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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF WESTINGHOUSE 19B-2 19B-8, AND 19XB-1 JET-PROPULSION ENGINES

I - OPERATIONAL CHARACTERISTICS

By William A. Fleming

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
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SUMMARY

An investigation was conducted in the NACA Cleveland altitude wind tunnel to determine the operational characteristics of the Westinghouse 19B-2, 19B-8, and 19XB-1 jet-propulsion engines. The 19B engine is one of the earliest experimental Westinghouse axial-flow engines. The 19XB-1 engine is an experimental prototype of the Westinghouse 19XB series, having a rated thrust of 1400 pounds. Improvements in performance and operational characteristics have resulted in the 19XB-2B engine with a rated thrust of 1600 pounds. The operational characteristics were determined over a range of simulated altitudes from 5000 to 30,000 feet for the 19B engines and from 5000 to 35,000 feet for the 19XB-1 engine at airspeeds from 20 to 380 miles per hour. The effects of altitude and airspeed on such operating characteristics as operating range, stability of combustion, starting, acceleration, and functioning of the fuel-control system are discussed. Damage to the engines that occurred during the investigation is also briefly discussed. The changes made in the combustion-chamber configuration to improve the operating range are described.

The operating range of the 19B engines was satisfactory below a pressure altitude of approximately 17,000 feet but operation above 17,000 feet was limited by combustion blow-out. The 19XB-1 engine had a considerably greater operating range at high altitude than the 19B engines. Several changes in the configuration of the combustion chambers in all three engines failed to increase materially the operating range. Approximately 1 minute was required to start and accelerate the 19B engines to an engine speed of 17,000 rpm at a pressure altitude of 5000 feet and an airspeed of about 20 miles per hour with the adjustable tail cone in the "in" position. Acceleration of the 19XB-1 engine was slightly faster. The starting characteristics of the 19XB-1 engine were satisfactory but the 19B engines did not start consistently.

INTRODUCTION

An investigation was conducted in the NACA Cleveland altitude wind tunnel during October and November 1944 to determine the operational and performance characteristics of the Westinghouse 19B-2, 19B-8, and 19XB-1 jet-propulsion engines at simulated altitude and at ram conditions. Tests were conducted for a range of pressure altitudes from 5000 to 30,000 feet for the 19B engines and from 5000 to 35,000 feet for the 19XB-1 engine at airspeeds in the tunnel test section from 20 to 380 miles per hour. At each pressure altitude the temperature was adjusted to the approximate value corresponding to NACA standard altitude.

The configuration of the combustion chamber was changed several times and fuel nozzles of various sizes were used in an attempt to increase the operating range of the engines at high altitudes.

Characteristic operational data are presented to show the effect of altitude and airspeed on operating range, acceleration, starting, functioning of the fuel-control system, and methods of operation. The operational characteristics of the three engines investigated for the standard configuration and with several modifications to the combustion chambers are discussed.

WIND-TUNNEL INSTALLATION

Description of Engine

Two Westinghouse 19B engines were investigated. These engines are similar in construction but the turbine and the turbine nozzles of the 19B-8 engine are modified, the tail-pipe-nozzle area is reduced, and the screen at the entrance to the combustion chamber of the 19B-8 engine has less restriction than the screen of the 19B-2 engine. The 19B engines have a sea-level rating of 1365 pounds static thrust at an engine speed of 17,500 rpm. The engine was designed for an air flow of 28 pounds per second and a fuel consumption of approximately 1800 pounds per hour at rated engine conditions. The over-all length of the engine is 8 feet $8\frac{1}{2}$ inches with the adjustable tail cone extended, the maximum diameter is $20\frac{3}{4}$ inches, and the total weight is 825 pounds. The maximum diameter does not include the accessory group, which can be mounted on the top, bottom, or either side of the front bearing support at the compressor inlet. The compressor has six axial-flow stages and provides a pressure ratio of

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approximately 3.5 at rated engine speed. A cylindrical oil cooler 2 feet long with an inside diameter of 14 inches is attached to the front of the engine. The inner wall of the cylinder provides the cooling surface for the oil.

The combustion chamber is an annulus in which is mounted an annular combustion basket (fig. 1) containing holes that meter the charge air to the primary and secondary burning zones. Fuel is supplied to the combustion chamber through 24 fuel nozzles circumferentially mounted in a manifold at the forward end of the chamber. The tail pipe is equipped with a movable inner cone with a total travel of 5 inches. When the inner cone is moved from the "in" position to the "out" position, the nozzle area decreases from approximately 140 to 105 square inches. A single-stage turbine drives the compressor.

The 19XB-1 engine has a sea-level rating of approximately 1400 pounds static thrust at an engine speed of 16,500 rpm. At this rating the air flow is 29 pounds per second and the fuel consumption is approximately 1600 pounds per hour. The physical dimensions and the combustion-chamber design of the 19XB-1 engine are the same as for the 19B engines. The compressor has 10 axial-flow stages and provides a pressure ratio of approximately 4 at rated engine speed. The inner cone of the 19XB-1 tail pipe is not adjustable. A single-stage turbine of different design than that of the 19B engines drives the compressor.

A control box containing an automatic timing system is used on all three engines for starting. The timing cycle is begun by first turning on the oil-pump switch and then the starter switch, which energizes the ignition system and the starter motor. The starter motor brings the engine speed up to about 2500 rpm. When the engine starts and thus reduces the load on the starter motor, the control box opens a contact that disengages the starter motor. If the engine has not started at the end of 30 seconds, the control box will also shut off the starter motor. The starter switch must then be re-engaged to begin another 30-second starting cycle.

On both 19B engines a barostat is used in the fuel system to serve as an altitude compensator to hold the engine speed approximately constant for a set throttle position when the altitude is changed. The function of the barostat is to bypass part of the excess fuel supplied by the constant-displacement fuel pump. Excess fuel is also bypassed by the throttle and the overspeed governor. The bypass mechanism of the barostat is activated by the compressor-inlet total pressure.

Installation

The engine was installed in a nacelle mounted under a stub wing having a 7-foot span, which was cantilevered from one side of the 20-foot-diameter test section of the wind tunnel (fig. 2). The engine air was admitted at the front of the nacelle and cooling air was admitted through a small inlet duct beneath the leading edge of the wing. For the static tests the portion of the cowling enclosing the tail pipe and the rear of the combustion chamber was removed because the test-section air velocity was too low to insure sufficient cooling-air flow through the cowling, A 6-mesh screen made of 0.032-inch-diameter steel wire was bolted to the front flange of the oil cooler to protect the compressor from flying objects in the tunnel. Temperature and pressure measurements were taken at seven stations in the engine (fig. 3) to obtain information on the individual components and the over-all operating characteristics.

An indirect method was used to determine the turbine-inlet temperature. The engines were equipped by the manufacturer with thermocouples at the compressor inlet (station 2), the compressor outlet (station 3), and in the tail pipe (station 5). These thermocouples were connected in series in such a manner that the resulting temperature indicated on a potentiometer was the sum of the tail-pipe indicated temperature and the indicated temperature rise through the compressor.

For the investigation, 62-octane unleaded fuel was used in the engines. The operational time of the engines in the tunnel was 48.5 hours for the 19B-2 engine, 43.2 hours for the 19B-8 engine, and 13.2 hours for the 19XB-1 engine.

TEST PROCEDURE AND RESULTS

Operating Range

The investigation indicated that the range of operable engine speeds for all three engines was limited by combustion blow-out at high altitudes. The combustion chamber and the fuel nozzles of the engines were modified several times in an attempt to increase the operable speed range. The modifications included four configurations on the 19B-2 engine, three on the 19B-8 engine, and two on the 19XB-1 engine.

<u>19B-1 engine</u>. - In the original configuration of the combustion chamber of the 19B-2 engine with the standard $10\frac{1}{2}$-gallon spray nozzles with a cone angle of 80°, the operating range above a pressure altitude of 17,000 feet was limited by combustion blow-out at

both maximum and minimum operable speeds (fig. 4). The idling speed of the engine, the lowest speed at which the engine could be operated without burning in the tail pipe and excessive tail-pipe temperatures, is shown by the dashed curve. The operating range with the tail cone moved in extended from approximately 14,000 to 17,300 rpm at a pressure altitude of 20,000 feet and from 15,500 to 16,500 rpm at 30,000 feet. When the tail-pipe-nozzle area was decreased to a minimum by moving the tail cone 5 inches out, the operable range at 20,000 feet was greatly reduced. With the tail-pipe-nozzle area fully reduced, the engine would not operate at 30,000 feet. When the airspeed in the tunnel was raised, the operating range was slightly increased in all cases.

In the first revision of this engine, 12 of the 24 alternately spaced fuel nozzles were extended $1\frac{1}{2}$ inches downstream of the manifold by means of an adapter. The standard $10\frac{1}{2}$-gallon, 80°-angle spray nozzles were used on the extensions and $10\frac{1}{2}$-gallon, 45°-angle spray nozzles were directly attached to the manifold. This modification of fuel-nozzle arrangement permitted operation at maximum design speed at all altitudes but did not appreciably change the minimum speed at which the engine would operate.

In order to induce more turbulence in the primary burning zone, the combustion chamber was then modified by welding 1/4- by 3/16- by 1/32-inch stainless-steel angles to the sides of the combustion chamber approximately $1\frac{5}{16}$ inches downstream of the fuel manifold (fig. 5(a)). Tests of this arrangement were made using $10\frac{1}{2}$-gallon, 45°-angle spray nozzles directly attached to the face of the manifold. The operating range of the engine with this modification was about the same as with the original configuration. The minimum engine speed above 17,000 feet and the maximum engine speed above 20,000 feet were limited by combustion blow-out.

An Inconel half-tube ring was then mounted in the combustion chamber approximately $2\frac{1}{2}$ inches downstream of the manifold (fig. 5(b)) in an attempt to provide a pilot flame in the combustion chamber that might serve to maintain combustion at altitude conditions. For the tests of this installation, $10\frac{1}{2}$-gallon, 45°-angle spray nozzles were mounted in the face of the manifold. The operating range of the engine with this modification was approximately the same as for the original configuration.

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19B-8 engine. - The operating range above a pressure altitude of 17,000 feet with the original configuration of the 19B-8 engine was limited by combustion blow-out in the same manner as was the 19B-2 engine. The operational ceiling of the 19B-8 engine with the tail cone in and at an airspeed of about 20 miles per hour was 29,000 feet. The operating range of the engine at 20,000 feet was similar to that of the 19B-2 engine but the upper limit of the operating speed range above 20,000 feet was lower than for the 19B-2 engine (fig. 6). With the tail cone 3 inches out, operation was very unstable above a pressure altitude of 10,000 feet and at 20,000 feet the speed range of the engine was from 15,000 to 16,000 rpm. Combustion blow-out occurred at a pressure altitude of 20,000 feet when the tail cone was moved out further than 3 inches. The slight increase in operating range obtained by raising the airspeed in the test section was similar to that obtained with the 19B-2 engine.

The first modification made in an effort to increase the operating range was to obtain a more finely atomized fuel spray. The standard $10\frac{1}{2}$-gallon, 80°-angle spray nozzles were replaced by $8\frac{1}{2}$-gallon, 80°-angle spray nozzles. The upper limit of safe engine operation was lower with these nozzles installed than with the $10\frac{1}{2}$-gallon nozzles as a result of higher tail-pipe temperatures. Because of high tail-pipe temperatures and excessive afterburning, operation of the engine with the tail cone 3 inches out was impossible at any altitude. The minimum operating speed of the engine with the tail cone in at a pressure altitude of 20,000 feet was approximately the same as with the $10\frac{1}{2}$-gallon nozzles. Because of the high tail-pipe temperatures and the afterburning encountered, operation of the engine with the $8\frac{1}{2}$-gallon nozzles was unsatisfactory at all airspeeds and altitudes.

Extensions were then so installed that all the fuel nozzles were approximately $1\frac{1}{2}$ inches downstream of the manifold. The $10\frac{1}{2}$-gallon, 45°-angle spray nozzles were used for runs with this modification. The two rows of holes nearest the turbine on the inner surface of the combustion basket were opened (location A, fig. 1), the first three rows of holes between each nozzle were closed (location B, fig. 1), and the nine small holes opposite each fuel nozzle were closed (location C, fig. 1). The operating range and the effects of airspeed and tail-cone position were the same as with the standard configuration. The engine operated with slightly higher tail-pipe temperatures than were initially obtained with this engine but the temperatures were not so high as those obtained with the $8\frac{1}{2}$-gallon nozzles.

19XB-1 engine. - The operating range of the 19XB-1 engine, which was considerably greater at high altitudes than that of the 19B engines (fig. 7), extended from 10,500 to 15,000 rpm at a pressure altitude of 30,000 feet and from 12,500 to 14,400 rpm at 35,000 feet. The maximum speed at which the engine could be safely operated was limited by the requirement that a turbine-inlet temperature of 1500° F should not be exceeded. Combustion blow-out at the minimum operating speed was encountered at 35,000 feet. Below this altitude a blue flame was emitted from the bottom of the tail pipe at low engine speeds, a condition that made maintenance of a constant engine speed difficult. The flame was apparently caused by the concentration of fuel in the bottom of the combustion chamber. The fuel manifold pressures encountered at these low-speed conditions were less than 10 pounds per square inch gage and the fuel was probably being improperly atomized by the nozzles. The idling speed of the engine is shown by the dashed curve in figure 7. The idling speed of the engine was the lowest speed at which the engine could be operated without burning in the tail pipe. When the airspeed was raised in the tunnel, the operating range increased slightly as with the 19B engines.

In an attempt to obtain lower idling speeds by more finely atomizing the fuel, 8.3-gallon, 45°-angle spray nozzles were installed. The idling speed and the operating characteristics of the engine were unchanged but higher tail-pipe temperatures lowered the maximum speed at which the engine could be safely operated.

Afterburning and Stability of Combustion

19B engines. - Burning of fuel in the tail pipe was encountered with the 19B engines at pressure altitudes above 20,000 feet. The amount of burning in the tail pipe increased when the tail cone was moved out. When the maximum operable speed of the engines at high altitudes was reached, a further increase in fuel flow resulted in the emission of 5- to 6-foot blue flames from the tail pipe. These flames constantly shifted about in the annulus of the tail-pipe nozzle. When the fuel flow was further increased, the flames became more unstable and combustion in the engine ceased completely.

After the 19B engines were started at a pressure altitude of 25,000 feet, the maximum speed obtainable was about 5000 rpm. In order to increase the engine speed, the altitude had to be reduced until at approximately 17,000 feet the engine could be accelerated to its normal operating range. This unstable operating range is shown by the hatched area in figures 4 and 6. In this region of operation the combustion was very unstable, the fuel consumption was excessive, and a blue flame was constantly emitted from the tail pipe. When the fuel flow was raised during operation of the engine in this unstable range, the engine speed decreased and 8- to 10-foot blue flames were emitted from the tail pipe.

19XB-1 engine. - The combustion characteristics of the 19XB-1 engine were much better than the 19B engines and considerably less afterburning was encountered at high altitudes. The unstable operating range of the 19XB-1 engine encountered above a pressure altitude of 30,000 feet is shown by the hatched area in figure 7.

Acceleration

19B engines. - Acceleration of the 19B engines was relatively slow at engine speeds below 10,000 rpm. At high airspeeds the acceleration was more rapid than at low airspeeds. At a pressure altitude of 15,000 feet and an airspeed of 200 miles per hour, approximately 45 seconds were required to accelerate from 5000 to 16,000 rpm; 30 seconds of this time were required to reach 10,000 rpm. When the airspeed was raised to 325 miles per hour the acceleration was so improved that 20 seconds were required to accelerate from 5500 to 16,500 rpm, 10 seconds of which were required to reach 10,000 rpm. Approximately 1 minute was required to start the engines from rest and accelerate to 17,000 rpm at a pressure altitude of 5000 feet and an airspeed of about 20 miles per hour. Three-fourths of this time was required to reach 10,000 rpm. During such rapid accelerations, considerable vibration in the engine and an excessive amount of burning in and behind the tail pipe were encountered.

When the engine was being accelerated from the unstable to the stable operating region at a pressure altitude of about 17,000 feet, a great deal of manipulation of the throttle was necessary and several minutes were often required to increase the engine speed from 7000 to 12,000 rpm. While such accelerations were being made, a blue flame burned in and 2 to 4 feet behind the tail pipe. During operation in the stable region above 20,000 feet, slow acceleration of the engine was necessary. Attempts to accelerate rapidly caused excessive burning in and behind the tail pipe and often resulted in combustion failure.

During operation of the engines at pressure altitudes of 5000 or 10,000 feet with an airspeed of about 100 miles per hour, attempts to accelerate too rapidly from low engine speeds with the tail cone moved either in or out resulted in an increase in fuel rate to about twice the normal consumption with no change in engine speed. The engine speed could be held nearly constant but experimental conditions could not be stabilized at the high fuel rate. A blue flame extended from the tail pipe, the turbine-inlet temperatures were 200° to 300° F higher than normal, and the tail-pipe temperatures were 100° to 200° F higher than normal. The temperature distribution around the tail pipe was not uniform when the engine was operating at the high fuel rate. The fuel rate could be reduced to the normal value by retarding the throttle. When the engine was accelerated more slowly, the high fuel rate was not encountered. The engine had to be accelerated more slowly through this region with the tail cone moved out. With the tail cone moved either in or out, rapid accelerations were normal at a pressure altitude of 5000 feet and an airspeed of 200 miles per hour. The high fuel rate was encountered with the tail cone moved out at a pressure altitude of 10,000 feet and an airspeed of 250 miles per hour, although acceleration was normal with the tail cone moved in.

19XB-1 engine. - Acceleration at all altitudes was more rapid with the 19XB-1 engine than with the 19B engines, although acceleration below 10,000 rpm was still rather slow. The amount of burning in and behind the tail pipe during rapid accelerations was about the same for both engines. Combustion blow-out, which limited acceleration of the 19B engines above a pressure altitude of 20,000 feet, had much less effect on the 19XB-1 engine. The high fuel rate obtained during rapid accelerations of the 19B engines was not encountered with the 19XB-1 engine.

Starting

19B engines. - In the standard configuration, the 19B-2 engine was much easier to start than the 19B-8 engine. From 15 to 20 seconds of the 30-second starting cycle were usually required to start the 19B-2 engine. During the starting cycle before the fuel ignited, the throttle position was about one-third open. With the 19B-8 engine, two starting cycles were usually required. During the first starting cycle, the throttle was about one-half open; after the cycle had elapsed, the engine speed was allowed to drop to between 500 and 1000 rpm. With the combustion chamber and tail pipe thus loaded with fuel, another starting cycle was begun. Usually the fuel ignited immediately and very high turbine-inlet and tail-pipe temperatures resulted. Numerous repetitions of the starting cycles were sometimes necessary before the fuel ignited.

After the angles were welded in the combustion chamber (fig. 5(a)) and the $10\frac{1}{2}$-gallon, 45°-angle spray nozzles were installed, the 19B-2 engine was very difficult to start. In order to start the engine, the method just described for the 19B-8 engine was adopted. Higher turbine-inlet and tail-pipe temperatures were obtained than with the 19B-8 engine, however, and flames extended from 15 to 20 feet behind the tail pipe during acceleration through the starting region.

When the $1\frac{1}{2}$-inch nozzle extensions were installed in the 19B-8 engine, one spark plug was placed $4\frac{1}{8}$ inches from the face of the fuel manifold between two longitudinal rows of holes in the combustion basket and in line with a fuel nozzle (location D fig. 1). The other spark plug was placed $2\frac{1}{8}$ inches from the fuel manifold in line with a row of holes in the combustion basket (location E, fig. 1). The hole immediately upstream of and in line with the spark plug was covered. The 19B-8 engine was much easier to start after these changes had been made.

The 19B engines could seldom be started when windmilling at an airspeed above 50 miles per hour. In the cases where the engines were started at higher airspeeds, the combustion chamber and tail pipe were loaded with an excess of fuel. Upon ignition of the fuel, extremely high temperatures were obtained through the turbine and a blue flame 10 to 15 feet long burned out of the tail pipe. The flame then withdrew into the combustion chamber and the temperatures dropped as the engine speed was increased.

Several attempts to start the 19B engines at a pressure altitude of 30,000 feet were unsuccessful. Both 19B engines were started at a pressure altitude of 25,000 feet with an airspeed of 50 miles per hour in the test section. The engines were started at a pressure altitude of 25,000 feet immediately after they were shut down and before the combustion chamber had time to cool off. As previously mentioned, the maximum engine speed obtainable after starting the engine at a pressure altitude of 25,000 feet was about 5000 rpm. In order to increase the speed still more, the altitude was lowered until at a pressure altitude of approximately 17,000 feet the engine could be accelerated to the stable operating range. The engines were started several times at a pressure altitude of 15,000 feet after they had been cooled 10 to 15 minutes. During these starts the combustion chamber had to be loaded with fuel, which resulted in high temperatures and burning in the tail pipe.

In cases where the engines failed to start after repeated attempts, fuel and oil eddied out of the tail pipe and settled between the tail pipe and the cowling. When the engine was then successfully started, the fuel in the cowling was ignited by the heat from the tail pipe. These fires usually burned in the bottom of the cowling and half way up either side of the tail pipe. In order to provide sufficient cooling air through the cowling to blow out the flame, the airspeed in the test section was raised to between 200 and 300 miles per hour.

<u>19XB-1 engine.</u> - With the throttle about one-third open, the 19XB-1 engine was usually started in 15 to 20 seconds. This engine could be started at a pressure altitude of 35,000 feet with an airspeed of 200 miles per hour. The maximum engine speed that could be obtained after starting the engine at this altitude was from 3800 to 4000 rpm. No attempts were made to start the engine at a pressure altitude higher than 35,000 feet. At a pressure altitude of 30,000 feet with an airspeed of 200 miles per hour, the engine was started and accelerated to normal operating speeds, although acceleration below 10,000 rpm was sluggish. When too much fuel was fed into the engine during the starts at 30,000 feet, combustion ceased at engine speeds between 8800 and 9500 rpm.

Fuel-Control System

<u>19B engines.</u> - The barostat control and the overspeed governor, which represent intermediate designs, did not give sufficient speed control at altitude in the high engine speed range.

<u>19XB-1 engine.</u> - The overspeed governor on the 19XB-1 engine was the same as on the 19B engine but the engine was not equipped with a barostat. Because the maximum speed of the 19XB-1 engine was limited by high tail-pipe temperatures in all cases, no observation was made of the reliability of the governor.

Substantial redesign of the fuel in a control system is under way to alleviate the difficulties encountered.

Tail-Pipe and Turbine Failure

<u>19B engines.</u> - When the 19B engines were received for testing, the exit nozzles of the tail pipes were considerably out of round. A circular wooden cone was forced into the tail pipes to return them to the correct shape and a stainless-steel strap of 1/8- by 3/4-inch section was tack-welded around the tail pipe at the nozzle exit.

After approximately 40 hours of operation on both engines, the tail-pipe nozzles were not warped more than $\frac{1}{4}$ inch out of round on the diameter.

After several hours of engine operation, the front portion of both tail pipes that forms a shroud around the turbine wheel began to warp. This warping decreased the tip clearance of the turbine blades and caused them to scrape the tail pipe. The tips of several turbine blades on the 19B-8 engine broke off during operation because of the reduced clearance. Before this failure occurred, the engine had been operating under unusual conditions with high tail-pipe temperatures and burning was present in the tail pipe. The first indication of the turbine failure, an increase in the engine fuel rate, was observed immediately after a burst of sparks and several small balls of fire had shot out of the tail pipe. After the turbine blades were damaged, the engine began to vibrate and the tail cone then became loose and blew out of the tail pipe.

19XB-1 engine. - After operation of the 19XB-1 engine for approximately 10 hours, partly under unusual conditions with burning in the tail cone, 12 of the 16 struts holding the tail cone in place were found to have broken away. In some cases the weld between the strut and the tail cone had failed and in other cases the struts had been torn out of the tail cone. The tips of the turbine blades had also scraped the tail pipe.

These findings on the 19B and 19XB-1 engines resulted in redesign that eliminated the trouble encountered.

SUMMARY OF RESULTS

The following operational characteristics were observed during an altitude-wind-tunnel investigation of the Westinghouse 19B-2, 19B-8, and 19XB-1 jet-propulsion engines with standard and modified combustion chambers for a range of pressure altitudes from 5000 to 35,000 feet and airspeeds from 20 to 380 miles per hour.

1. The operating range of the 19B engines was satisfactory below a pressure altitude of approximately 17,000 feet but above 17,000 feet operation was limited by combustion blow-out. The operating range of the 19B-2 and the 19B-8 engines in the original configuration with maximum tail-pipe-nozzle area extended from engine speeds of 14,000 to 17,300 rpm at a pressure altitude of 20,000 feet.

The operating range of the 19B-2 engine extended from 15,500 to 16,500 rpm at 30,000 feet; however, the operational ceiling of the 19B-8 engine was 29,000 feet. A decrease in tail-pipe-nozzle area further reduced the operating range.

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2. At high pressure altitudes the operating range of the 19XB-1 engine was considerably greater than for the 19B engines and combustion blow-out did not limit the operating range below a pressure altitude of 30,000 feet. The range of operable engine speeds extended from 10,500 to 15,000 rpm at a pressure altitude of 30,000 feet and from 12,500 to 14,400 rpm at a pressure altitude of 35,000 feet.

3. No material improvement was obtained by several modifications of the combustion chamber that were investigated in an attempt to increase the operating range of the engines at high altitudes.

4. Approximately 1 minute was required to start and accelerate the 19B engines to 17,000 rpm with the tail cone in at a pressure altitude of 5000 feet and an airspeed of about 20 miles per hour. Three-fourths of this time was required to reach 10,000 rpm. Acceleration of the 19XB-1 engine was slightly faster.

5. The starting characteristics of the 19XB-1 engine were satisfactory; it could be started at a pressure altitude as high as 35,000 feet at an airspeed of 200 miles per hour. The 19B engines were difficult to start at airspeeds above 50 miles per hour at all altitudes.

6. Satisfactory operation of the lubricating system was encountered under all conditions investigated. The barostat and the overspeed governor installed on the 19B engines gave operational difficulty at high engine speed.

7. Under the unusual conditions of operating the engine with burning in the tail cone beyond its operational range, damage occurred to the 19B turbine blades and to the struts in the 19XB-1 tail cone.

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

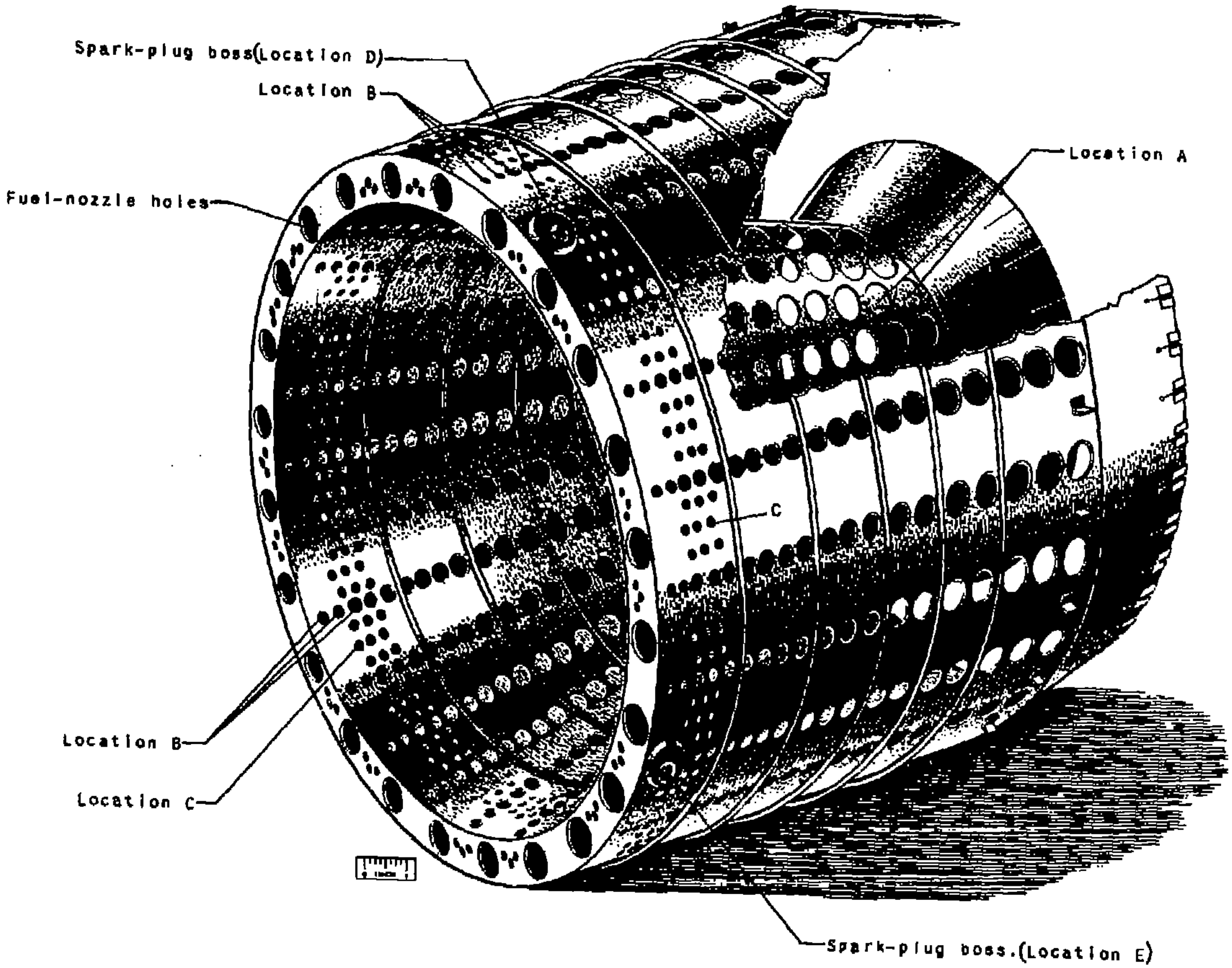

Figure 1. - Combustion-chamber basket of Westinghouse 19B and 19XB jet-propulsion engines.

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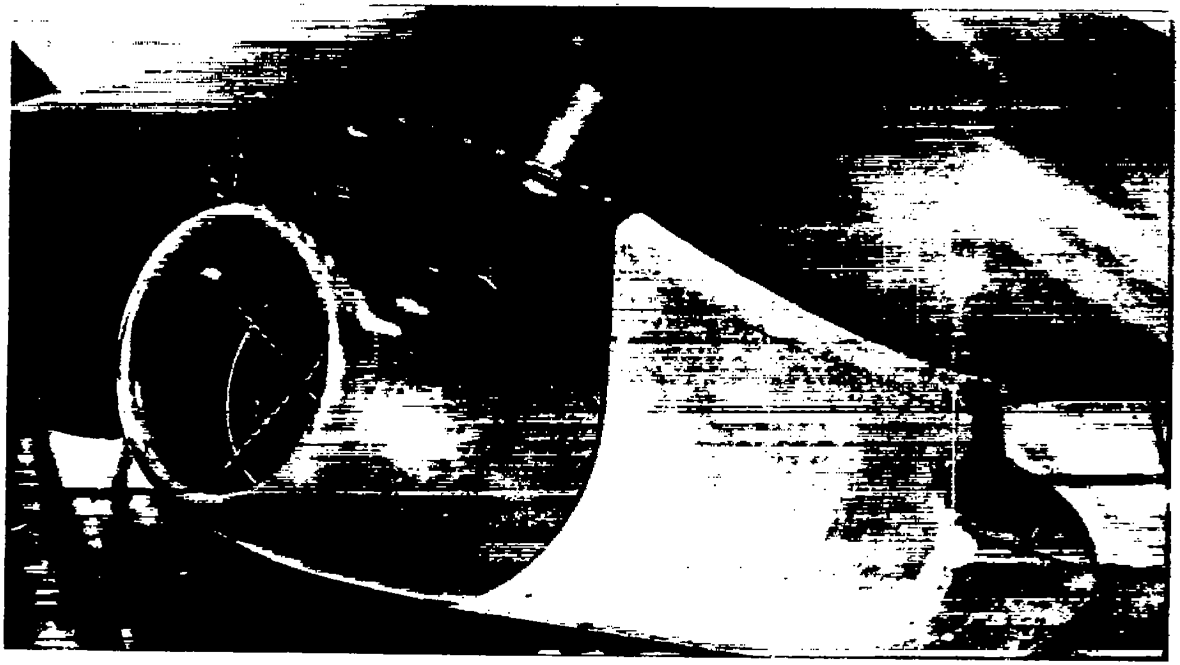
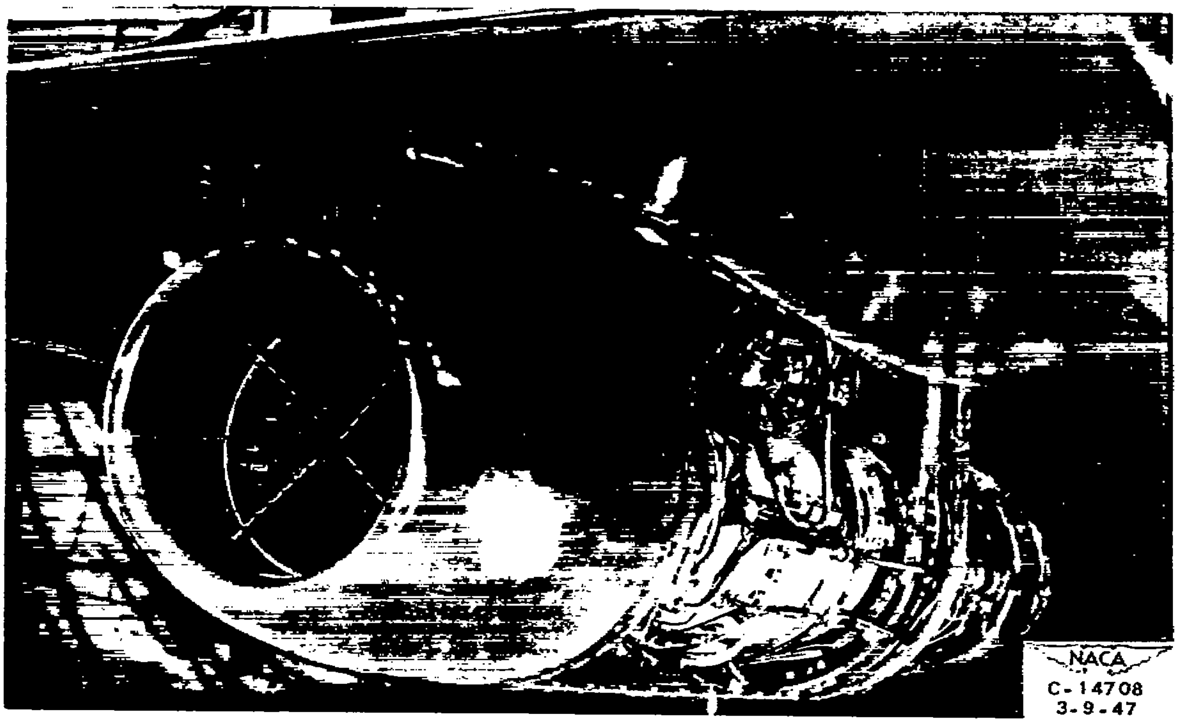


(a) With cowling.



(b) Without cowling.

Figure 2. - Installation of Westinghouse 19-B jet-propulsion engine in wing nacelle for investigation in altitude wind tunnel.

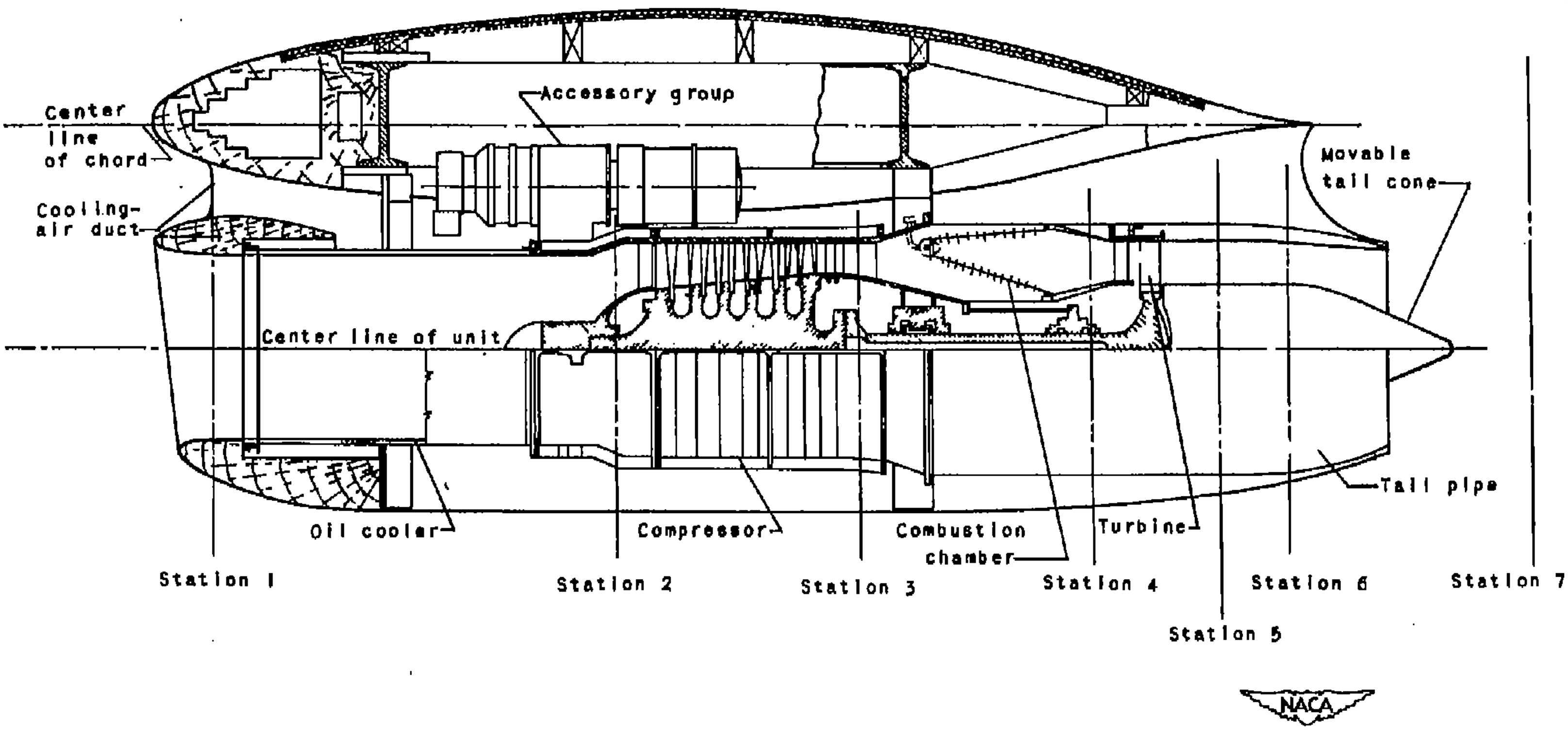


Figure 3. - Side view of Westinghouse 19-B jet-propulsion installation showing measuring stations.

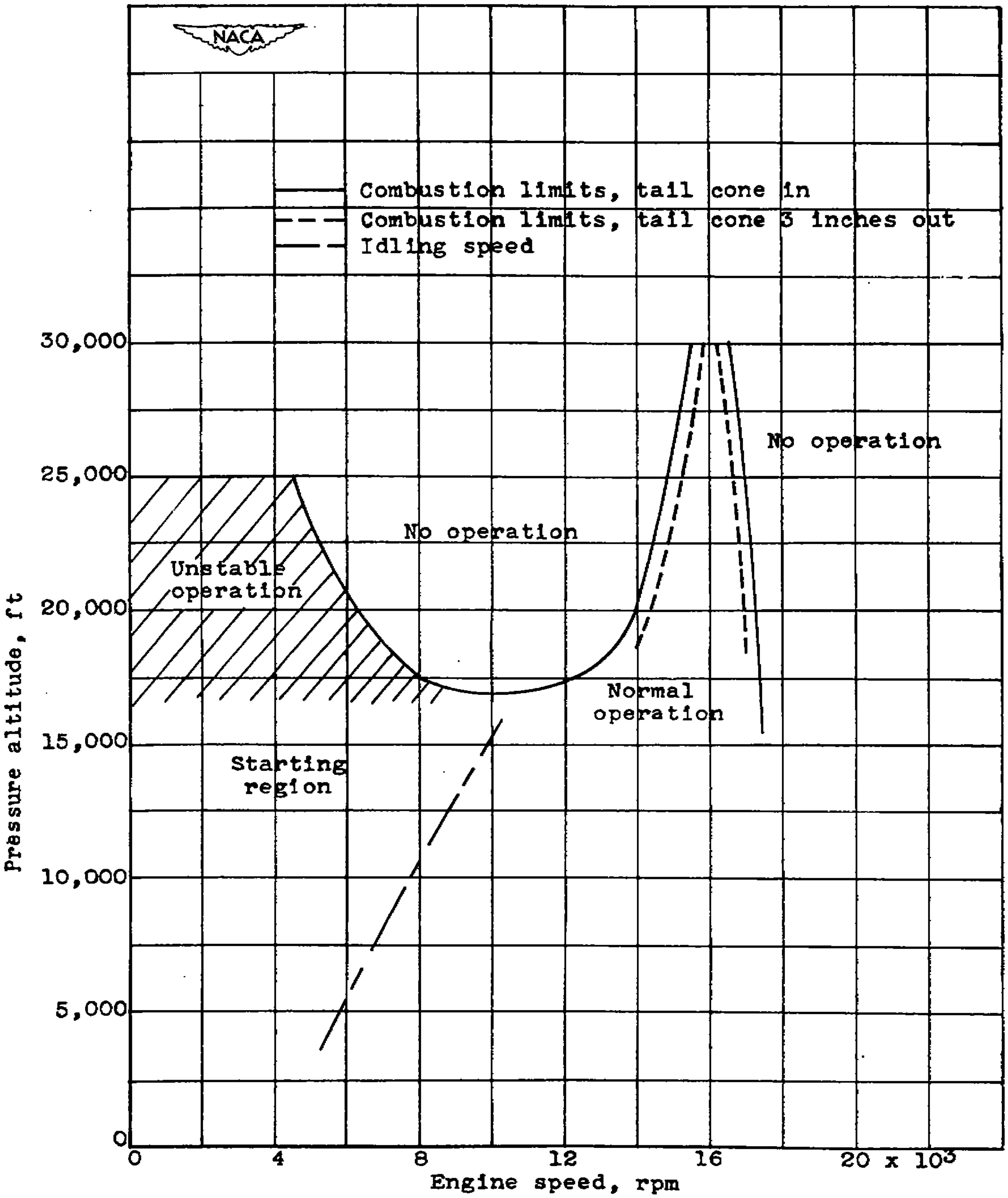
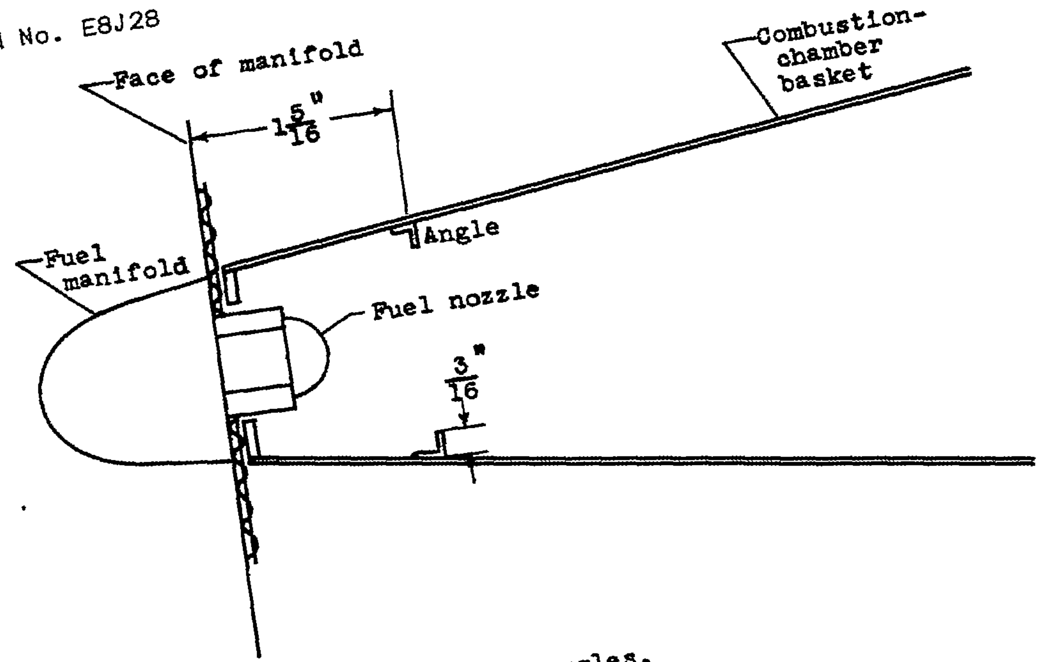
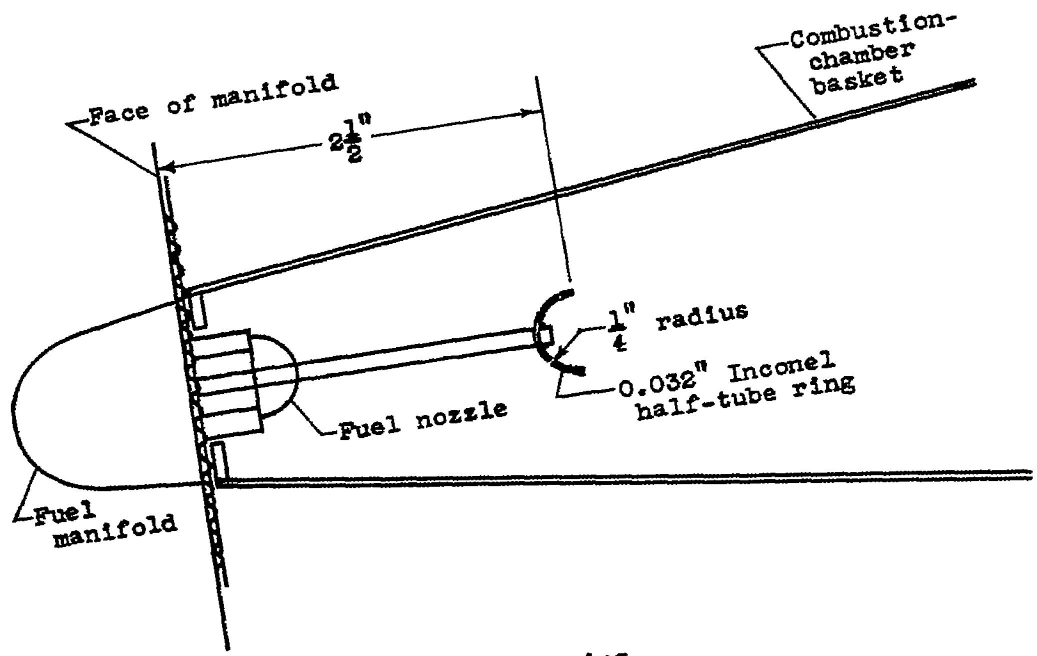


Figure 4.- Variation of operating range with pressure altitude at an airspeed of 20 miles per hour with tail cone in and 3 inches out with original configuration. Westinghouse 19B-2 jet-propulsion engine.



(a) Position of steel angles.



(b) Position of half-tube ring.

Figure 5.- Sketches showing two modifications installed in combustion chamber of Westinghouse 19B-2 jet-propulsion engine.

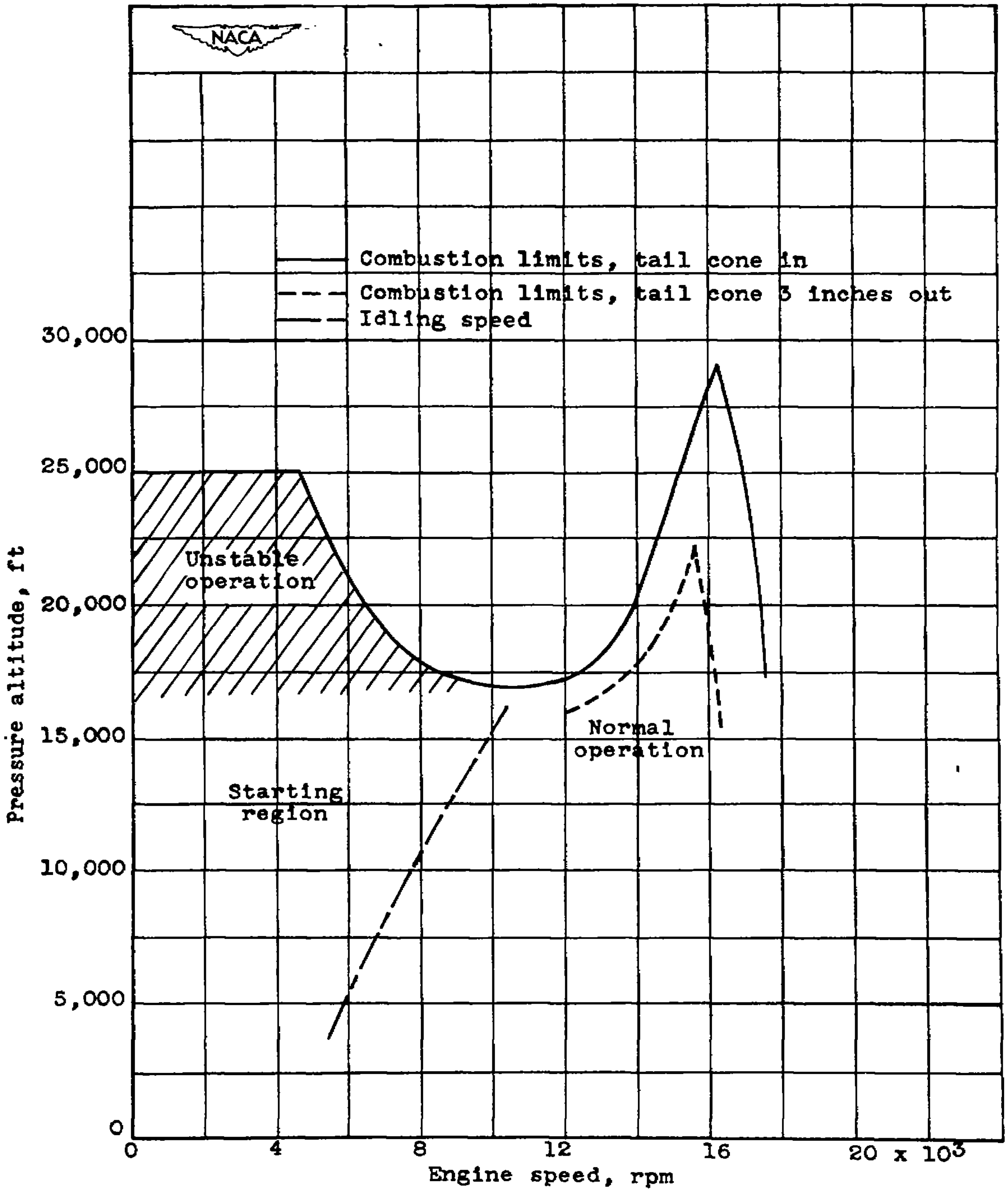


Figure 6.- Variation of operating range with pressure altitude at an airspeed of 20 miles per hour with tail cone in and 3 inches out with original configuration. Westinghouse 19B-8 jet-propulsion engine.

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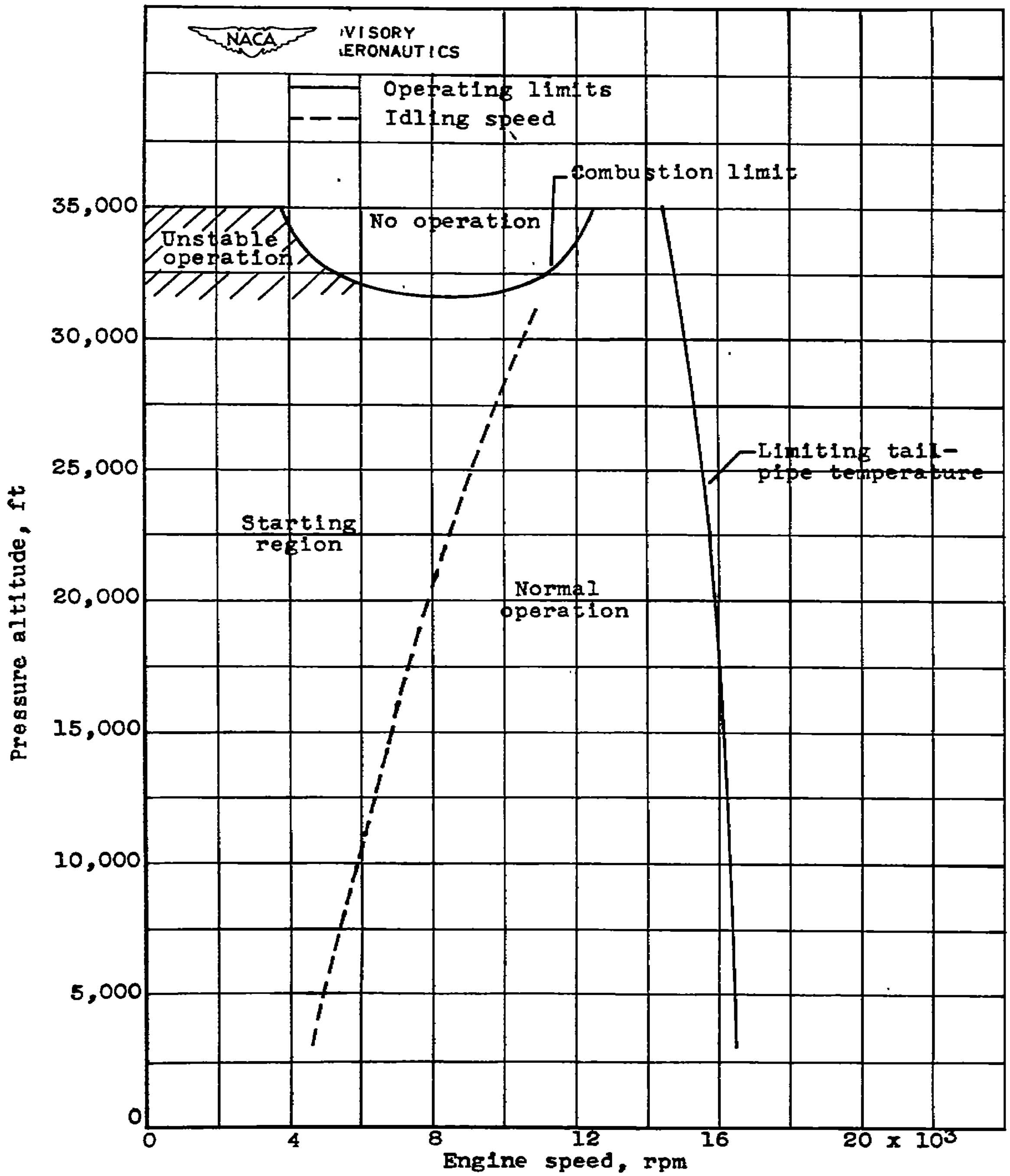

Figure 7.- Variation of operating range with pressure altitude at an airspeed of 20 miles per hour with original configuration. Westinghouse 19XB-1 jet-propulsion engine.