[redacted]

RM No. SE8G02

CLASSIFICATION CHANGED TO Uncl
BY AUTHORITY OF Nasa TD-73-403
ON 1/24/74 BY D. Markweather

NACA

RESEARCH MEMORANDUM

for

Bureau of Aeronautics, Department of the Navy

ALTITUDE-TEST-CHAMBER INVESTIGATION OF A SOLAR AFTERBURNER ON THE 24C ENGINE.

I - OPERATIONAL CHARACTERISTICS AND ALTITUDE LIMITS

By Harry W. Dowman and John O. Reller

Flight Propulsion Research Laboratory
Cleveland, Ohio

ENGINEERING DEPT. LIBRARY
CHANCE VOUGHT AIRCRAFT
INCORPORATED
DALLAS, TEXAS

Restriction/Classification Cancelled

...ENT

...ied information ... of the United States within the meaning of the Espionage Act, USC 50:31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law. Information so classified may be imparted only to persons in the military and naval services of the United States, appropriate civilian officers and employees of the Federal Government who have a legitimate interest therein, and to United States citizens of known loyalty and discretion who of necessity must be informed thereof.

TECHNICAL EDITING WAIVED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

JULY 6 1948

[redacted]

RM No. SE8G02

RM SE8G02

998

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for

Bureau of Aeronautics, Department of the Navy

ALTITUDE-TEST-CHAMBER INVESTIGATION OF A SOLAR AFTERBURNER ON THE 24C ENGINE

I - OPERATIONAL CHARACTERISTICS AND ALTITUDE LIMITS

By Harry W. Dowman and John O. Reller

SUMMARY

An altitude-test-chamber investigation was conducted to determine the operational characteristics and altitude blow-out limits of a Solar afterburner in a 24C engine.

At rated engine speed and maximum permissible turbine-discharge temperature, the altitude limit as determined by combustion blow-out occurred as a band of unstable operation of about 8000 feet altitude in width with maximum altitude limits from 32,000 feet at a Mach number of 0.3 to about 42,000 feet at a Mach number of 1.0. The maximum fuel-air ratio of the afterburner, as limited by maximum permissible turbine-discharge gas temperatures at rated engine speed, varied between 0.0295 and 0.0380 over a range of flight Mach numbers from 0.25 to 1.0 and at altitudes of 20,000 and 30,000 feet. Over this range of operating conditions, the fuel-air ratio at which lean blow-out occurred was from 10 to 19 percent below these maximum fuel-air ratios.

Combustion was very smooth and uniform during operation; however, ignition of the burner was very difficult throughout the investigation. A failure of the flame holder after 12 hours and 15 minutes of afterburner operation resulted in termination of the investigation.

ENGINEERING DEPT. LIBRARY
CHANCE VOUGHT AIRCRAFT
INCORPORATED
DALLAS, TEXAS

APR 26 1955

[redacted]

998

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, (TED-NACA-PP-203) an investigation has been conducted in a Cleveland NACA 10-foot altitude test chamber to determine the operational and performance characteristics of various types of afterburner on the 24C engine. The first phase of an investigation of an afterburner manufactured by the Solar Aircraft Company, in which the operational characteristics and altitude limit of the afterburner were determined, is presented.

The altitude blow-out limits at various engine operating conditions are presented for a range of simulated flight Mach numbers from 0.25 to 1.0. The operational range of afterburner fuel flows is also presented for zero ram conditions at an altitude of 5000 feet and for a range of flight Mach numbers at altitudes of 20,000 and 30,000 feet. The problems of burner ignition, the stability of burner operation, and the structural failures that occurred are also discussed.

APPARATUS AND INSTRUMENTATION

A sketch of the Solar afterburner is shown in figure 1. The afterburner has an over-all length of about $8\frac{1}{2}$ feet and a maximum internal diameter of 23 inches. Shell cooling of the burner section is accomplished by an ejector cooling jacket, which utilizes the exhaust jet to pump air from approximately altitude static pressure in the test chamber over the burner. An inner cooling jacket accelerates the cooling air over the burner shell to increase the cooling effectiveness.

The flame holder and the fuel injection system are shown in sections A and B of figure 1 as well as in figure 2. The flame holder consists of two semicircular, gutter-type rings joined with four radial struts of similar construction. Both the rings and radial struts are provided with small transverse slots on the upstream face. The mean diameters of the inner and outer flame-holder rings are $8\frac{5}{8}$ inches and $19\frac{1}{4}$ inches, respectively. Both the rings and struts have a maximum width of $1\frac{1}{4}$ inches and together provide approximately 31 percent blocked area. The fuel is injected through a series of small holes drilled in circular manifolds located 1/2 inch upstream of the flame holder. Two fuel manifolds located between the flame-holder rings and a third manifold within the inner flame-holder ring spray fuel directly upstream; two other

fuel manifolds located directly upstream of the flame holders (see fig. 1; not visible in fig. 2) spray fuel downstream through the slots in the flame holder. A total of 161 holes of 0.025-inch diameter are drilled in the five manifolds. The fuel-injection pressure was about 100 pounds per square inch for a flow of 6000 pounds per hour.

Ignition of the burner was originally provided by a single spark plug located with its gap in the sheltered zone behind the outer flame-holder ring. The second spark plug shown in figure 2 was installed during the investigation. The discharge of the burner was fitted with a pneumatically controlled, two-position clam-shell-type exhaust nozzle having an equivalent circular diameter of $15\frac{3}{8}$ inches in the closed position and a diameter of $18\frac{7}{16}$ inches in the open position.

The investigation of the Solar afterburner was conducted on a modified 24C-4B engine (serial No. WE-002037) having a rated engine rotor speed of 12,500 rpm and a limiting turbine-discharge temperature of 1300° F. For investigation of normal performance, the engine was fitted with an NACA design adjustable-area exhaust nozzle.

The fuel used in both the afterburner and engine was 62-octane gasoline (AN-F-22).

The general arrangement of the engine setup in the altitude test chamber is shown in figure 3. A photograph of the engine in the test section of the chamber is presented in figure 4. The test chamber is 10 feet in diameter and 57 feet long and is of welded-steel construction. The entire surface of the chamber from the forward baffle to the exhaust end, as well as the exhaust piping, is cooled by a water jacket. A honeycomb is installed in the test chamber upstream of the test section to straighten and smooth the flow of inlet air. The engine was mounted on a thrust platform, which was supported on ball-bearing pivoted supports. A keyed arm is connected to the shaft connecting the two front supports, and is supported by a balanced pressure diaphragm for measuring the thrust.

The forward baffle, which incorporated a flexible neoprene impregnated diaphragm, was used to confine the air flow to the engine inlet and to provide a means of maintaining a pressure difference across the engine. The 24C engine was fitted to the flexible airtight diaphragm by means of the nozzle section shown in figure 3. A 12-inch butterfly valve was installed in the bottom of

the tank along with suitable ducting to induce cooling air to flow along the engine by virtue of the altitude pressure in the tank. The rear baffle was installed to act as a radiation shield and to prevent recirculation of exhaust gases about the engine. A 5-inch sheet of glass-fiber insulation was installed on the downstream side of the rear baffle with a covering of sheet Inconel to protect the rear baffle from the extremely hot exhaust gases during afterburner operation. The outer cooling shroud (fig. 5) surrounding the tail pipe was installed to prevent recirculation of the exhaust gases around the outside of the burner, downstream of the rear baffle, thus protecting the instrumentation as well as the burner. The intermediate shroud between the outer shroud and the burner cooling jacket was fitted closely to the burner cooling jacket and supported on the outer shroud in order to minimize the flow of cooling air over the outside of the burner cooling jacket and hence its drag on the burner. Although the drag of the cooling air over the engine proper was evaluated by calibration, this minimization of the cooling-air drag over the burner jacket was necessary because of the varying and indeterminate amount of air pumped through the jacket by the exhaust jet at the various operating conditions.

A periscope was installed in the engine control room so that operation of the afterburner could be observed.

Engine fuel flow, afterburner fuel flow, air flow, rotor speed, and pressure and temperature measurements at various stations in the engine, afterburner, and test chamber were measured with standard instrumentation. The turbine-discharge gas temperature was measured by the engine manufacturer's three stagnation- (aspirating) type thermocouples located in the supporting struts of the exhaust collector. The readings of these thermocouples were calibrated against the calculated turbine-inlet temperature in order to provide an indication of the engine manufacturer's specified maximum turbine-inlet temperature limit of 1425° F. A reading of 1300° F was determined as the maximum permissible turbine-discharge temperature.

PROCEDURE

The operational limits of the Solar afterburner were investigated in two phases:

(1) Determination of altitude blow-out limit of operation over range of simulated flight Mach numbers

998

(a) Preliminary tests at engine rotor speed of 11,000 rpm; turbine-discharge temperature well below limiting value

(b) Tests at engine rotor speed of 12,500 rpm; maximum permissible turbine-discharge temperature (called balanced-cycle operation)

(2) Determination of operational range of afterburner fuel flow at altitude of 5000 feet, zero ram, and at 20,000- and 30,000-foot altitude over range of simulated Mach numbers

The afterburner was usually started at a pressure altitude of approximately 7000 feet, a ram pressure ratio of 1.07 across the engine, and engine rotor speed of 9000 rpm. Immediately after ignition of the afterburner had been obtained, the exhaust nozzle was opened and the engine speed, afterburner fuel flow, altitude, and ram pressure were adjusted to the desired operating conditions. During the preliminary investigation of altitude blow-out limit (engine rotor speed, 11,000 rpm) the rotor speed was held constant and pressure altitude increased until blow-out occurred. The afterburner fuel flow was regulated to maintain what appeared to be a stable and satisfactory operating condition as viewed through the periscope. The more extensive investigation of altitude blow-out limit at rated engine rotor speed was conducted in a slightly different manner. As soon as stable operation of the afterburner had been obtained the engine rotor speed was increased to the rated value and the pressure altitude was increased until blow-out occurred. Balanced-cycle operation at rated rotor speed was maintained during the increase in altitude by proper adjustment of engine and afterburner fuel flows. Blow-out was detected by the change in noise level, the surge of operating conditions such as altitude pressure and engine speed, and by visual observations of the exhaust flame through the periscope.

Operational ranges of afterburner fuel flow were established by first recording data while operating the burner on balanced cycle at given conditions of pressure altitude and simulated Mach number and then reducing the afterburner fuel flow until blow-out occurred.

The conditions for which the operational range was established are listed in the following table:

866

Pressure altitude (ft)	Mach numbers	Engine rotor speed (rpm)
20,000	0.25, 0.4, 0.6, and 0.85	12,000
20,000	0.25, 0.4, 0.6, and 0.85	12,500
30,000	[a]0.4, [a]0.6, 0.85, and 1.0	12,500

[a]Incomplete data.

Because of temporary limitation of the service equipment, proper regulation of engine inlet-air temperature in accordance with simulated altitude and Mach number was impossible. Engine inlet total temperature prevailing during the tests are indicated in the legends of the data figures.

RESULTS AND DISCUSSION

Altitude Blow-out Limits

The results of preliminary tests to determine the altitude blow-out limits of the afterburner at an engine speed of 11,000 rpm are shown in figure 6 in which the altitude at which blow-out occurred is plotted against the simulated flight Mach number. The afterburner fuel flows at which blow-out occurred are noted in the legend of the figure and the turbine-discharge temperature is given at each data point. The blow-out altitude increased rapidly with an increase in flight Mach number from about 15,000 feet at Mach number of 0.45 and to about 32,000 feet at Mach number of 0.80. As indicated in the legend of figure 6, the engine inlet-air temperature provided by the test facilities at the time of the tests was -16° F; this temperature is from 5° to 15° F lower than the temperature corresponding to NACA standard air at the higher altitudes and flight Mach number conditions and about 40° F lower at the lowest altitude conditions. Because the turbine-discharge pressure would increase with decreased inlet-air temperature, it is possible that the blow-out limits indicated in figure 6 are somewhat higher than would be experienced at standard inlet-air temperature conditions.

The altitude blow-out limits at an engine speed of 12,500 rpm for balanced-cycle operation are shown in figure 7. A band of unstable operation of about 8000 feet in width was obtained within which blow-out occurred during variation in one or more of the operational variables indicated in the figure. As mentioned

866

previously, the engine speed and the turbine-discharge temperature were held constant during the increase in altitude; the changes indicated in the legend refer to minor adjustments that were in progress at the instant of blow-out. The highest altitude reached varied from about 32,000 feet at a Mach number of 0.3 to about 42,000 feet at a Mach number of 1.0; minimum blow-out limits occurred at altitudes as much as 8000 feet lower. Comparison of these data with that for figure 6 indicates that the altitude blow-out limit is considerably increased by operation at a higher engine speed and higher turbine-discharge temperature, particularly in the range of Mach numbers below 0.5. The engine operating conditions for the altitude blow-out points shown in figure 7 are given in table I. The inlet-air temperature prevailing during these tests, which are included in table I, are about 20° to 30° F higher than NACA standard air in the low-Mach number, low-altitude region of the data and about 15° to 25° F lower than standard at the higher altitudes and Mach numbers. The altitude blow-out regions indicated in figure 7 may therefore be somewhat lower at the lower Mach numbers and higher at the high Mach numbers than would occur with standard inlet-air temperatures.

Fuel-Flow Operational Limits

The operational range of the afterburner over a range of Mach numbers at an altitude of 20,000 feet is presented for an engine speed of 12,000 rpm in figure 8(a) and for an engine speed of 12,500 rpm in figure 8(b). Both the afterburner fuel flow and the afterburner fuel-air ratio, which is defined as the fuel flow to the afterburner divided by the air flow to the engine, are presented. The maximum fuel flow represents the condition of maximum permissible turbine-discharge temperature (balanced-cycle operation) and the minimum fuel flow represents the condition of lean blow-out.

The afterburner fuel-air ratios for both limits of operation changed only slightly with increase in the flight Mach number. Whereas the shape of the curves of limiting fuel-air ratio exhibits slightly different characteristics for the two engine speeds (fig. 8(a) and 8(b)), the magnitude of the limiting fuel-air ratio are approximately the same for both. The fact that at the higher flight Mach numbers the fuel-air ratio is slightly less at an engine speed of 12,000 rpm than at 12,500 rpm in spite of the higher fuel flow is a result of the lower inlet-air temperature, which was provided by the test facility at the time of these tests and the associated higher air flow at the lower engine speed.

For the complete range of Mach numbers and engine speeds investigated, the spread between the maximum and minimum operable

fuel flows was about 600 pounds per hour. At an altitude of 20,000 feet and an engine speed of 12,500 rpm (fig. 8(b)), the maximum fuel-air ratio of the afterburner, as limited by maximum permissible turbine-discharge temperature, varied from 0.036 to 0.038. The fuel-air ratio at which lean blow-out occurred was about 19 percent below this maximum at a flight Mach number of 0.25 and about 11 percent lower at a flight Mach number of 0.85.

The inlet-air temperature of 75° F, which prevailed during these tests at an engine speed of 12,500 rpm, is about 20° F higher than standard at the high Mach numbers and 80° F higher at a Mach number of 0.25. Because it is possible that the combustion efficiency of the afterburner may increase with increased turbine-discharge pressure, and hence with decreased inlet-air temperatures, the fuel-air ratios for maximum permissible turbine temperature at standard conditions may be somewhat lower than indicated in figure 8(b), particularly at the lower flight Mach numbers.

Data similar to that presented in figure 8(b) are shown in figure 9 for an altitude of 30,000 feet. The determination of lean blow-out limits at the lower Mach numbers was prevented by a structural failure of the afterburner, as will be discussed later. The maximum fuel-air ratio at an altitude of 30,000 feet is somewhat lower than at an altitude of 20,000 feet and, within the limited range of the data (Mach numbers of 0.85 and 1.0), the spread of fuel flows over which the burner could be operated was slightly less than at 20,000 feet. The fuel-air ratios at which maximum permissible turbine-discharge temperatures were obtained varied from 0.035 at low flight Mach numbers to about 0.0295 at a flight Mach number of 1.0. Lean blow-out occurred at fuel-air ratios from 10 to 11 percent below these maximum values. The inlet-air temperatures for these tests were from 10° F higher than standard at the lowest flight Mach number to about 50° F lower than standard at the highest flight Mach number. Because of the possible effect of inlet-air temperature on combustion efficiency previously mentioned, the fuel-air ratios at high flight Mach numbers may be somewhat higher for standard inlet-air temperatures than are indicated in figure 9.

The lower fuel-air ratio for conditions of limiting turbine temperature at an altitude of 30,000 feet than at 20,000 feet is attributed to the tendency for the turbine-discharge temperature of the standard engine with fixed exhaust nozzle to increase with increasing altitude (reference 1) or to a possible increase in combustion efficiency of the afterburner.

Although the combustion efficiency would normally be expected to decrease with increasing altitude, it is possible for an increase

998

to have occurred for these test conditions as a result of the non-standard inlet-air temperatures used. The greater than normal difference in inlet-air temperature at the two pressure altitudes resulted in a sufficient difference in engine pressure ratio to provide almost the same turbine-discharge pressures at the two altitudes and a lower tail-pipe gas velocity at the higher altitude.

For the run conducted at an altitude of 5000 feet, zero Mach number, and an engine speed of 12,500 rpm, limiting turbine-discharge temperature was obtained at an afterburner fuel flow of 4420 pounds per hour and a resulting afterburner fuel-air ratio of 0.0285. No lean blow-out limit could be obtained with a fuel flow as low as 1500 pounds per hour, or a fuel-air ratio of 0.0097. Further reduction of afterburner fuel flow was not attempted because at this low fuel-air ratio the means for detection of blow-out (surge in operating conditions or appearance of flame through the periscope) were no longer of adequate sensitivity.

These relatively low fuel-air ratios for limiting turbine-discharge temperature for all operating conditions investigated indicate that higher fuel flows and hence greater engine thrust may be possible by an increase in the area of the exhaust nozzle.

Afterburner Operational Characteristics

Throughout the investigation great difficulty was experienced with afterburner ignition. Approximately 200 attempts were made to ignite the burner in its original configuration but about five out of six attempts were unsuccessful. Starts were attempted during this operation at engine speeds from 8500 to 11,000 rpm and altitudes from 7000 to 20,000 feet with flight Mach numbers from 0 to 0.8. Various combinations and methods of controlling these variables were attempted without any consistently successful starting technique being established. No starts were obtained at altitudes greater than 8000 to 9000 feet and only rarely at engine speeds over 9500 rpm.

A modification was made to the burner that permitted successful ignition on about three out of four attempts. As shown in the photograph of figure 2, a clip about 2 inches wide was attached to the flame holder and bent around the fuel manifold to form a U-shaped sheltered zone centered about the spark plug between the fuel manifold and the flame holder. Attached to the downstream face of the flame holder was a box about 2 inches square by $1\frac{1}{2}$ inches long closed on the four sides and open on the upstream and downstream ends, which

formed a sheltered zone downstream of the flame holders. Although this modification increased the frequency of successful starts, it did not completely eliminate false starts.

During operation, the afterburner ran very smoothly with a bluish flame, which filled the tail pipe and was uniform in intensity throughout. Slight flickering could be noticed occasionally near the blow-out points and some stratification of flame was apparent at very rich fuel-air ratios near the blow-out points. Blow-out occurred very suddenly with no rough cycling in transition. Although some hot bands could be observed in the burner wall at high fuel-air ratios, no overheating of the burner sufficient to cause any failure occurred.

Two types of structural failure of the afterburner occurred during the investigation. The first of these was a failure of the cooling jackets illustrated in figures 10 and 11. This failure, which occurred after 3 or 4 hours of afterburner operation, consisted of warping and buckling of the inner and outer jackets but was not of sufficient extent to interfere with burner operation. After straightening and reassembly of the jackets, the program was reinstituted; at the completion of the program the jackets were again found in a buckled condition. The second type of failure was of a more serious nature and occurred in the flame holder after a total operating time of about 81 hours of engine time of which 12 hours and 15 minutes were afterburner operation. Figure 12 illustrates the condition of the flame holder after the failure. The failure consisted of several cracks in the outer flame holder and supporting members with complete separation of the flame holder at three points. Because a segment of the flame holder was completely lost and because the condition of the metal was such as to prevent satisfactory repairs, this failure resulted in termination of afterburner operation.

SUMMARY OF RESULTS

An altitude-test-chamber investigation of the operational characteristics of the Solar afterburner on the 24C engine gave the following results:

1. At rated engine speed and maximum permissible turbine-discharge temperature the altitude limit, as determined by combustion blow-out, occurred as a band of unstable operation of about 8000-foot altitude in width with maximum altitude limits from 32,000 feet at a Mach number of 0.3 to about 42,000 feet at a Mach number of 1.0

2. At rated engine speed, the maximum fuel-air ratio of the afterburner, as limited by maximum permissible turbine-discharge gas temperatures, varied between 0.0295 and 0.0380 over a range of flight Mach numbers from 0.25 to 1.0 and altitudes of 20,000 and 30,000 feet. Over this range of operating conditions, the fuel-air ratio at which lean blow-out occurred was from 10 to 19 percent below these maximum fuel-air ratios.

3. Ignition of the afterburner was very difficult throughout the investigation with no satisfactory starting technique being established. All starts were limited to low altitude and low engine speed.

4. A failure of the flame holder occurred after 12 hours and 15 minutes of afterburner operation, which terminated the afterburning program.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, July 2, 1948.

Harry W. Dowman

Harry W. Dowman,
Aeronautical Research Scientist.

John O. Reller

John O. Reller,
Aeronautical Research Scientist.

Approved:

Eugene J. Manganiello,
Aeronautical Research Scientist.

Benjamin Pinkel,
Aeronautical Research Scientist.

je

REFERENCE

1. Prince, William R., and Bloomer, Harry E.: Preliminary Results of Altitude-Wind-Tunnel Investigation of X24C-4B Turbojet Engine. V - Performance of Modified Engine. NACA RM NO. SE7L22b, Bur. Aero., 1947.

998

TABLE I - OPERATING CONDITIONS FOR ALTITUDE BLOW-OUT

Mach number	Altitude (ft)	Engine speed (rpm)	Turbine-discharge temperature (°F)	Afterburner fuel flow (lb/hr)	Inlet-air total temperature (°F)
0.24	29,200	12,500	1275	2260	-16
.25	27,400	12,800	1300	2260	-18
.26	29,000	12,500	1285	2350	-18
.31	32,300	12,500	1300	2260	-15
.40	29,500	12,500	1285	2700	-17
.41	30,300	12,500	1225	2790	-20
.45	34,500	12,500	1285	2540	-12
.56	34,100	12,500	1255	3240	-9
.60	30,000	12,500	1200	2860	-22
.67	29,400	12,500	1285	2870	-20
.70	34,100	12,500	1275	2610	-21
.72	29,200	12,500	1270	3010	-19
.73	32,500	12,500	1275	2940	-15
.80	31,200	12,500	1290	3010	-13
.81	36,800	12,500	1260	2490	-25
.90	39,000	12,500	1265	3100	-19
.97	41,100	12,500	1260	3650	-22

NACA

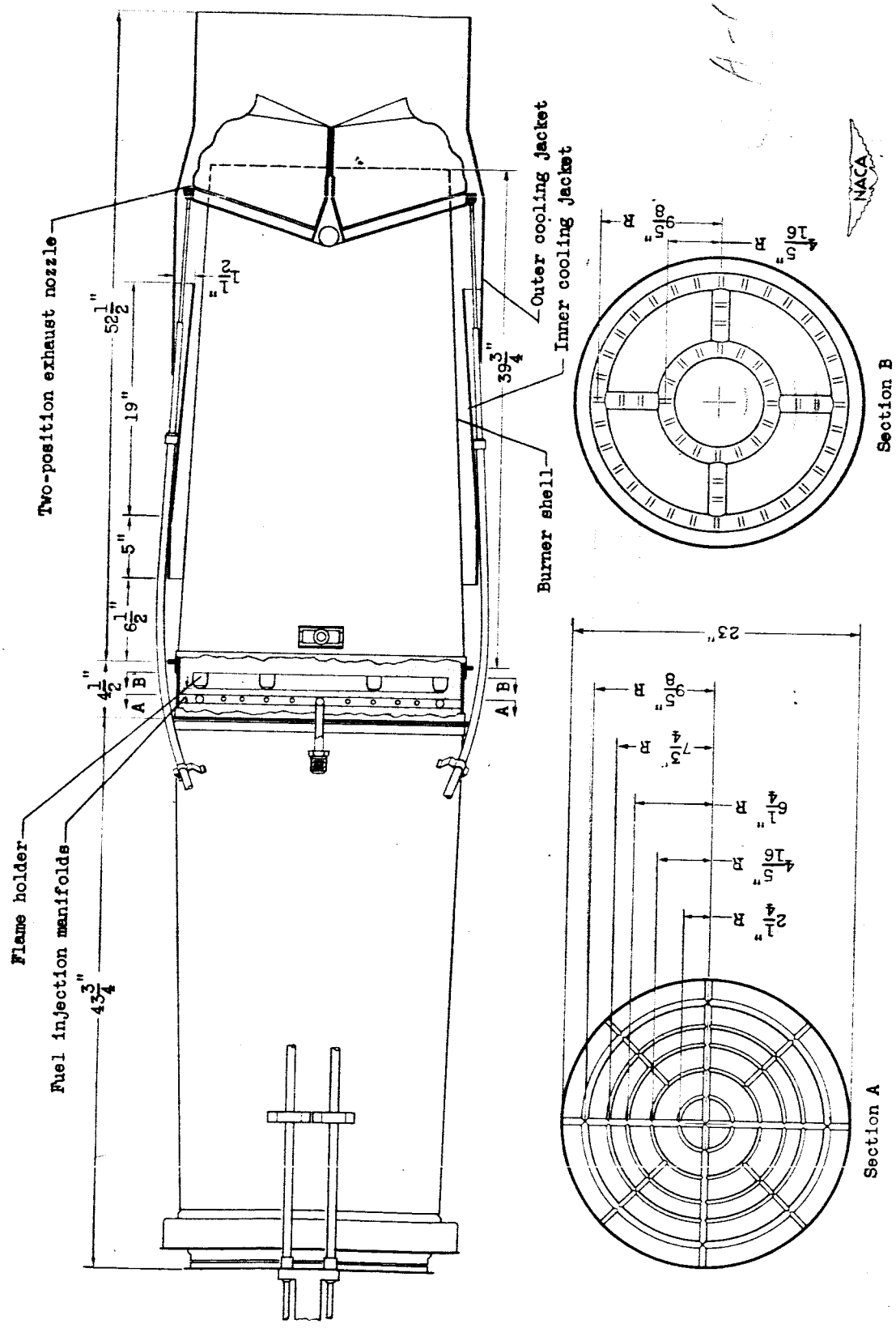


Figure 1. - Diagrammatic sketch of solar afterburner.

998
409-1430

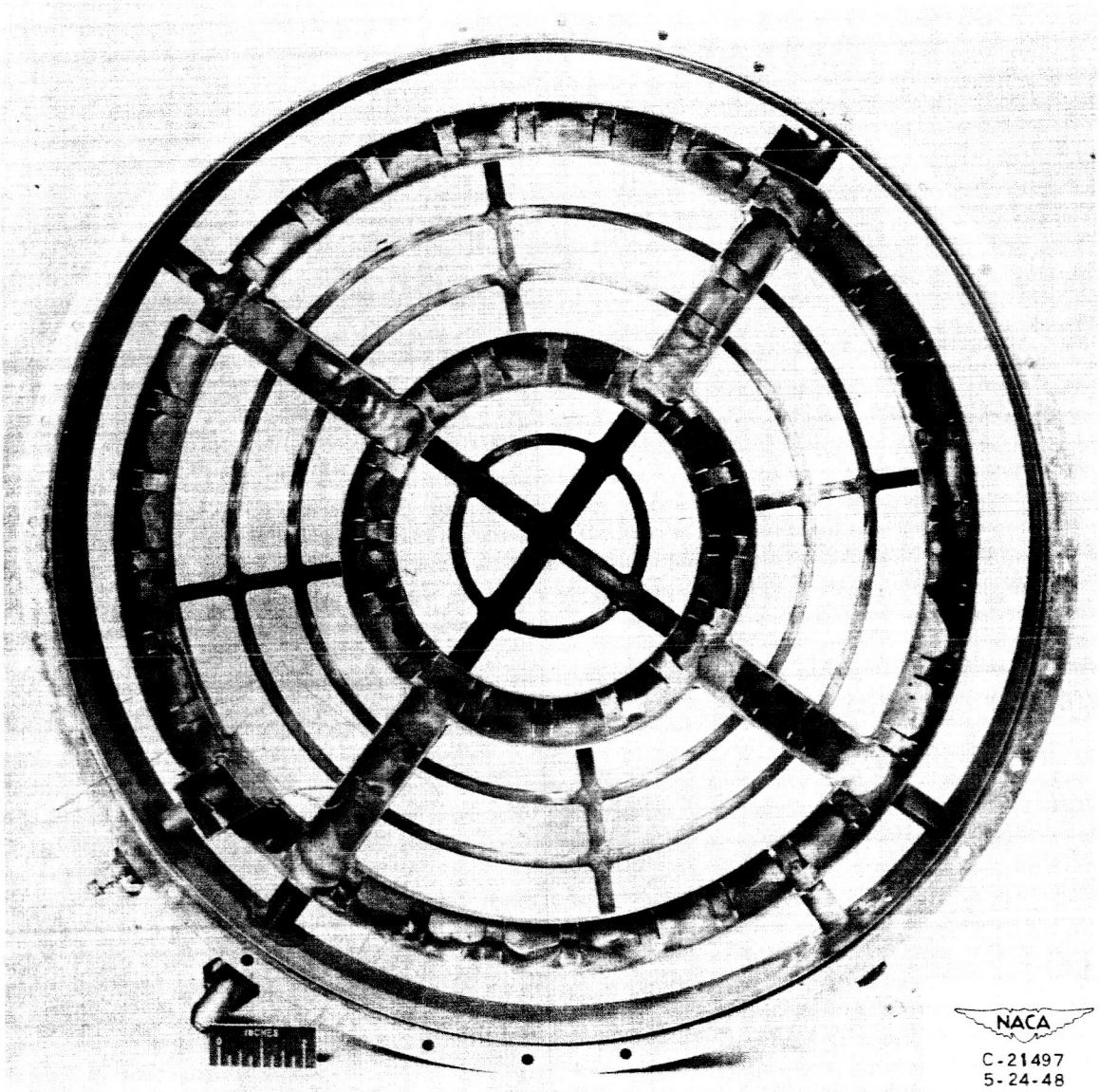


Figure 2. - Fuel injection system and flame-holder section of solar afterburner (looking upstream).

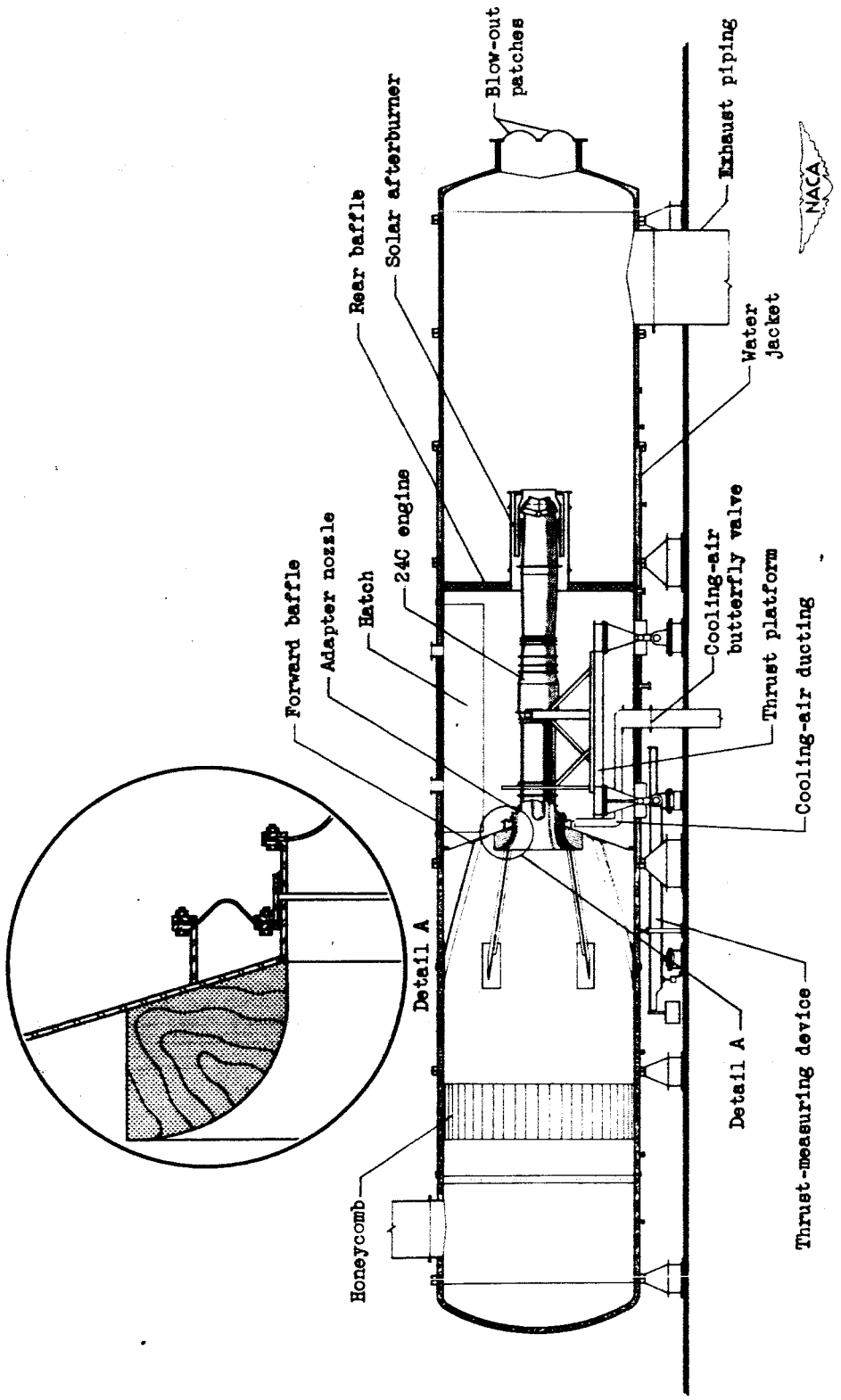
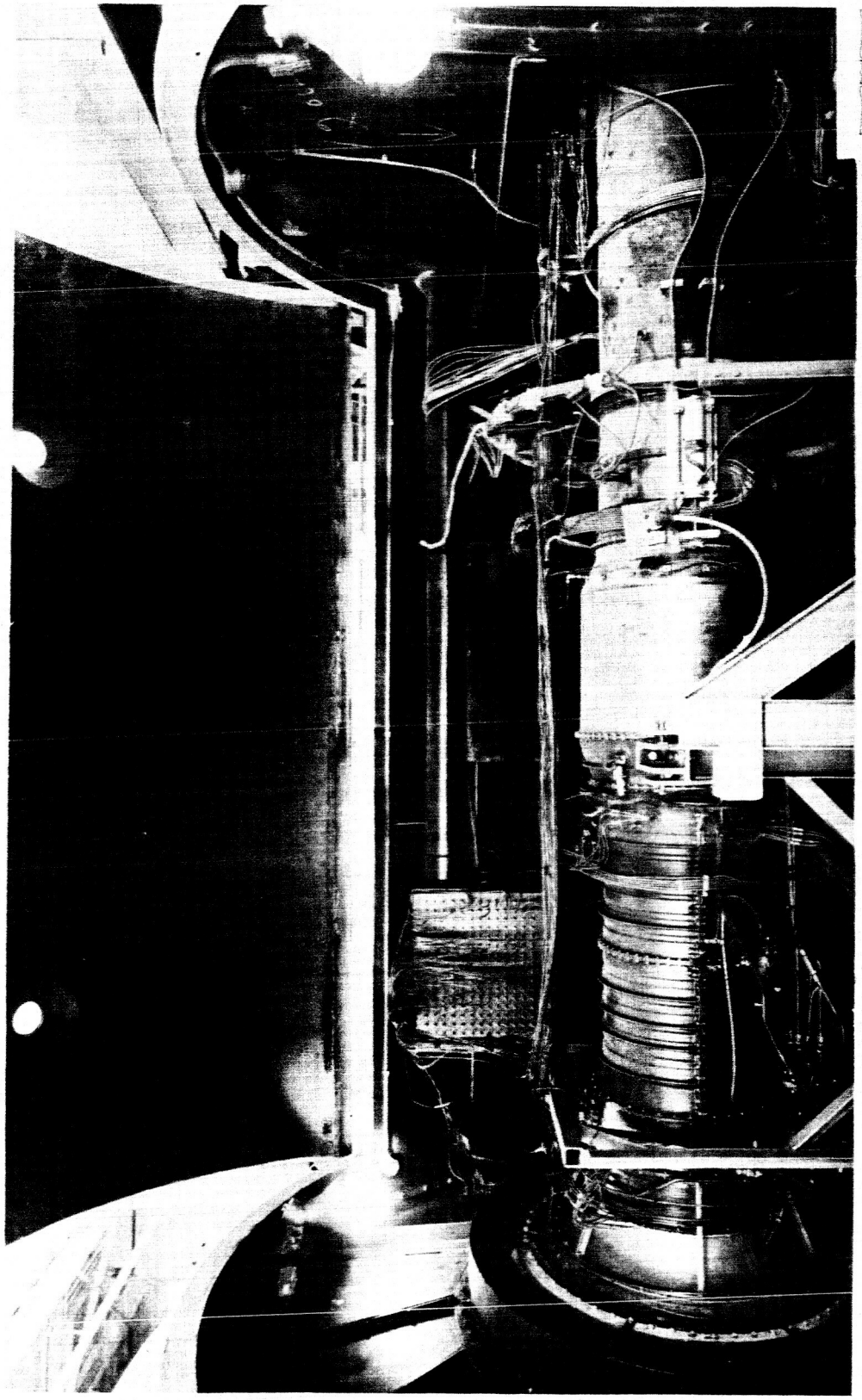


Figure 3. - Diagrammatic sketch of altitude test chamber with 24C engine and solar afterburner installed.

998
389-1359-A



NACA
C-21567
5-27-48

Figure 4. - Side view of 24C engine and solar afterburner installed in altitude test chamber.

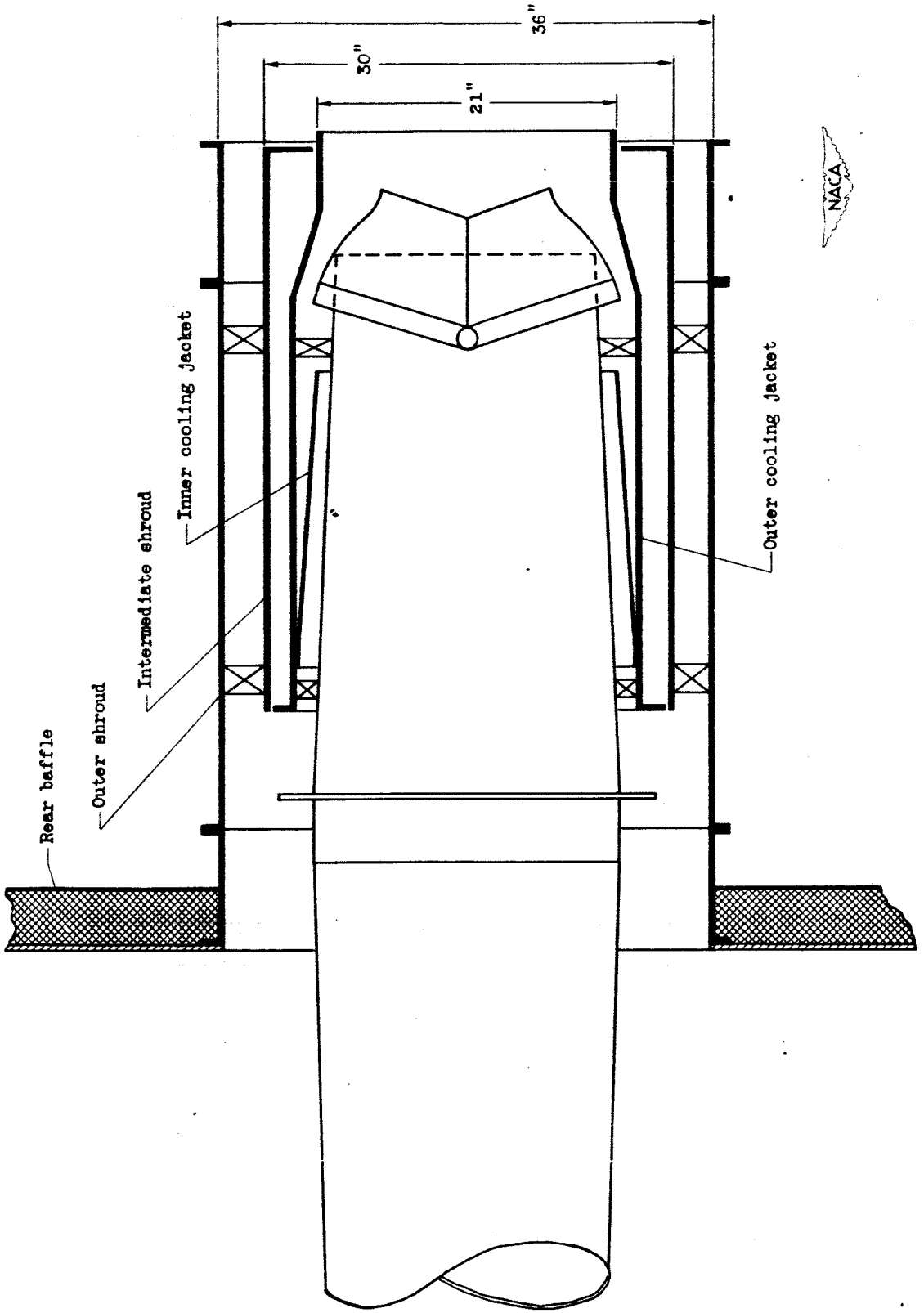


Figure 5. - Detail of afterburner cooling jackets and shrouds.

998
409-1929

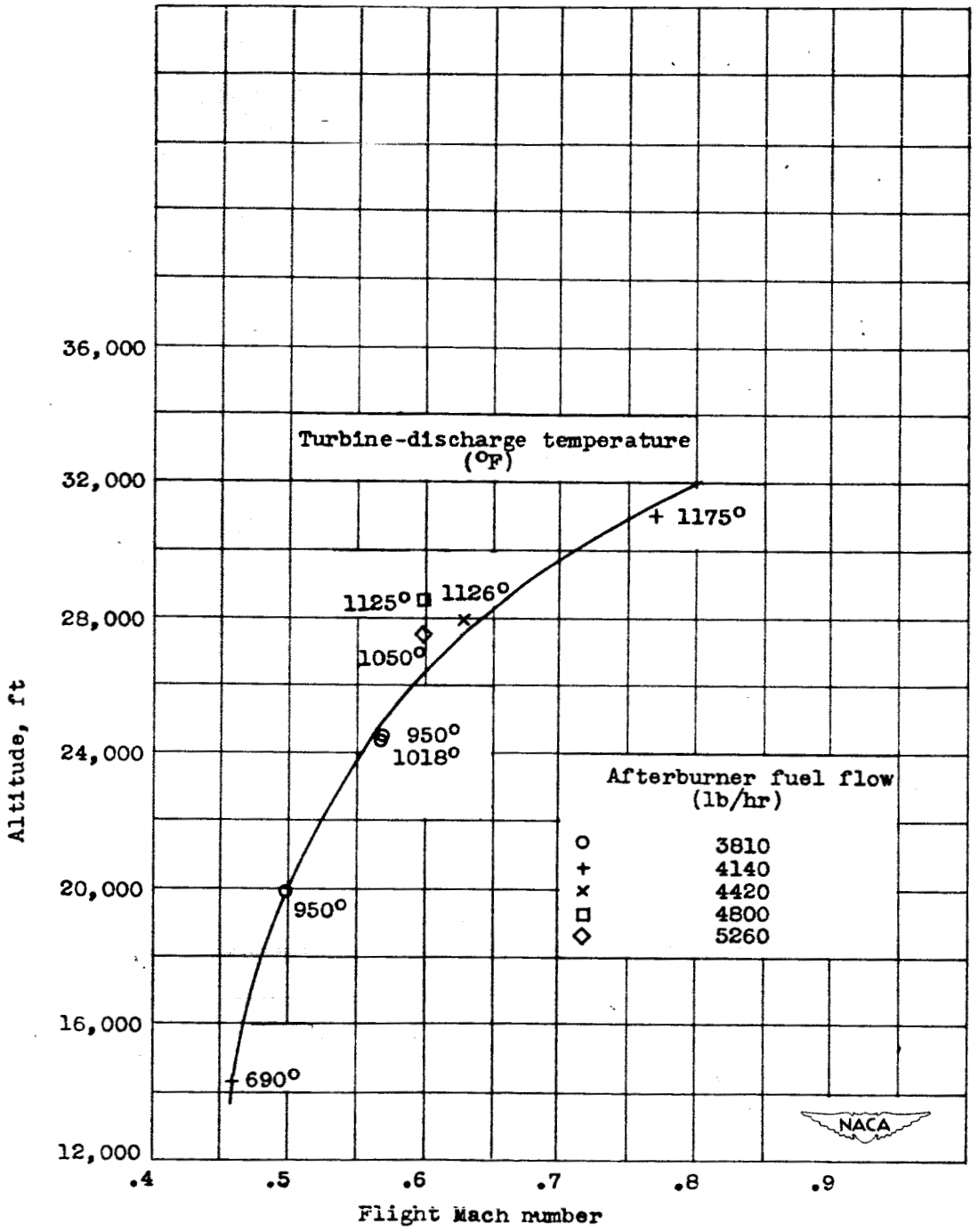


Figure 6. - Altitude blow-out limits at an engine speed of 11,000 rpm for various afterburner fuel flows. Inlet-air total temperature, -16° F.

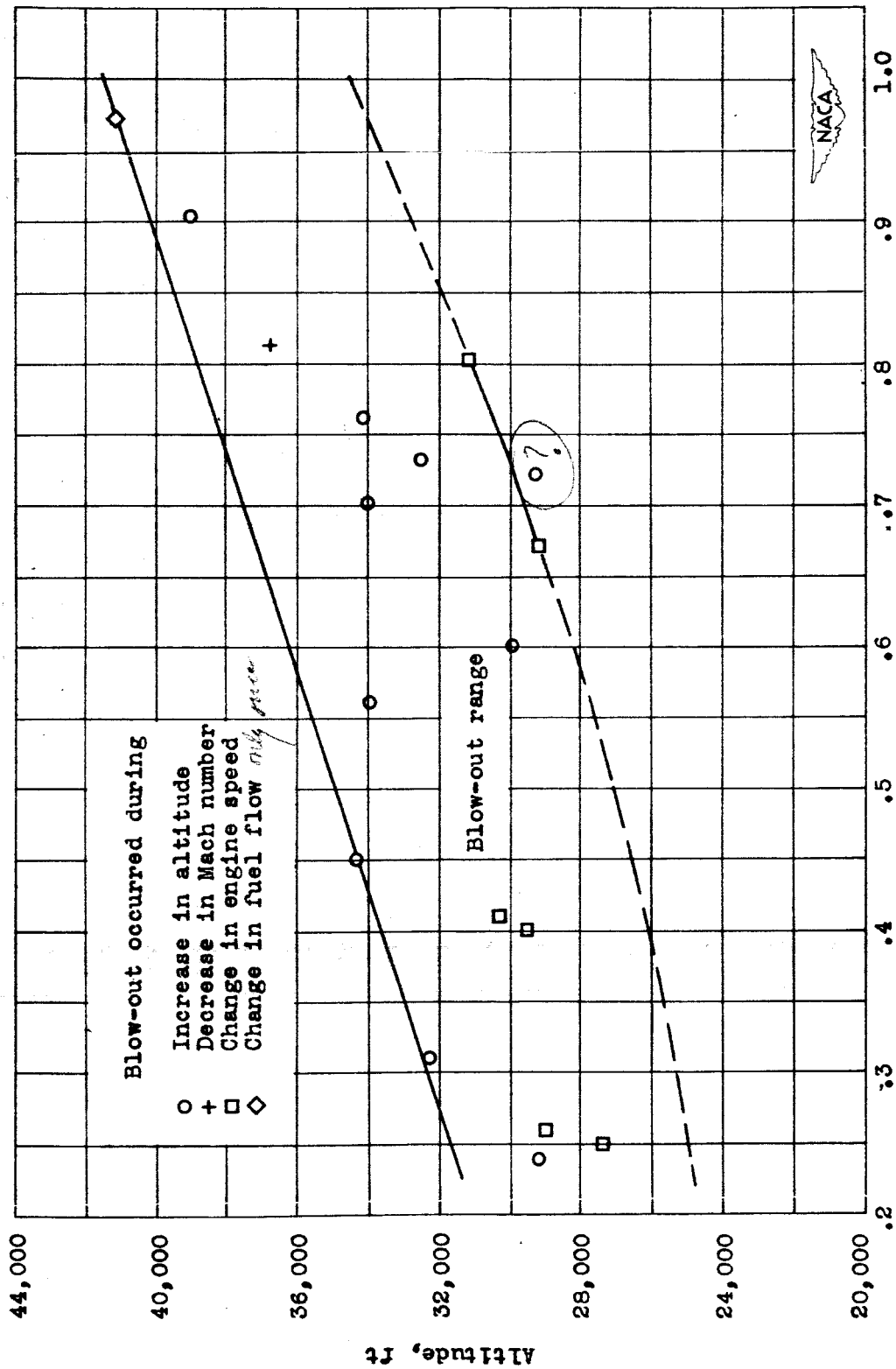
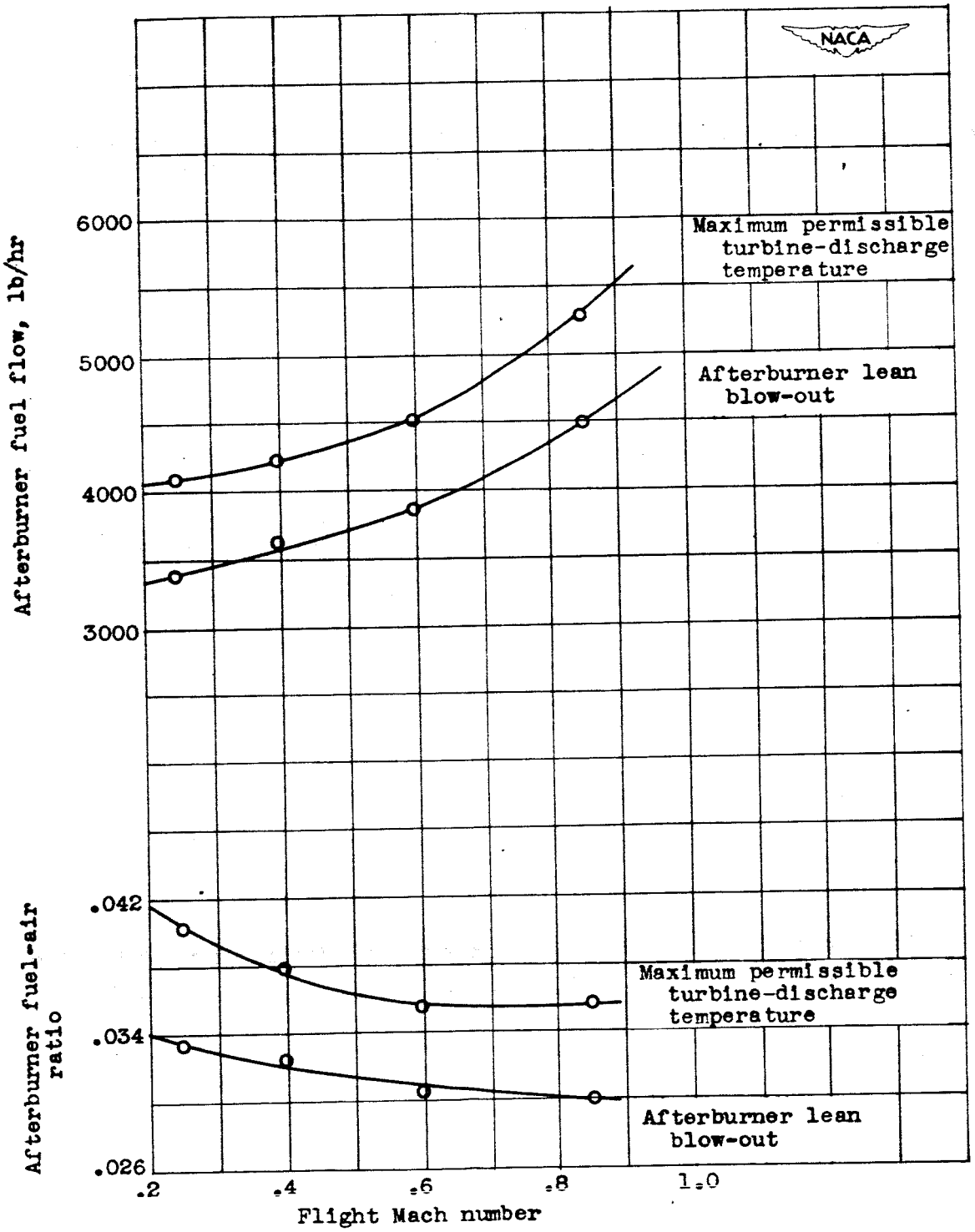


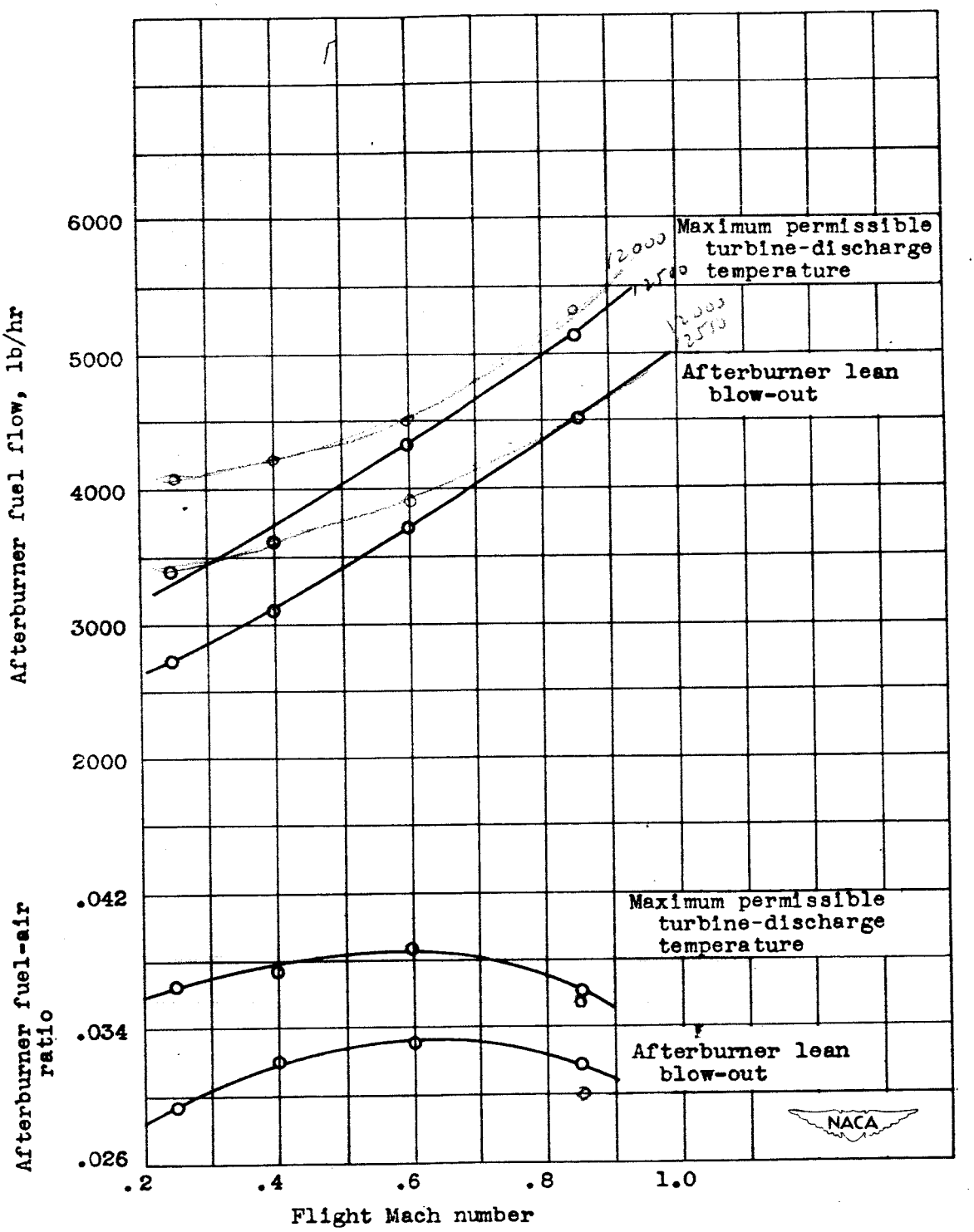
Figure 7. - Altitude blow-out limits at an engine speed of 12,500 rpm for balanced cycle operation. Inlet-air total temperature, -20° F.

998



(a) Engine speed, 12,000 rpm; inlet-air total temperature, 10° F.

Figure 8. - Operational range of afterburner at an altitude of 20,000 feet.



(b) Engine speed, 12,500 rpm; inlet-air total temperature, 75° F.

Figure 8. - Concluded. Operational range of afterburner at an altitude of 20,000 feet.

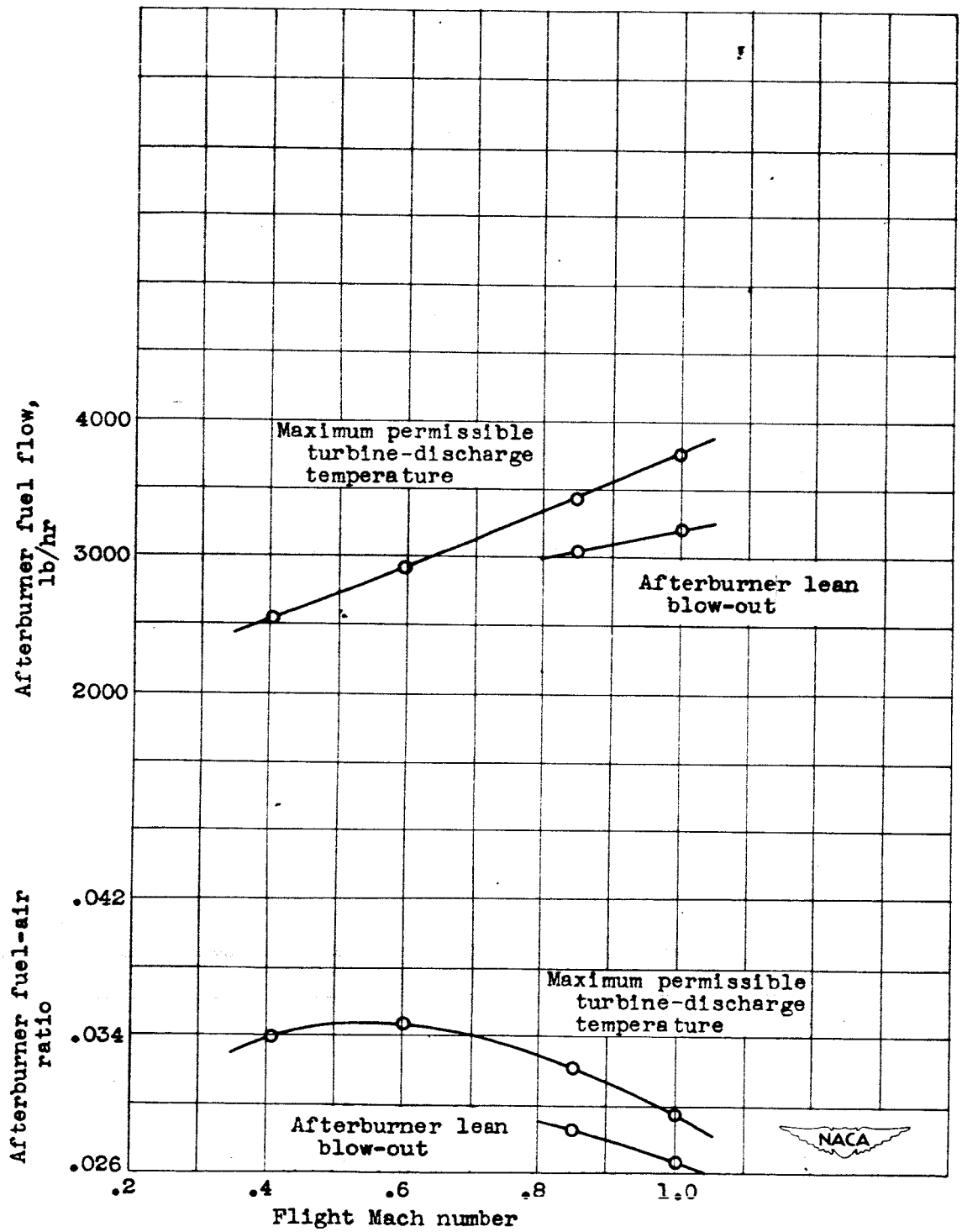


Figure 9. - Operational range of afterburner at an altitude of 30,000 feet and an engine speed of 12,500 rpm. Inlet-air total temperature, -20° F.

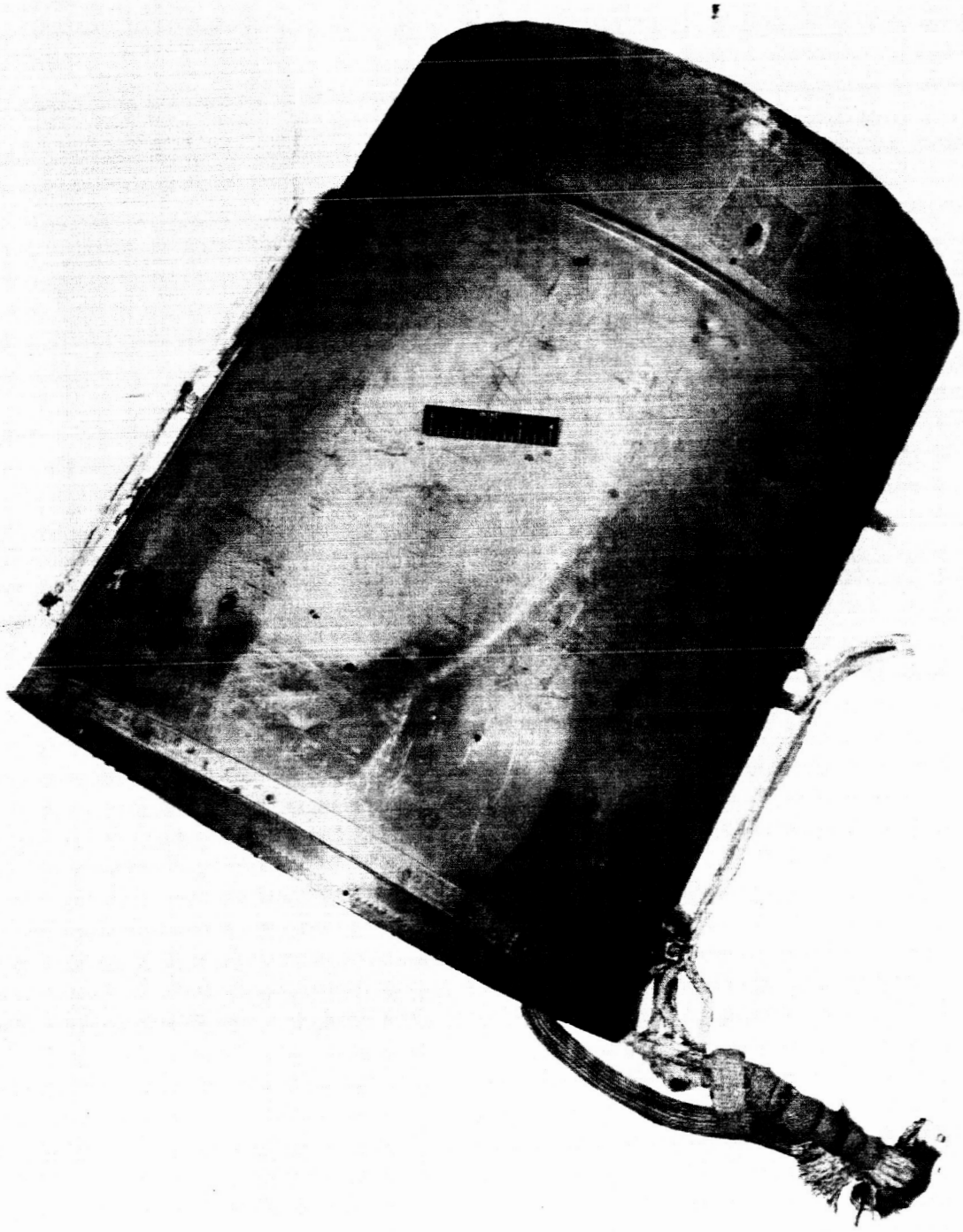
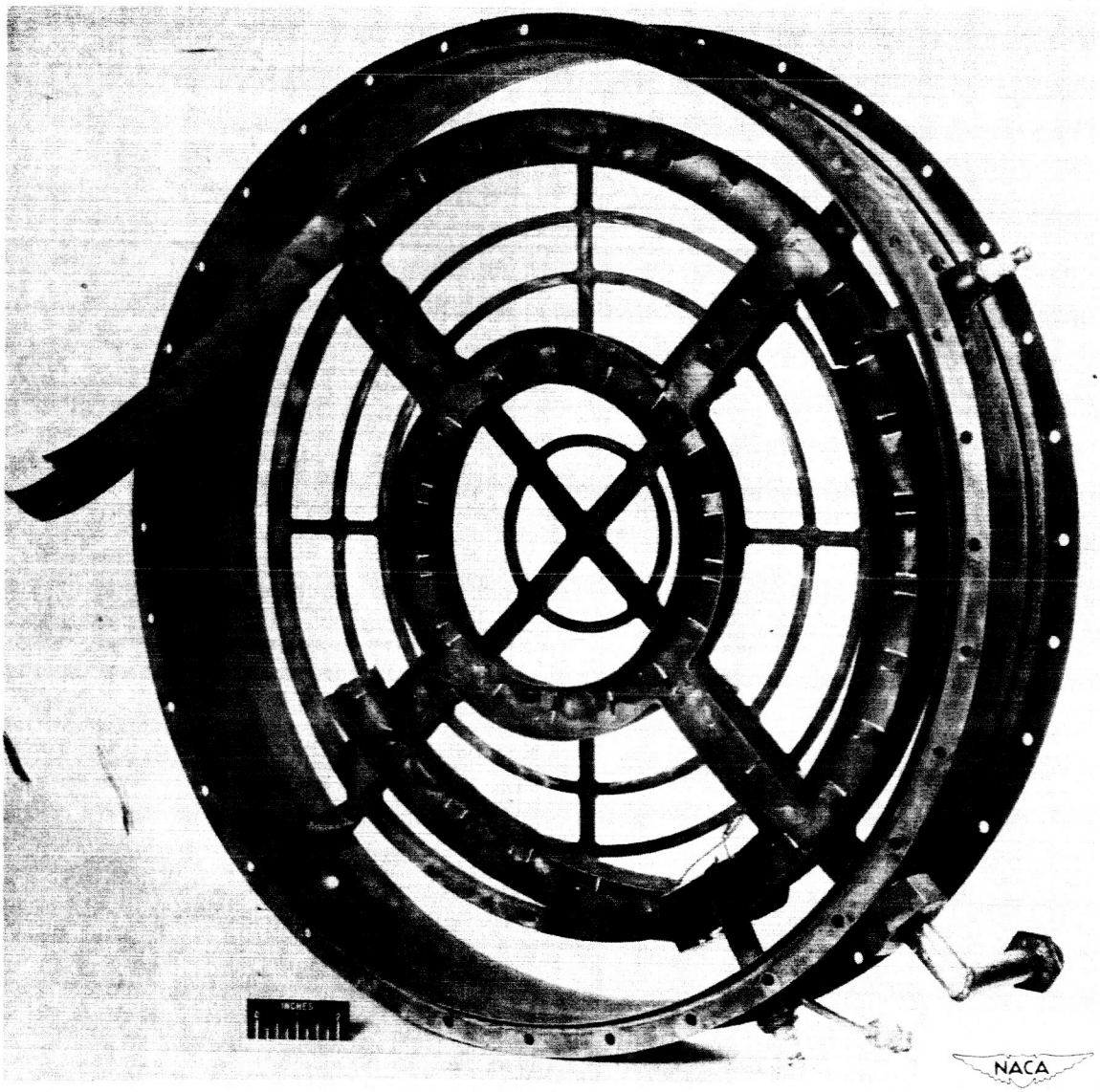


Figure 10. - Outer cooling jacket after failure.

NACA
C-21304
4-26-48

998

Figure 11. - Inner cooling jacket after failure.



C-21496
5-24-48

Figure 12. - Flame holder after failure.