reliability are essential. This view is apparently shared by the Army Aviation Materiel Laboratories, as they are now sponsoring a further program at Boeing/Vertol for a flight demonstration of a Chinook helicopter equipped with a supercritical-speed rotor synchronizing shaft.

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DISCUSSION

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In the paper the authors discuss the redesign of a helicopter power-transmission shaft from the stand point of satisfactory supercritical operation regarding lateral vibrations. The exciting force considered was that due to the inherent unbalance contained in the system. Although the writer is not very familiar with aircraft design procedures, several helicopter rides have convincingly demonstrated that they possess very severe vibration levels throughout the structure. Such craft are also subjected to additional dynamic loadings in the form of landings, wind buffeting, etc.

Elastic systems that are exposed to random or impulse type excitations will respond predominantly in the lower modes. It is not unlikely, therefore, to imagine that the power transmission shaft in question, although operating above the lower modes regarding unbalance excitation, will not also respond almost continuously in the lower modes due to the general high levels of environmental vibration and other forms of excitation.

It would appear then that additional dampers or snubbing devices would be required to mitigate vibration amplitudes in the lower modes. Observation of Fig. 8 suggests that for the first three modes three additional dampers would suffice. Their approximate locations would be at the 110, 200, and 275-in. shaft stations. Such devices would of course constitute additional weight and maintenance depending on their method of operation.

When entertaining the occurrence of any system resonance it is of paramount importance to be able to predict and account for the resulting stresses. Unfortunately, when dealing with random or impulse type excitation such predictions are extremely difficult. As a minimum effort, however, assumptions as to maximum allowable amplitudes and associated alternating stresses should be made. These should be combined together with the mean stresses in the form of a modified Goodman diagram for an estimation of the overall factor of safety.

In any event, it is strongly recommended that the dynamic response of this shaft be measured during initial flight demonstrations to assure that the resulting stresses are within acceptable limits.

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Authors' Closure

The authors wish to thank Mr. Zaloumis for his constructive comments on the paper. We also wish to add some remarks concerning the points that he raised.

The dampers developed for the supercritical-speed shafts described in the paper are quite effective for suppressing vibration at the low modes as well as at the higher ones. While the amplitudes of vibration at the low modes are larger, the actual forces acting and the stresses developed in the shaft are both quite small. Consequently, for transient loadings such as the maximum anticipated 4 *g* accelerations expected at helicopter touchdown, deflections on the order of 2 in. might be experienced at the center of a shaft such as that designed for the Chinook helicopter, yet the stresses and consequent fatigue effects on the shaft itself would be negligible. No instability is produced by transient disturbances of this type, and hence the response of the supercritical-speed shafts to flight disturbances is similar to that of a well-damped beam.

For the case of retrofitting a supercritical-speed shaft to the Chinook helicopter, however, Mr. Zaloumis' point is quite pertinent, in that insufficient clearance exists in the present shaft tunnel to permit the 2-in. transient shaft deflection without contacting the structure. For the purpose of the flight demonstration program which is now in preparation it was deemed inappropriate by Boeing/Vertol engineers to modify the fuselage structure to provide additional shaft clearance. Rather, they decided to install a bearing support near the center of the shaft to avoid the necessity of increasing the structural clearance. It should be emphasized that this decision was made as an expedient for the experimental program rather than as an inherent requirement of supercritical shaft systems. In a new design the appropriate procedure would be either to provide adequate clearance around the shaft to permit transient deflections without striking the structure, or to provide cushioned snubbing rings at one or more stations which the shaft could strike without any damage to its surface. Provision of additional bearing supports or dampers to overcome these deflections is not necessary for the protection of the shaft itself, and would offset the advantageous weight and maintenance reductions offered by the supercritical-speed shaft.

A final remark may be in order regarding fatigue effects on a supercritical-speed shaft. When running at a critical speed the shaft deflection curve is stationary with respect to the shaft itself. Thus no fatigue results, as the deflected shaft whirls without flexing. A transient deflection in flight as mentioned by Mr. Zaloumis does result in flexure of the shaft, as the shaft centerline is displaced and the shaft rotates about its centerline while in the deflected position. With realistic "*G*" loads encountered in flight or upon landing, however, the stress levels expected would be well below values that would result in fatigue damage to the shaft.