1949 INSPECTION OF THE NACA LEWIS LABORATORY

TALKS ON SUPERSONIC PROPULSION

Speakers - D. Wyatt or I. Pinkel

(See Lobby Exhibit Photo C-24159 - See Stage Photo C-24160 and Color Photo)

Sustained supersonic flight speeds for aircraft are imminent. Supersonic flight speeds of short duration have already been accomplished by the X-1 airplane. These speeds are possible because of recent achievements in aerodynamics and propulsion systems. Our discussion will outline the major problems of engines suitable for sustained supersonic propulsion, the research methods employed to solve the problems, the progress that has been made, and the indicated course of future work.

The basic supersonic propulsion problem is that of obtaining engine types capable of developing extremely large powers. The magnitude of the powers the engines will have to develop and the dependence of the power requirement on airplane speed is illustrated by a consideration of the following airplanes, each designed for the same gross weight.

Shown first is a model of a conventional subsonic airplane designed for flight at 400 miles per hour at an altitude of 30,000 feet. The airplane is propelled by two engines developing a total of 3000 horsepower at the design condition.

The airplane type designed for flight at a supersonic speed of approximately 1.5 times the speed of sound is shown next. The appearance of the airplane is markedly different than the subsonic airplane, chiefly because of the sweptback lifting surfaces required by aerodynamic design considerations. For flight at a speed of 1000 miles per hour at an altitude of 50,000 feet, the airplane engine must provide 15,000 horsepower.

The third airplane type is designed for a flight speed of 2-1/2 times the speed of sound, or 1500 miles per hour at an altitude of 70,000 feet. This unconventional appearing airplane is equipped with wings having thin supersonic sections, fuselage of high fineness ratio, and canard arrangement of the stabilizing surfaces. It has been calculated that about 45,000 horsepower are required to propel this configuration.

The increase in engine power requirements as the design flight speed is increased is striking. The power increases would be even greater if the advantages of high altitude flight were not employed at the high speeds. These advantages stem from the reduced resistance to flight through the rarified atmosphere at high altitudes. The reduction in power gained by high altitude flight can be appreciated from the fact that the 1500 mile per hour airplane which needs 45,000 horsepower at 70,000 feet would require that its power be doubled to 90,000 horsepower at 30,000 feet and more than quadrupled to 200,000 horsepower for sea level operation. The important conclusion is therefore reached that engines for supersonic propulsion must develop extremely high powers at high flight altitudes.

The power developed by any engine is obtained from the combustion of fuel with air under compression. The development of the very large powers needed for supersonic flight will require the use of engines capable of inducting large quantities of air to burn the required large quantities of fuel. The first slide (C-24175-B) illustrates the relative air inducting capacities of three current engine types of the same size at the same flight speed.

The reciprocating engine handles a small quantity of air relative to its size. An engine capable of developing the high powers required for supersonic flight would have a prohibitive size and weight, so that this engine is automatically excluded from application to supersonic propulsion.

The turbo-ram and ram-jet engines handle large quantities of air relative to their size. They have the further characteristic that their air flow and consequently their power increases with flight speed in the same way that the airplane power requirements increase with speed. Because of these characteristics, turbo-ram and ram-jet engines of reasonable size and weight are suited for supersonic flight over a wide range of speeds.

Both of these engines have been the subject of intensive investigations in our laboratory facilities. For supersonic applications, the engines are basically the same and have common problems. In the ram jet, air compression is achieved by slowing the air down in a divergent inlet. Fuel is injected and burned with the compressed air downstream of a flame seating or flame holding device and the products of combustion are exhausted as a high velocity jet.

At supersonic speeds the turbo-ram jet engine operates essentially the same as the ram-jet engine. The principal difference is the additional compression furnished by this turbine powered compressor. The problems of the compressor and turbine components of the turbo-ram jet engine will be discussed elsewhere today. The problems common to both engines will be discussed here in terms of the ram-jet engine. Before we discuss the details of the problems, the laboratory facilities and research techniques used in our studies will be reviewed.

The principal facilities available for investigation of supersonic engines are shown on the next slide (C-24177-C). These include the altitude wind tunnel and the altitude tanks, our free flight facilities, several small supersonic tunnels, and the new 8- by 6-foot supersonic tunnel.

(Ref. C-24177-C Highlighted) The altitude wind tunnel and the altitude tanks are used for investigations of the internal characteristics of full-scale engines. These investigations can be conducted under conditions corresponding to engine operation at altitudes as high as 80,000 feet at speeds up to about twice the speed of sound. In these facilities the inlet characteristics of supersonic engines can also be investigated over a narrower range of flight speeds and altitudes through the use of a free-jet technique, in which the engine inlet is immersed in a supersonic jet of air.

Typical installations in these facilities are shown on the following slide (C-24173-B). Here is shown a ram-jet engine installed in the altitude wind tunnel for an investigation of internal operational characteristics. Air is inducted into the engine through a pipe connected to the engine inlet. We call this the "connected-pipe" technique. During tests the space around the engine is maintained at the pressure corresponding to the desired altitude.

The next slide (C-24173-A) shows a ram-jet engine installed for an investigation using the "free-jet" technique. In this case the engine inlet is not attached to the duct supplying the air. The jet velocity from the supply duct could be varied to speeds as high as 1100 miles per hour for the investigation shown.

(C-19821) Another technique employed in testing complete large supersonic engines involves the free flight of the engine upon release from an airplane at high altitude. With this technique the internal and external characteristics of the engines can be determined over the entire speed range from the launching speed to the supersonic speed reached before termination of the flight. Speeds as high as 1300 miles per hour have been achieved by this technique.

This motion picture shows the release of a typical 16-inch ram-jet engine. Data are automatically radioed during the flight to a ground receiving station from instruments located in the engine.

(Ref. C-24177-C Highlighted) For investigations of internal and external characteristics of engines where scale is not an important factor, a number of small supersonic tunnels are available. These vary in size and cover speed ranges from 1.9 times the speed of sound up to 6 times the speed of sound. The recently completed 8- by 6-foot supersonic tunnel will permit the investigation of large-scale engines. All of these supersonic tunnels are of the nonreturn-passage type, so that fuel and air can be burned in the engine under actual operating conditions. The 8- by 6-foot tunnel will be described to you in greater detail later.

The problems common to supersonic engines are those involving the compression of the air, the combustion of the fuel and air, the aerodynamic efficiency of the engine, and the interrelated effects between the engine and the airplane. The next speaker will discuss the compression problems of supersonic engines.

Mr. E. M. Cortwright, Jr. or Mr. E. Perchonok:-

The efficient conversion of the heat energy released by burning fuel with air to useful propulsive energy requires that the combustion process occur with the highest possible compression of the combustion air. The compression in a ram-jet engine is obtained by slowing the air down from flight velocity at the inlet to a low speed in the combustion chamber. In slowing down, the air converts its velocity energy to pressure energy. The compression that occurs is called the ram compression. The amount of ram compression possible increases with flight speed. We shall illustrate this by a demonstration using a small wind tunnel.

This tunnel is located in the adjacent shop building and is not in the room because of the noise. We shall watch its operation by television. The tunnel can be operated at a subsonic speed of 300 miles per hour and a supersonic speed of 1300 miles per hour. The model to be used in the demonstration is shown as the top figure on the next slide (C-24175-C). A diverging inlet passage is connected to a cylindrical body. The high velocity air entering the inlet is slowed down in the diverging channel and in slowing down is compressed. At supersonic speeds a normal shock is present either in or ahead of the inlet. A pressure tube at the end of the inlet is connected to this manometer tube and will indicate the compression in the inlet, that is, the difference in pressure between the air in the free stream ahead of the inlet and the pressure at the end of the inlet passage. (TV)

On the television screen we see a mechanic holding the model. The tunnel in which the demonstration will be conducted is here. The air flow through the tunnel is from right to left on the screen. While the mechanic installs the model in the tunnel, the television camera will focus on a special optical device which will permit us to see the air flow about the inlet through glass walls in the side of the tunnel.

The tunnel will now be started. It is now operating at a speed of 300 miles per hour, as shown by this airspeed indicator. The compression, as indicated by the height of mercury in this tube, is low. The tunnel will now be brought up to a speed of 1300 miles per hour. On the television screen we see the shock waves that have formed on and ahead of the inlet. The compression has increased greatly.

Although the compression has increased with speed, this simple inlet is inefficient at supersonic speeds and greater compressions than indicated here are possible. Referring back to the slide, the normal shock seen ahead of the inlet is the source of a compression loss. By causing oblique shocks to form ahead of the inlet, the intensity of the normal shock can be reduced, and higher compressions can be obtained.

The lower figure on this slide shows the next model to be demonstrated. Instead of a fully open inlet, a central body fills part of the inlet. Oblique shocks will form ahead of the inlet and, as I have said, will increase the inlet compression by reducing the shock losses.

The supersonic inlet model has been installed in the tunnel. (TV) The tunnel is brought to a speed of 1300 miles per hour again. As indicated by the height of this tube, the compression has been increased beyond that possible with the simple inlet.

Now these two demonstrations have shown that ram compression increases with flight speed, but that special inlet designs are necessary to obtain efficient compression at supersonic speeds. All the laboratories of the NACA have been investigating the compression problem at supersonic speeds. The progress that has resulted from these investigations is summarized on the next slide (C-24176-C).

Ram compression is plotted as a function of flight speed. The upper curve represents the theoretical maximum compression at each speed. The lower curve represents the maximum compression possible with the simple inlets. The middle curve shows the maximum compressions obtained by the NACA from our inlet research. A considerable improvement over the simple inlet is evident at all speeds. Research is continuing to bring the actual compressions even closer to the theoretical compressions.

The values of compression for the supersonic inlets shown on this slide are maximum values of compression corresponding to operation at design values of airplane speed, fuel flow, and the engine outlet area. The unique characteristic of inlets at supersonic speeds as contrasted with inlets at subsonic speeds is their sensitivity to operation at off-design points. The effect on compression of operating the engine with an off-design value of outlet area is illustrated by the next demonstration.

The model is the same model used in the previous demonstration for which we have marked the values of maximum compression, but the outlet area has been increased. We will again operate the tunnel at a supersonic speed of 1300 miles per hour. The actual compression delivered by the inlet has decreased. This reduction in compression results from additional losses that occur across the normal shock, now located on the inside of the tube several inches downstream of the inlet.

The position of the normal shock, which largely determines the compression losses, is also influenced by the flight speed and fuel flow rate of the engine. The effect of operating the engine at other than design fuel flows is illustrated by the data on the next slide (C-24176-A) obtained by the free-jet technique from tests of a 16-inch ram-jet engine in the altitude wind tunnel.

At the design fuel flow (point) the normal shock in the inlet is located at its optimum position. As the fuel flow is decreased the shock moves from its optimum position with an attendant loss in compression. When the fuel flow is increased above the design value, the normal shock is detached from the inlet, but the compression remains constant. The inlet design which results in a flat compression curve is the result of NACA research at the Langley laboratory. Some other supersonic inlet designs would give as high or higher compression at the design fuel rate, but would have a reduced compression at the higher fuel rates.

The next slide (C-24176-B) illustrates the effect on compression of operating the engine at other than the design flight speed. These data were obtained by our free-flight technique using a 16-inch ram-jet engine dropped from an altitude of 35,000 feet. The theoretical maximum compression is shown on the chart. At the design speed the measured compression approximated the theoretical value. When the flight speed was greater than the design value, the difference between the theoretical maximum and the measured compression increased as the normal shock receded in the inlet. At flight speeds below the design value, the shock was detached, but again with this inlet the compression was not sensitive in the detached shock condition.

Our present and future research is directed toward evaluating the off-design characteristics of different supersonic inlets in order to determine how the characteristics influence the utility of engines of fixed design.

Some of our earlier work with small-scale ram-jet engines showed that pressure pulses associated with combustion may seriously reduce ram compression. In the past year we have extended our investigation of this problem to include studies on a 16-inch ram-jet engine in the altitude wind tunnel using the free-jet technique. The motion pictures to follow show the air flow pulsation about the inlet of that engine. (Motion picture)

The inlet is submerged in a 1000 mile per hour air stream. The pictures were taken 100 times as fast as they are being projected. The nozzle from which the supersonic jet was discharged is on the right, the engine inlet on the left. A distinct flow pulsation can be seen; however, with this engine the reduction in ram compression due to the pulsation was slight.

Studies such as this, where the pulsing did not affect compression, indicate that the engine design and engine operating conditions influence the pulsing problem. Research is under way to ascertain how the pulsations arise, that is, whether the problem is an inlet or combustion phenomena. Other research efforts are directed towards determining the quantitative effects of pulsations on compression over a range of operating conditions.

The research program includes detailed study of the pressure fluctuations. The next slide (C-24175-A) shows the time history of a pulsating pressure in a small scale engine. These data were obtained in the 20-inch supersonic tunnel. The manner in which the pressure fluctuated is shown by the wavy curve. This pressure fluctuation can be correlated with air flow photographs. The rising pressure forces the shock ahead of the inlet, and the shock returns into the inlet when the pressure falls. Included on this chart is the compression recorded by manometers that were insensitive to the fluctuations. This is the effective compression experienced by the engine during the pulsing condition. It has been found that the compression measured in this manner is the mean value of the fluctuating compression.

Mr. Wyatt or Mr. Pinkel: - We have discussed the problems associated with obtaining high compressions in supersonic engines. These compressions are necessary in order to utilize efficiently the heat released in the combustion process. Now efficient combustion is required in order to provide the heat with the least expenditure of fuel. Efficient combustion is made difficult by several factors. Because it is desirable that the engines be as small and light as possible, the air must pass through the combustion chamber at high velocity.

This tends to blow the flame out and makes good combustion difficult. Because it is desirable to operate the engines at high altitudes where the power requirements for the airplane are reduced, low pressures will occur in the combustion chamber, even with high ram compression. These low pressures make good combustion difficult.

The next slide (C-24177-B) illustrates the desirability of having high combustion chamber velocities. The data were obtained from our free-flight investigations of 16-inch ram-jet engines. The chart shows the power obtained from two engines of the same size as a function of the ratio of fuel to air burned. The flight speed was 1100 miles per hour.

The engine represented by the lower curve was designed for a low combustion chamber velocity. The engine represented by the upper curve had about twice this combustion chamber velocity. As a consequence, although both engines were the same size, 16 inches in diameter at the combustion chamber, the upper engine inducted almost twice the amount of air handled by the lower engine and produced much higher powers.

The problem of stabilizing the flame and burning efficiently becomes more acute as the combustion chamber velocity is increased. Considerable research has been conducted in all the laboratory facilities on this problem. Our progress is shown on the next slide. (C-24175-D)

Since 1945, when our major efforts were begun on this problem, the velocities at which high combustion efficiencies can be maintained have been increased almost 170 percent. It is expected that further progress will be made in the next few years.

Present altitude limits for satisfact ry combustion efficiency also represent considerable gains over the limiting altitudes of a few years ago. This progress has been accomplished by intensive research on flame-seating or flame-holding devices, fuel-injection methods, and combustion-chamber designs. Based on existing information, it is believed that the combustion problems of ram-jet engines intended to operate at altitudes above 50,000 feet and at speeds up to twice the speed of sound can be solved in the design stage without the necessity of intensive research on each individual engine.

In discussing the compression and combustion problems associated with the production of high powers in supersonic engines, we have been concerned only, up to this point, with the internal passages of the engines. In our propulsion studies we can not neglect the drag of the engine associated with the external air flow. In the next airplane configuration, designed for flight at 1500 miles per hour, the power is produced by two engines located at the tips of the vertical stabilizers. Of the total power produced by each engine, a portion must be used to overcome the engine drag, and this portion is of no value in meeting the propulsion requirements of the remainder of the airplane. The problem of designing engines that have the lowest values of drag is a major objective of our research on the supersonic propulsion problem. Our next speaker will consider this problem.

Mr. W. W. Carlton or Mr. R. W. Luidens: - NACA research many years ago established the fact that even at low subsonic speeds the engine drag could be reduced by suitably housing the engine in a streamlined nacelle. The proper design of these nacelles is even more imperative at supersonic speeds. A typical increase in drag of an engine nacelle is illustrated by the data on the next slide (C-24174-B), which were obtained by our free-flight technique. The nacelle drag slowly increases in the subsonic speed range, then increases very rapidly in the region of flight speeds near the speed of sound, where the influences of shock waves are first encountered, and then increases at a somewhat slower rate in the supersonic speed range.

It has been pointed out in previous discussions that the powers of ram-jet and turbo-ram jet engines also increase with increases in flight speed. The power required to overcome the engine nacelle drag shown on this slide must be subtracted from the total power output of the engine and the remaining net or useful propulsive power of the engine must be sufficient to overcome the drag of the remainder of the airplane. The nacelle shape, and therefore the nacelle drag, varies with the design details of the engine. The necessity for determining engine designs that result in the least nacelle drag for a given engine power is therefore evident and much research is required in this field.

Up to the present time, the facilities in which data of these kind could be obtained have been limited. In order to conduct this research, it is necessary to have the nacelle completely submerged in a supersonic air stream. Reliable drag data can only be obtained with large-scale models. The free-flight technique employed to obtain these data has until recently been the only technique by which large-scale engines could be studied with completely supersonic flow over the entire engine. The recent completion of the 8- by 6-foot supersonic tunnel now gives us another tool for this research. The free-flight technique remains unique in enabling us to obtain these data through the transonic speed range.

The next slide (C-24177-A) shows how the nacelle drag at any one speed can change as a result of different engine operating conditions. These data were obtained by the free-flight technique. The total power produced by an engine flying at 1100 miles per hour and the power required to overcome the nacelle drag are plotted as a function of the fuel-flow rate in the engine.

At low fuel flows the total engine power was not enough to overcome the engine drag. Above this fuel rate, the total power was greater than the engine drag. The difference between the total power and the drag power curves in this region is the net propulsive power available for overcoming the drag of the remainder of the airplane. The total engine power continuously increases with fuel rate. The engine drag is constant until a certain fuel rate is reached, at which time it also increases. Because of the increase in engine drag, the maximum net propulsive power is reached at this fuel rate, and increasing the fuel flow does not result in any increase in net propulsive power. The obvious maximum operating fuel flow for the engine is therefore at this value.

Now the total engine power curves can be determined from connected-pipe and free-jet experiments. The engine drag curve can only be determined by investigation of large-scale engines completely submerged in a supersonic air stream. The engine drag rise shown here represents an influence of the engine on the air flow about the front of the nacelle, as illustrated by the diagrams.

We have discussed the effect of engine operation on the drag of the engine nacelle. When the engine is totally submerged in the fuselage, as in the airplane examples before you, the fuselage serves as a nacelle and experiences the same effects. In addition, the air flow disturbances induced in the engine inlet by the engine operation may seriously alter the effectiveness of the lifting and control surfaces which are adjacent to the fuselage. It thus becomes apparent that the engine can not be isolated for separate study, but must be investigated with the complete aircraft configuration.

Many types of aircraft configuration will have to be investigated because of the special interaction problems arising from each type. For example, because of the nature of the load and the mission, it may not always be possible to submerge the engine in the fuselage. We have already shown you one alternate arrangement in which the engines are located at the tips of the vertical stabilizers. Another configuration showing some promise is one in which the engine is located at the rear of the fuselage with a scoop inlet projecting from the fuselage, as illustrated by this next model. The choice of location of the inlet scoop is not arbitrary, but is influenced by the contours of the aircraft fuselage. You will recall that the function of the inlet is to realize the available ram compression in the high-velocity air stream as efficiently as possible. We have found from our research that at certain regions adjacent to the body the air which is to enter a scoop inlet of this type has already undergone a loss in available pressure because of friction, so that the maximum compression that can be realized by the inlet is greatly reduced from the ideal value.

The nature of this problem is illustrated on the next two slides, which present data obtained from the first research investigation in the new 8- by 6-foot supersonic tunnel. The figure at the top of this slide (C-24174-C) shows the body used in the investigation, a body of revolution 6 feet long and 6 inches in diameter, which is similar to the fuselage illustrated on this airplane model. The sketch also shows the growth of the layer of air slowed down by friction between the air and the body. In this case the body is at 0^0 angle of attack, that is, the body axis is aligned with the flight direction. The figure at the bottom of the chart shows the loss in compression pressures in the air adjacent to the body at a plane at the rear of the body when the body is moving at a speed of 1000 miles per hour.

The air immediately adjacent to the body has lost a very high percentage of the available compression pressure. Since the body is aligned with the flight path, the pattern is symmetrical. An appreciable protion of the air entering a scoop at any point around the circumference, as for example at the bottom as on this model, will have a low available compression. The presence of this low-energy air in the inlet introduces additional compression losses inside the inlet, with the total result that the actual compression of the inlet is much less than the theoretical maximum compression.

When the body is inclined at 6^0 to the flight direction, as shown on the next slide (C-24174-D), the low-compression air is swept to the top side of the body. Practically all of the air collected by scoops located in the upper body surface would be low-compression air. If, on the other hand, the scoop is located on the bottom of the body, substantially all the inducted air will have a high available compression.

From an engine viewpoint, it is desirable to operate the airplane fuselage at a slight angle of attack and to locate the scoop on the bottom of the body, as illustrated by this model. However, because of interaction effects, the performance characteristics of the entire aircraft configuration must be evaluated. This can only be done by large-scale models studied in facilities such as the 8- by 6-foot supersonic tunnel.

Thus far in discussing the problems of entire airplane configurations, we have treated the interaction effects associated with the engine inlet flow. In some instances the exhaust jet from the engine must also be considered in arriving at the complete airplane design. Take, for example, the model shown here. Because of the proximity of the tail boom and stabilizer surfaces to the exhaust jet, serious structural problems may be raised from the heating of these surfaces by the jet, and the effectiveness of the stabilizer may be altered by pulsations in the exhaust flow. A knowledge of the flow path taken by the jet and a knowledge of how the jet affects the adjacent flow is therefore very improtant. Because the same scale effects are involved here as in other configuration problems, these studies must ultimately be evaluated on large-scale models.

A preliminary study of the exhaust-jet problem has been undertaken. This study is being made on small-scale jets discharging into still air and is intended to derive an understanding of some of the basic phenomena involved. The next slide (C-24173-C) shows the airflow pattern produced by a single jet at two operating conditions. The upper jet originates from an engine operating with a low compression ratio. The lower jet originates from an engine having a high ram compression. The most obvious difference is the greater spread of the jet from the high compression engine.

When two jets issue side by side, as from the engine of this model, the zone of interaction complicates the jet pattern. The next slide (C-24173-D) shows the top and side views of the flow from twin jets. The boundaries of the single jet at the same operating condition are superimposed as dotted lines to show how the interference between the two jets broadens the jet pattern. A further study of this problem will be undertaken in the 8- by 6-foot tunnel.

Mr. Wyatt or Mr. Pinkel: - We have now completed a cycle in our discussion of supersonic propulsion problems. We started off to find the propulsion problems dictated by the airplane. We learned the powers required for supersonic flight, the types of engine necessary to produce those powers, and the special problems of the engine. We end by finding that the special problems of the engine so influence the airplane design that in the final analysis we can not entirely segregate the engine for isolated study, but must investigate the entire airplane.

We have shown that much research relative to the internal operational problems of the engines can be studied by connected-pipe techniques with no flow over the engine. Other information about compression and combustion problems as affected by the inlet can be studied by using free jets with only the engine inlet submerged in the stream. The whole class of problems relative to the net propulsive power of the engine and the interrelated airplane-engine characteristics can only be studied by techniques in which the entire model is submerged in a supersonic stream. These models must be of fairly large scale in order to correctly reproduce air flow and combustion effects of full-scale aircraft.

Until recently the only way the latter research could be conducted was by our free-flight technique. This 8- by 6-foot supersonic tunnel has been operating as a research tool for about three months and the horizons of our supersonic propulsion research are now greatly broadened. Our next speaker will describe the tunnel and its operation.

Mr. R. Godman or Mr. C. Schueller: - A schematic view of the 8- by 6-foot supersonic tunnel is shown on the next slide. (C-22352) You are now seated in the control room and observation room located here (point). The tunnel proper is behind me. The purpose of the tunnel is to provide a stream of air at a supersonic velocity into which models may be inserted for desired investigations. A lot of work is required to achieve the required air flow.

In the first place, the air passing through the tunnel must be extremely dry in order to prevent condensation and a consequent non-uniform velocity in the test section. The drying is done in this building.

Air is drawn into the building from the atmosphere. At maximum operating conditions as much as two million cubic feet of air a minute are drawn into the building; that is about a ton and a quarter of air a second. The air passes through beds of a drying agent called activated alumina, where most of the water in the air is removed by absorption. Some of you may use a similar material to keep your basements dry. In this building there are 1150 tons of alumina. On a hot humid summer day, as much as one ton of water is removed from the air every minute.

The dry air is drawn from the air dryer building to the inlet of the compressor (point). The air passes through the compressor where the pressure is increased to as much as 1.8 atmospheres, depending on the tunnel speed. Compressing over a ton of air a second to this pressure takes a lot of power - about 87,000 horse-power to be exact. This power is furnished by three electric motors connected in tandem on a single shaft to the compressor (point).

The air leaves the compressor at a high pressure, but low velocity, and is then expanded to produce the desired speed in the test section of the tunnel (point). This speed can be varied from about 1.5 times the speed of sound up to twice the speed of sound. After passing through the test section, the air is slowed down and is eventually discharged back into the atmosphere.

An enlarged view of the nozzle and test section of the tunnel is shown on this Model, (Ref. Color Photo) on which we can demonstrate the method of speed control used with the tunnel. After being discharged from the compressor the air moves at a low speed along a large passage to the left of the chart. The passage is contracted, which results, although not obviously, in an expansion of the air and a flow acceleration. At the minimum area the air reaches the local speed of sound. The passage is then re-expanded and the air continues accelerating until the desired supersonic speed is reached in the test section.

The airspeed in the test section can not be varied merely by changing the compression pressure. In order to change the speed, it is necessary to change the amount of area expansion downstream of the minimum section of the nozzle. We do this by flexing the nozzle side plates to a new contour by means of 14 hydraulically operated screw jacks on each side. The nozzle plates are made of stainless steel and are 35 feet long, 8 feet high, and 1 inch thick. The nozzle position shown is for a tunnel Mach number of 1.5. The side plates are contracted about 14 inches more, as illustrated, to obtain a Mach number of 2.0. The contours can be set to give any intermediate speed.

While I have been talking to you, the tunnel has been started

It is now at the operating condition shown on this slide. The speed at the throat is 780 miles per hour, and the speed at the test section is 1000 miles per hour. By means of the television camera, we shall look at the air flow past the nose of the model now in the tunnel.

The model that you see in the tunnel is part of the study of engine nacelle drags. It is shown schematically on the next slide (C-24174-A). The dotted area is the region that you see on the television screen. The dots indicate pressure orifices that are connected in the same sequence on this manometer board. The heights of the columns of mercury will be indicative of the drag on the outer surface of the engine. The operating condition you now see corresponds to low-power operation of the engine. We will now regulate the discharge area of the engine to correspond to increased power output. Notice how the air-flow picture changes and how the surface pressures increase, indicating increased drag. We shall repeat the variation several times to permit you to follow the connection between the air-flow picture and the engine drag.

This demonstration illustrates the interrelation between internal and external engine air flows and the effect on nacelle drag. Studies of this type will increase our knowledge of how to design maximum compression engines having minimum drag.

Mr. Wyatt or Mr. Pinkel - You have now heard a discussion of our propulsion problems for supersonic speeds, and you have seen a demonstration of one research program for this tunnel. At this time you will be taken on a short tour of the tunnel. Please leave by this door to your left. Thank you. (Ed. Note: The visitors were then led to the South Side of the Drive Motor Bldg. where Mr. F. Hausmann talked to them about the drive equipment and especially about the compressor which they could see through the windows. An array of blading from the compressor was also displayed (See C-24158). Next the visitors were taken to the test section level of the test chamber where Mr. J. Slomski described the equipment).

SUPERSONIC PROPULSION

A

Stage Color Print of Speaker, Models, etc.	
Display Supersonic Engine for Test	C-24159
Stage Supersonic Propulsion. Hypothetical Airplanes.	C-24160
Control Room 8 x 6 Ft. Supersonic Wind Tunnel	
Display 8 x 6 SWT Drive Motor Bldg. - Compressor Display	C-24158


SUPERSONIC
PROPULSION


SUPERSONIC ENGINE
FOR TEST IN
8'×6' SUPERSONIC TUNNEL
C-24159
9-21-49

NACA

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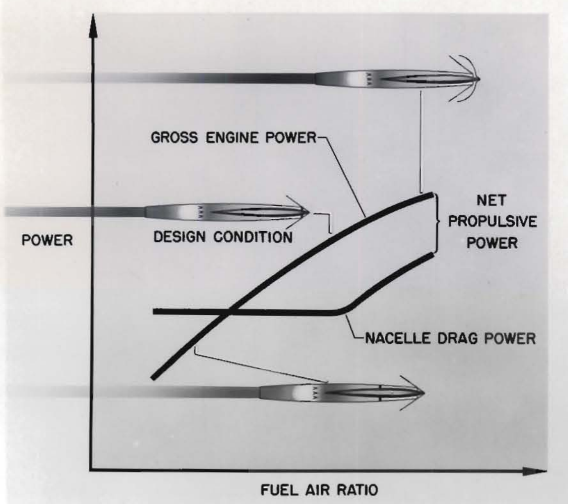
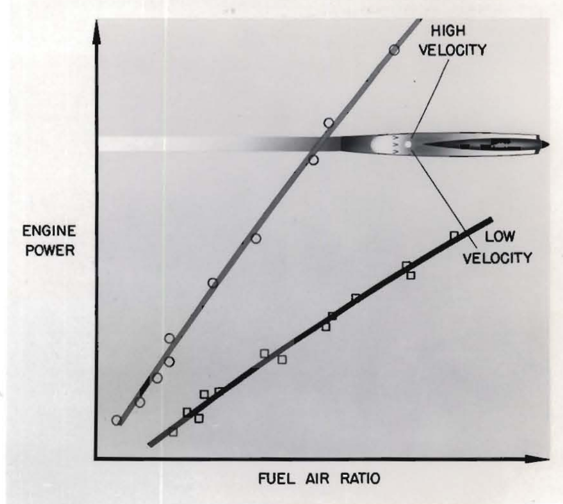
FUEL FLOW AFFECTS NET PROPULSIVE POWER



COMBUSTION CHAMBER VELOCITY AFFECTS POWER



PROPULSION RESEARCH FACILITIES

ALTITUDE WIND TUNNEL
ALTITUDE TANKS

FREE FLIGHT

SMALL SUPERSONIC TUNNELS

18-BY-18 INCH, MACH NO.1.9
20 INCH, MACH NO.1.9
2-BY-2 FOOT, MACH NO.4.0
6-BY-6 INCH, MACH NO.6.0

8-BY-6 FOOT, SUPERSONIC TUNNEL

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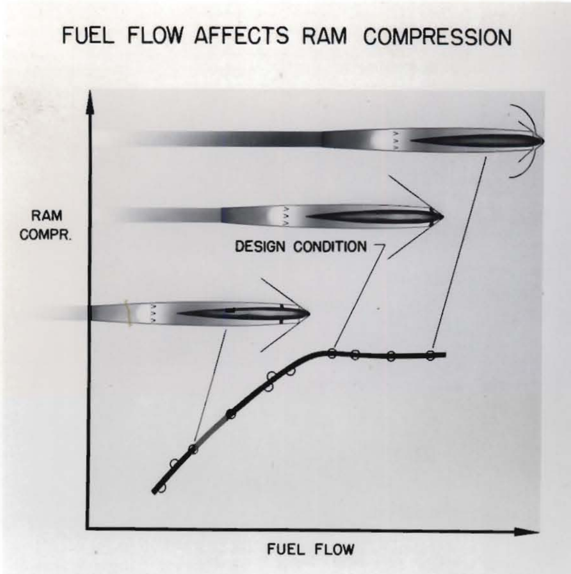
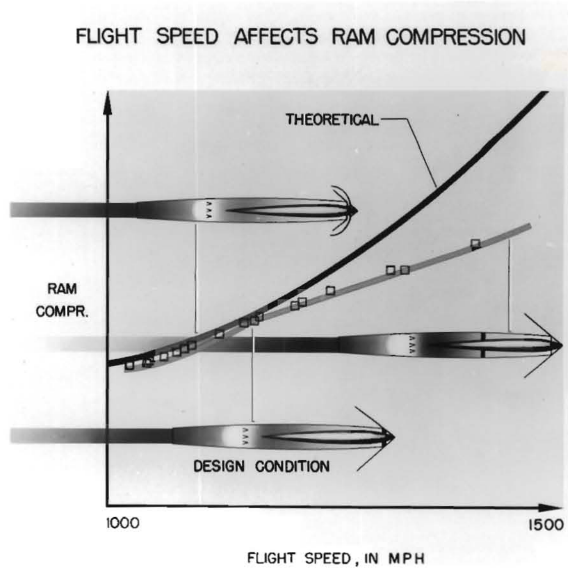
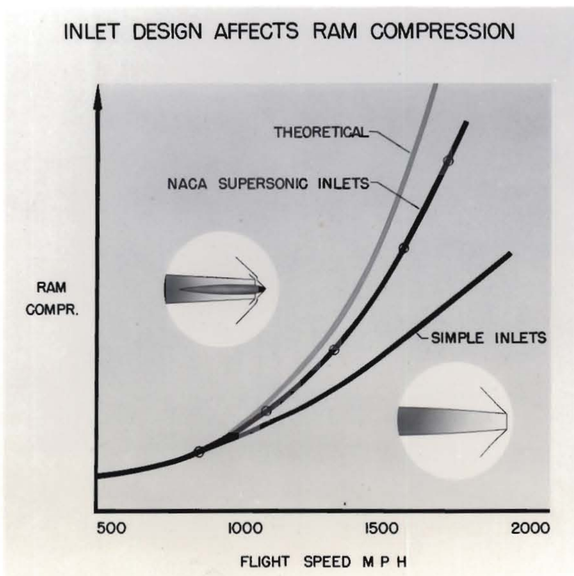
9.23.49







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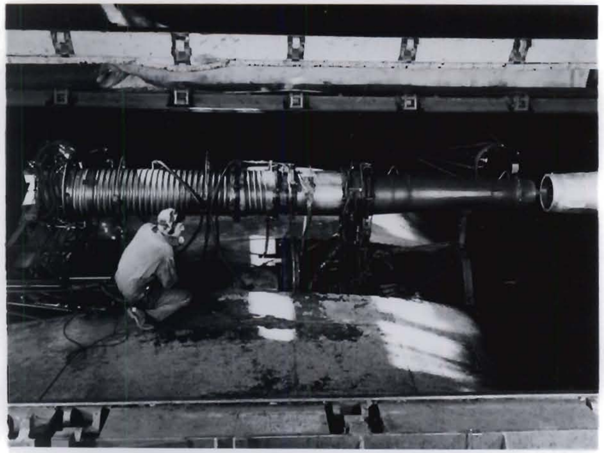
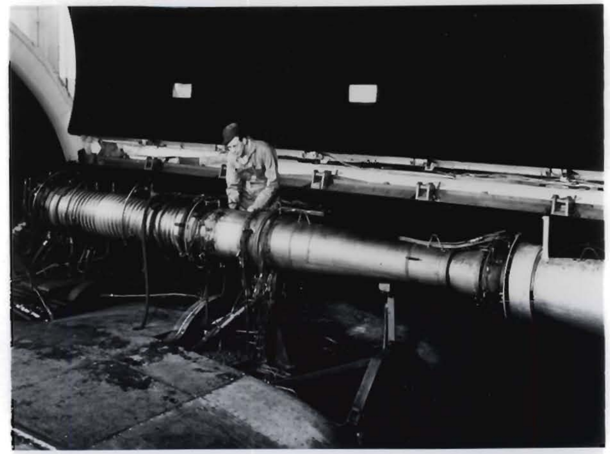
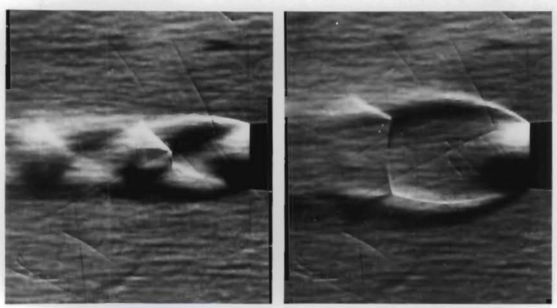
FREE JET



CONNECTED PIPE

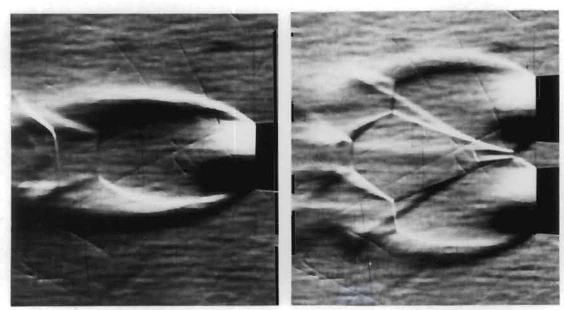


SPREAD OF SINGLE JETS



LOW COMPRESSION HIGH COMPRESSION

SPREAD OF TWIN JETS



SIDE TOP

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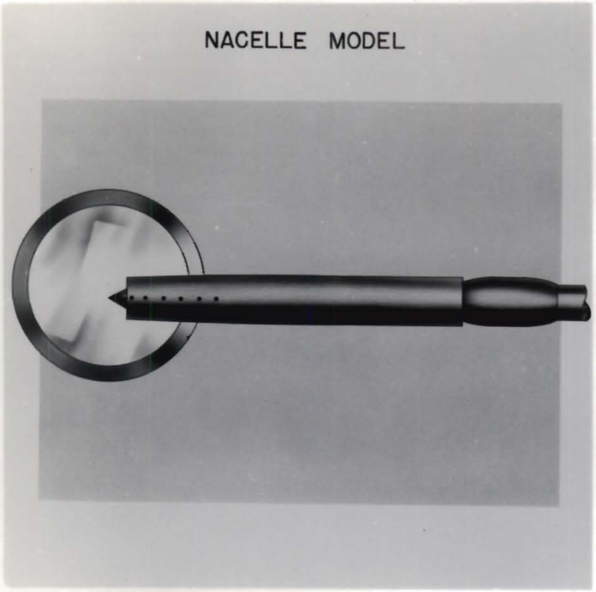
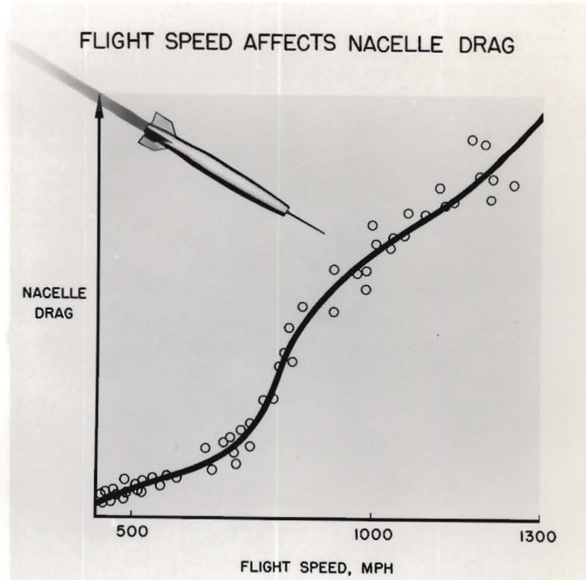
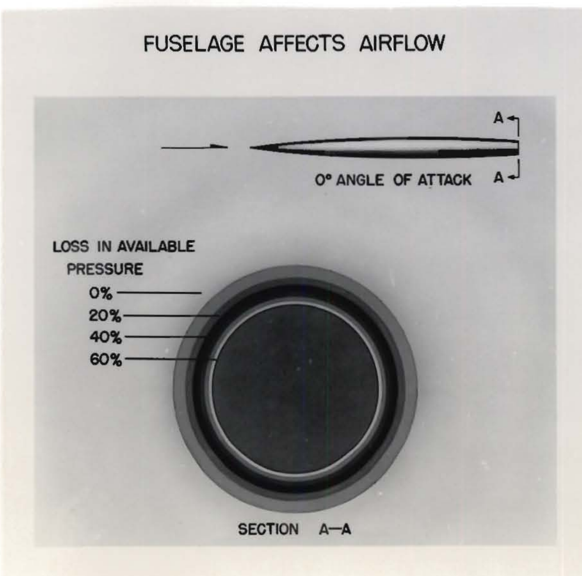
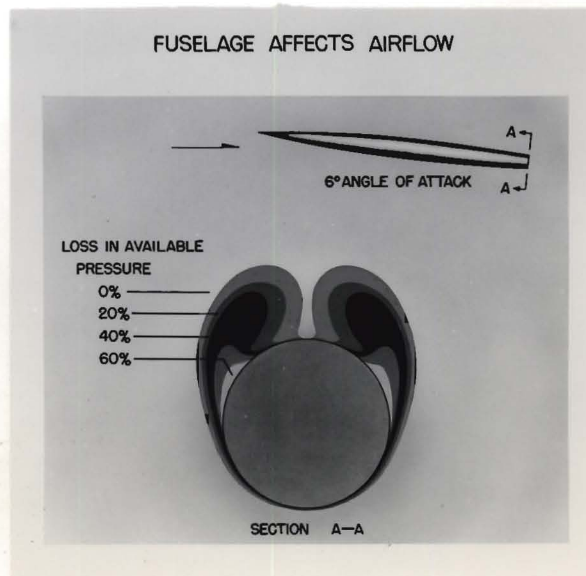
9.23.49









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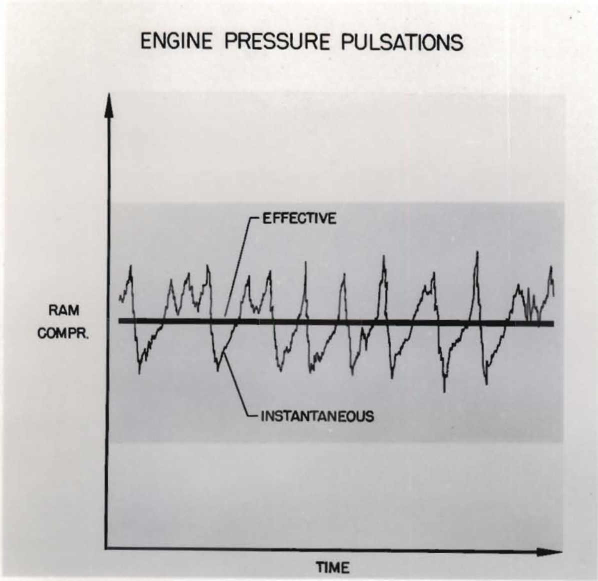

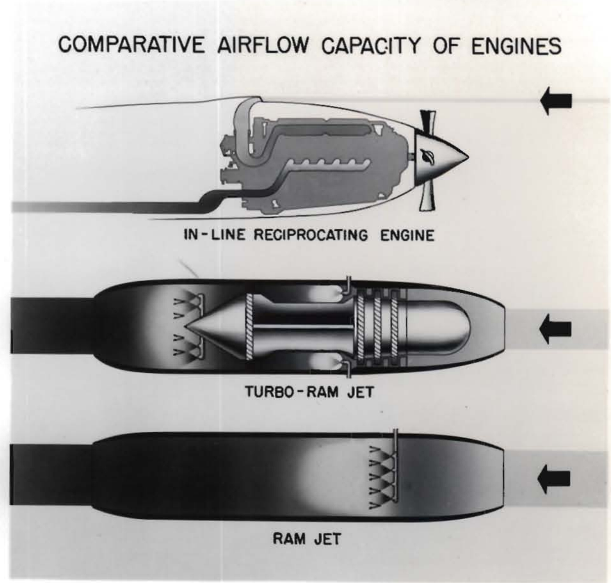

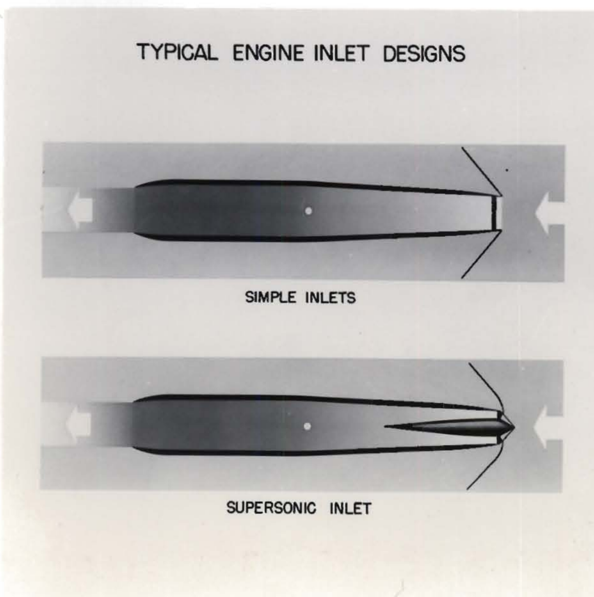

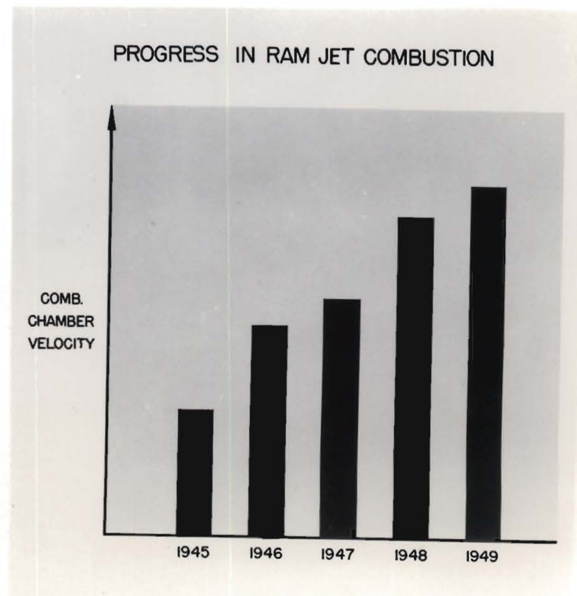

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9.23.49