PROPELLERS AND HELICOPTERS

presented by

12-Foot Pressure Wind-Tunnel Section

At the Inspection of the Ames Laboratory in 1950 and at the Langley Laboratory in 1951 we discussed the theory, performance, and structural problems of the supersonic propeller. Despite the high propulsive efficiency of the supersonic propeller, application to commercial and military airplanes has been delayed because of the severity of the structural problems. Because of the extreme thinness of the blades and the high rotational speeds, supersonic propellers are susceptible to flutter and to several types of vibration. NACA research is continuing on the prediction and alleviation of the conditions that lead to propeller flutter and vibration and the associated high stresses.

As a topic for today's discussion we have selected still another avenue of NACA research concerning the supersonic propeller. The problem to be discussed is not the supersonic propeller itself but rather the effects of the propeller on the aerodynamics and on the structure of the airplane.

The effects of propellers on the stability and control of single and multi-engined airplanes do not constitute a new problem. In fact a large amount of research was conducted by the NACA in the late thirties and early forties to determine these effects and to develop theories enabling their prediction. Practically every airplane in service during the last war was tested as a powered model with operating propellers in at least one of the NACA's wind tunnels. Upon successful development of the jet engine and with the emphasis on higher and higher speeds for both military and commercial aircraft, the conventional propeller driven by a reciprocating engine was gradually displaced by the jet. With the jet engine, the main effect of power on the stability and trim of the airplane is the pitching moment resulting from the jet thrust and this can be calculated without recourse to powered model tests. Because of the high fuel consumption and the poor take-off and landing performance of jet airplanes, we are again looking to the propeller for certain classes of airplanes. However, there is an important difference between the propeller-driven airplane we are now considering and the propeller-driven airplane on which we have an accumulation of knowledge from past research. That difference is speed. Instead of speeds of 350 or 400 miles per hour, we are now designing for speeds of 550 or 600 miles per hour. Instead of reciprocating engines of 2000 or 3000 take-off horsepower, we are now considering turboprop engines with 12,000 or 15,000 horsepower. Instead of large-diameter slow turning propellers with disc loadings of 12 or 15 horsepower per square foot, we are now considering supersonic propellers with disc loadings of 100 horsepower per square foot. Instead of straight wings, we must use large amounts of wing sweep. Every one of these design changes increases the possibility of serious effects of propeller operation on the stability and trim of the airplane.

On this model, I will demonstrate briefly what these power effects are and show why it is believed necessary to conduct additional research to evaluate these effects for a modern high-speed airplane configuration. This is a wind-tunnel model being used to study the effects of propeller operation on the aerodynamics of the airplane. It can be considered to represent an airplane capable of flying 550 or 600 miles per hour at altitudes of 40,000 feet and above.

The horsepower required for this performance is about 6000 per engine and a turboprop engine with this power at speed and altitude would have a take-off rating of about 12,000 horsepower. The airplane which this model simulates, would be slightly larger than the B-50. The B-50 has a top speed near 400 miles per hour and a take-off rating per engine of about 3500 horsepower. Let us first assume that this is a model of the B-50. The thrust of the propeller absorbing 3500 horsepower can be shown by this arrow and the propeller normal force can be shown by this arrow. This propeller normal force results from the fact that the propeller is inclined to the airstream and produces lift somewhat like a wing. These two forces result in a pitching moment about the center of gravity of the airplane, causing the airplane to climb as the propeller thrust is increased. This climbing moment can be represented by this third arrow. This third arrow is important as changes in its length will indicate the relative magnitude of the power effect on the airplane stability and trim. Let us now assume that our B-50 airplane has 12,000 horsepower per engine instead of 3500 horsepower. The thrust is increased in proportion to the change in power, but the normal force and climbing moment will be increased by only about 30 percent. If we now sweep the wings of the B-50 airplane and make other changes in order to reduce the drag so that it can fly at 550 miles per hour, we will have an airplane closely resembling this model. In sweeping the wing we have not changed the propeller thrust or normal force but we have more than doubled the distance from the airplane center of gravity to the inboard propeller disc and have increased slightly the distance from the center of gravity to the outboard propeller. As a result, the moment due to the propeller normal force has almost doubled and this arrow must be replaced by one still larger. In other words, in going from the B-50 to our high performance airplane, the effect of the direct propeller forces on the stability and trim has increased by a factor of about 2.

The effects of these direct forces from the propeller have been predicted on the basis of data and theoretical work on subsonic propellers. One objective of the present investigation is to determine whether the existing theory can be extended to the case of the supersonic propeller.

In addition to the forces exerted by the propeller itself, the slipstream behind the propeller also affects the stability of the airplane. The slipstream for one propeller is shown on this chart. It consists of a cylindrical region behind the propeller in which the air pressure, density, and speed are all increased by the thrust of the propeller. The amount of this increase is determined by the disc loading of the propeller and, as I mentioned previously, the disc loadings presently contemplated for supersonic propellers are greater than those previously experienced by a factor of about 7. Since the lift, drag, and moment of the wing and tail are dependent on the local air velocities, densities, and inclination, the properties of the air in the slipstream must be known if the airplane stability is to be calculated. As was the case with the direct propeller forces, our existing theories permit these calculations but experimental verification is required. This is especially true at the higher Mach numbers where we have no experimental data with which to evaluate the adequacy of existing theory.

To compare the measured effects of power with those predicted by theory, this model is being tested in the Ames 12-foot pressure wind tunnel at Mach numbers up to 0.92. Powered models of this type are exceedingly complex, and lack of adequate motors for driving the propellers has previously limited tests of this type to low forward speeds. This present model has a 75-horsepower electric motor inside each nacelle -- a motor which is only 4-1/2 inches in diameter and 12 inches long. The 14-inch supersonic propeller is driven through a gear box at speeds up to 27,000 revolutions per minute. With this model we can simulate airplane powers as large as 15,000 horsepower per engine. Measurement will be made of the direct propeller forces, the properties of the air in the slipstream, and the overall effects of propeller operation on the drag, stability, and trim of the airplane. The experimental data will be compared with the theoretical calculations we have made of power effects in order to ascertain the validity of the assumptions upon which the theory is based. It is hoped that the results of this investigation will enable the designer of multi-engined, swept-wing airplanes to evaluate the effects of propeller operation for his particular design by calculation rather than by the more expensive and time consuming process of powered model tests. So far in our discussion we have considered the effects of propeller operation on the stability and trim of the airplane. At this point I wish to introduce Mr. __________ who will discuss some of the effects of propeller operation on the structure of the airplane. The propeller also affects the structure of the airplane as a result of the intense oscillating pressures or sound waves emanating from the propeller blades. These oscillating pressures induce loads in the surfaces of certain portions of the wing, nacelles, and fuselage, which must be considered in the structural design to avoid failures. At the Langley Laboratory the NACA has recently measured the oscillating air pressures near conventional and supersonic propellers. The results are shown on this chart. Considering first the upper portion of the chart, we have shown the measured pressure on the vertical scale plotted as a function of time, for the subsonic propeller and for the supersonic propeller. This peak pressure corresponds to the passage of one of the propeller blades. A fraction of a second later, the pressure falls to zero until it is again raised by passage of the next blade, and so on. Both the magnitude and the shape of this pressure pulse depend on whether the propeller is operating at subsonic or supersonic tip speeds. With a subsonic propeller, pressure disturbances sent out by the blades travel at a speed faster than the blade itself, and the resulting pressure pulse has a rather low peak magnitude and persists for a considerable length of time. On the other hand, the supersonic propeller, with its blades traveling faster than the disturbances they create, produces a very sharp pressure pulse of large amplitude and short duration.

To study the stresses resulting from these pulsating pressures, we must realize that vibrations will be induced in the airplane that are approximately sinusoidal in character. Any pressure pulsation of the type shown in the upper part of the chart can be duplicated by a series of sinusoidal disturbances of various frequencies and amplitudes. These equivalent sinusoidal disturbances are the ones which excite the sinusoidal vibrations in the airplane structure. The lower part of this chart shows the intensities and frequencies of the sinusoidal disturbances which combine to give the measured pressure pulse. What this part of the chart indicates is that once every time a blade passes by, the pressure will attain this value; twice every time a blade passes by it will attain this value, etc. This first frequency is called the fundamental and the others are called 1st harmonic, 2nd harmonic, etc. For the subsonic propeller, the most intense disturbance is at the frequency of blade passage. For the supersonic propeller the pressure pulse at the frequency of blade passage is more than double that for the subsonic propeller and at the higher harmonics, corresponding to frequencies 2, 3 and 4 times the frequency of blade passage, the pressure pulses are even greater.

It is evident that, with the supersonic propeller, it will be necessary for the designer to avoid resonance of the aircraft structural components at not only the frequency of blade passage, but also at the higher harmonics of this frequency. NACA research has provided measurements of the loads resulting from these pulsating pressures for specific installations and has also developed theories permitting prediction of the loads for the general case.

At this point I wish to introduce Mr. __________ who will discuss some of the research being conducted by NACA on helicopters.

The unique abilities of the helicopter guarantee it a place in aviation, both civil and military. As for all types of aircraft, there are demands for increased speed, improved flying and handling qualities, increased pay load, and reduced weight. NACA helicopter research at the Langley Laboratory is helping in all these fields and today I would like to report briefly on research conducted on helicopter rotor drives and on helicopter stability and control.

Helicopter propulsion systems may be considered to fall into either one or the other of the two general types shown schematically on this chart. On top is the direct-drive system in which the piston engine or gas turbine is directly connected to the rotor shaft through a speed-reduction unit. The power plant is completely enclosed in the helicopter and normally is subject to no loads other than its own weight or gravitational force. In the other type of drive, power is supplied to the rotor by a device which produces thrust at the blade tips. The propulsion system is thus located at the region of highest velocity on the rotor blade, where it must overcome its own aerodynamic resistance before it can produce a useful thrust. Tip-located powerplants must therefore be capable of a large power output for a given engine size. Small size and low drag are also important if excessive rates of descent following a power failure are to be avoided. The weight of a tip-located powerplant is an important factor since the centrifugal forces imposed on the rotor may reach values as high as 1500 times the weight of the engine. These centrifugal forces have so far limited blade-tip propulsion schemes to jet systems. The effect of type of powerplant on helicopter pay load and endurance is shown in this chart. The tip-jet rotor drives include the rocket, the ram jet, the pulse jet, and the pressure jet. The principle of the first three types of jet drives is well known. For the pressure jet, the air compressed by a turbine engine in the fuselage is ducted through hollow rotor blades to burners located at the rotor tips. The gas-turbine drive is similar to a turboprop engine and drives the rotor directly through a gear reduction unit. Its advantage over the piston engine is its lower weight per horsepower. The lighter weight of blade-tip jet-propulsion powerplants permits helicopters to carry much larger pay loads, although the greater fuel consumption results in decreased endurance. This relationship is typical of current helicopters and represents a wide range of helicopter sizes.

As part of its search for means to improve the performance and operating range of blade-tip rotor drives, the NACA, at the Langley Laboratory, has tested a tip-located ram-jet engine on a rotor mounted on an outdoor test stand. The power output of the ram-jet engine is shown here by the lower curve. This same engine was then tested, stationary, in a jet of air. The power output is shown by the upper curve on the chart. It can be seen that a large reduction in power, amounting to nearly 40 percent, occurred when the unit was whirling. Calculations show that the centrifugal force, which at this highest speed was approximately 1500 times the force due to gravity, would cause most of the atomized fuel particles to impinge on the wall of the diffuser and combustion chamber with a resulting loss in burning efficiency. At the lowest speed the difference between the two curves is considerably smaller, since the centrifugal force is approximately half the value previously mentioned.

Work is currently under way to increase the ram-jet performance by modifying the burner so as to minimize this adverse centrifugal effect. The work also includes research on engines designed to blend more smoothly into the rotor blade, in order to reduce their drag.

In working toward the improvement of the stability and control of helicopters, it is necessary to determine the outstanding problems, to establish goals for improvement, and to develop methods whereby the designer can predict and avoid undesirable characteristics. As a typical example of a problem of this type I would like to discuss some research conducted by the Langley Laboratory on a tandem-rotor helicopter. Helicopters with this rotor arrangement are susceptible to combined lateral and directional oscillations which may require constant attention on the part of the pilot to prevent the oscillations building up to a dangerous level. This oscillation combines yawing and rolling motion (demonstrate with model) and has a period of about 7 seconds.

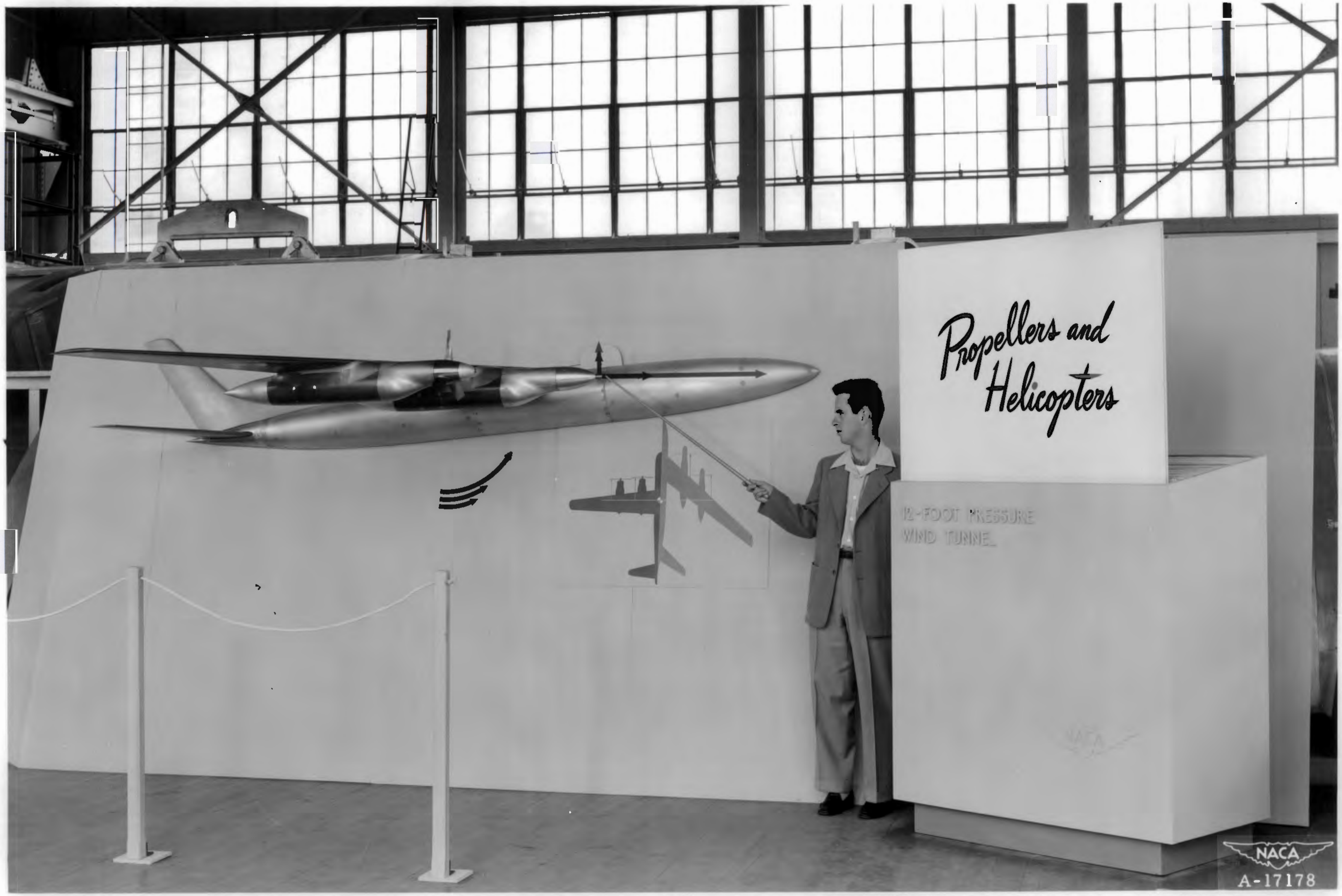
By extending existing stability theory it was found possible to predict such oscillations. The agreement between theory and experiment is shown in this chart.

At this point, the pilot applied lateral control to the helicopter and then returned the control to a neutral position. After the control was centered, the rolling velocity increased and a rolling oscillation occurred which increased in magnitude until corrected by the pilot. Note that the theory predicts both the magnitude and the period of the oscillation. Using this same theory it was predicted that a 50-percent reduction in the rolling moment per unit sideslip would be effective in preventing divergence of the oscillation. To check this prediction, the roll due to sideslip was reduced by this amount. This change was accomplished by attaching panels to the landing-gear strut.

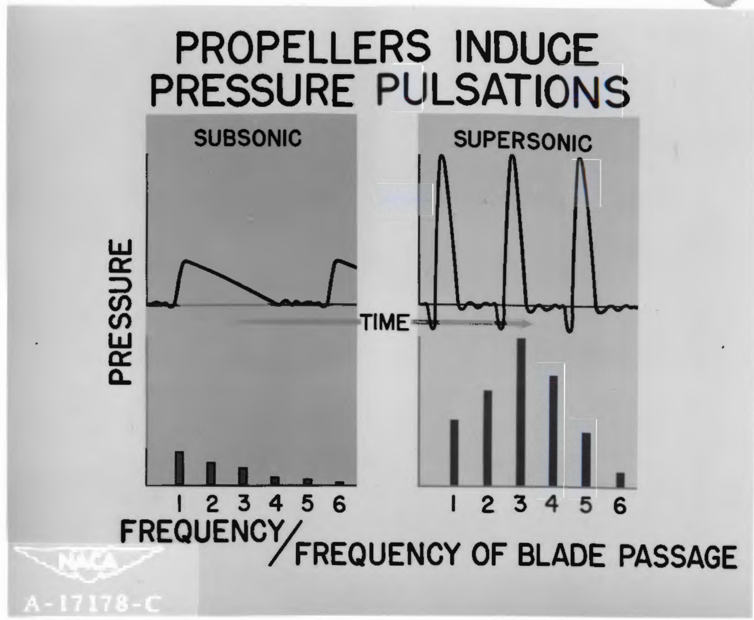
The oscillations were again measured. It was found that the predicted improvement had been achieved, the oscillations now being about neutrally damped. This is shown by the lower curve on the chart.

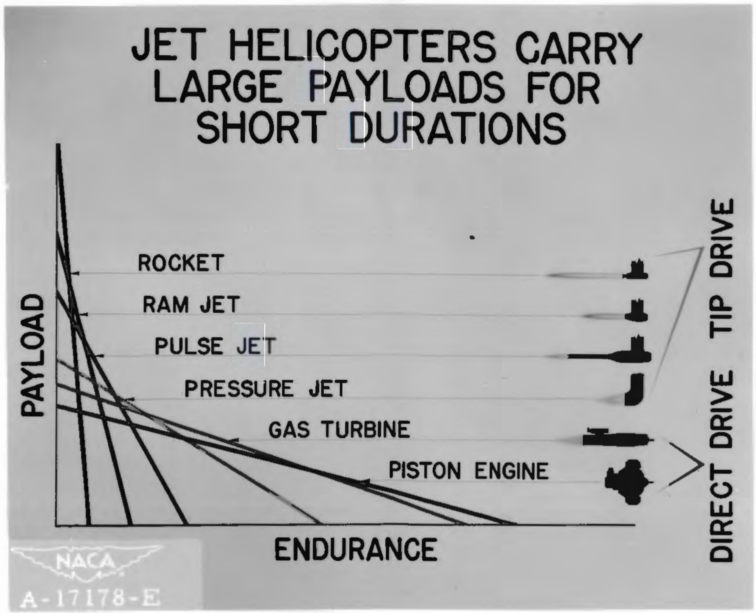
Modifications of this nature can often be made by the manufacturer without interfering with production. Our chief point, however, is that we have arrived at a procedure whereby means for improvement can be examined theoretically, and have demonstrated its accuracy to be adequate.

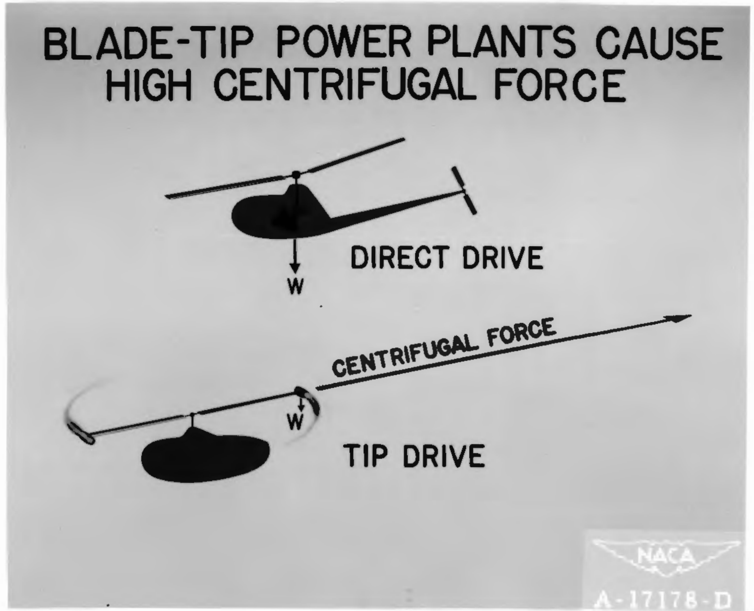
This concludes our presentation at the 12-foot tunnel. I will now return you to your group leader.



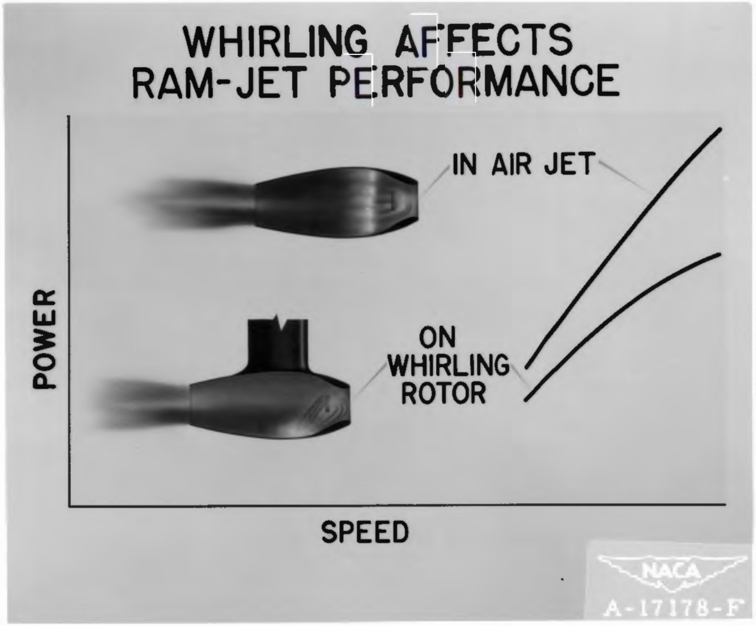
Display for presentation of "Propellers and Helicopters"

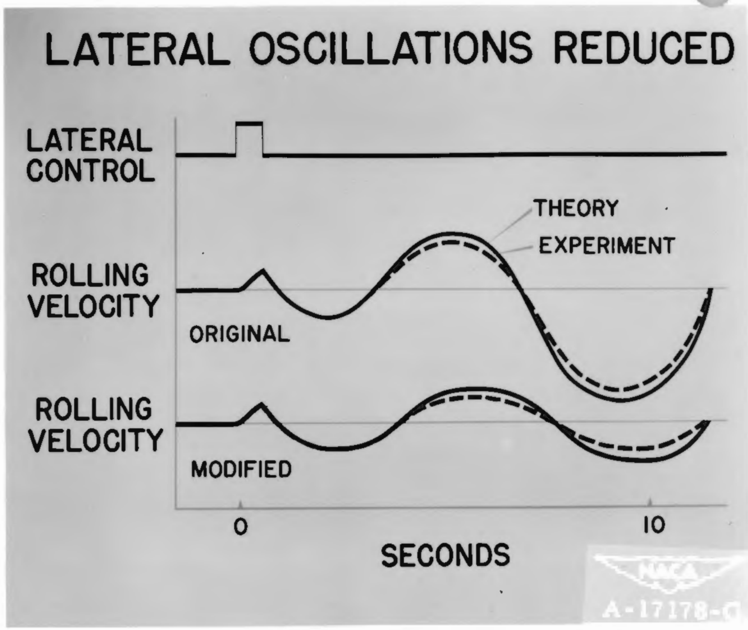






NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF


WHIRLING AFFECTS
RAM-JET PERFORMANCE
IN AIR JET
ON
WHIRLING
ROTOR
POWER
SPEED
NACA
A-17178-F


LATERAL OSCILLATIONS REDUCED
LATERAL
CONTROL
THEORY
EXPERIMENT
ROLLING
VELOCITY
ORIGINAL
ROLLING
VELOCITY
MODIFIED
0
10
SECONDS
NACA
A-17178-G