Demonstration for
First Annual Inspection
Altitude Test Chambers
By Bruce Lundin

At an altitude of 50,000 feet the pressure ~~of the air~~ is just slightly over one and one half pounds per square inch, or about one tenth the pressure at sea level, and the temperature is 67° below zero. These very low pressures and temperatures, which are experienced by an aircraft engine in flight at high altitude, are greatly increased as the flight speed is increased or the altitude reduced. At a flight Mach number of 1.7 at moderate altitudes, the inlet air pressure to the engine is over 40 pounds per square inch absolute and the inlet air temperature rises to over 250° F. These extremes of conditions under which turbojet engines are required to operate introduces many research problems which can be investigated only with extensive full-scale facilities that duplicate the pressure and temperature conditions experienced by the engine at various altitudes and flight speeds. A major extension of this laboratory's research facilities to provide the equipment necessary for these investigations has recently been completed by the installation of the two altitude test chambers located on each side of us.

The details of construction of the altitude test chamber and some of the essential features of the engine installation are shown in this diagram. The test chamber is 10 feet in

Fig. 30

diameter and 57 feet long and is of welded steel construction. The entire circumference of the chamber from the test section to the exhaust outlet is cooled by a water jacket. A honeycomb and screen are installed in the chamber before the test section to straighten and smooth the flow of inlet air. The engine is mounted on a thrust platform which is 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 thrust measuring device. The engine inlet is sealed from the exhaust system with a partition and a flexible neoprene impregnated diaphragm.

Some of the equipment which is necessary to provide the desired operating conditions in the test chamber is illustrated diagrammatically in this sketch. Fig. 31 Air is supplied to the test chamber under pressure by a series of centrifugal compressors having a combined capacity of 80 pounds per second. This air may be either refrigerated to -70° F in this refrigeration unit or heated to about 200° F in this heater. The exhaust gases from the engine are cooled by two shell and tube type coolers and delivered to a series of exhausters which are capable of maintaining an altitude pressure of 50,000 feet in the test chamber. Four new centrifugal exhausters, having a combined driving motor power of over 11,000 horsepower, have recently been installed as part of this system in the wing of the building through which you just passed. These new exhausters may be operated in conjunction with other exhausters ~~in~~ at this laboratory and either in series or in parallel to provide the desired range of operational conditions.

The range of simulated flight conditions provided by these facilities, interpreted in terms of flight Mach number and altitude, is shown in this diagram. Fig. 32 The maximum flight Mach number which may be simulated at the various altitudes is indicated by this curve and all conditions represented in the area below the curve may be obtained. As indicated, these limits are for a 4000 pound thrust engine. For smaller engines, the limiting Mach number will be somewhat higher and for larger engines, the possible Mach number will be reduced below those shown. A Mach number of about 1.7, which is equivalent to a velocity of over 1100 miles per hour, may be obtained at altitudes between 40,000 and 50,000 feet. For moderate altitudes, say between 10,000 and 20,000 feet, Mach numbers slightly greater than one or flight speeds of about 800 mph may be simulated.

These altitude test chambers are admirably suited to investigations of engine performance under altitude conditions and one of the principal fields of research to which they will be devoted in the near future is thrust augmentation of turbojet engines. Because the propulsive efficiency of the turbojet engine is inherently low at low flight speeds, the take-off and climb characteristics of jet planes are relatively poor as compared to the propeller driven aircraft. Augmentation of the thrust of the turbojet engine is therefore required to improve the climb characteristics and combat maneuvers of jet planes. The long take-off runs now required by jet planes is also a serious limitation of their usefulness that may be overcome by suitable thrust augmentation systems. In addition to these take-off and climb considerations an increase in thrust output above the performance of current engines is also necessary to provide the power required for flight at supersonic speeds. Various methods of increasing the thrust of turbojet engines have been under investigation by the NACA for some time, both in the Altitude Wind Tunnel and at the Jet Propulsion Static Laboratory.

One of the thrust augmentation methods under investigation, which is illustrated in this diagram, Fig. 33 is tail-pipe burning, or afterburning, wherein the gas temperatures, and hence the jet velocities and thrust, are increased by burning additional fuel in the tail pipe of the engine. A diffuser is installed between the turbine discharge and the inlet to the burner section to reduce the gas velocities sufficiently to obtain efficient combustion and reduce the pressure losses in the tailpipe. The fuel is introduced through spray nozzles and a flame seat is provided by a suitable flame holder at the burner entrance. The discharge of the burner is fitted with an adjustable-area exhaust nozzle in order to permit control of the turbine back pressure and hence prevent the turbine gas temperatures from increasing during the burning of the fuel in the tail pipe.

Another very simple method of augmentation which has been investigated is the injection of water and alcohol at the compressor inlets. The cooling effect of these injected liquids results in an increase in both the air flow through the engine and an increase in the compressor discharge pressure. The increased thrust produced is a result of the increased mass flow of air and liquids and the increased jet velocity provided by the higher combustion chamber pressure.

The third augmentation system investigated here is the air bleedoff system and is also illustrated by this diagram, Fig. 34. Water and alcohol are injected in the compressor inlets, as in the method previously discussed. Secondary air is bled off from the combustion chambers at approximately compressor discharge pressure, collected in a manifold, and burned to a very high temperature in an auxiliary combustion chamber. Additional water and alcohol are injected into the primary combustion chambers to replace the air that is bled off. We have thus provided the engine with a secondary jet of very high temperature, high velocity gases.

A summary of the principal results obtained from investigations of these augmentation systems at sea-level take off conditions on a 4000 pound thrust engine is presented in this next chart. Fig. 35 On this chart the percent increase in thrust is plotted against the increase in the liquid or fuel consumption and the three lines represent the performance of the tail-pipe burning, the water-alcohol injection and the air bleedoff system.

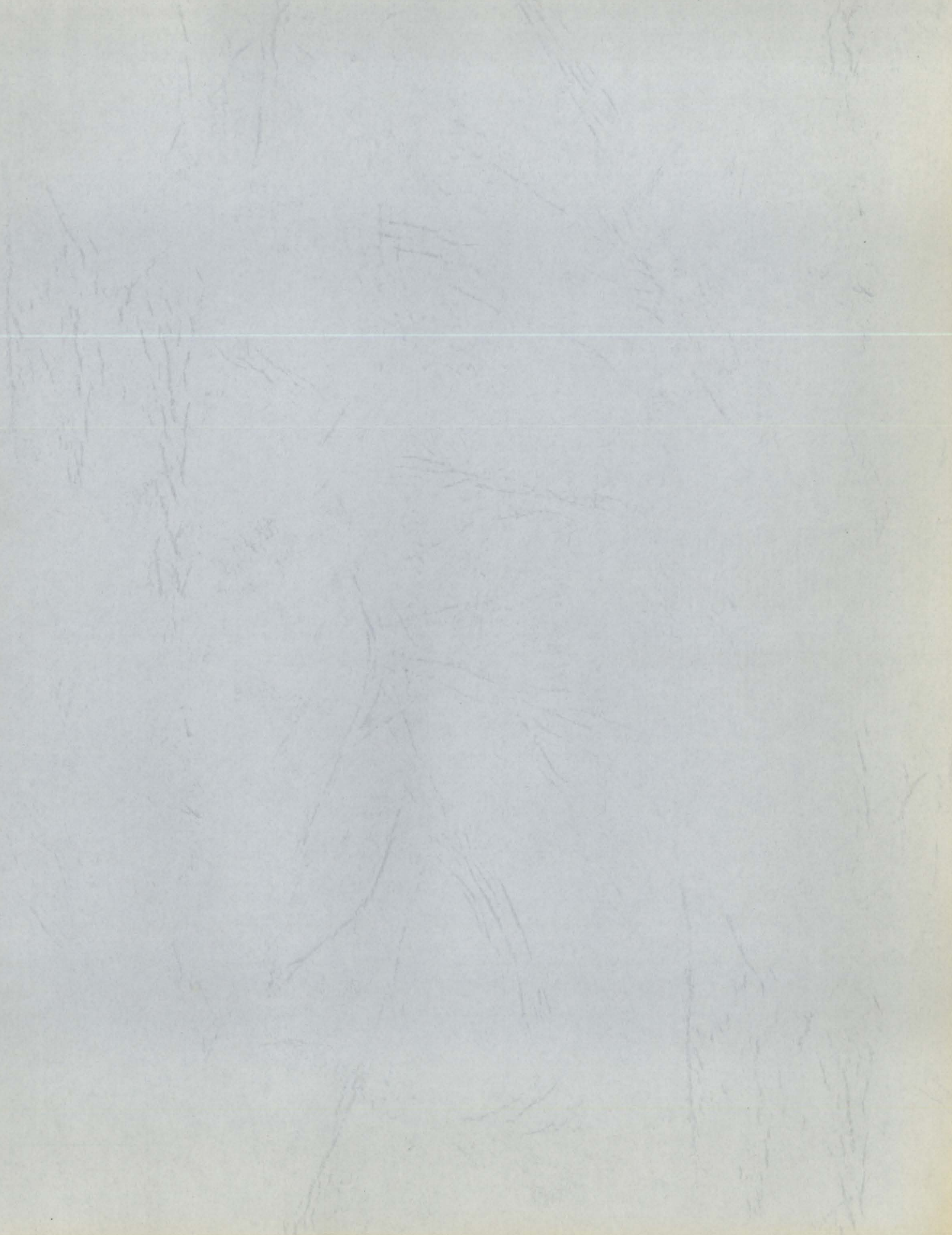
It is apparent that the tail-pipe burning system is the most economical of the three, that is, for a given thrust increase, the liquid consumption of this system is the smallest. A thrust increase of 40 percent was obtained for a fuel flow of 3 pounds per second to the tail-pipe burner. Although this point approached stoichiometric combustion in the tail pipe and the gas temperature was about 3500° F, the design of the burner was such that no external cooling of the burner shell or adjustable exhaust nozzle was required.

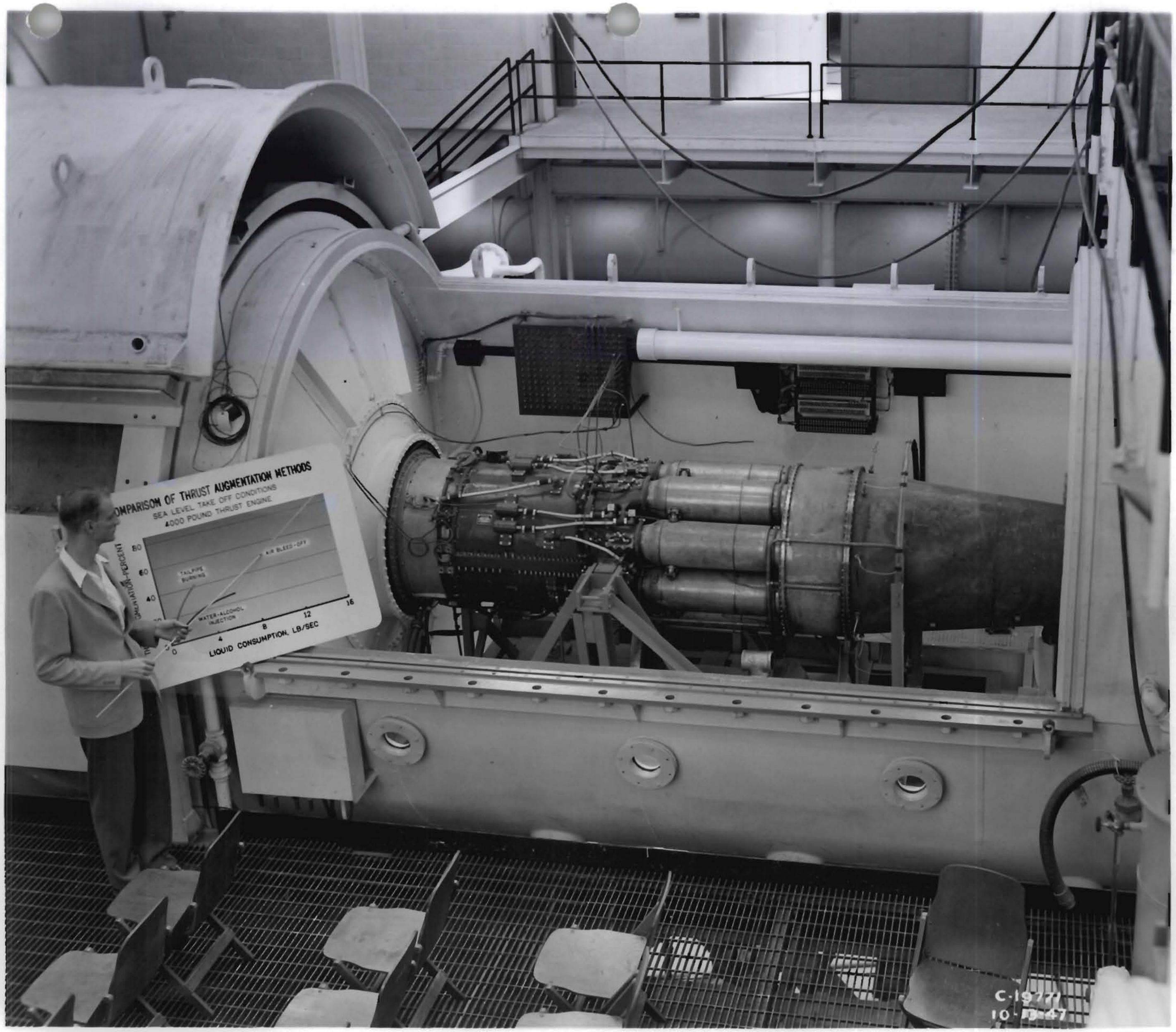
The performance of the water-alcohol injection system, shown by this curve, indicates a maximum thrust increase of about 26 percent for a liquid consumption of 6 pounds per second. This system of augmentation therefore finds application where simplicity of installation is of primary importance and where the thrust augmentation is required for only short periods of time. The principal feature of the air bleedoff system, shown by this curve, is the very large thrust increases that are possible at the expense of a relatively high liquid consumption. Because this air bleedoff system includes the injection of water and alcohol at the compressor inlets, the curve intersects the water-alcohol injection curve at this point instead of continuing to the point of zero thrust increase. The maximum augmentation obtained by this system is over 80 percent for a liquid consumption of 15 pounds per second. By means of this system, the normal 4000 pound thrust engine may be converted into a 7000 pound thrust engine for short periods of time. This increase in thrust would permit the take-off distance to be reduced to 48 percent of its normal value, or from say 3200 feet to about 1500 feet. If the same take-off run were permissible the total take-off weight of the airplane could be increased about 40 percent which would result in even greater increases in the payload.

All of these results are for sea-level, take-off conditions, that is, at zero airplane speed, and as such represent only part of the required field of investigation. Both investigations in the Altitude Wind Tunnel and analysis indicates that the magnitude of the thrust augmentation increases considerably with increased flight speed. For example, analysis indicates that at a flight Mach number of 1.5 the maximum thrust augmentation by tail-pipe burning is about six times as great as at take-off conditions. Expressed in terms of engine power, the output of an engine at this flight speed at 30,000 feet altitude would be 19,000 horsepower with tail-pipe burning as compared with only 8000 horsepower without tail-pipe burning. Not only are the effects of flight speed of importance, but the effect of altitude pressure on the combustion characteristics of tail-pipe burners and auxiliary combustion chambers and on the effectiveness of water-alcohol injection may be significant and requires experimental investigation.

The installation of these altitude test chambers has multiplied threefold the facilities now available at the Altitude Wind Tunnel to investigate many of these problems in the field of thrust augmentation, as well as in other fields of engine research. As previously mentioned, altitudes up to 50,000 feet may be obtained in the test chambers and the flight speeds obtainable in the Altitude Wind Tunnel are extended to Mach numbers up to 1.7.

The necessary research data for these investigations may therefore be obtained conveniently and accurately under conditions actually experienced by a turbojet engine in high altitude, supersonic flight.





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INSTALLATION OF TURBO-JET ENGINE IN ALTITUDE CHAMBER

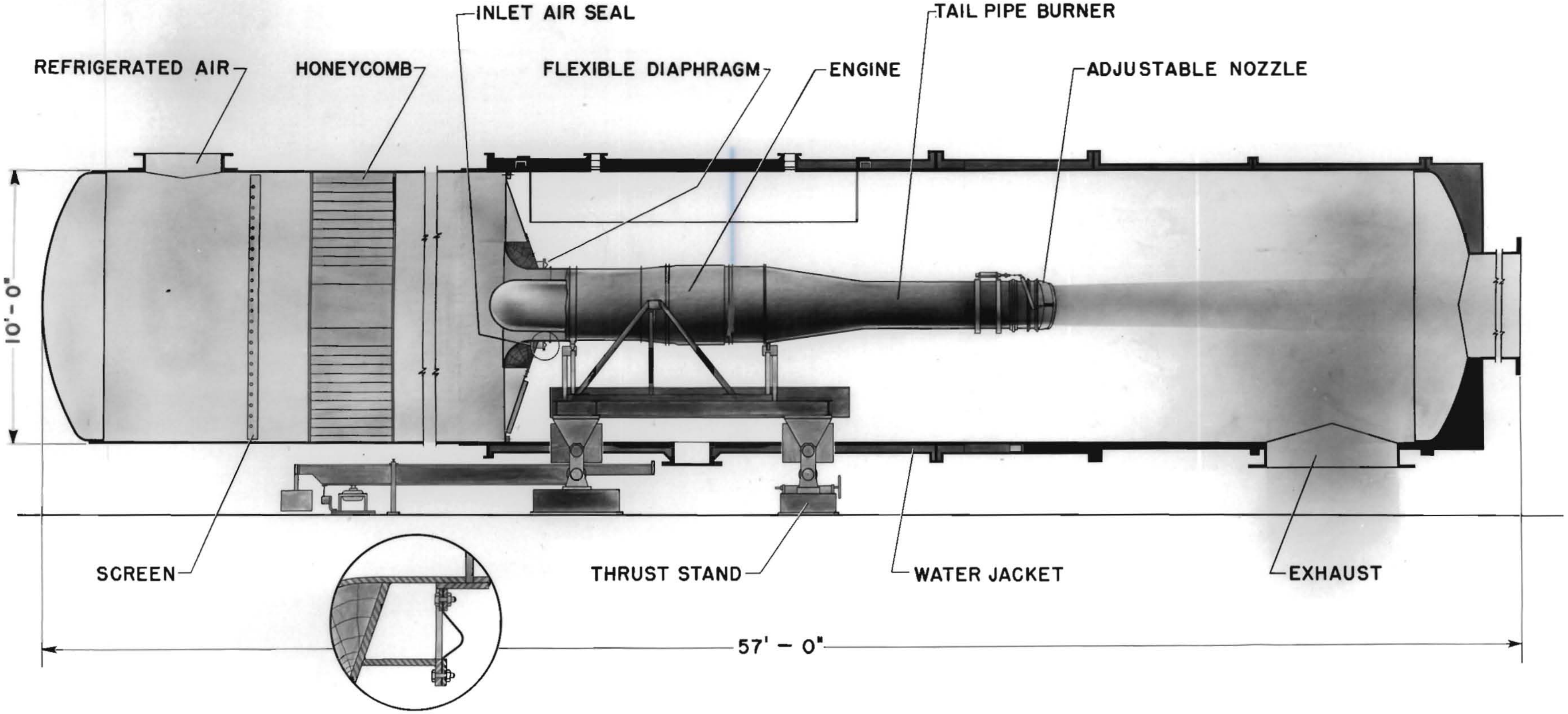

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Fig 30

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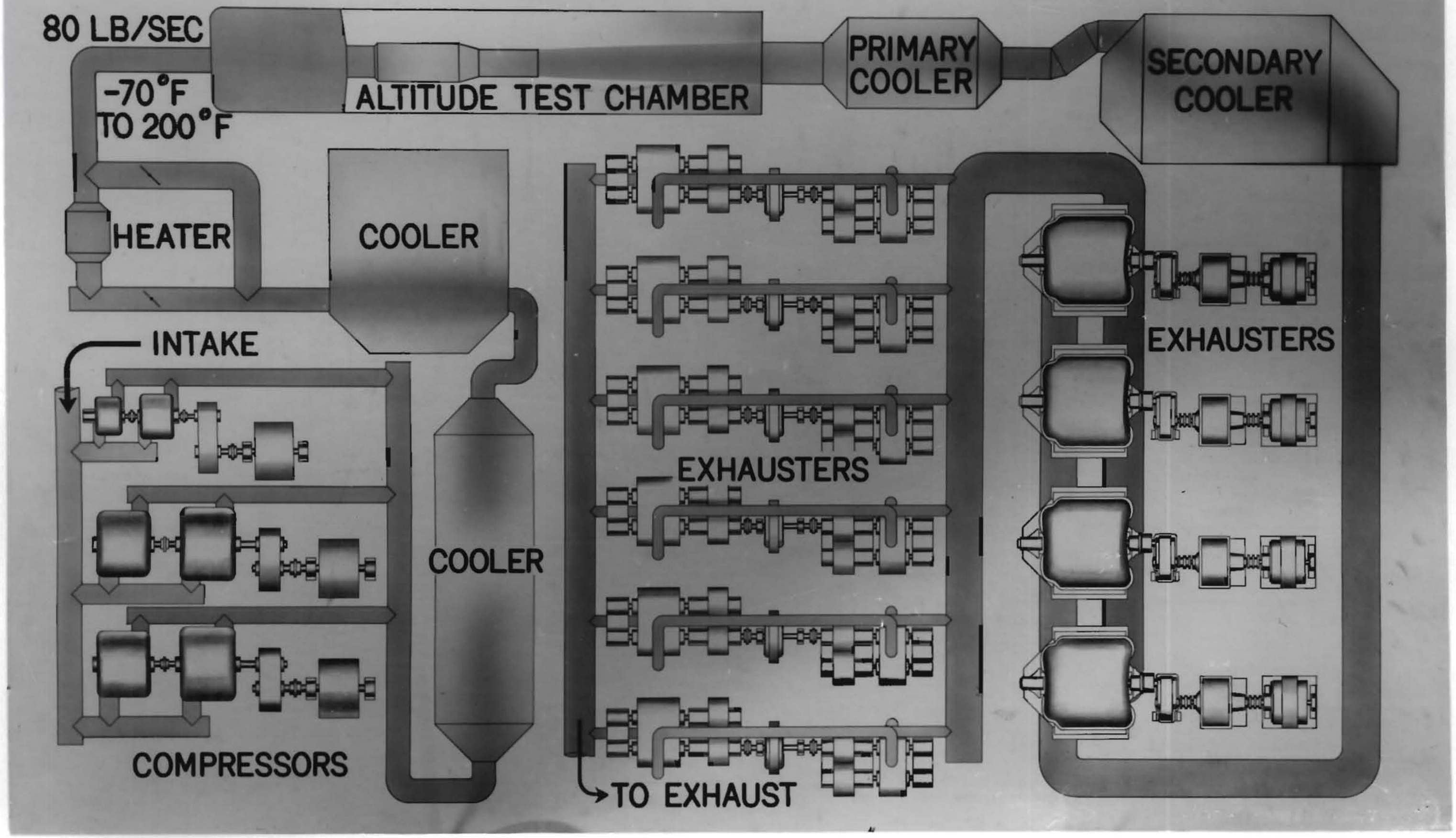
SERVICE FACILITIES FOR ALTITUDE TEST CHAMBER



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NACA

Fig 31

OPERATIONAL RANGE

4000 POUND THRUST ENGINE

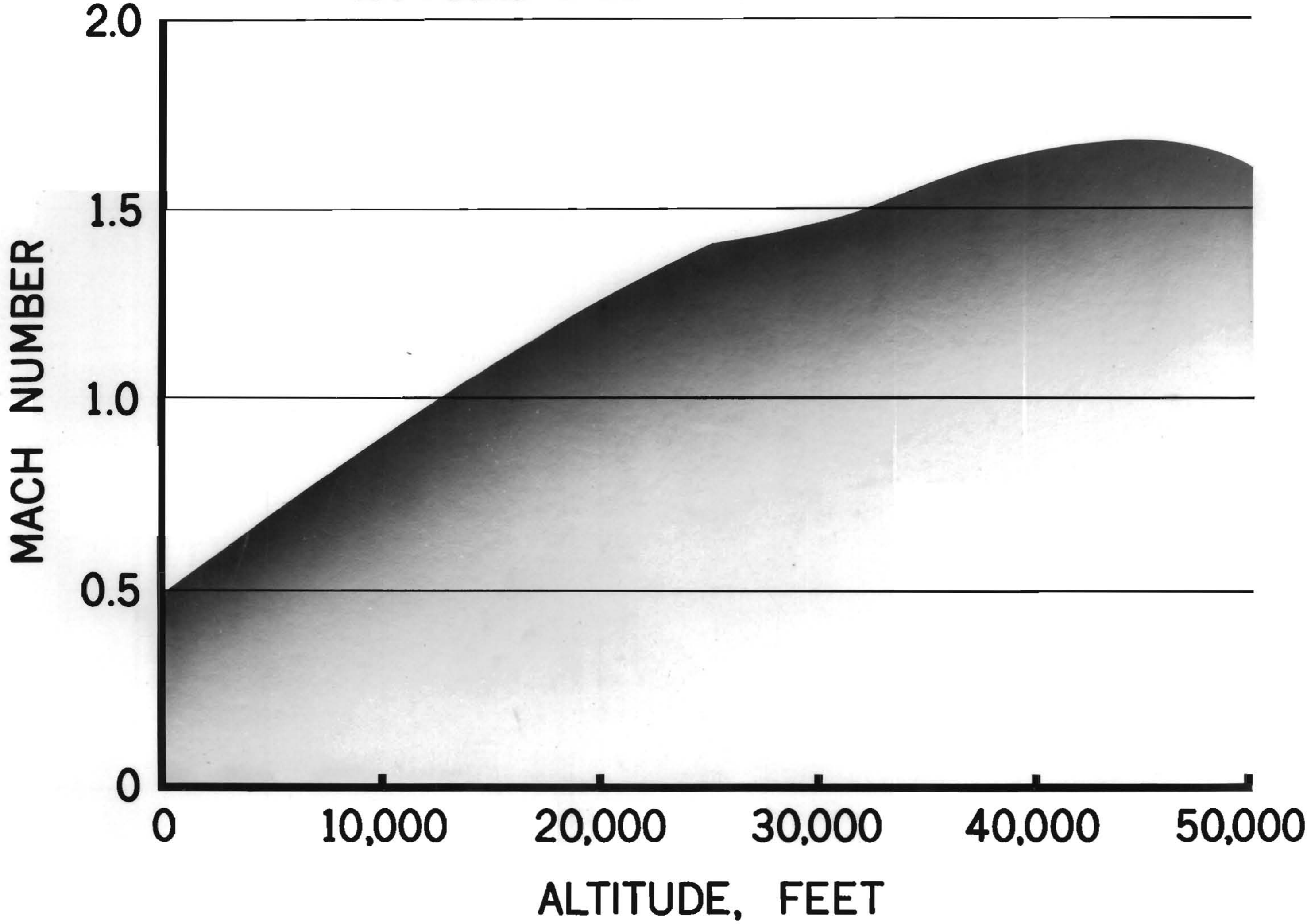

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Fig 32

THRUST AUGMENTATION BY TAILPIPE BURNING

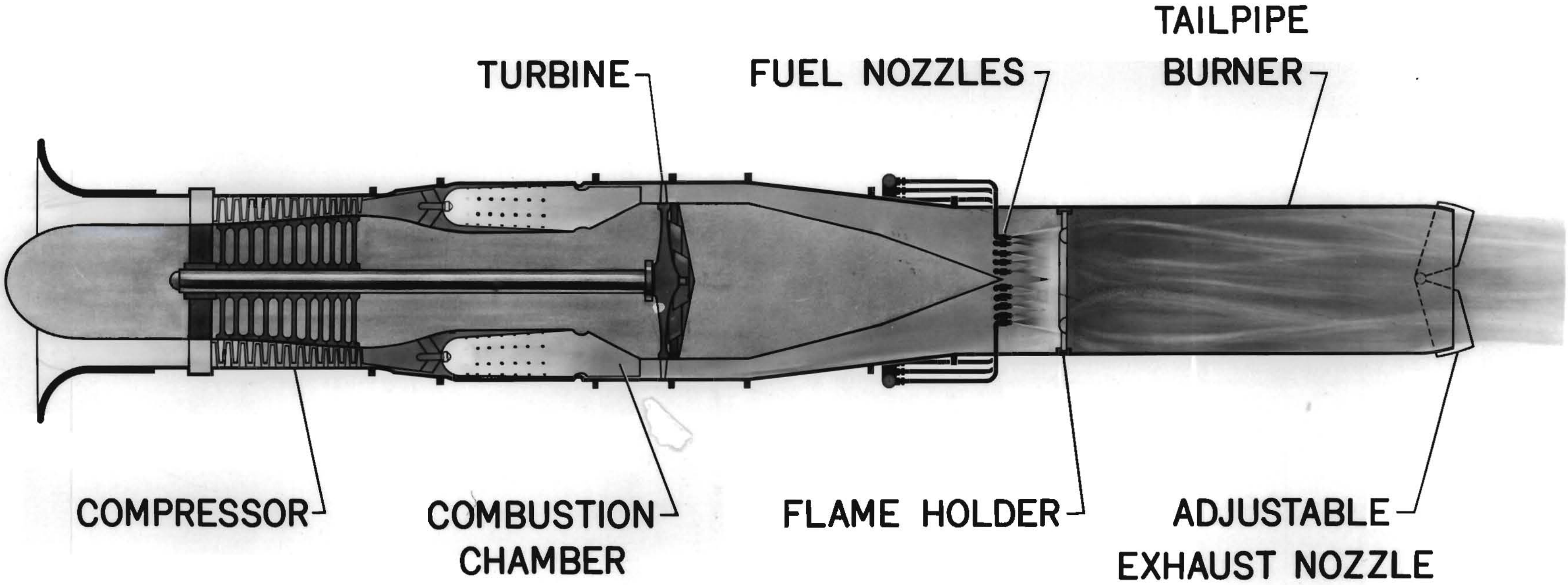

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Fig 33

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THRUST AUGMENTATION BY AIR BLEED-OFF

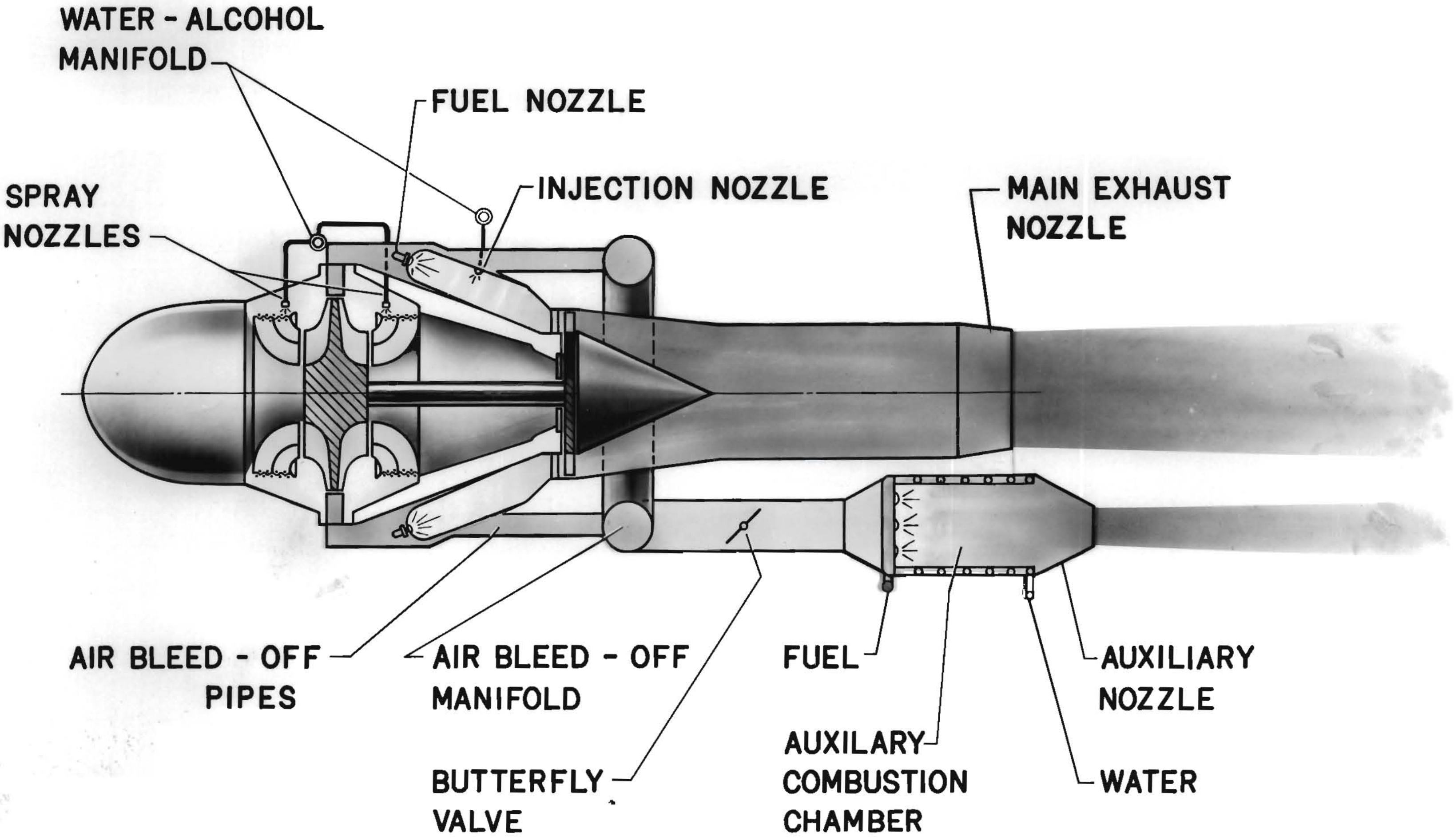

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Fig 34

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COMPARISON OF THRUST AUGMENTATION METHODS

SEA LEVEL TAKE OFF CONDITIONS
4000 POUND THRUST ENGINE

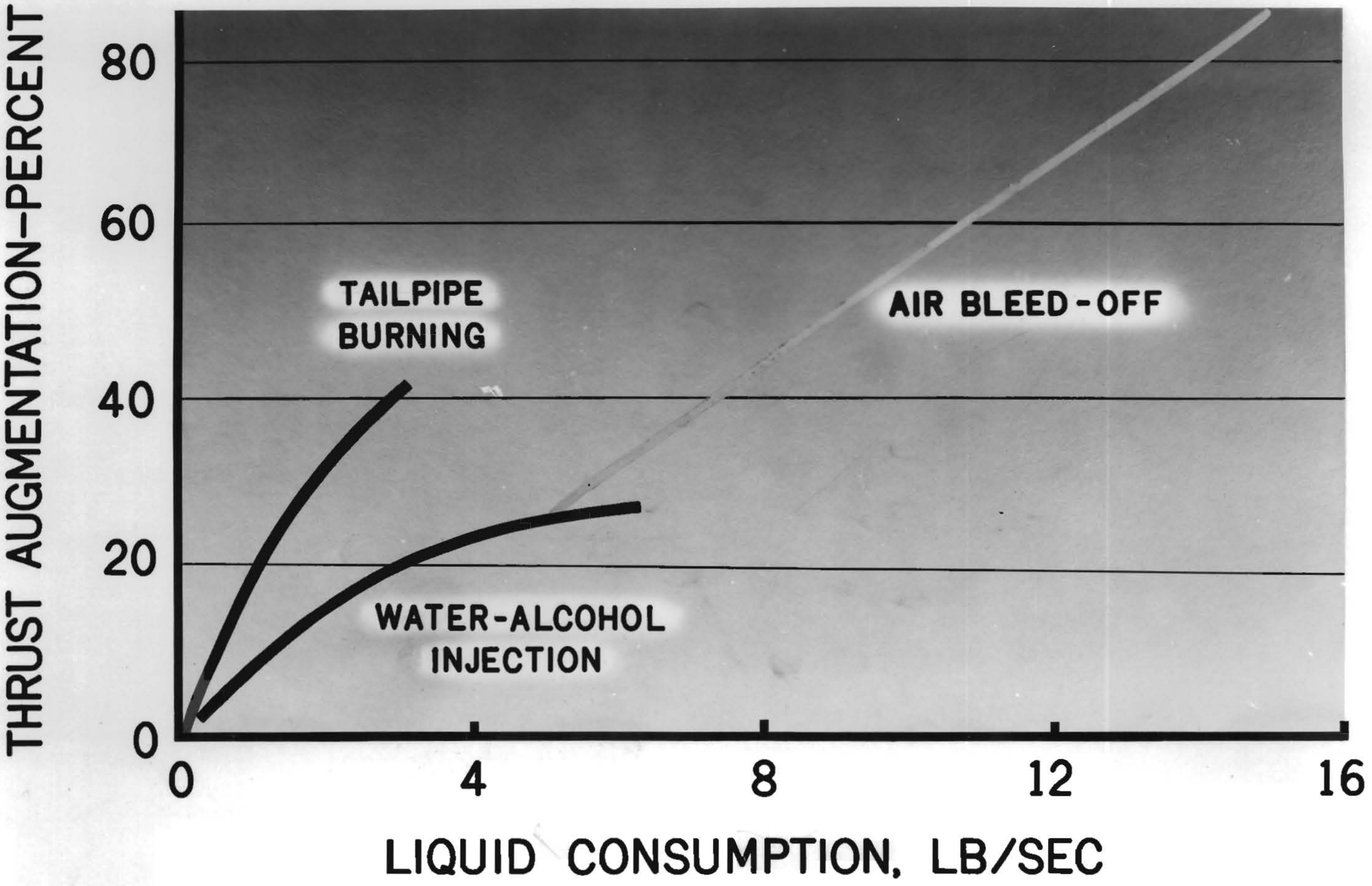

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Fig 35

NACA

PROCESS SYSTEMS FACILITIES

IN

ENGINE RESEARCH BUILDING and COMPRESSOR AND TURBINE RESEARCH WING

Speakers: H. R. Ehlers, J. N. Vivien, L. H. Rieman, and David Berg.

Gentlemen:

You have seen aircraft engines and parts installed for testing under altitude conditions. You will now see process machinery and systems necessary for these tests.

The altitude-exhaust system evacuates exhaust gases from engines under tests at simulated altitudes up to and including 50,000 feet. Exhausters located in the Altitude Wind Tunnel Exhauster Building may be used in parallel with the machines in this building, making the total connected capacity 70 pounds per second at 50,000 feet and 145 pounds per second at 30,000 feet altitude. The equipment you will see in this area is capable of handling 35 pounds per second at a 50,000-foot altitude.

The refrigerated-air system furnishes air to the test stands at 80 pounds per second with temperatures as low as minus 70° F and pressures up to 25 pounds per square inch absolute.

The combustion-air system supplies air to the test stands up to 90 pounds per second at 55 pounds per square inch absolute pressure, also, 40 pounds per second at 140 pounds per square inch absolute pressure. At the present time the project to make these capacities available is about 90 percent complete.

There is a central control room or nerve center which coordinates these facilities among approximately 90 test installations through remote controlled valves in the piping of the various process systems throughout the Engine Research Building.

We will now start our tour - - please follow me.

HRE:cgj
AGG
BEA
CSM

10/23/47

ANNUAL INSPECTION - - OCTOBER 8-9-10, 1947

OPERATIONAL ICING PROBLEMS

W. H. Swann

1. The research conducted in flight covers a wide range of topics. We have arbitrarily selected two researches in order to illustrate the nature of our work. The first on which I will speak is in regard to the icing problem.

2. The existence of liquid-water droplets at freezing temperatures in the atmosphere is the cause of the icing problem. Flight through clouds which exist as liquid water below 32° F produces ice formations on the airplane which reduce the operational usefulness of the craft.

3. (Figure 36 - photograph of ice on propeller and loss in propeller efficiency and lights on B-25 propeller.) The formation of ice such as that shown produces serious unbalance of the propeller, physical damage to the side of the airplane by the particles shed from the propeller, and a loss of propeller efficiency which has been measured by the NACA to be as high as 15 percent. Meteorological conditions other than those in which our flights were conducted might produce a more serious loss in propeller efficiency.

4. (Figure 37-showing photograph of ice on empennage of B-25 airplane and statement of effect of ice on the wing empennage drag coefficient and lights on B-25 empennage). Ice on the leading edge of the wing and tail surfaces reduces the maximum lift coefficient, therefore increasing the stalling speed, and increasing the drag coefficient. The formation of ice on the tail surfaces such as that shown and the ice which formed simultaneously on the wings caused an increase of 38 percent in the airplane drag coefficient.

5. (Photograph of icing on antenna masts and ILS receiving antennas and data indicating the increase of drag due to ice on miscellaneous exposed regions and lights on B-25 antenna masts). Fig. 38 The formation of ice on the radio antennas shown in this picture - - together with the ice on the inboard leading edges, engine cowling, fuselage and other unprotected protuberances caused an increase in the drag coefficient of 43 percent.

6. (Illustration showing B-25 airplane and the speed increments gained as ice was removed from the various regions). Fig. 39 The B-25 airplane illustrated in the figure and displayed here was flown into the icing condition at 205 miles per hour with full thermal protection applied to the propellers. The ice-protection equipment on the rest of the airplane was turned off. After remaining in the icing condition for a few minutes at constant power, the airspeed had dropped to 165 miles per hour. The airplane was then flown into clear air with constant engine power and the components successively deiced. The change in performance was indicated in the following order: removing ice from the inboard-wing panels increased the speed 3 miles per hour; from the tail surfaces an additional 4 miles per hour; from the outboard-wing panels 12-1/2 miles per hour; and, from the engine cowling 4 miles per hour. The airspeed still remained 17 miles per hour less than the starting speed. This increment was attributed to the ice on the fuselage, radio antennas, and other unprotected protuberances such as those shown in the last photograph.

7. (Illumination of B-25 airplane propeller). The formation of ice on airplane propellers may be prevented by heating the propeller-

blade leading edges with electric power. The B-25 airplane propeller is heated from an auxiliary power unit within the airplane, the electricity being conducted to the propeller through slip rings at the propeller hub.

8. (Illumination of B-24 propeller - focus spot on generator). The electric power for heating the blade leading edges of the B-24 airplane propellers is obtained by a hub-type generator on each propeller which eliminates the need for slip rings.

9. (Spot-light illumination of B-24 heat exchanger and between nacelle wing leading edge). Ice is prevented on the leading edges of wings and tail surfaces by the passage of heated air through the surfaces of the leading edge. The heated air may be obtained from the heat exchangers in the engine-exhaust system such as displayed here -- or by combustion heaters in which fuel is burned to heat the air. The capacity of four heat exchangers of the type shown is adequate to provide ice protection for all parts of the airplane and for cabin heating.

10. (Back lighting of pilots' windshield). Ice on the windshields can be prevented by the passage of heated air between two parallel panes of windshield glass or by the dissipation of electric power in transparent coatings of high electric resistance on the glass.

11. Data whereby anti-icing equipment may be designed for all parts of the airplane have been established through NACA flight research and distributed to the aviation industry. All of the new commercial transport airplanes and all of the new multi-engine military aircraft employ the thermal ice-prevention system which has been developed through the conduct of these researches.

12. (Illumination of radome on B-24 airplane). One phase of our present investigation will determine the usefulness of airborne radar in locating icing conditions and in avoiding such conditions during aerial operations.

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13. A better understanding of the meteorological conditions which cause the formation of ice in the atmosphere is being sought by the NACA in order that more efficient and lighter weight anti-icing equipment may be designed. It is expected that the investigation of the meteorology of icing will result in better weather forecasting and safer air operations in the vicinity of ice conditions both of which may help to reduce the amount of anti-icing equipment required on the airplane.

14. That is all that I have to contribute. The next topic has to do with aircraft propulsion at high speeds. Mr. Kinghorn will discuss our research on the ram-jet engine.

JMB
10/14/47