If the engine failed to start within 30 seconds from the time ignition and fuel were supplied to the engine, the attempt was considered a failure and a second attempt was made at the same conditions. If the second attempt also failed, this altitude was considered to be above the starting altitude limit of the engine. Altitude conditions were then reduced 5000 feet to the last altitude at which a successful start had been made. If the engine again started at this condition, this altitude was considered the limiting altitude at which a windmilling start could be made.

Because of difficulties with the automatic-starting control, which may have been due to lack of an adequate fuel-system filter, only manual-throttle controlled starts are reported. The manual starts were made by allowing the engine speed to stabilize under windmilling conditions; the ignition was then turned on and the throttle momentarily opened to about the one-half open position and then returned to the idling position. The burst of fuel supplied by momentarily opening the throttle serves to supply sufficient fuel under pressure to give a good spray, which allows comparatively cool starts because the engine is not loaded with fuel. If the engine did not start within 30 seconds, the throttle was closed and the engine purged by blowing air through the engine for approximately 5 minutes.

For both fuels, the altitude limit for windmilling starts increased with increase in Mach number at the lower flight speeds (fig. 10). Altitude limit was constant for AN-F-32 fuel above a Mach number of 0.60 and for AN-F-58 above a Mach number of 0.40.

At Mach numbers of 0.25 and 0.40, the altitude limit of AN-F-58 fuel was 20,000 feet greater than that of the AN-F-32; at Mach numbers of 0.60 and higher it was 15,000 feet greater. The AN-F-58 fuel thus exhibits improved performance over AN-F-32 fuel with respect to altitude limit for windmilling starts.

Carbon-Deposition Rates

No investigation was made to determine carbon-deposition rates of the two fuels but a qualitative comparison was made from data obtained during the foregoing part of the investigation. Photographs of spark-plug carbon deposits were made at each inspection of the spark plugs and photographs of the burner liner and dome deposits were made at the end of the investigation with each fuel. The carbon deposits after approximately $14\frac{1}{4}$ hours of operation with AN-F-58 fuel are shown in figure 11(a). The carbon deposits on the ceramic insulator, the spark-plug body, and the electrodes were soft and easily removed. Figure 11(b) is a similar photograph of carbon deposits after approximately 11 hours of operation with AN-F-32 fuel. These deposits were much lighter than for the $14\frac{1}{4}$-hour operation with the AN-F-58 fuel. In order to provide a better comparison, a photograph of the carbon deposits accumulated during a run of $23\frac{1}{4}$ hours with the AN-F-32 fuel is presented in figure 11(c). The carbon deposits again are lighter than those obtained in figure 11(a), indicating a somewhat higher carbon-deposition rate for the AN-F-58. Ignition failure was not caused by spark-plug contamination at any time with either fuel.

Typical carbon deposits in the burner-liner inlet are shown in figure 12. This typical deposit resulted from approximately $45\frac{1}{4}$ hours of operation with AN-F-58 fuel. Similar deposits, although not quite so heavy, were obtained with the AN-F-32. Burner domes after operation with either fuel were covered with a light carbon deposit. In general, the carbon-deposition rate was somewhat higher when using AN-F-58 fuel but insofar as can be determined for limited periods of operation, these carbon formations were not detrimental to engine operation or performance.

Iron Oxide Contamination

During the part of the program using AN-F-58, a gradual deterioration of the distribution of temperature from burner to burner occurred, that is, some burners were operating at higher temperatures than others and the spread in temperature from burner to burner appeared to be increasing. The fuel injectors were therefore removed from the engine for examination and the fuel-injector filters were found to be coated heavily with a reddish-brown material, which chemical analysis identified as iron oxide. A number of the fuel injectors and the variations in the coating of the filters are shown in figure 13. One filter element had accumulated sufficient iron oxide to cause its collapse.

A complete examination of engine filters and fuel-system filters showed that two fuel-system filters had removed only the larger particles of iron oxide. The main engine fuel filter (50-micron spacing screen) had removed some additional material; the filters in the fuel lines in the air adapters just upstream of the fuel-injector filters (50-micron size) were clean; and the 10-micron spacing filters in the fuel injectors had accumulated considerable material passed by all the larger filters.

Malfunctioning of the automatic-starting control previously mentioned resulted from accumulation of iron oxide on its inlet screen to the point at which the screen finally ruptured and dumped the residue into the control mechanism.

An examination of AN-F-58 fuel samples taken during the investigation showed the same type particles as were found in the engine filters. The iron oxide may have been picked up from tank cars, storage tanks, or piping systems. This difficulty has not been encountered with fuels previously used probably because they had remained in storage long enough for the foreign particles to settle out. Although this contamination is probably a result of rapid handling of the fuel, it is of particular importance because in a national emergency, fuels for turbine engines would require rapid handling in much the same manner as the AN-F-58 fuel used in this investigation and precautions would have to be taken to remove any possibility of engine malfunctioning as a result of iron-oxide contamination.

Inasmuch as aircraft using the engine investigated are currently equipped with 10-micron filters between aircraft fuel booster pumps and the inlet of the engine-driven fuel pump in accordance with the engine manufacturer's specifications (reference 1), flight installations are in general protected from such foreign particles. If the aircraft filter becomes clogged, however, the fuel will be by-passed around the filter through a safety valve. The engine would then receive unfiltered fuel.

SUMMARY OF RESULTS

The results of the comparative altitude performance investigation of AN-F-58 and AN-F-32 fuels in the J33-A-23 turbojet engine may be summarized as follows:

1. No appreciable change in engine thrust and fuel consumption nor in engine operating temperatures occurred when a change was made from AN-F-32 to AN-F-58 fuel.

2. The AN-F-58 fuel allowed windmilling starts to at least 15,000-foot higher altitudes than was possible with AN-F-32 fuel.

3. Low-speed burner blow-out occurred at 5 to 10 percent lower engine speed with AN-F-58 fuel than with AN-F-32 fuel, which indicates a wider range of engine operation without danger of engine blow-out.

4. The idling control gave somewhat higher engine idling speeds when using AN-F-58 fuel. Automatic controls would therefore require adjustment if a change in fuels were to be made in service.

5. Although carbon-deposition rates were slightly higher with AN-F-58 fuel, neither spark-plug fouling nor burner-liner carbon deposits were considered troublesome for the periods of operation investigated (total time, $23\frac{1}{4}$ hr).

6. The AN-F-58 fuel contained iron oxide particles, which probably were held in suspension because of rapid handling of the fuel. These particles can cause malfunctioning of engine fuel systems unless suitable protection is provided.

CONCLUSION

From the foregoing summary of performance and operational parameters, it may be concluded that within the limits of this investigation AN-F-58 is essentially equal in performance and in some respects slightly exceeds AN-F-32 fuel in the turbojet engine investigated. The AN-F-58 fuel is therefore considered satisfactory for service flight investigations in the J33-A-23 turbojet engine.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Anon.: Installation and Performance Handbook for J33 Turbo-Jet Engines. Allison Div., General Motors Corp., June 1, 1947.

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.

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TABLE I - SPECIFICATIONS AND ANALYSES OF FUELS USED

NACA fuel	Specifications		Analyses	
	AN-F-32	AN-F-58	AN-F-32	AN-F-58
			48-306	48-249
A.S.T.M. distillation, D 86-40, °F				
Initial boiling point	---------	---------	336	110
Percentage evaporated				
5	---------	---------	349	135
10	410(max.)	---------	355	157
20	---------	---------	360	198
30	---------	---------	365	230
40	---------	---------	370	272
50	---------	---------	375	314
60	---------	---------	381	351
70	---------	---------	387	388
80	---------	---------	394	427
90	490(max.)	425(min.)	405	473
Final boiling point	572(max.)	600(max.)	446	560
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.)		Below -76
Aromatics, (percent by volume)				
A.S.T.M. D-875-46T	20(max.)	30(max.)	--------	17
Silica gel[a]	---------	---------	15	19
Viscosity, (centistokes at -40° F)	10.0 (max.)	10.0 (max.)		2.67
Bromine number	3.0(max.)	14.0(max.)		13.8
Reid vapor pressure (lb/sq in.)	---------	5 to 7		5.4
Hydrogen-carbon ratio	---------	---------	0.154	0.163
Heat of combustion, (Btu/lb)	---------	18,200 (min.)	18,530	18,640
Specific gravity	0.850(max.)	---------	0.831	0.769
Flash point, °F	110(min.)	---------		---------
Accelerated gum, (mg/100 ml)	8.0(max.)	20.0 (max.)	0	2.9
Air-jet residue, (mg/100 ml)	5.0(max.)	10.0 (max.)	1	3
Sulfur, (percent by weight)	0.20 (max.)	0.50 (max.)	0.02	0.03

[a]Reference 2.

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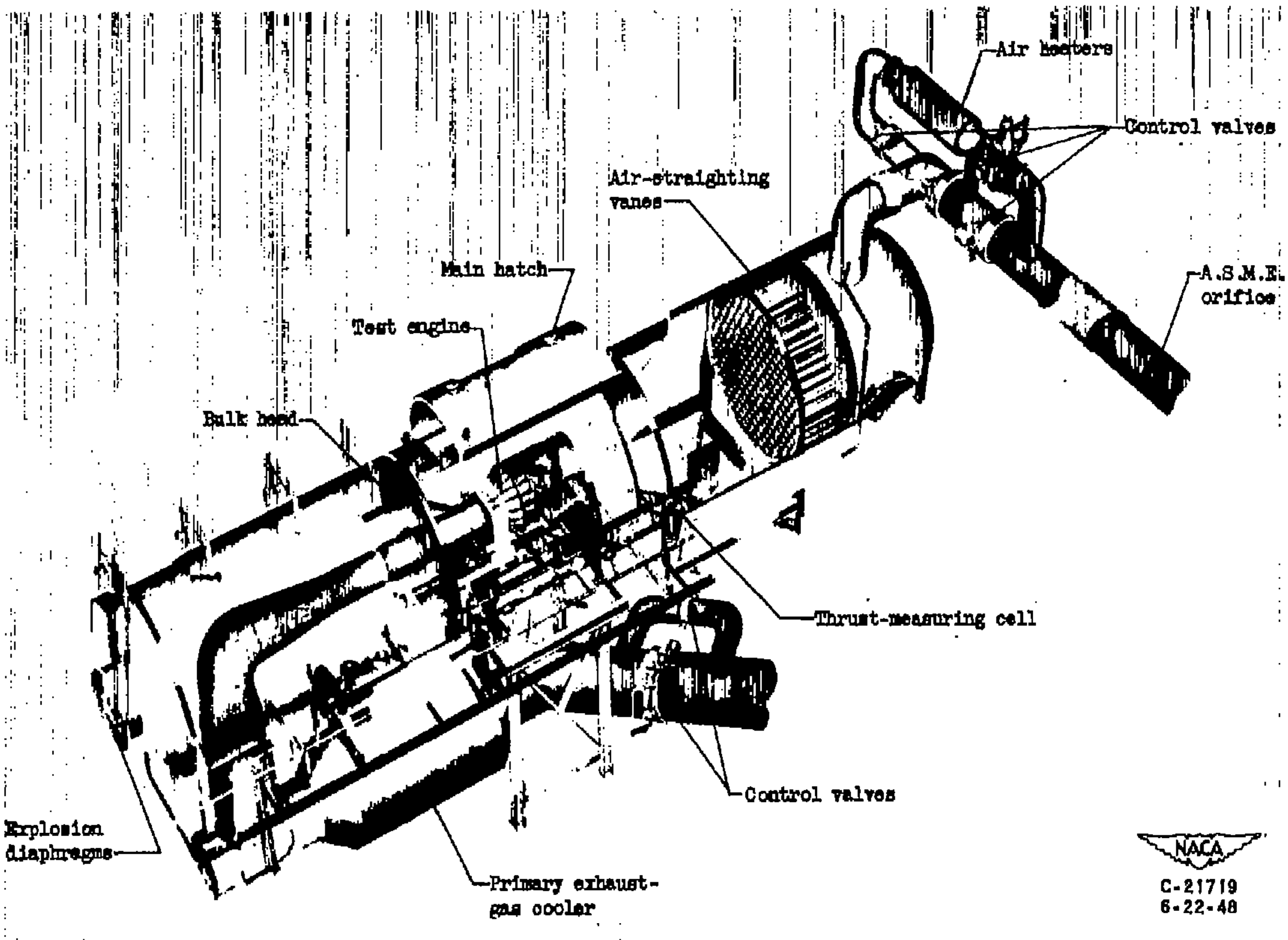

Figure 1. - Altitude chamber showing engine installation.

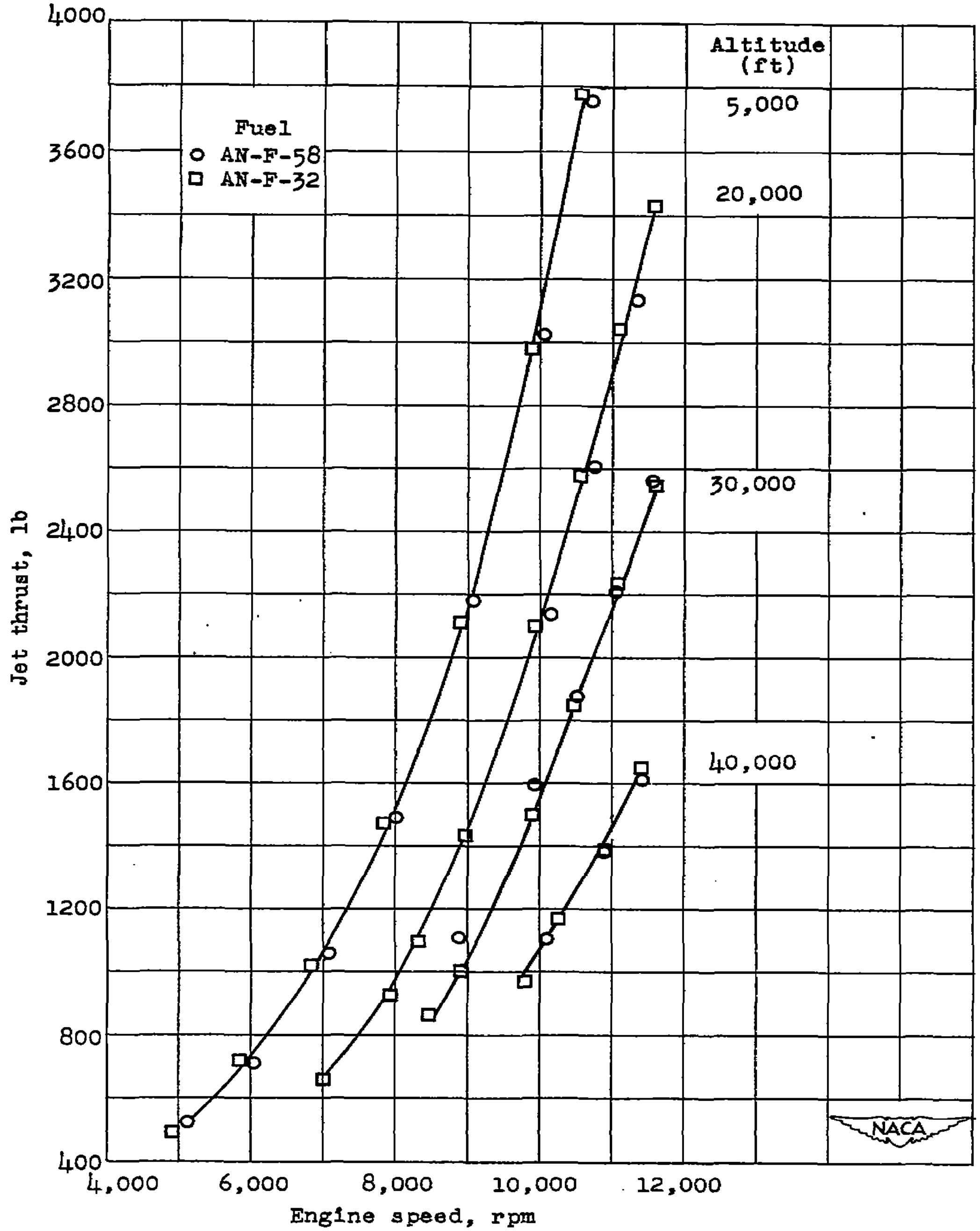

Figure 2. - Jet thrust using AN-F-58 and AN-F-32 fuels at various altitudes. Flight Mach number, 0.60.

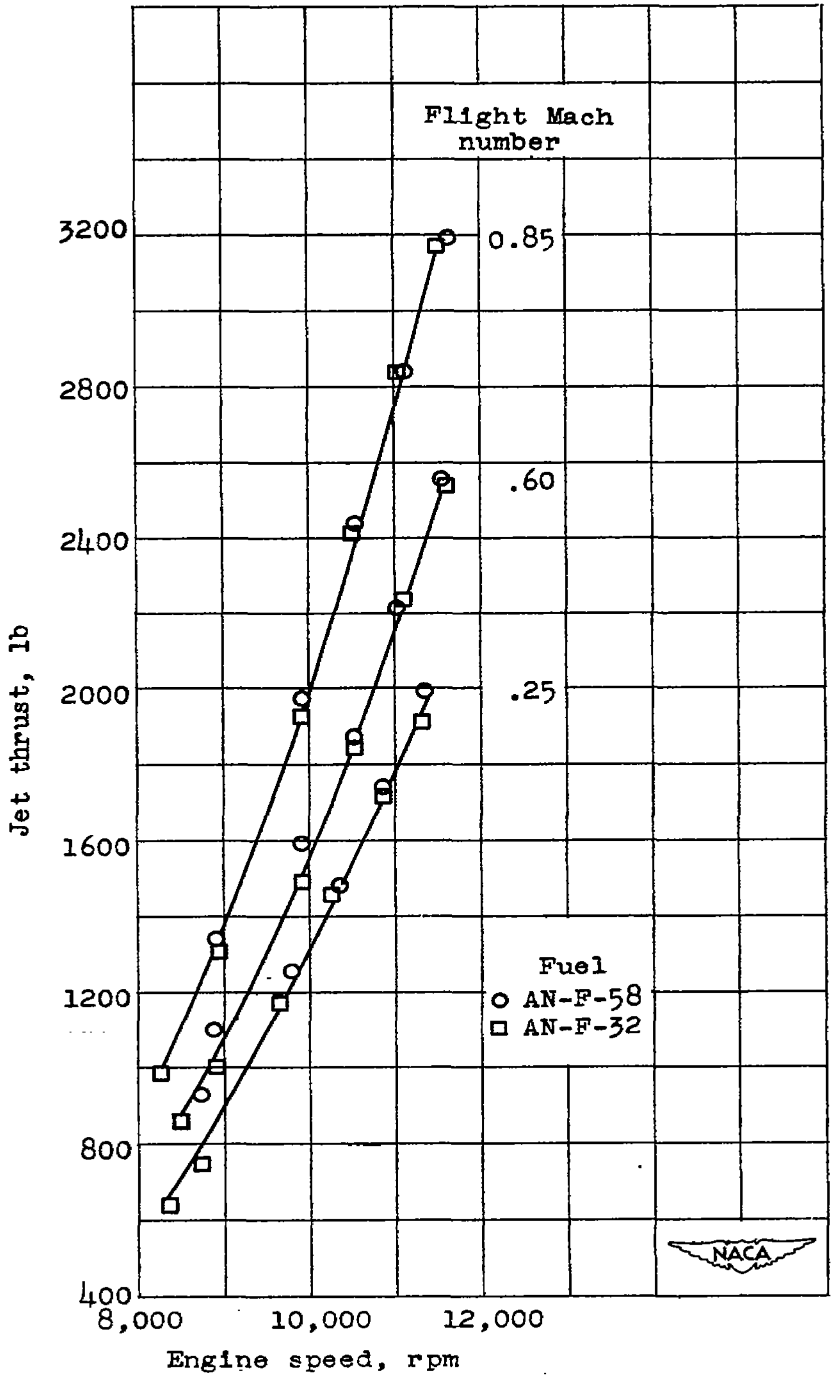

Figure 3. - Jet thrust using AN-F-58 and AN-F-32 fuels at various flight Mach numbers. Altitude, 30,000 feet.

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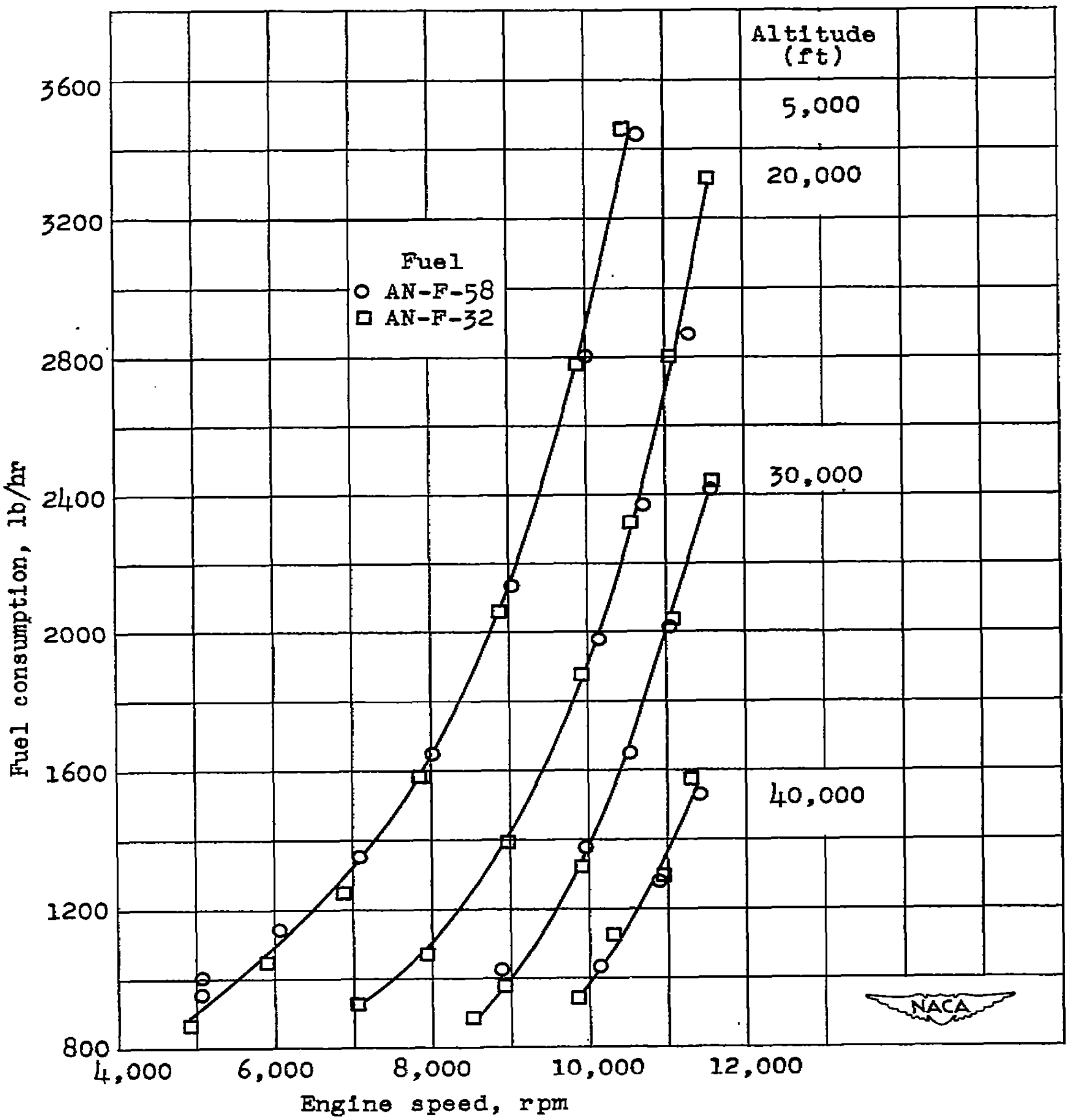


Figure 4. - Fuel consumption using AN-F-58 and AN-F-32 fuels at various altitudes. Flight Mach number, 0.60.

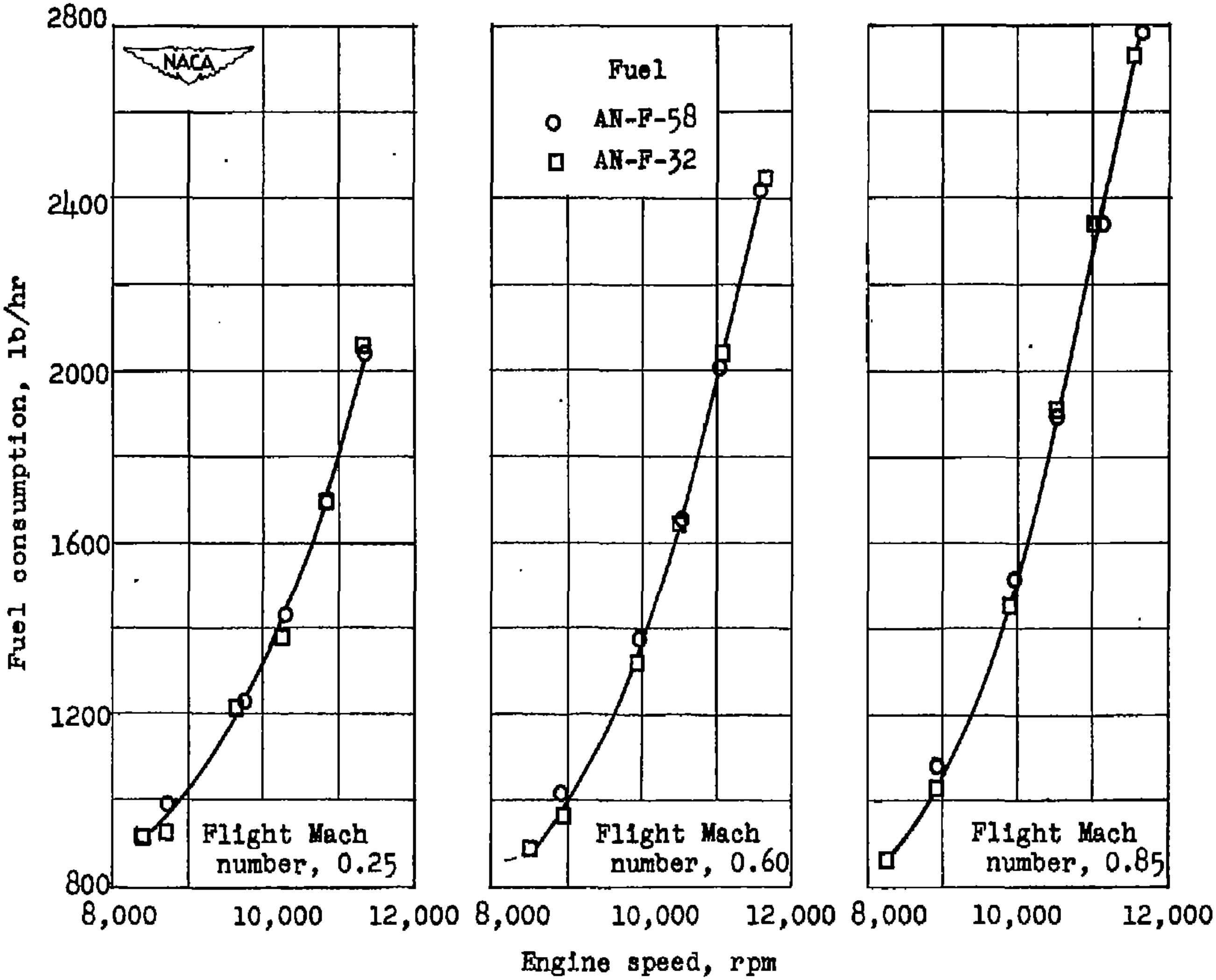


Figure 5. - Fuel consumption using AN-F-58 and AN-F-32 fuels at various flight Mach numbers. Altitude, 30,000 feet.

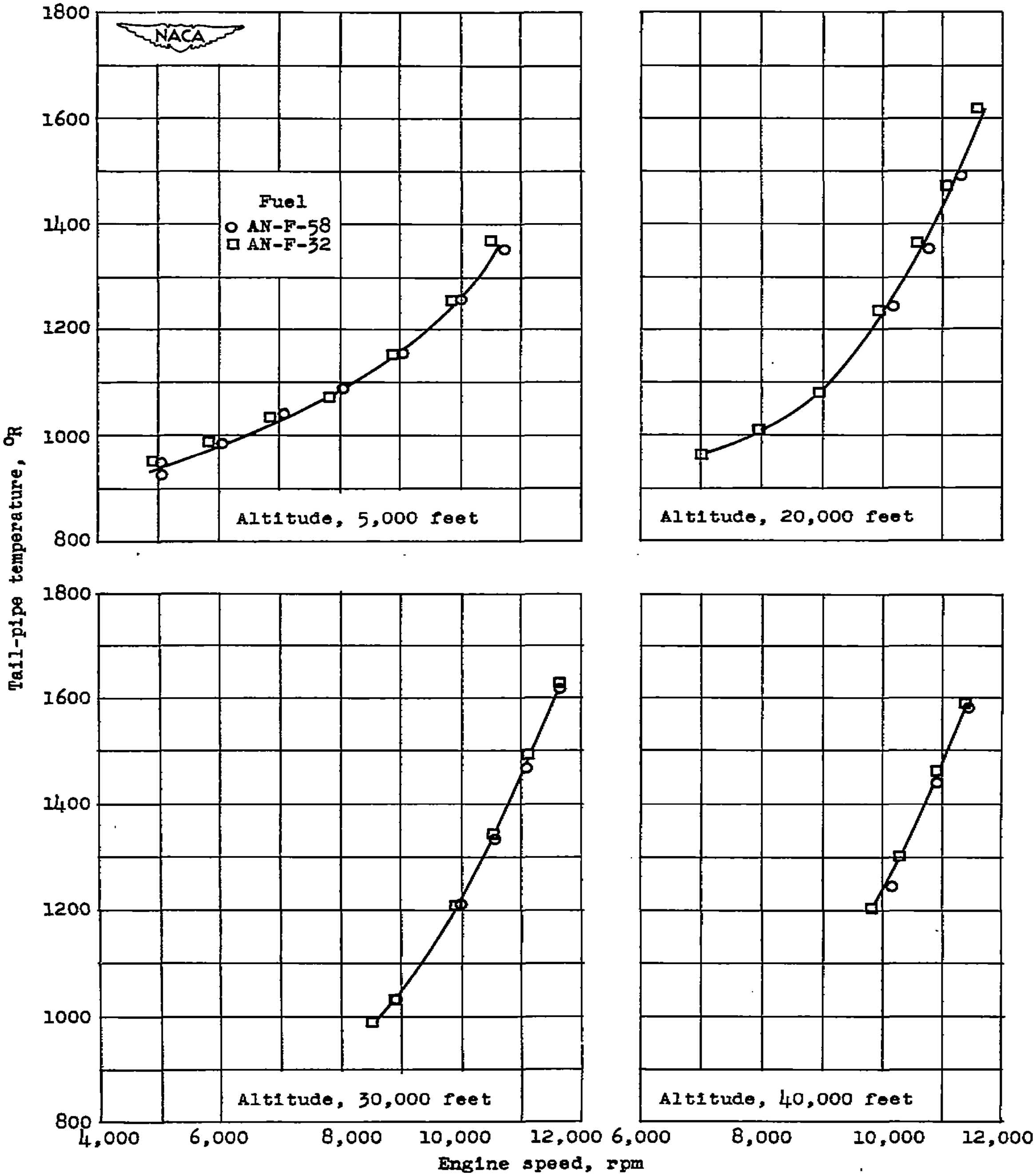


Figure 6. - Indicated tail-pipe temperature using AN-F-58 and AN-F-32 fuels at various altitudes. Flight Mach number, 0.60.

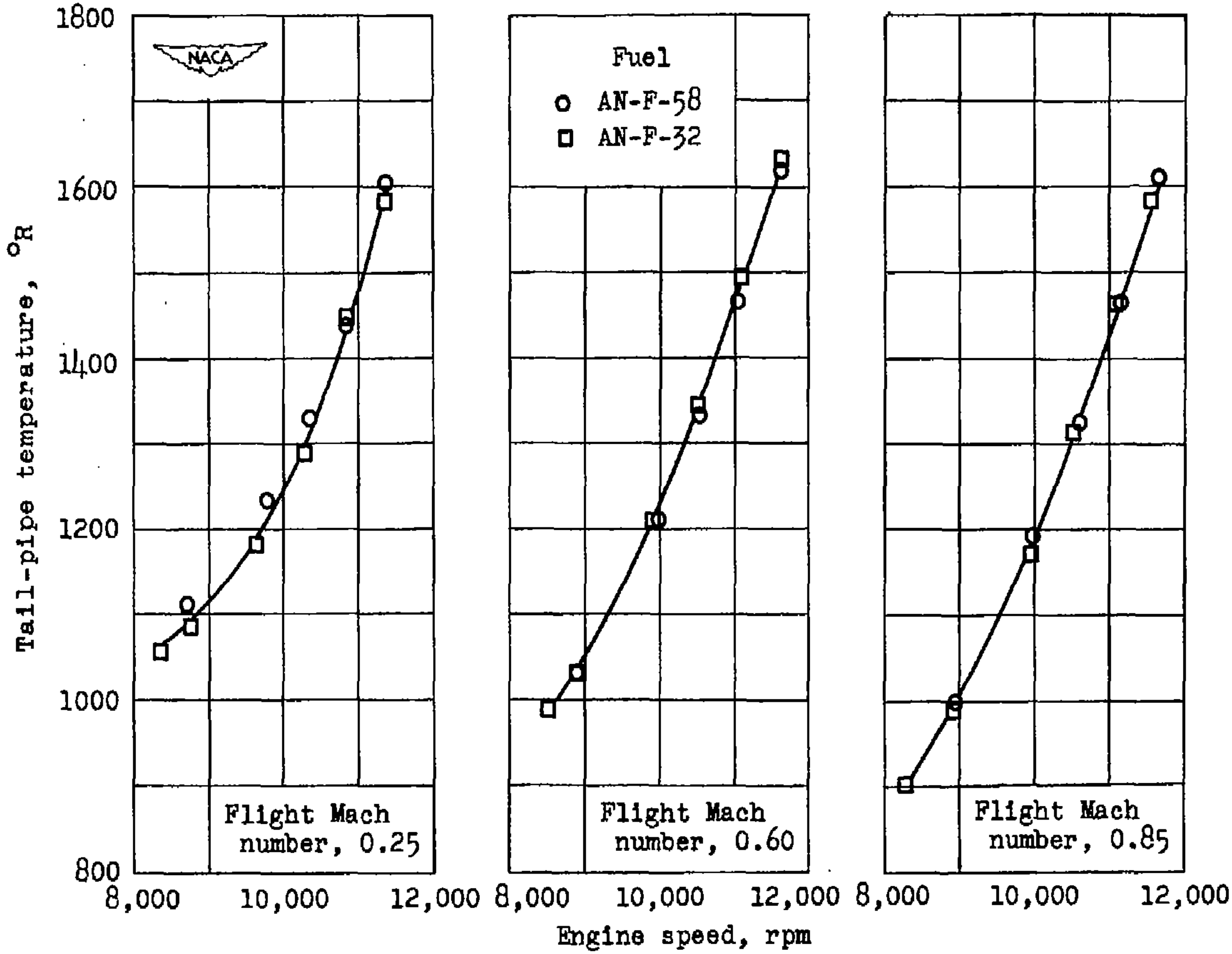


Figure 7. - Indicated tail-pipe temperature of AN-F-58 and AN-F-32 fuels at various flight Mach numbers. Altitude, 30,000 feet.

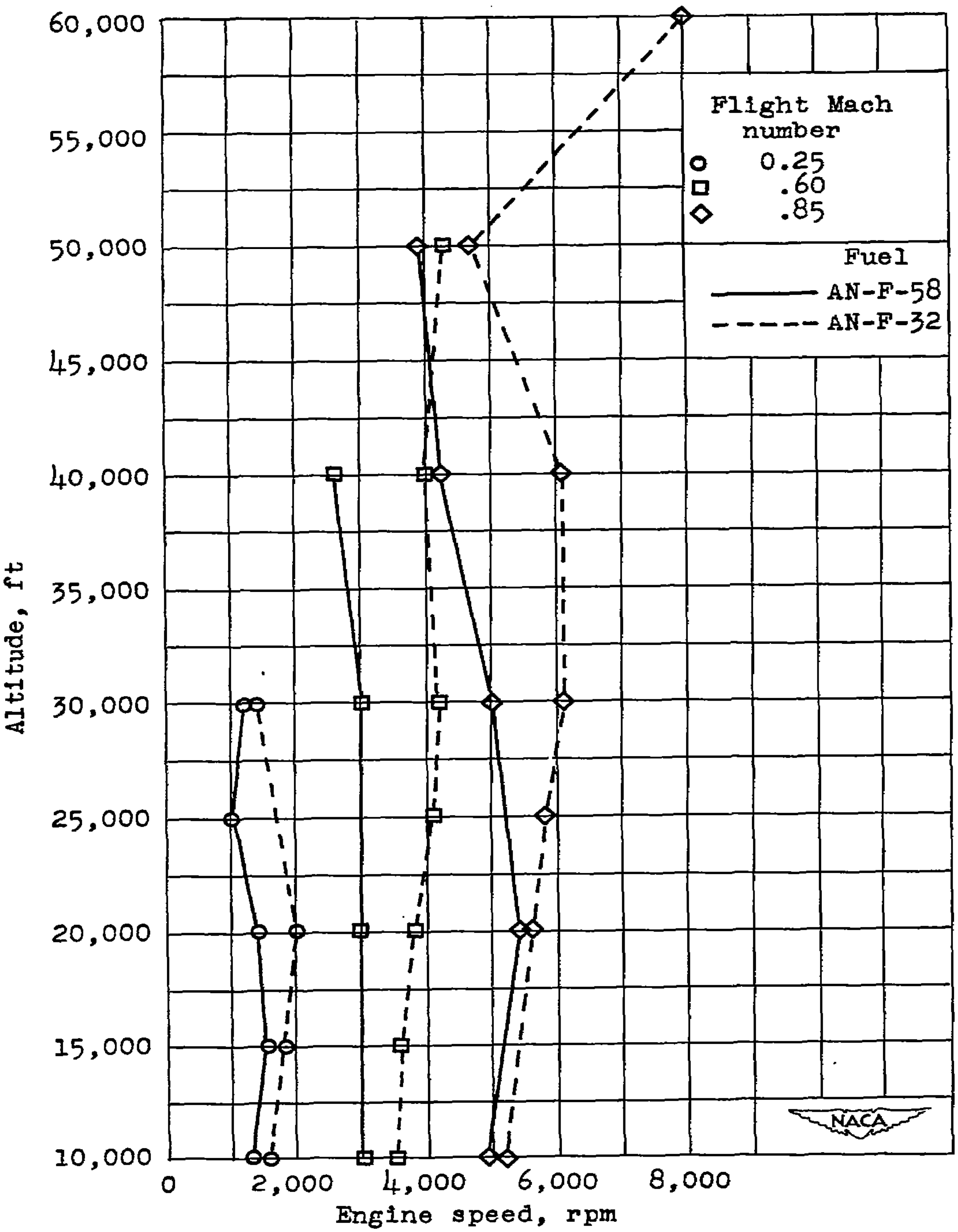


Figure 8. - Low-speed blow-out limits of AN-F-58 and AN-F-32 fuels.

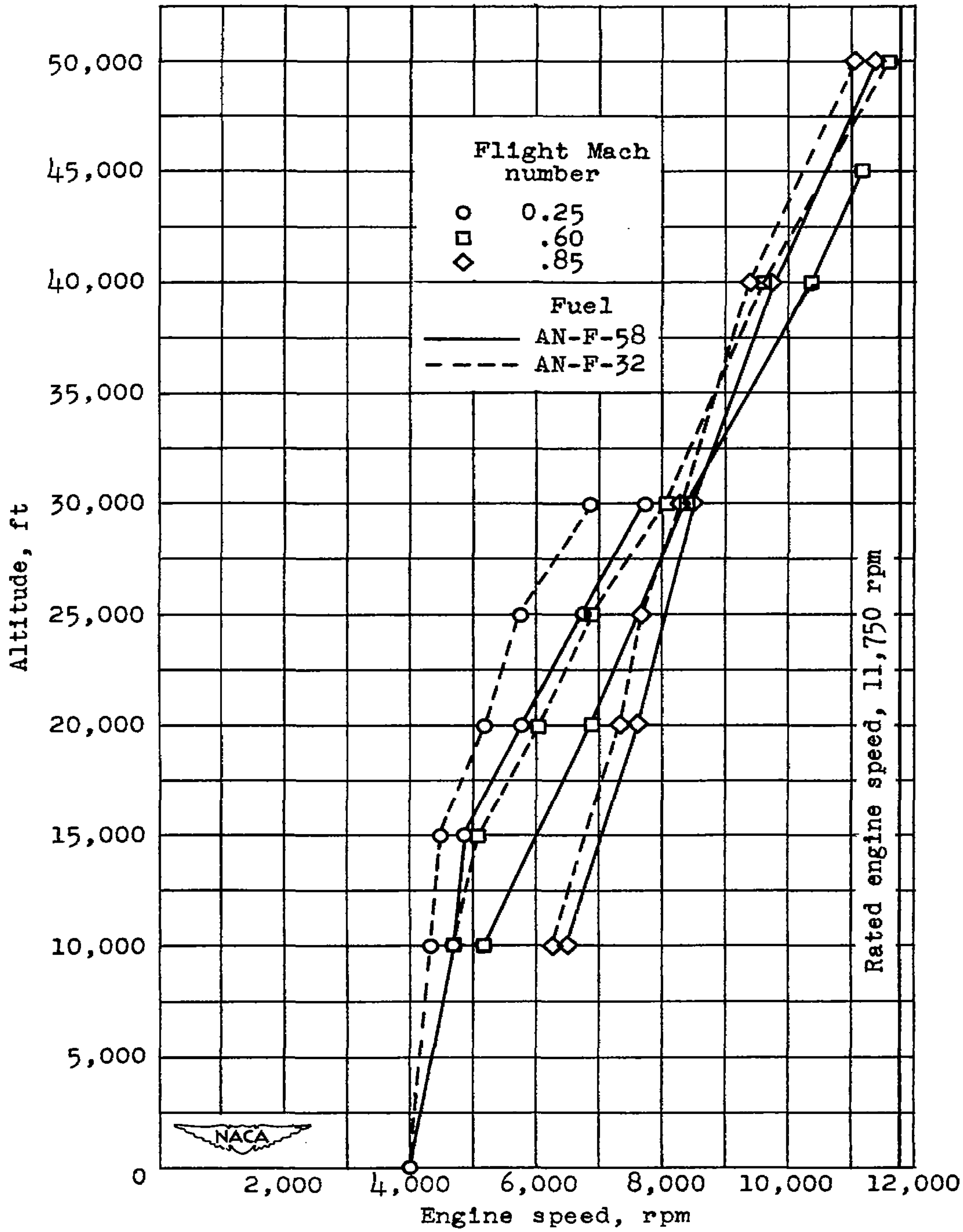


Figure 9. - Idling limits of fuel-metering control using AN-F-58 and AN-F-32 fuels.

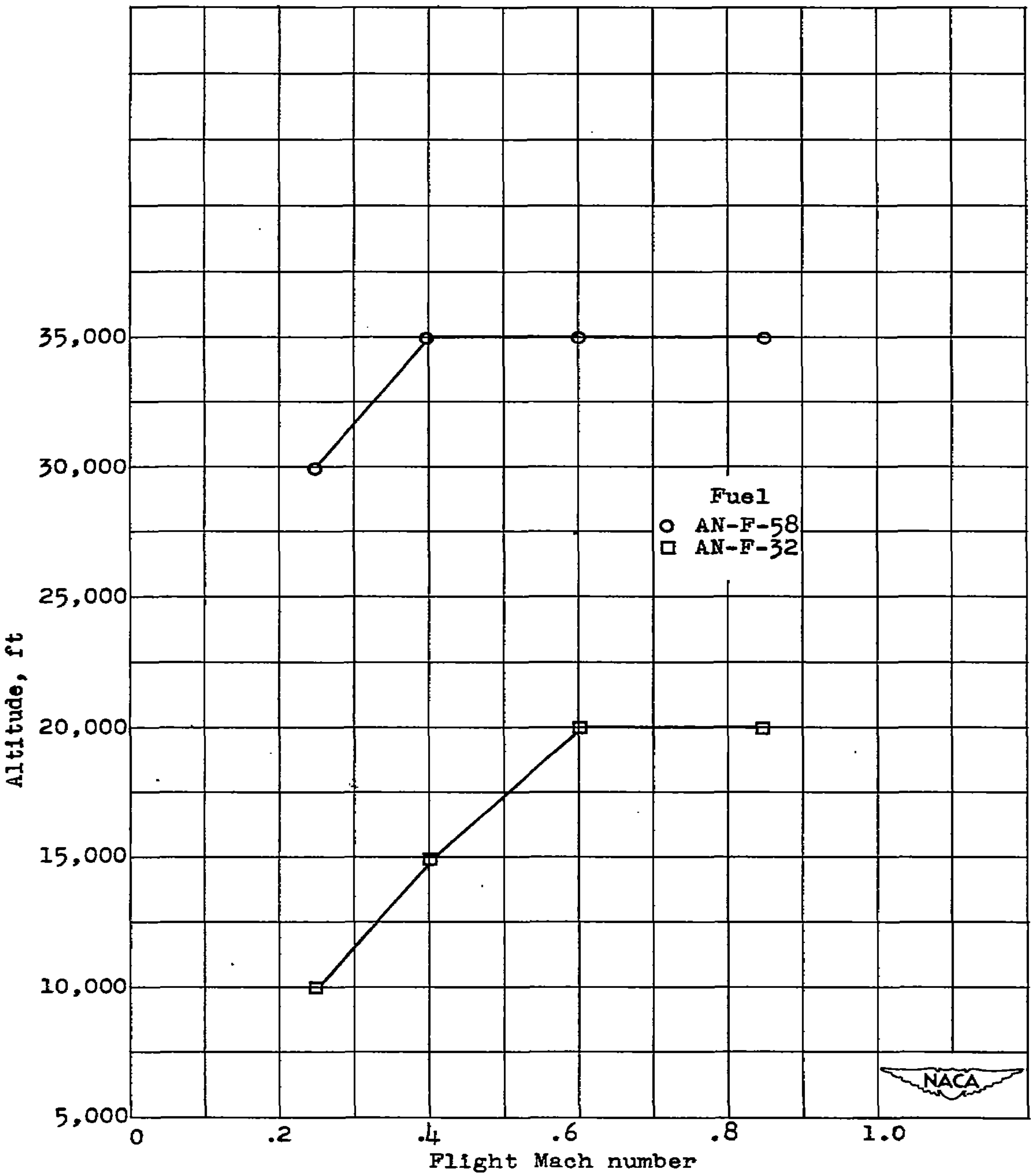
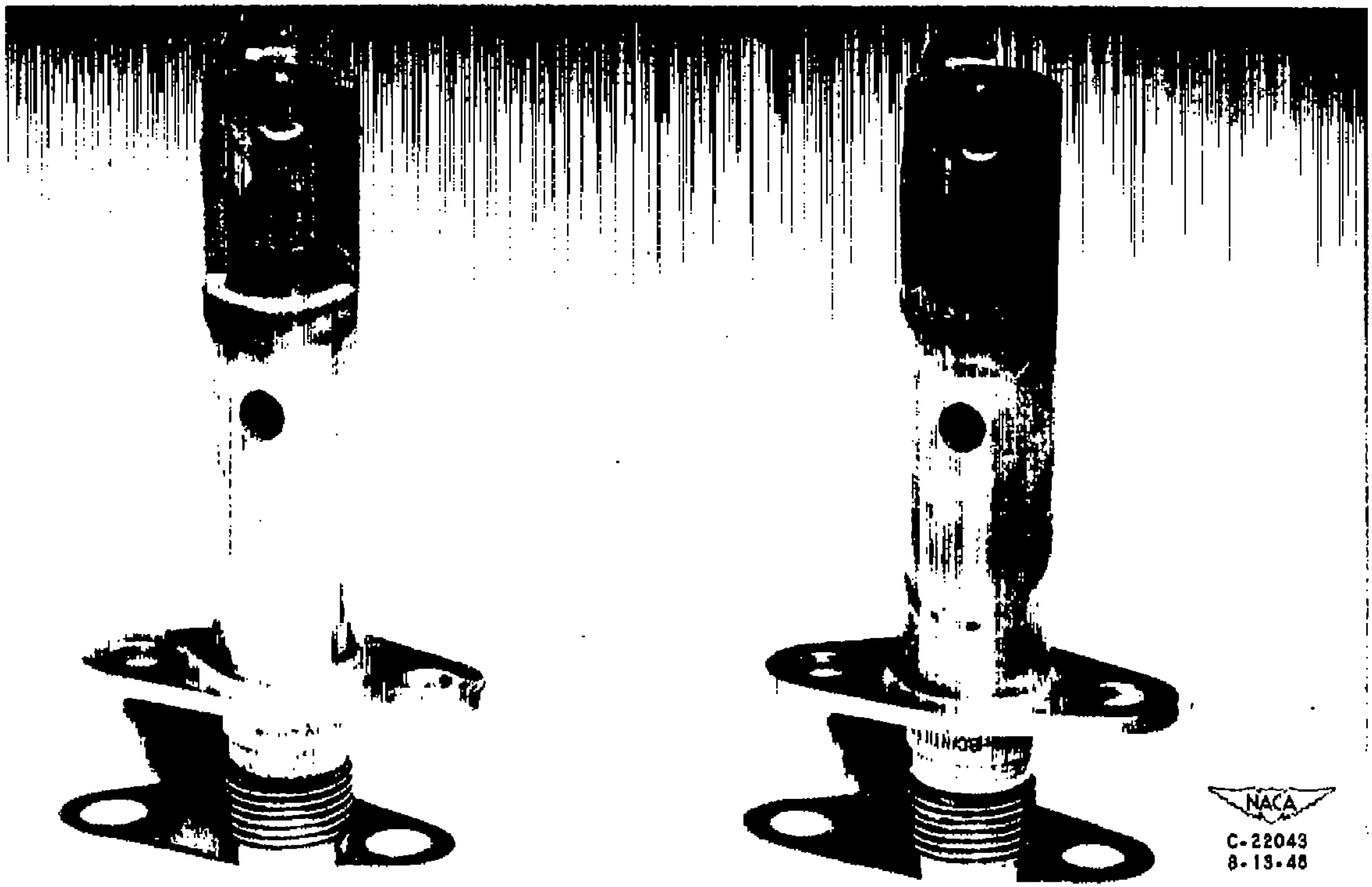
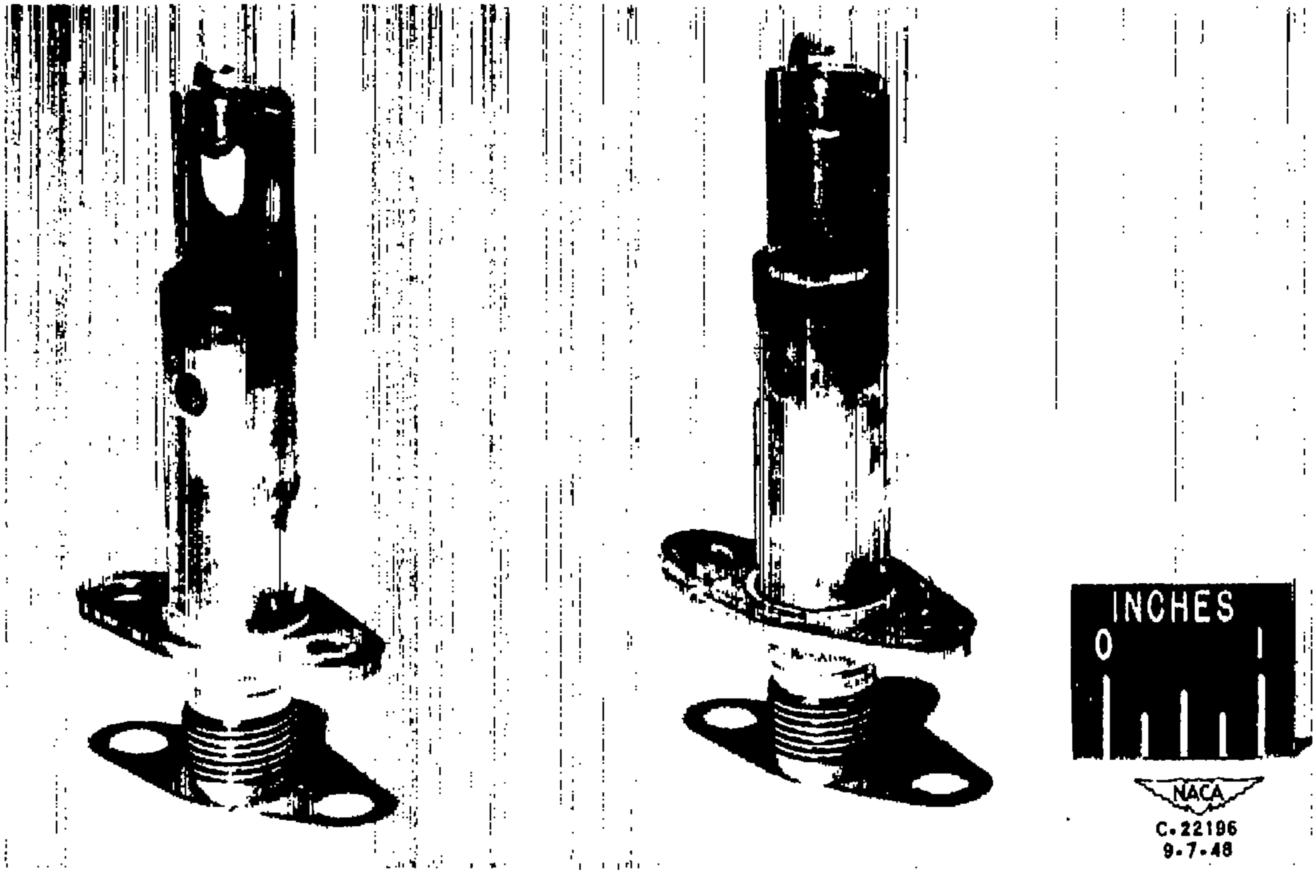


Figure 10. - Maximum altitudes at which windmilling starts were possible (using manual controls) with AN-F-58 and AN-F-32 fuels.



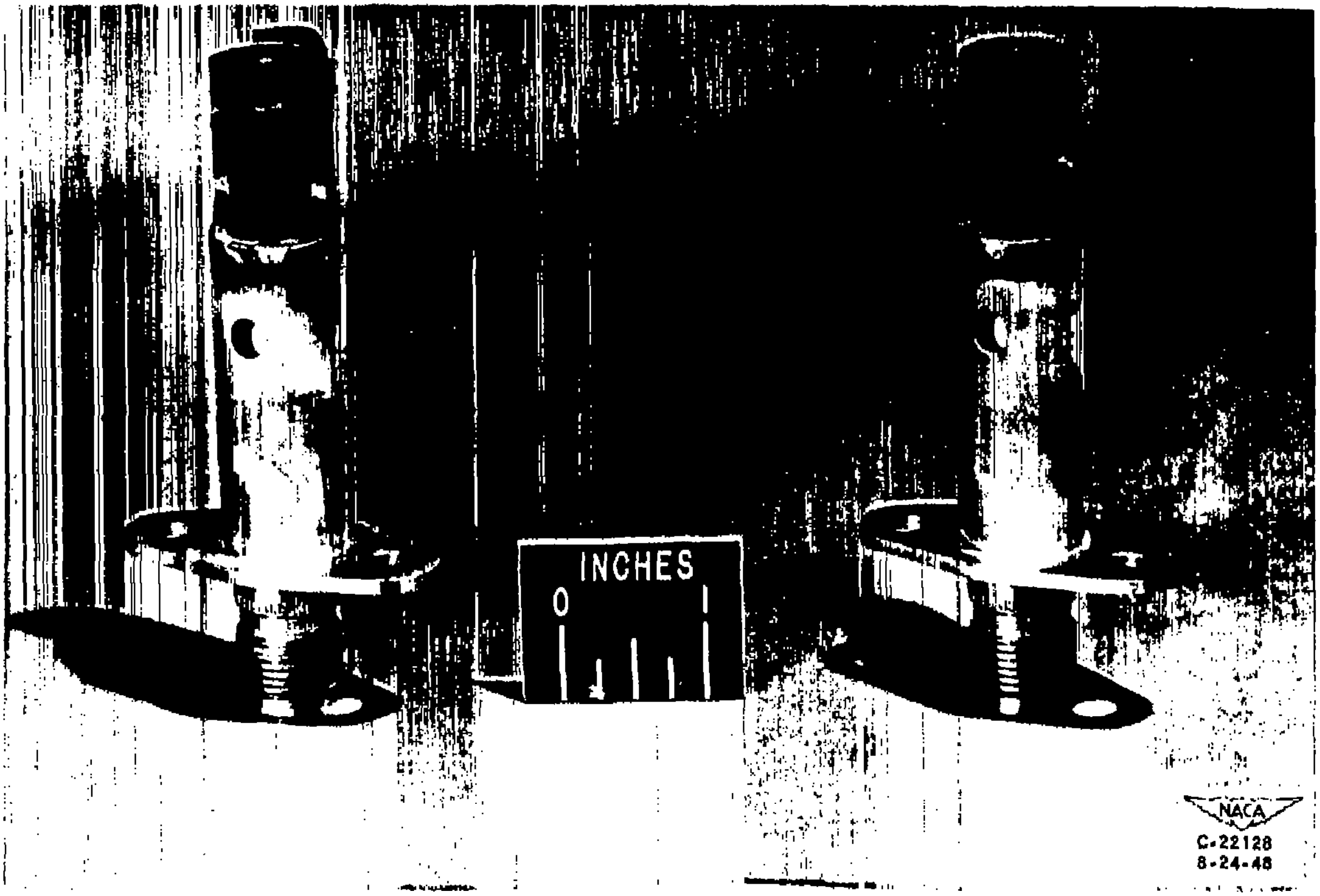
(a) Operating time, $14\frac{1}{4}$ hours; fuel, AN-F-58.

Figure 11. - Spark-plug carbon deposits.



(b) Operating time, 11 hours; fuel, AN-F-32.

Figure 11. - Continued. Spark-plug carbon deposits.



(c) Operating time, $23\frac{1}{4}$ hours; fuel, AN-F-32.

Figure 11. - Concluded. Spark-plug carbon deposits.

Figure 12. - Typical carbon deposits in burner liner from J33-A-23 turbojet engine operating time, $45\frac{1}{4}$ hours.

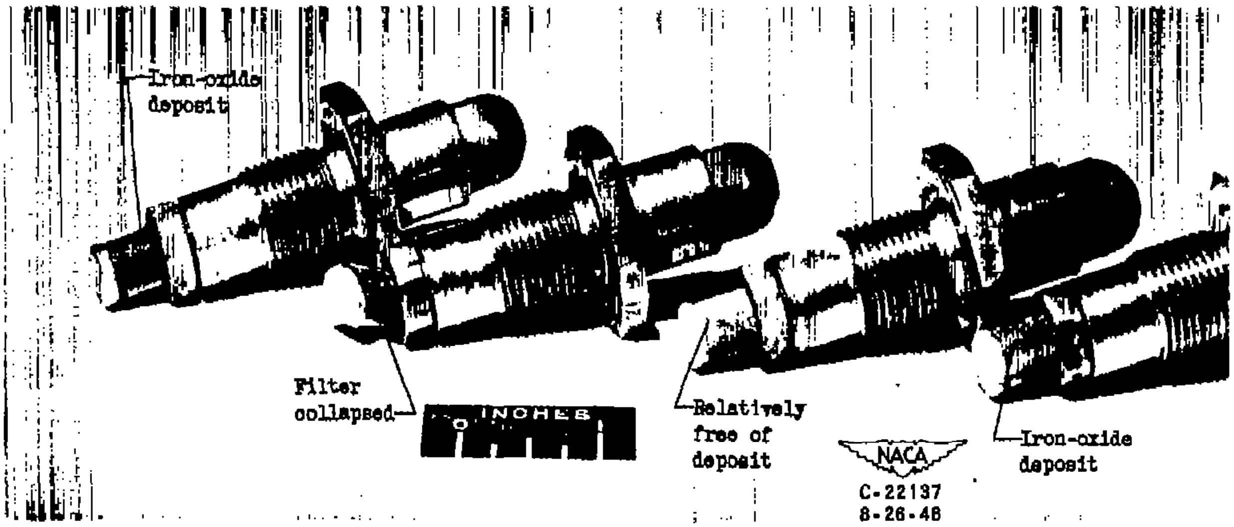


Figure 13. - Fuel injectors showing iron oxide deposits on injector-inlet filters.