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Analysis Code

The acoustics analysis (ref. 28) is based on dividing the rotor blade surface into a number of panels. Appropriate numerical integrations are carried out using the integrand value at the panel center for the entire panel area. The program determines the panel center and calculates the contribution to the noise from the panel for a specified number of times (azimuth angles). This is repeated for each blade and for all panels to complete the integration over the blade surface.

The program requires a namelist input and three input subroutines. The namelist provides the flight conditions and program control parameters. The subroutines describe the physical and aerodynamic characteristics of the rotor blade and allow great flexibility in the definition of the blade geometry and loading. One subroutine defines the blade-section geometric twist, chord, pitch change axis location, maximum thickness ratio and maximum camber ratio as a function of radial position along the rotor blade. A second subroutine defines the camber and thickness as functions of radial and chordwise locations. The third subroutine describes the aerodynamic blade loading on either the actual blade surface or the mean camber surface as a function of azimuthal position. The blade loading input will be provided by the output of the CAMRAD calculations for all flight conditions, for each of the rotor designs to be evaluated.

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AIRFRAME DESIGN CONSIDERATIONS

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Overview

The purpose of this section of the paper is to provide a discussion of those aspects of airframe structural dynamics that have a strong influence on rotor design optimization. Primary emphasis is on vibration requirements. The constraints imposed on rotor design by airframe dynamics and included in Table 2, are discussed.

The section also includes a description of rotor/airframe modeling enhancements which may be incorporated in later phases of this work.

Constraints Imposed by Airframe on Rotor Design

The design of a rotor which, when coupled to an existing airframe, will result in minimum vibration levels in the airframe requires knowledge of the latter's dynamic characteristics. Because the airframe design is fixed, it is assumed that its dynamic description in terms of both its frequency response characteristics and its frequencies, mode shapes, and modal structural damping are known. It is also assumed that the airframe hub impedance can be computed for the excitation frequencies of interest (which depend on the number of blades and the rotor rotational speed).

Constraints due to vibration response.- To insure that the vibratory responses of the airframe are at minimum levels requires: (1) insuring that none of the frequencies of the major airframe modes is close to the predominant transmitted rotor exciting frequencies; and (2) minimizing the rotor induced loads which are transmitted to the airframe.

The proximity of airframe modes to a rotor exciting frequency as well as an indication of the vibratory response levels under excitation are usually determined by inspection of frequency response functions which are computed (or measured) for the airframe structure. Frequency response curves typically have the form depicted in figure 9, which shows the airframe response (usually the acceleration in g's) at some point (and direction) as a function of hub excitation frequency. Usually, many curves of this kind are generated corresponding to each unique combination of the type (force or moment) and direction (vertical, lateral, etc.) of excitation and the response points and directions of interest. The peaks on the curve occur at the natural frequencies of the airframe; the higher peaks correspond to modes which are major contributors to the total response. The valleys represent low levels of response. As previously mentioned, the oscillatory loads transmitted from the rotor to

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the airframe occur at integer multiples of $N\Omega$ (where N is the number of blades). Because the magnitude of these loads decreases with increasing harmonic number, usually only $N\Omega$ (and sometimes $2N\Omega$) need be considered in practice. Now the number of blades and the rotor rotational speed are generally dictated by aerodynamic requirements. Usual practice is to design the airframe to avoid frequency placement which would result in either resonance or high amplification at $N\Omega$ (and perhaps $2N\Omega$). Because the airframe structural design is assumed to be fixed in phase I of the current work, the design requirement necessitated here is to select N and Ω such that the rotor excitation frequencies $N\Omega$ and $2N\Omega$ are sufficiently removed from the frequencies of the major airframe modes.

Aeromechanical stability constraints.- Aeromechanical instabilities are phenomena in which the inertial coupling between the motion of the first inplane blade mode and any airframe mode that involves hub motion in the plane of the rotor produces a growing oscillation. This may occur on the ground (ground resonance) or in flight (air resonance) (refs. 34 and 35).

Assessment of both ground and air resonance can be made from plots of the type shown in figure 10, which show the variation with rotational speed of the pertinent airframe and rotor mode frequencies, both expressed with respect to the nonrotating system. For simplicity, the uncoupled system frequencies are shown in figure 10. The open circles denote points of frequency coalescence between the critical rotor mode and an airframe frequency and are regions of potential instability. The rotor design requirement to avoid instabilities is to insure that, within the operating speed range of the rotor, there are no coincidences of the frequency of the critical rotor mode with an airframe mode.

Future Design Role of Rotor/Airframe Coupling

It has long been recognized that the dynamic (and aerodynamic) interaction of the rotor and the airframe is important in analysis of helicopter vibrations.

However, the complexity of the problem has been so overwhelming that it has long been customary to compute the blade (and hence rotor) vibratory loads assuming that the hub is fixed. These loads are then applied to separate analytical models of the rotor and the airframe for determining their respective responses. It is clear that this approach cannot entirely account for the interactions between the rotor and the airframe. A simplified view of how the rotor and the airframe interact to produce vibrations is depicted in figure 11. The airframe motions caused by blade response excite the hub to vibrate which alters the aerodynamic loading on the blades and hence the loads transmitted back to the airframe. Depending on the type and configuration of the hub, this interaction can substantially affect the loads which act both on the rotor and on the airframe (ref. 36).

Among the practical methods for calculating the vibrations of a helicopter as a single system, those methods that are based on impedance matching techniques which effect a solution in the frequency domain rather than in the time domain appear to be better suited for use in design work. While impedance methods have been known to the helicopter community for many years and have been employed in analysis of helicopter vibrations (see, for example, refs. 37-39), they have not been used extensively in design to limit vibrations. A rotor impedance matrix can be generated to represent a correction to the gross rotor vibratory forces resulting from small displacements of the rotor from equilibrium during trimmed flight conditions. Compatibility conditions between the hub and airframe lead to "harmonic balance" equations. This set of simultaneous linear algebraic equations are solved for the hub motions, from which the more accurate airframe (and rotor) vibrations are computed. Although not included in the phase 1 activity, the above modeling improvement is planned for incorporation in phases 2 and 3.