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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

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF WESTINGHOUSE 19B-2
19B-8, AND 19X6-1 JET-PROPULSION ENGINES

I - OPERATIONAL CHARACTERISTICS

By William A. Fleming

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 15 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 15-1 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 19X9-1 engine was slightly faster. The starting characteristics of the 19XB-1 engine were satisfactory but the 19B engines did not start consistently.

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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 19X8-1 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 822 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

576 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 **ad** justable. 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.

19B-1 engine. - 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

576 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 $1\frac{1}{2}$ -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 $\frac{1}{4}$ - by $\frac{3}{16}$ - by $\frac{1}{32}$ -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 20,090 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.

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 run 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** 8 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 **oper-**ating **range** of the **19XB-1** engine encountered above **8 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 19X8-1 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 8s 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.

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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 **tailpipe**. **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.

19XB-1 engine. - 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 8 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

19B engines. - 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.

19XB-1 engine. - 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 8 control system is **under** way to alleviate the difficulties encountered.

Tail-Pipe & Turbine Failure

19B engines. - 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 360 **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**.

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 8 pressure altitude of 30,000 feet. The range of operable engine speeds **extended from** 10,500 to 15,000 **rpm** at 8 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 8 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**.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio

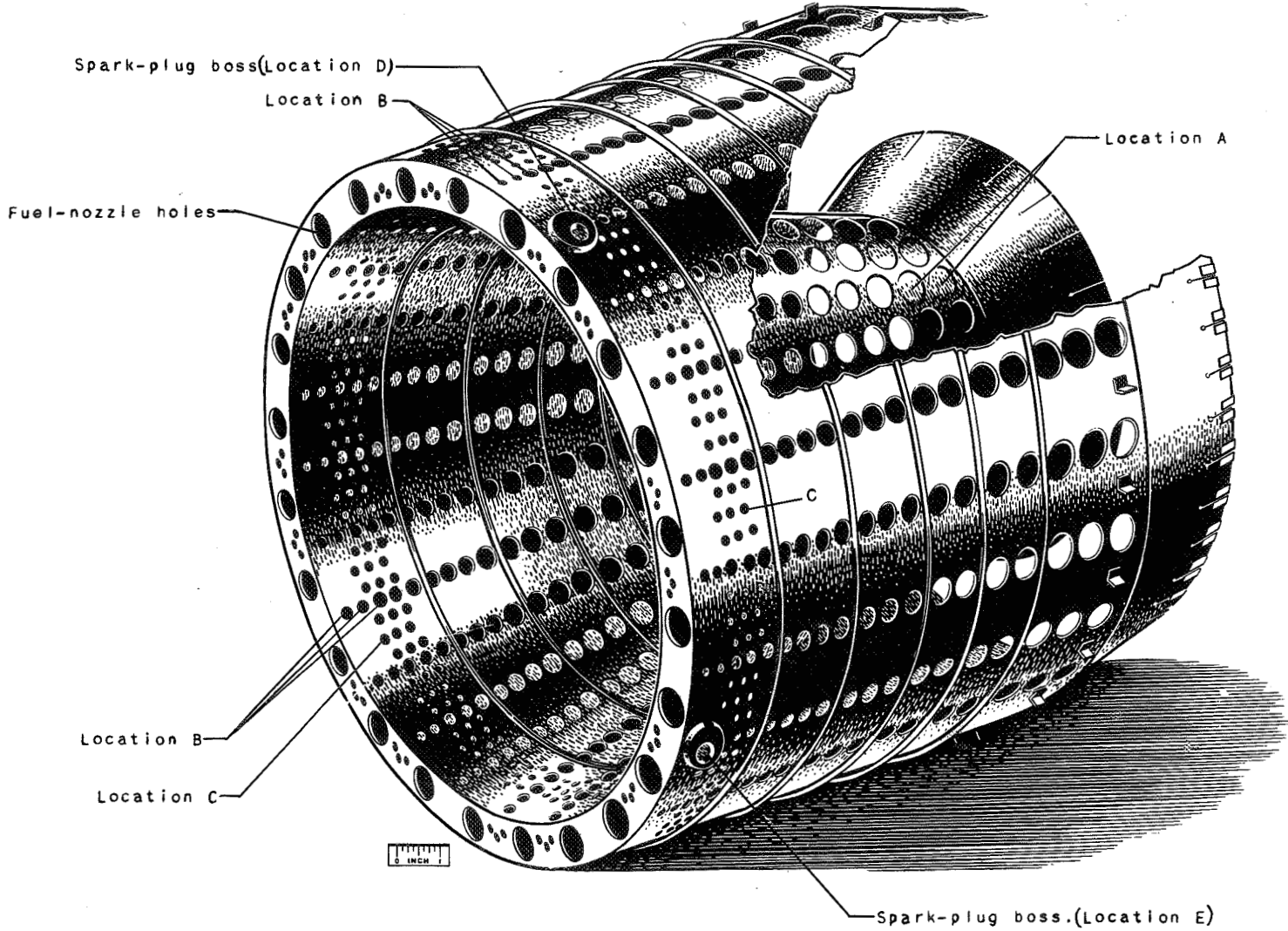
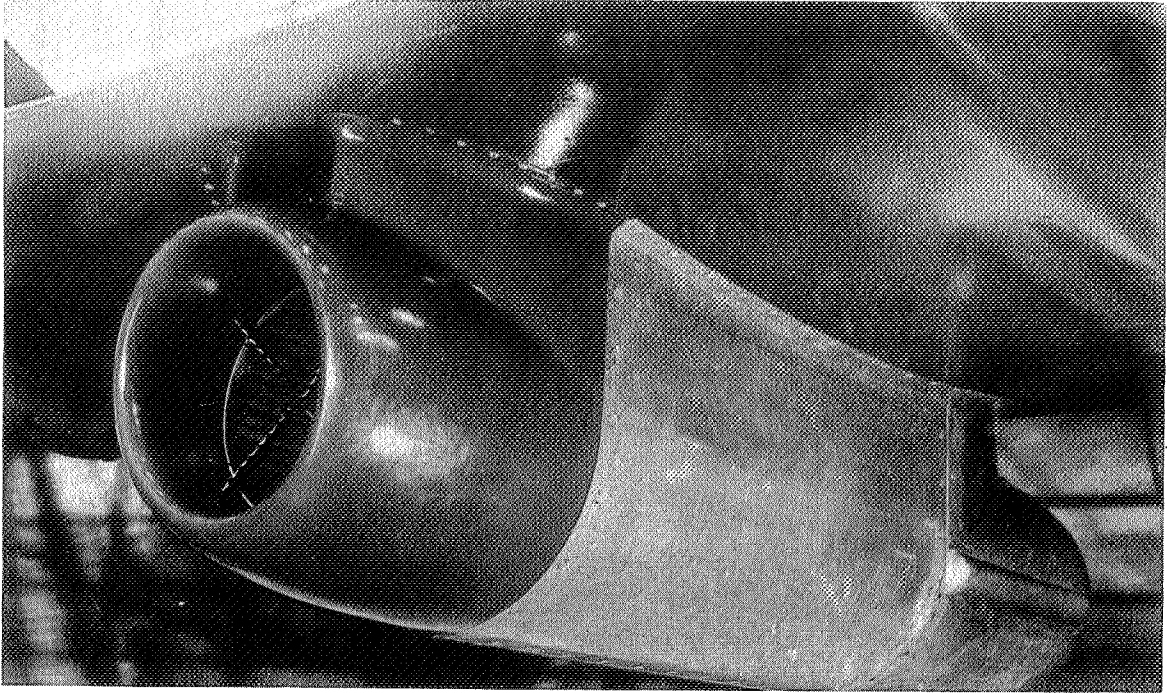
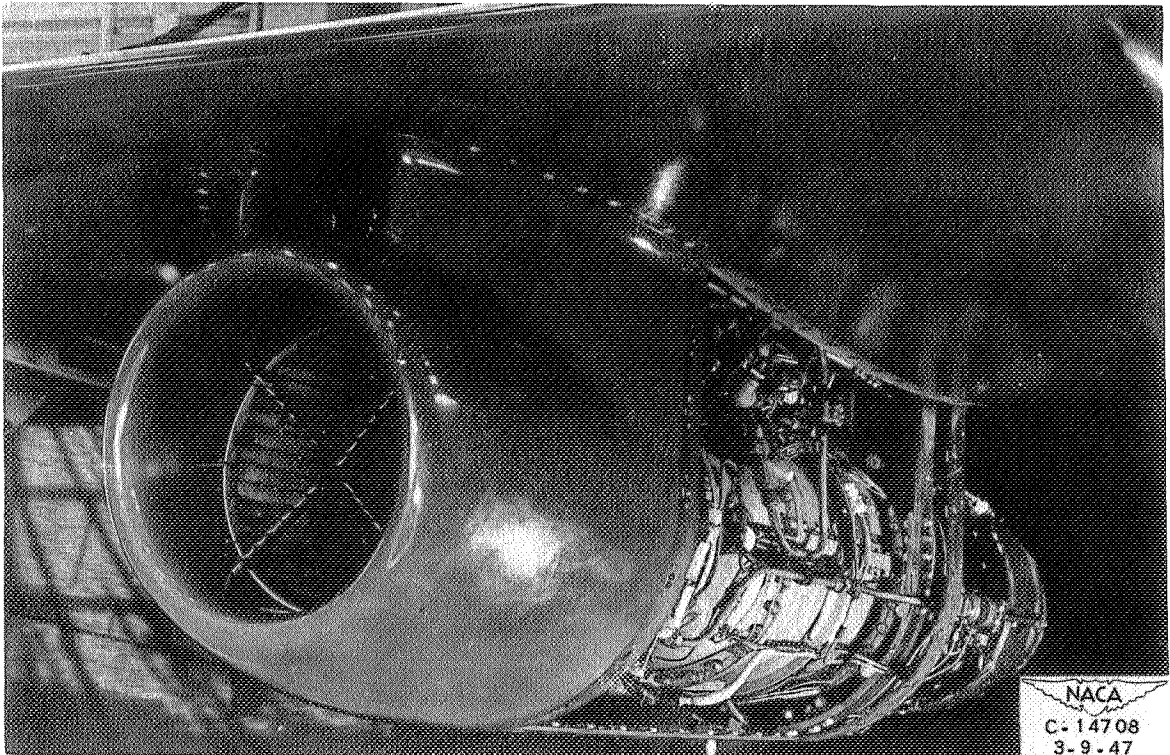


Figure 1. - Combustion-chamber basket of Westinghouse 19B and 19XB jet-propulsion engines.



(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.

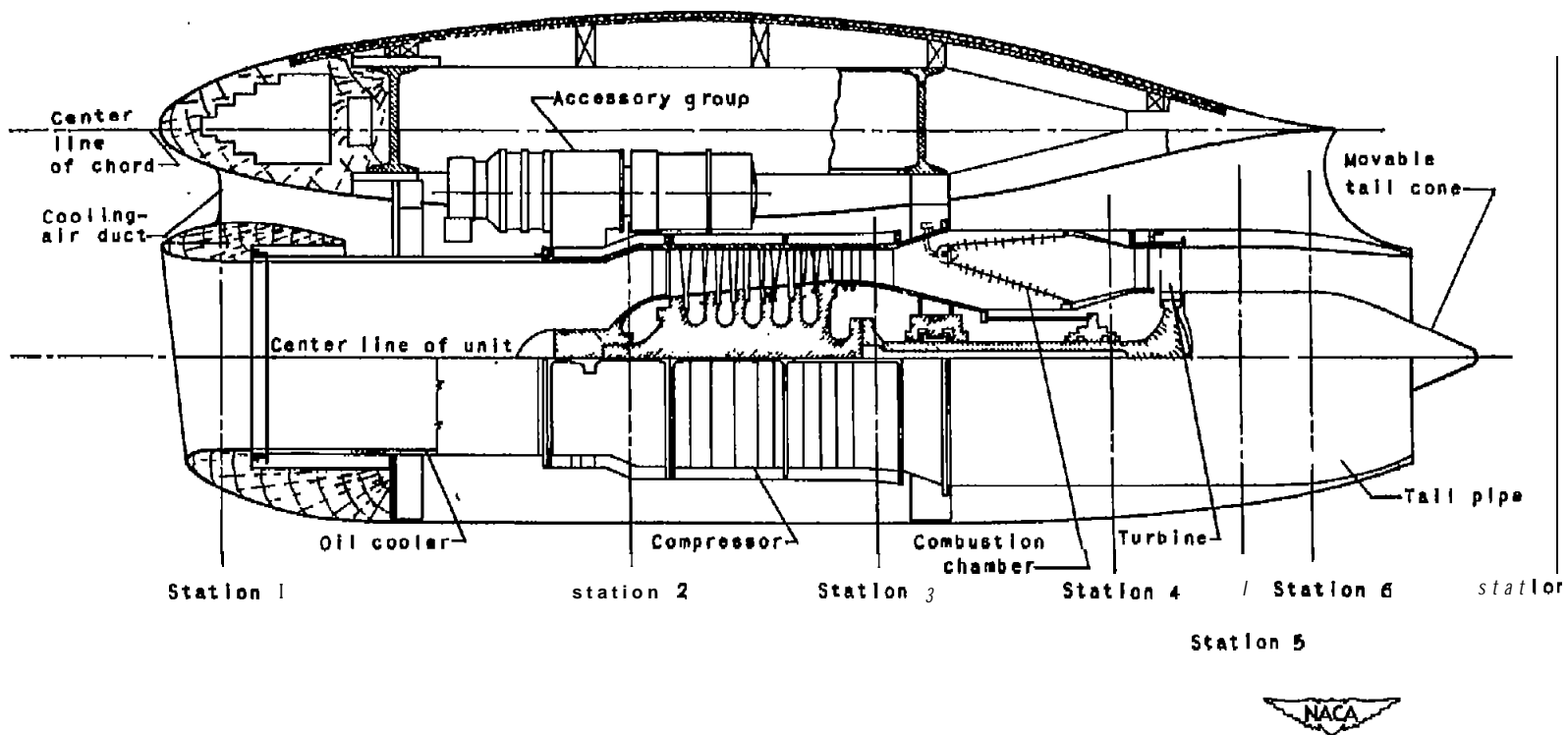


Figure 3. - Side view of Westinghouse 19-B jet-propulsion installation showing measuring stations.

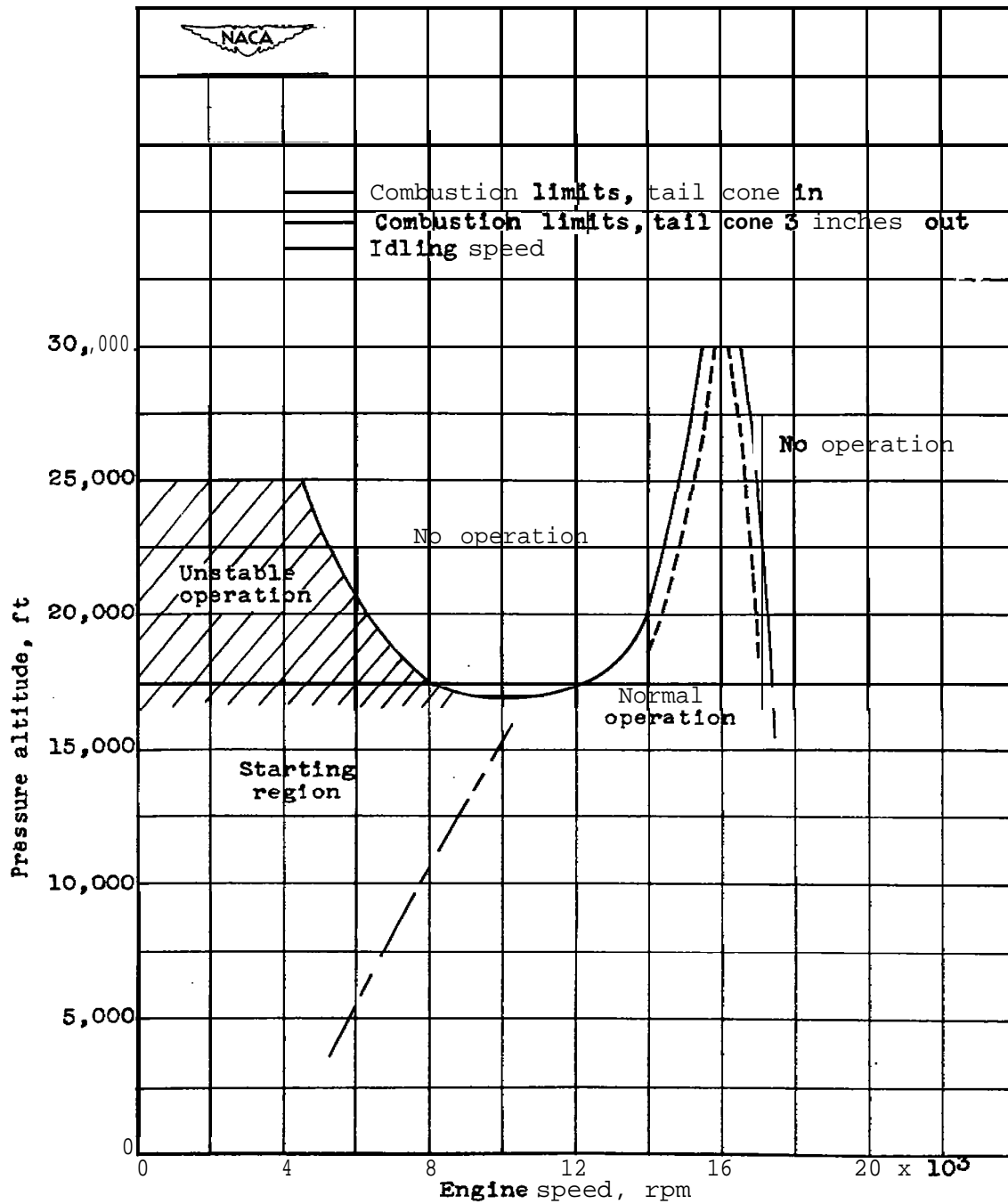
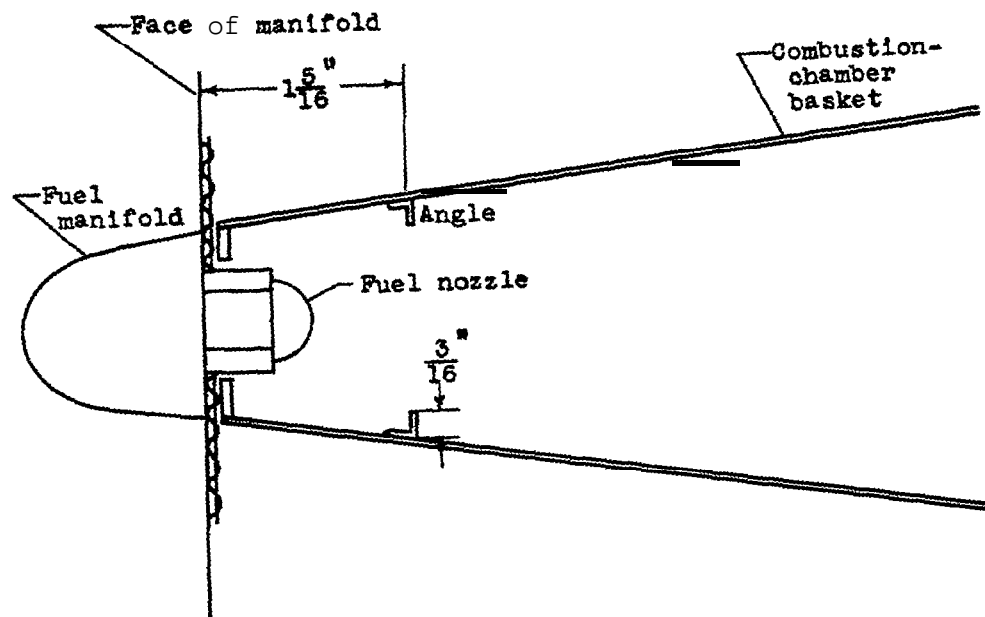
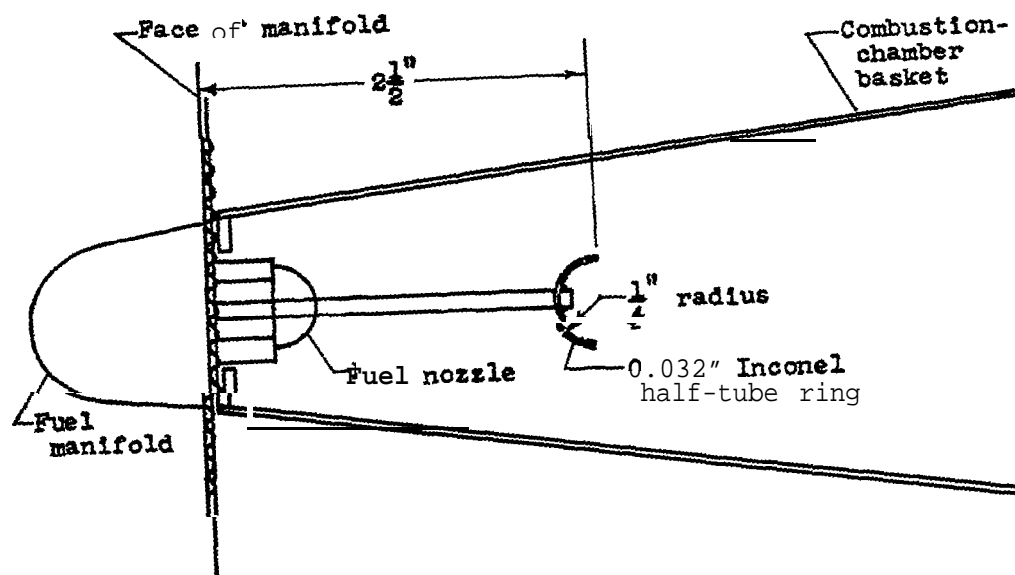


Figure 4.- Variation of operating range with pressure altitude at an airspeed of 20 miles per hour with tail cone in and 3 inches out with original configuration. Westinghouse 19B-2 jet-propulsion engine.



(a) Position of steel angles.

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(b) Position of half-tube ring.

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

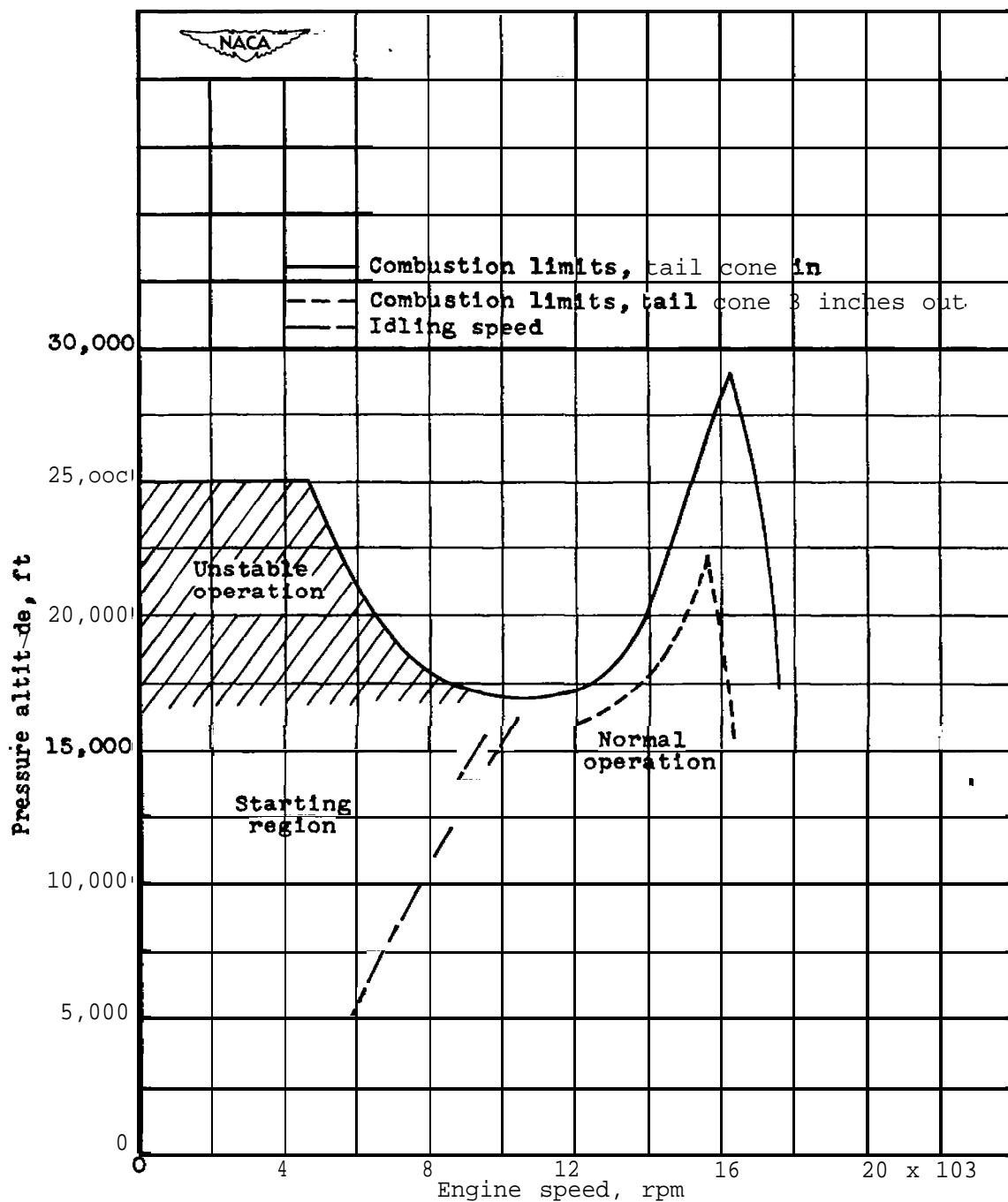


Figure 6.- variation of operating range with pressure altitude at an airspeed of 20 miles per hour with tail cone in and 3 inches out with original configuration. Westinghouse 19B-8 jet-propulsion engine.

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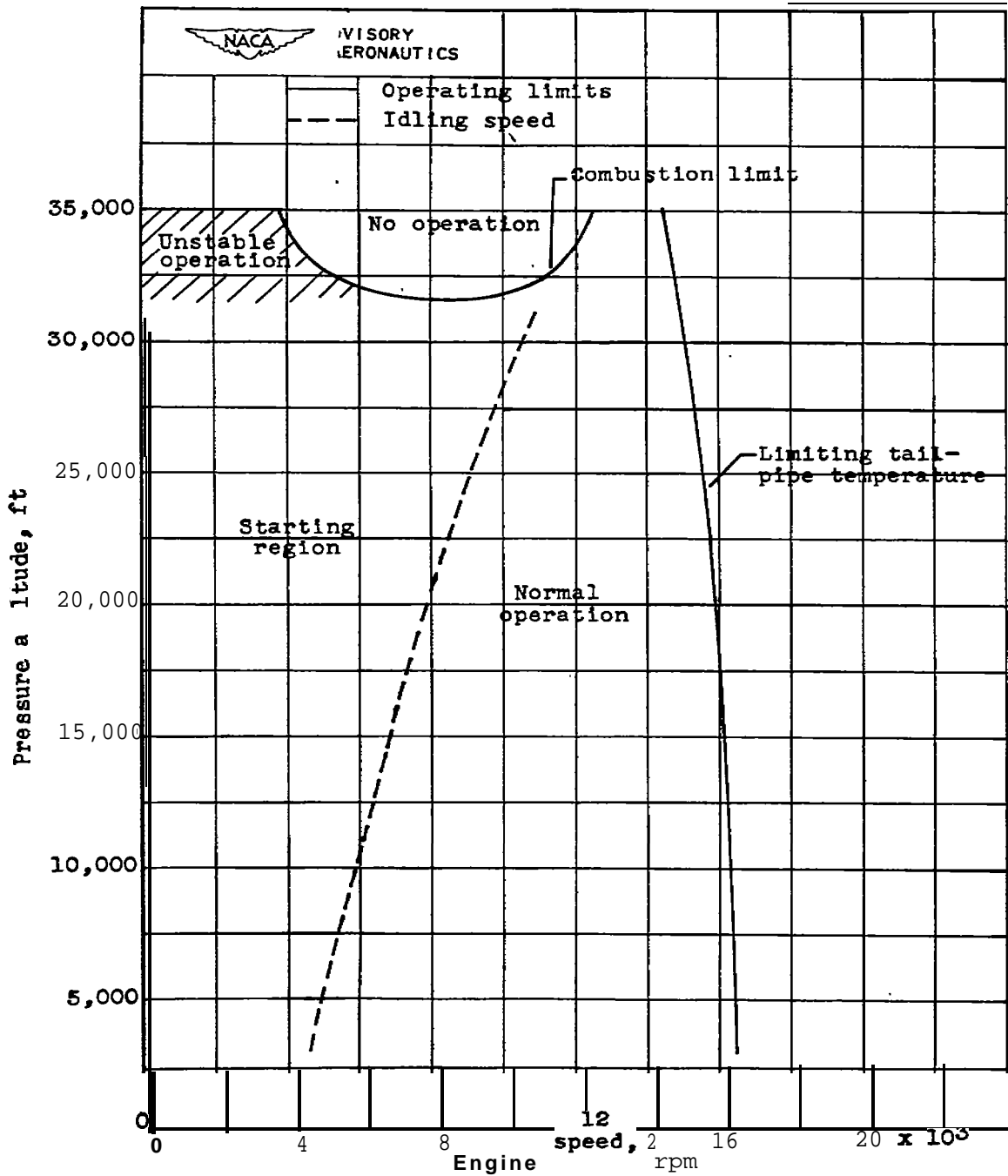


Figure 7.- Variation of operating range with pressure altitude at an airspeed of 20 miles per hour with original configuration. Westinghouse 19XB-1 jet-propulsion engine.