Engineering Notes

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Helicopter Rotor Performance Degradation in Natural Icing Encounter

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Introduction

CURRENT emphasis on helicopter icing has resulted because of the desire to increase the overall utilization of the helicopter with a minimum of weather associated restrictions. The requirements for rotorcraft icing research have been identified by Peterson et al.,[1] where the analytical prediction methods and test techniques necessary to define the ice accretion mechanism in addition to the primary areas of research have been outlined. One such area of fundamental research currently being carried out is the analytical prediction of the performance degradation of rotors due to ice.

Analysis

The analytical model as described by Korkan et al.[2] as applied to the prediction of performance degradation of propellers in a natural icing encounter has been examined to determine the feasibility of predicting helicopter performance degradation in hover during natural icing. The front rotor of the CH47D helicopter was selected for analysis where the rotor consists of three blades with a radius of 30 ft, a constant chord of 32 in., and which rotates at 225 rpm. The rotor blade utilizes the VR-7 and VR-8 airfoils having a maximum thickness/chord ratio of 12 and 8%, respectively. The blade transitions linearly from the VR-7 to the VR-8 airfoil at the tip, i.e., a constant VR-7 section is used from the cutout to 85% of the span. Also, a 6-deg trailing-edge tab deflected up is employed along the entire span.

The flight condition selected for analysis was at an altitude of 3000 ft and a free-air temperature of 1°F. The Boeing Vertol B-92 helicopter performance analysis yielded the range of the thrust coefficient and horsepower for the CH47D rotor in the hover condition. Examination of the radial variation of the local Mach number, angle of attack, and twist distribution for a thrust coefficient (C_T) range of 0.004-0.008 indicates reasonable quantities for analysis as do the corresponding values of C_L and C_D.

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The rime ice condition selected for analysis consisted of an average liquid water content of 0.44 g/m^3, average particle diameter of 25 μm, and a free-air temperature of 1°F. A typical impingement efficiency variation over the airfoil surface at an r/R of 0.65 is shown in Fig. 1 for a C_T of 0.008 at an angle of attack of 4.69 deg. As in the propeller case,[2] the total collection efficiency and the accumulation parameter have been determined for all radial locations along the rotor blade. These values have then been used in the rime ice drag coefficient correlation of Bragg and Gregorek[3] with no modifications to the constants, i.e.,

$$\Delta C_D / C_D = 0.010(15.798 \ln(k/c) + 28{,}000\, Ac\, E + I) \qquad (1)$$

where k/c is the roughness height, Ac the accumulation parameter, E the total collection efficiency, and the constant I

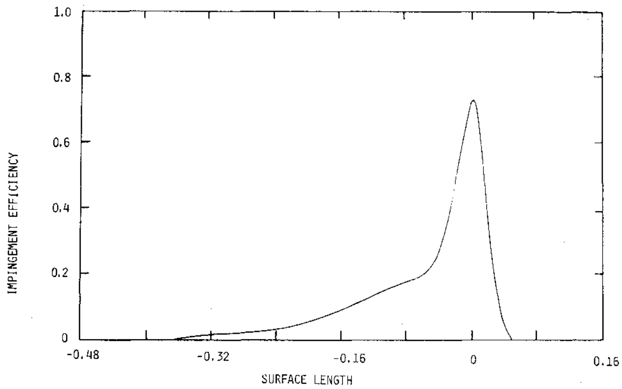

Fig. 1 Example of impingement efficiency variation vs airfoil surface length, CH47D helicopter rotor blade, $r/R = 0.6507$, $C_T = 0.008$, $\alpha = 4.691$ deg.

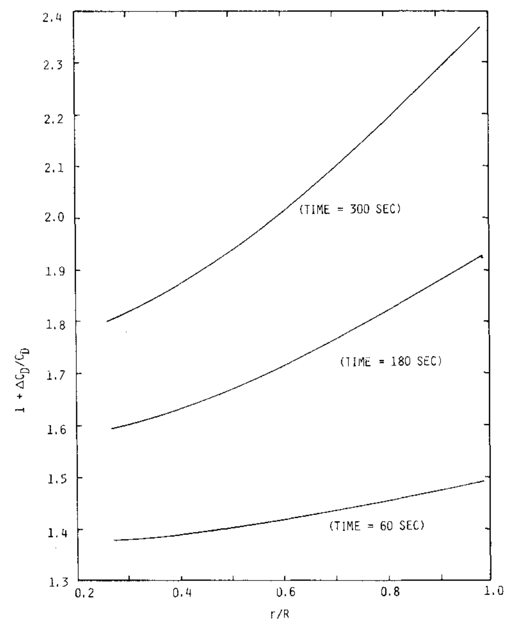

Fig. 2 Variation of $(1 + \Delta C_D / C_D)$ along CH47D helicopter rotor blade for selected icing times of 60, 180, and 300 s. $C_T = 0.004$, hover condition.

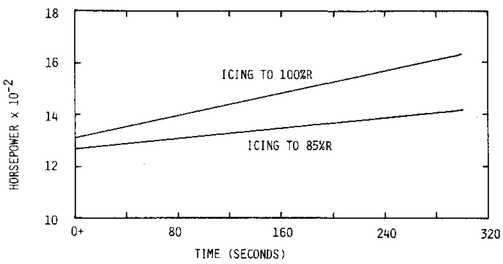

Fig. 3 Horsepower required to maintain a C_T of 0.004 as a function of icing time, CH47D helicopter rotor blade, hover condition.

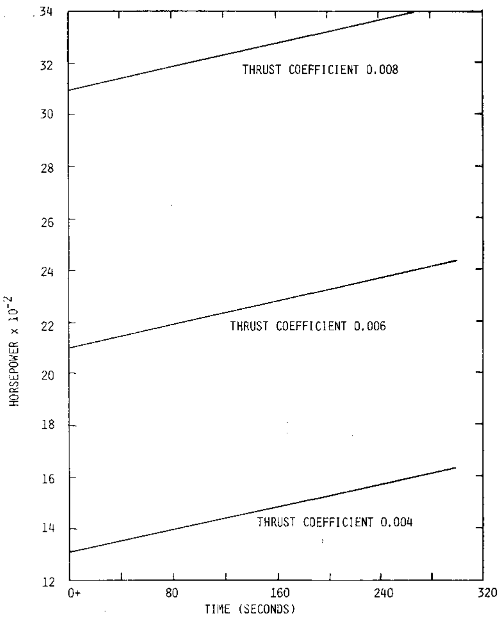

Fig. 4 Horsepower required to maintain a C_T of 0.004, 0.006, and 0.008 as a function of icing time, CH47D helicopter rotor blade, hover condition.

is dependent on the airfoil type.[3] The step drag increase at the inception of icing is based on surface roughness data.[3] The drag of the airfoil during icing is then found from the expression

$$C_{D_{\rm ice}} = (1 + \Delta C_D / C_D) C_D \tag{2}$$

where C_D is the two-dimensional profile drag prior to icing as described in the airfoil data bank or found by existing airfoil analyses and/or experiment.

The factor $1 + \Delta C_D / C_D$, plotted as a function of radial location for selected times of 60, 180, and 300s in Fig. 2, indicates the strong dependence of the performance degradation on actual icing time. Also, these data can be displayed as a function of time for selected radial locations, where the growth in drag is linear with time starting from the frost point which is noted as a step in the $(1 + \Delta C_D / C_D)$ variation at time $0+$ s.

When these drag increments are included in the airfoil data used for the hover analysis of the CH47D rotor, the resulting increase in required horsepower necessary to maintain a thrust level C_T of 0.004 as a function of icing time is shown in Fig. 3. The approximate 24% increase in required horsepower for a five minute natural icing encounter for this C_T is evident. It should also be noted that if ice accretion is allowed to take place only up to the 85% radial location, the horsepower increment needed to maintain a C_T of 0.004 is reduced to approximately 12%. This illustrates the sensitivity of the rotor tip region in the degradation of the helicopter performance in an icing encounter, and stresses the need to quantify the mechanism of both ice accretion and shedding.

Other thrust coefficient levels, such as C_T of 0.006 and 0.008, for the assumed natural icing encounter are shown in Fig. 4. As can be seen, the trend is the same for all values of C_T for required horsepower. However, it may be noted that the slope of the required horsepower is linear with icing time and is approximately the same for all three thrust coefficients examined.

Summary

The analytical model which provides theoretical values of performance degradation due to rime ice accretion on helicopter rotor blades in hover yields values that are representative of those experienced in actual flight. However, further test/theory correlation is needed to determine the validity of the present approach. Emphasis is also being placed on selected forward flight conditions through performance data available at the Boeing Vertol Company. In this case, the rotor disk is divided into 24 15-deg sectors and the cyclic variation in local Mach number and angle of attack is assessed for each specified flight condition, i.e., forward flight, hover, etc. The results of analytical predictions, such as torque rise as a function of time, are currently being examined in detail to determine the validity of such an approach in modifying only the steady component of the forces experienced by the rotor blade in a natural icing condition.

Acknowledgment

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References

[1] Peterson, A.A., Dadone, L., Bevan, D., and Olsen, W., "Rotorcraft Icing Research Requirements," AHS Preprint 81-39, 37th Annual Forum of the American Helicopter Society, May 1981.

[2] Korkan, K.D., Dadone, L., and Shaw, R.J., "Performance Degradation of Propeller/Rotor Systems due to Rime Ice Accretion," AIAA Paper 82-0286, Jan. 1982.

[3] Bragg, M.B. and Gregorek, G.M, "Aerodynamic Characteristics of Airfoils with Ice Accretion," AIAA Paper 82-0282, Jan. 1982.

A Method for Predicting Wing Response to Buffet Loads

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Introduction

BUFFETING is the aeroelastic response of aircraft structures to aerodynamic excitation arising from random loading due to flow separations on the wing. It is almost always encountered when the aircraft approaches the limiting usable lift at high speeds. The maneuvering capability of aircrafts is thus usually limited by buffet or buffet-related unsteady phenomena which induce the pilot to restrict the maneuver. Methods for predicting the buffet intensity as the aircraft penetrates into the buffet regime are extremely useful and much needed in aircraft design.

The random nature of the loading on the wing due to flow separations requires statistical theory in predicting the

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