HELICOPTER LOADS STUDIES

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The loads encountered by a helicopter in flight fall into two categories; one, the loads applied by the rotor system through the pylon thus producing stresses on the fuselage, and two, the inherent periodic loads and stresses on the rotor system itself, which are always present even in steady flight in smooth air. This latter situation results from the fact that the rotor disk moves through the air edgewise, so that each individual blade encounters a widely varying velocity distribution as it goes around and is therefore continually bent back and forth, and up and down.

This second item may need some explaining, so we have a continuous record (chart no. 1) showing the effect on periodic blade stresses of moving a model at increasing speeds. In hovering, the stress at a point on the model blade is substantially constant. As the helicopter begins to move forward, even though this is smooth air, we see that a periodic stress appears due to the varying velocity which the blade encounters with every revolution and we see this stress increases with forward speed.

To study these loads intelligently, we need to know the loads and operating conditions to which the user actually subjects his helicopter. Therefore, we have put instruments like this one in helicopters being used in established types of operation (chart no. 2). Shown here are typical records for two types of operation; vertically are altitude, airspeed, and normal acceleration traces, while horizontally we have the time scale in minutes. The top record represents a scheduled air-mail flight take-off, climb, level flight, descent and landing. The average time for such a flight is about 9 minutes. The lower record is a sample obtained from a military training operation involving practice autorotational landings. To date, we have analyzed the records from about 4,000 flights, of which 2,500 were air-mail operations, 1,000 were military pilot training, and about 500 were other miscellaneous military operations.

The first thing we want to call to your attention is the large percentage of time spent at cruising speeds and above by the air-mail helicopter. This result has been consistently shown throughout our sampling of flights of two air-mail carriers. Since the periodic blade stresses for these speeds are high, this large amount of time at high speeds is important in determining the fatigue life of air-mail helicopter rotor blades.

Although speed as such produces high periodic stresses, there are other factors shown indirectly on these records which may modify these stresses. In particular, this hash means moderately gusty air, while these more prolonged displacements are maneuvers. Separate investigations are underway to learn the extent to which these factors must be taken into account in using the records for blade fatigue studies.

This completes our discussion of the subject of periodic stresses in the rotor system. Now we will consider the other category, that is, the loads applied by the rotor system through the pylon, thus producing stresses in the fuselage. As shown here, we find that large maneuver loads are the outstanding feature of the military training records. We have recorded a number of values over 2 g, which is large for a helicopter. While before we were chiefly concerned with fatigue, the primary significance of these maneuver loads is that one extra large load might break the fuselage or pylon.

While statistics of this type could be used directly to increase or decrease established design load factor values, intelligent choice of such values requires that we have a more fundamental knowledge of what limits such loads. This is particularly true for radically new designs.

Design requirements of the various purchasing agencies currently specify that the structure withstand accelerations of around 2-1/2 to 3-1/2 g without permanent deformation. There has been much concern over the suitability of these values.

It is quite tempting to simplify the problem by assuming that the maximum loads reached in practice will correspond to the assumption of maximum lift coefficient on all blades at all radii at the same time. This would mean no sections beyond the stall angle, as well as none below.

In view of the varying conditions already described as occurring through each revolution, and the practical issue of what maneuvers can actually be carried out, this approach of maximum lift coefficient on all sections at once may sound like wishful thinking. In fact, this method has been largely ignored for such reasons. To put it to the test, we analyzed a number of time histories of deliberately severe maneuvers. These maneuvers were part of a joint CAA-NACA flight investigation and involved two different helicopters. A variety of types of maneuvers were made, with successively more severe control deflections being made at each of a series of airspeeds. For the most severe maneuvers a comparison with the section maximum lift coefficient assumption is afforded by this chart. Plotted vertically is normal acceleration due to a maneuver; while horizontally we have a variable called trim mean lift coefficient which shows whether, prior to the maneuver, the blades were being run at low angles of attack or at angles near the stall, and so on.

The use of a mean lift coefficient is pretty similar to using an average lift coefficient for a wing. The big difference is that most of the airspeed over the blades is due to their rotation, and not due to the forward speed of the aircraft. Consequently, it is the design of the aircraft, not the speed at which the maneuver is made, which will move a data point to the right or left. Therefore, we do not get much spread for our two test helicopters even though we did cover airspeeds from zero on up.

The process involved is that the pilot is flying at a given trim mean lift coefficient, in steady flight at 1 g at most any forward speed, and makes a severe maneuver. If he gets an acceleration corresponding to the maximum lift coefficient at every blade section, the test point will fall on this line. You can see that for both test helicopters, accelerations close to the predicted maximums were repeatedly reached. We can see, too, that these maximums correspond pretty closely to the most commonly used requirements, that is, 2-1/2 or 3 g.

We thus find not only that these current design requirements make a lot of sense, but also that we have a very simple way to examine trends for future designs. For example, many high-speed helicopter designs, in dodging blade stalling effects in steady flight, tend to go to the left on this plot and invite higher accelerations. Some types of load-lifters may go this way, to the right, and design loads below present values may prove warranted.

Now to summarize what we have said. Item one, periodic stresses are inherently produced in the rotor blades as a function of forward speed and other flight conditions. As one contribution to a better prediction of rotor blade fatigue life, we are determining the time spent in the various conditions for particular classes of helicopter operation. Item two, we now have a simple method of estimating, for new designs, the maximum obtainable load factor for any given flight condition.

As indicated by this chart, among the problems which confront the people who build and fly helicopters are those of vibration and flutter. The next portion of the talk, by Mr. Brooks, will be devoted to a brief discussion of helicopter rotor blade flutter under hovering conditions.

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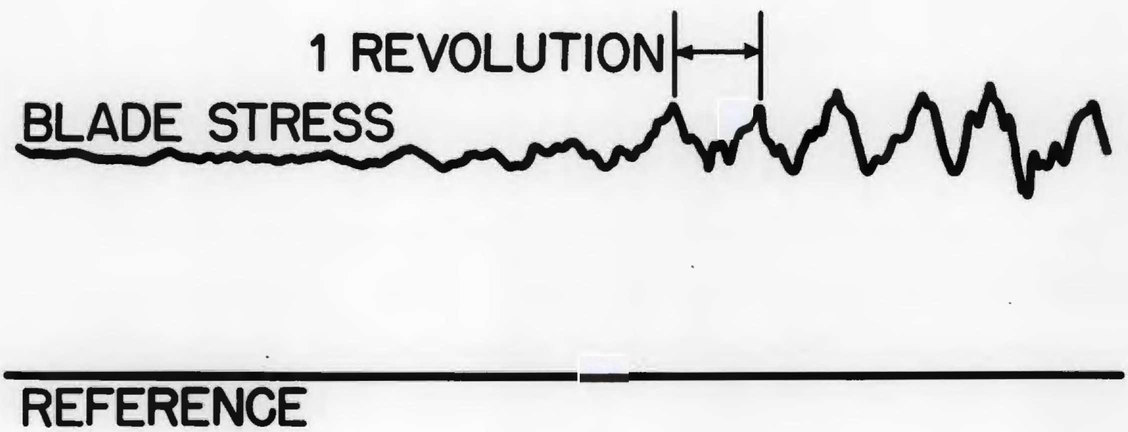
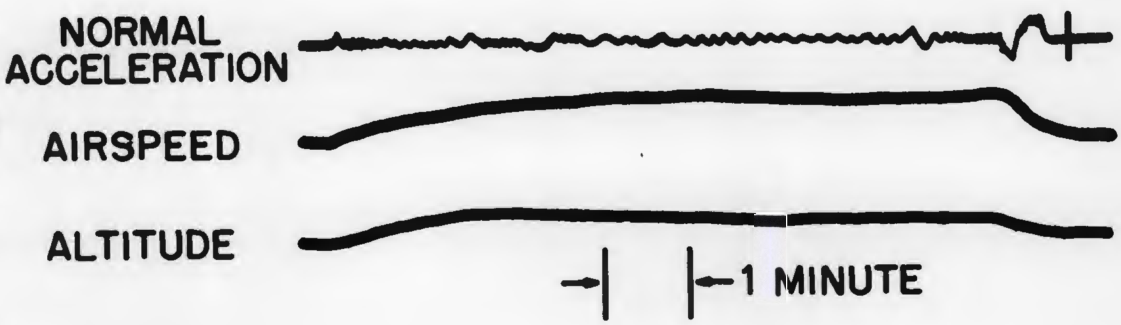

1 REVOLUTION
BLADE STRESS
REFERENCE

SPECIAL RECORDER DEPICTS HELICOPTER OPERATING CONDITIONS



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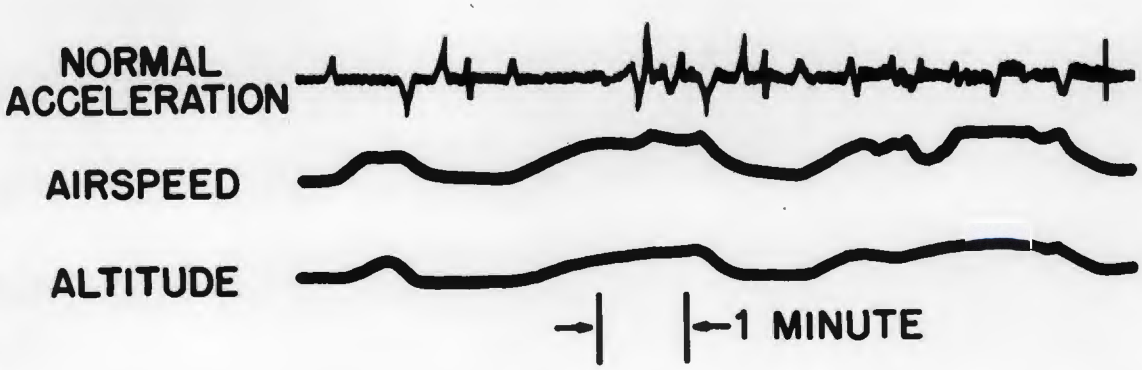

MILITARY TRAINING

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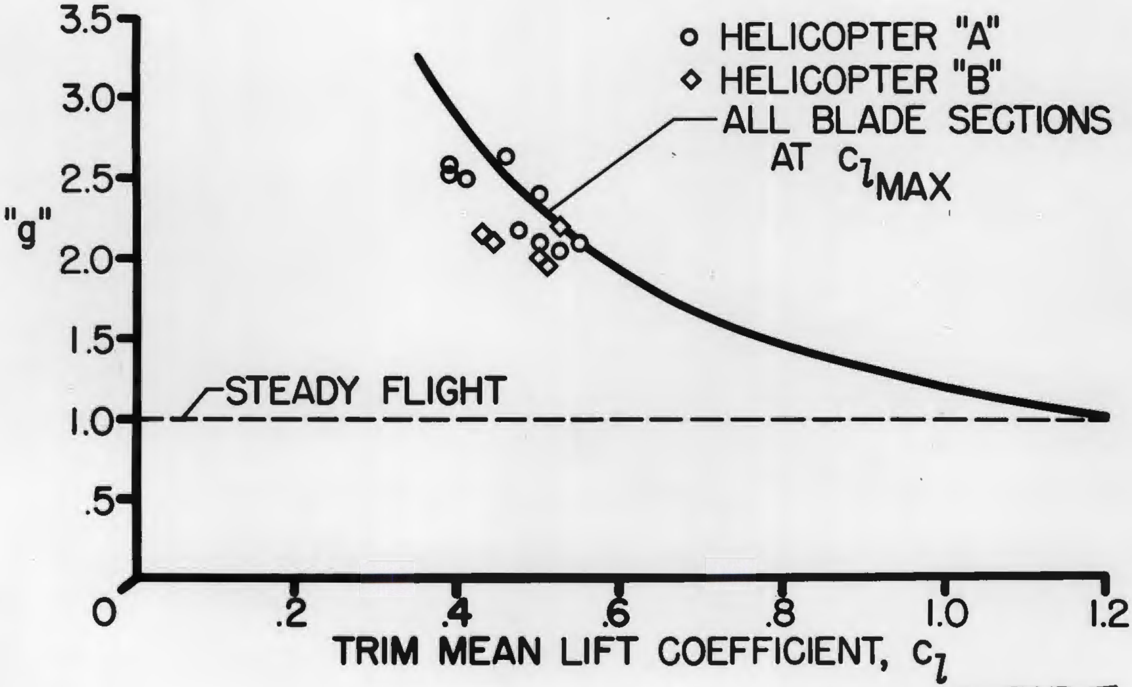
MANEUVER LOAD FACTOR



HELICOPTER ROTOR FLUTTER

It has been known for some time that helicopter blades can be prevented from fluttering simply by adding weights to move the center-of-gravity of the section forward. This can be easily demonstrated with this simple model. If the model is held before this fan, you will see the model flutter. The flutter motion is accentuated by the attached pointer. The flutter can be stopped by placing a weight on the pointer in front of the leading edge. When the weight is removed, the flutter continues. We have shown that, if you are not concerned about the amount or shape of the added weight, you can prevent flutter. However, the designers of helicopter blades are greatly concerned with the aerodynamic and structural efficiency of the blades, and the addition of a weight to a blade in the manner shown would represent poor design practice. The effect of weight balance is illustrated by the next slide. The slide shows the flutter boundaries for three blade cross sections with different amounts of weight balance. The ordinate is the blade tip speed and the abscissa is the angle of attack. The flutter boundary separates the flutter or unstable region from the flutter-free or stable region. The boundary shown by the solid line is representative of typical production type blades which are balanced by the addition of weight in the nose to the extent that the center-of-gravity is located near the center of lift. In this case, the steady flight region which is the region wherein the helicopter normally operates lies well within the stable region to the left of the flutter boundary. In the past, it has been necessary to add this weight in the nose so as to eliminate undesirable stick forces in order to make the helicopter flyable. Despite the fact that balancing the blade in this fashion eliminated both the undesirable stick forces and flutter, the added weight results in higher centrifugal blade loads and, therefore, leads to a "beefed up" structure and a loss in pay load. With the use of powered controls, complete balance is no longer mandatory from a control standpoint, and to carry more weight than necessary to prevent flutter would result in an inefficient structure. A knowledge of the flutter boundaries is necessary in order to give the designer the information as to how much balance and stiffness is required to keep the operating region in the stable region. For example, if the blade is designed for maximum strength per unit weight the center-of-gravity will be located rearward of the center-of-pressure as indicated by the lower section diagram, and the corresponding flutter boundary would lie below the steady flight region. In this case, the blade would flutter before the desired tip speed is reached.

With sufficient flutter information, the designer can make a compromise by accepting the minimum added weight which will put the operating region in the stable region. Such a blade might be represented by the center section diagram and the corresponding flutter boundary. You may observe that the normal operating region lies below this boundary and the helicopter can be operated flutter free. Inasmuch as the flutter speed is also dependent on the spanwise distribution of blade weight, the judicial placement of the added weight along the span is significant in the attainment of an efficient structure and from an aerodynamic standpoint, it is desirable to keep as much of the weight as possible inside the blade. On helicopters having small, rather inexpensive blades, the question of the most favorable amount and location of added weight for balance can be answered by the cut and try method with the actual blades being tested on whirl test stands. On larger helicopters the information must be obtained through the combination of theoretical and experimental research with models such as this simple blade or the complete dynamic model on display.

So far, we have been primarily discussing the classical type flutter which occurs at the lower angles of attack in comparatively unseparated flow. As the angle of attack is increased, the flow around the blade begins to separate and the flutter speed, as indicated by these flutter boundaries, drops off sharply. Furthermore, the flutter boundaries for balanced and unbalanced blades converge indicating that weight balance is no longer beneficial. Fortunately, this effect generally occurs at conditions which are beyond the normal operating regions for best performance, however, some caution must be exercised in the operation of helicopter blades during jump take offs and high acceleration pull-up or flare outs since these maneuvers may lead to stall flutter.

Theoretical analyses are limited at present to the treatment of classical type flutter, however, considerable effort is being made to obtain a better analytical understanding of the flutter phenomena in the stall region with the hope of developing applicable theories.

HELICOPTER FLUTTER