40- BY 80-FOOT WIND TUNNEL

HIGH-SPEED PROPELLER RESEARCH

Adrien Anderson or David Graham

In these days of talk about rocket and jet propelled aircraft broaching the sonic barrier, one tends to forget the potential performance of the propeller-driven aircraft in the subsonic-speed range. Consider the curves of this chart, (fig. 12(b)). Here we have maximum efficiency plotted against flight Mach number. The curve for the ideal jet unit — and for all practical purposes the actual jet unit — rises steadily with forward speed, while the curve for the actual propeller remains at a high value until a flight Mach number of 0.6 is exceeded — then drops rapidly. Without compressibility losses the propeller efficiency curve would remain high. The advantage of the propeller over the jet unit as regards efficiency at the lower flight speeds is obvious. Even at higher speeds, the propeller offers a fertile field for research from which large gains in propulsive efficiency may result.

The NACA recognizes the importance of improving propeller efficiency in the high speed range and now has several of its high speed research facilities devoted exclusively to propeller study.

Among the means of improving propeller efficiency are the use of thin sections, reduced camber and sweep. An investigation into the effects of various amounts of sweep is now underway but the results are not yet available.

Another factor of importance — namely the effect of forward Mach number on blade thrust load distribution, has been investigated recently, at the Langley Laboratory and the results summarized on this chart, (fig. 12(c)). The section thrust loading coefficient is plotted as a function of the blade radius. At a forward Mach number of 0.35 the distribution of the thrust closely approaches the type of loading for minimum induced losses. But, at 0.85 forward Mach number, the resultant velocity along the blade is such that a loss in thrust loading occurs near the root due to super-critical operation of these sections. The increase in the thrust loading at the tip regions of the propeller is believed to be associated with the ultimate rise in the lift coefficient when large regions of supersonic flow are first established on the blade. A change in pitch distribution to more closely approach the ideal type of loading at the higher forward speeds would, therefore, be expected to improve the efficiency of this propeller.

In order to properly determine the amount of pitch change required to obtain the ideal type of loading, it is necessary to know the actual, propeller-section characteristics. At such high forward speeds, two-dimensional airfoil data are no longer satisfactory for predicting propeller-loading changes.

Therefore the NACA has embarked on a program of obtaining propeller-blade-section characteristics direct from an operating propeller. A propeller blade has been fitted with rows of chordwise pressure orifices at nine radial stations, and the pressure distribution obtained.

Section normal-force coefficients obtained from integrating the resultant pressure diagrams at the 80 percent radius station are shown on the next chart, (fig. 12(d)). Here, section normal-force coefficient is plotted as a function of the section Mach number, for two angles of attack. The propeller data are indicated by the orange curves and, for purposes of comparison, two-dimensional data by the yellow curves. It will be noted that for both angles of attack the propeller data indicates a less rapid change in normal-force coefficient at the higher Mach numbers.

It is planned, by testing a systematic series of propellers having different airfoil sections, to obtain a complete family of propeller airfoil section data through the transonic range. This will provide propeller section data for use in the study of propeller phenomena at high speeds as well as for the accurate prediction of propeller performance.

In summarizing the work on high-speed propeller research, it should be emphasized that although the propeller offers large advantages over a jet as regards efficiency at high subsonic speeds, a very considerable amount of research is necessary and is being conducted into all factors affecting propeller performance.

PROPELLER VIBRATIONS

John C. Roberts or Rogallo

The present trend in propeller design has made the problem of reducing vibratory stress increasingly difficult.

Of particular concern is propeller first order vibration, that is, propeller vibration that occurs once per revolution. The excitation of this type of vibration has been found to be present when operating a propeller in a pitched or yawed attitude and also as a result of fuselage or wing interference.

For illustration purposes we shall consider only the effect of pitch. When operating normal to the relative air stream the blade thrust loading is constant for all positions of the blade; consequently the thrust loading is uniform around the entire periphery of the propeller disk.

In contrast, when the propeller is pitched with respect to the relative air stream, the thrust loading is non-uniform. The downgoing blade experiences an increase in loading and the upgoing a reduction. The loading is a maximum at 90°, and a minimum at 270°, as indicated here by the difference in color intensity. The relative magnitude of the thrust loading may be seen on the next chart (fig.12(e)). (Maximum at 90°, minimum at 270°.) Very large effects on thrust variation arise from small angles of attack. Small inclinations are very important at high speed since the oscillating loads on the blade increase as the square of the airspeed.

This curve is a plot of actual test data, and although good agreement in magnitude was obtained between the computed and experimental values, many similar cases for the same type of calculations have resulted in very serious disagreement. Phase relations also show great discrepancy.

It has become apparent that simple calculations are not sufficient to obtain consistently accurate predictions of blade loads and that proper consideration must be given to such factors as blade deflection, flexibility of motor mountings, unsteady induced flows, as well as induced fields of flow caused by various components of the airplane. The effects of these factors are currently being studied by the NACA.

The Langley Laboratory is considering the case of the isolated propeller.

Our major study here in the Ames 40- by 80-foot wind tunnel will be to investigate the effects of wing and fuselage interference.

A flight test program is also contemplated for the purpose of correlating wind tunnel data.

The twin-engine airplane now in the tunnel will be equipped with several different propellers that have been known to exhibit the particular vibration under study. The configuration of the airplane will be systematically altered so that the effect of wing and fuselage interference may be studied.

One of the propellers installed on this airplane has been instrumented with flight slip rings and strain gages.

We will now operate this propeller. The propeller will be brought up to a speed at which it will vibrate. By means of a strain gage which is cemented to the propeller we will show a measure of the vibratory stresses. This stress oscillation will be shown on the oscillioscope.

The strain gage is located on the longitudinal axis of the blade, thus the oscillating stress is a result of the flatwise bending. Vertical displacement is a measure of the stress. This oscillation represents one revolution of the propeller.

PROPELLER ICING RESEARCH

James Selna or Carr B. Neel Jr.

The formation of ice on airplane propellers has several undesirable effects. Of primary concern is the loss in propeller thrust caused by ice on the propeller blades. A second undesirable result is the vibration problem encountered when ice formations are thrown off one blade and not off the others, as shown here: (fig.12(a)).

The psychological effect on passengers of large sections of ice from the blades striking the fuselage is not to be ignored, nor can the possibility of puncturing pressure cabins.

As part of a comprehensive investigation of aircraft icing, this laboratory has conducted tests to determine the effects of ice accretions on propeller performance, and the electrical heating requirements for ice prevention. The tests were conducted in flight during the last two winters with a Curtiss Wright C-46 airplane, which is on display in the large hangar.

In considering the effects on propeller performance, it is of interest to note that the maximum values of thrust loss recorded this winter did not exceed 10 percent, and for the most part were below 5 percent. An example of an accretion producing an appreciable thrust loss is shown on this chart (fig. 12(f)).

The step in the formation here was caused when a primary ice formation broke off down to this point and a second accretion built over the first. This formation produced a reduction in thrust of 10 percent, as shown here (fig. 12(g)), over the normal operating range of v/nD. In general, the larger thrust losses were obtained at low temperatures, about 10° F, in which instances the ice would form along the leading edge almost to the blade tips. These accretions usually were shaped somewhat like an isosceles triangle with the base against the leading edge. At higher temperatures, say, 15° F to freezing, the ice accretions were frequently much larger and more irregular in shape, often covering a larger percentage of the blade chord, but usually did not extend beyond about 50 percent of the radius, due to the effect of increased kinetic heating and centrifugal force as the radius is increased.

A consideration of the thrust loading on a propeller blade, such as shown on this chart (fig.12(f)) is of aid in the interpretation of the thrust loss results. The shaded area represents the total thrust and the predominant contribution of the outer portion of the blade is evident. Thus, although the ice accretions experienced at the higher temperatures are frequently very formidable in appearance, they fortunately are located on the inner half of the blade where their effect on thrust is minimized. On the other hand, and again fortunately, the ice accretions which form on the outer part of the propeller tend to conform to the blade contour and produce small losses considering their critical location from a thrust distribution standpoint.

The thrust loss data obtained this winter agree with similar data obtained previously in flight tests by this laboratory and by the Cleveland Laboratory as far as the predominance of low values of thrust loss is concerned. For these tests, about 90 percent of thrust loss recordings were less than 10 percent and 38 percent were less than 5 percent. In only a few instances were losses greater than 10 percent observed. The maximum thrust loss value recorded was 19 percent. It should be noted, however, that although most of the icing encountered produced losses less than 10 percent which, at times, could be tolerated, thrust losses should be maintained to less than five percent, from the standpoint of efficient airplane operation.

It appears, then, that for operations at temperatures from 15°F to freezing, which in the past have constituted the majority of airline travel in the United States, thrust losses in excess of 10 percent would be rare even with no protection. With the installation of electrical heating shoes of this type (on blades) to the 50 or 60 percent radius station, as shown on this chart (fig.12(h)).

The losses probably could be maintained to a value less than 5 percent. In the case of high altitude transport operations which now confront the airlines, and in practically all operations in the Arctic region, temperature below 15°F would be the rule and ice accretions extending to the blade tips could be anticipated. This would not necessarily entail an increased power supply for propeller protection, but possibly only a redistribution and intensification of the heating, as shown here, since the accretions tend to be limited to the leading edge and usually do not cover as large a percentage of the blade chord as in the case of higher temperature icing. For airplanes which might be called upon to operate under all flight conditions a composite shoe for which the pilot can select one or the other of two heated regions, is indicated.

Heating of propellers at the present time is usually accomplished by electrically heated shoes of the type mounted on these blades. The heater element consists of an electrical resistance material which is cemented between two layers of rubber. The metal strips were installed at this laboratory to protect the shoes from abrasion.

HELICOPTERS

Woodrow Cook or Ralph Salisbury

The NACA facilities for helicopter testing are located at the Langley Laboratory and include the rotor test tower shown in your booklet, the full-scale, free-flight, and other wind tunnels, as well as actual helicopters equipped with special flight recording instruments.

With these facilities are conducted the three main phases of helicopter research: performance, vibration, and stability and control.

Shown in this chart (fig. 12(i)) are some of the performance-test results for one of the rotors tested on the tower. Here we have the horsepower required for the rotor plotted against wind speed. The reduction in power required amounts to 25 percent due to a wind speed or forward speed of 20 miles per hour. As there is little change in power up to 3 miles per hour the rotor tower gives reliable hovering data in winds of 3 miles per hour or less and is being used for additional tests for the improvement of rotors. On this particular investigation theoretical and experimental results agree very closely.

During the helicopter flight tests that have been made to date, several undesirable stability and control characteristics were encountered. These characteristics made the helicopters difficult to fly, especially in gusty air or with poor visibility. As a consequence of these difficulties a general study of helicopter flying characteristics was initiated.

For the particular helicopters tested, three outstanding stability and control problems were indicated.

First, while in forward flight the helicopters were unstable with angle of attack change.

Second, there was excessive sensitivity of control in hovering flight. And third, there were undesirable stick forces.

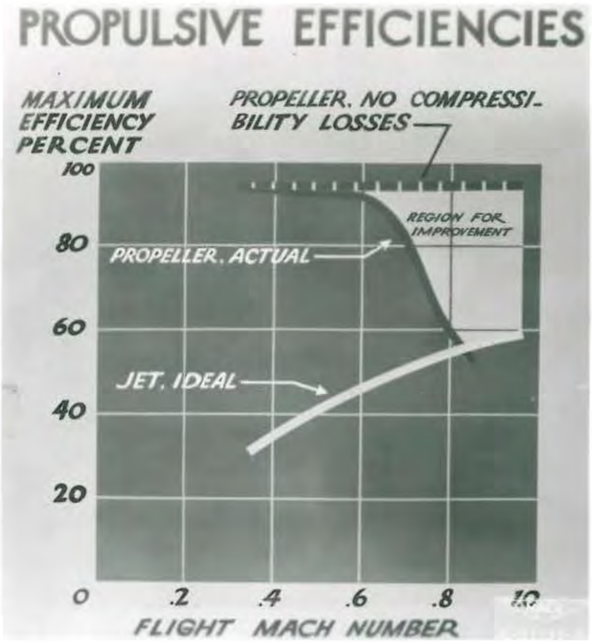
To illustrate the first problem, that of instability with angle of attack change, this chart (fig. 12(j)) presents the variation of fuselage attitude in degrees with time in seconds following a sudden control stick movement and release or, what would give similar results, a sudden gust. Shown on the lower half of the chart is the corresponding variation of normal acceleration or "g's." During this period of approximately 25 seconds the helicopter was flown hands off. At this point, control was resumed because of the violence of the oscillation. At 65 miles per hour the oscillation increased so rapidly that the pilot was forced to resume control after a period of 10 seconds indicating that the instability with angle of attack change is even more pronounced at higher speeds.

Solutions to the problem of pitching instability with forward flight as well as the other two problems, the extreme control sensitivity in hovering and the undesirable stick forces are being studied. In the course of these studies it has become apparent that there is a definite need for the establishment of requirements for satisfactory helicopter handling qualities comparable to those which are in use today for the conventional airplane.

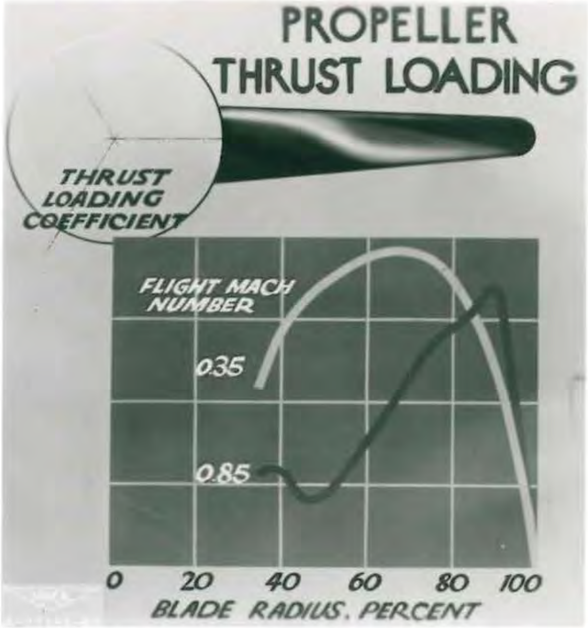
This is the status of NACA's research on helicopters today. Future research should provide solutions to the problemswhich at present are preventing the fullest utilization of the helicopter

(a) General view.

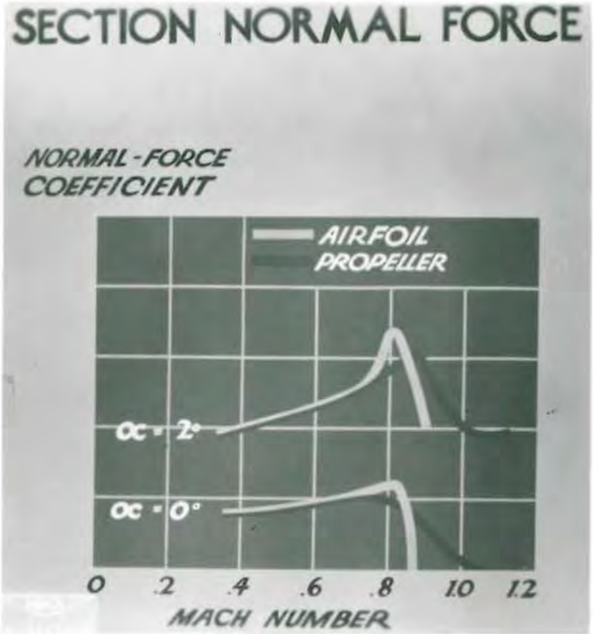
Figure 12.— 40— by 80—foot wind—tunnel exhibits.



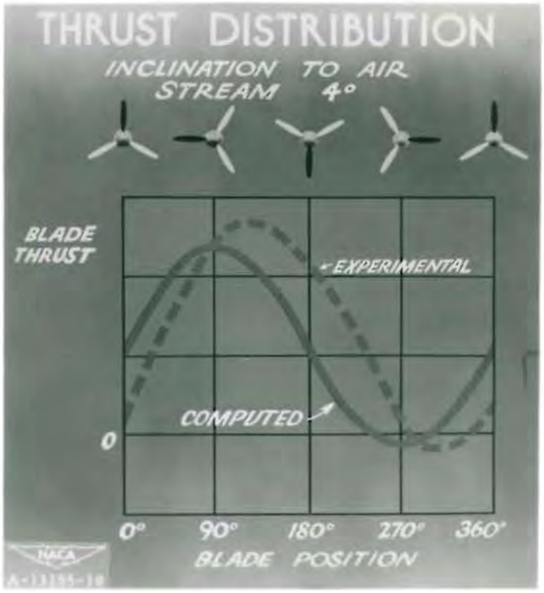
(b) First chart.



(c) Second chart.



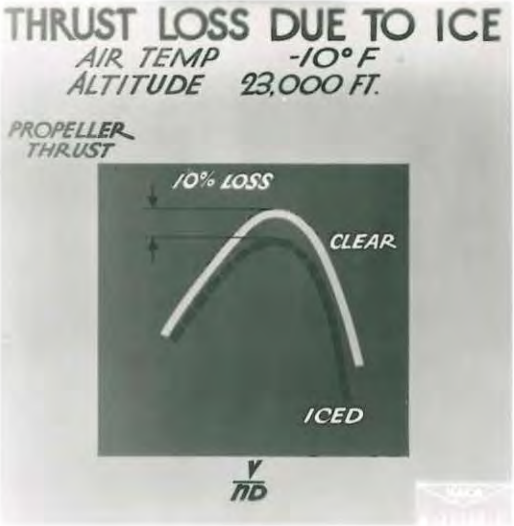
(d) Third chart.



(e) Fourth chart.

Figure 12.- Continued.

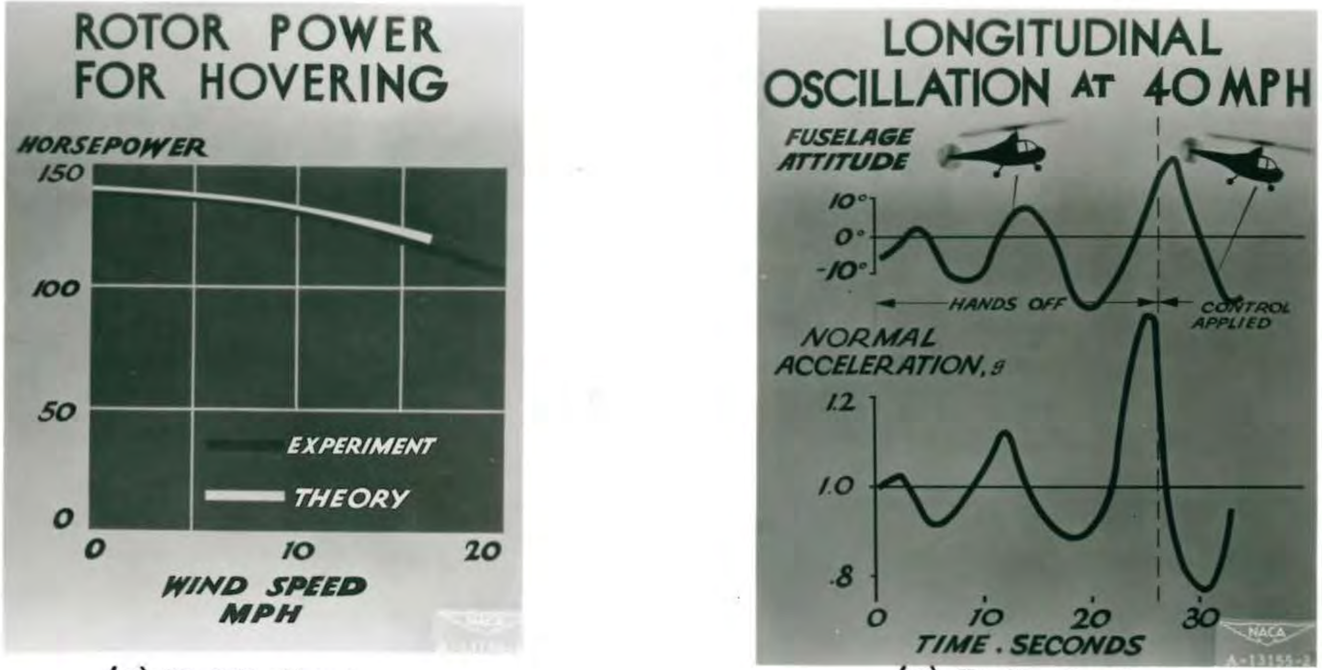
(f) Fifth chart.



(g) Sixth chart.

(h) Seventh chart.

Figure 12.-- Continued.



(i) Eighth Chart.

(j) Ninth chart.

Figure 12.- Concluded.